Capacity for Rail

Towards an affordable, resilient, innovative and high-capacity European Railway System for 2030/2050

Requirements toward the freight system of 2030-2050 (intermediate)

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Foreword

This is a report for a Work Package in a more extensive project called Capacity4Rail. The project is financed by the EU and is organized into several SPs and many Work Packages. This report, "Progress beyond State of the Art in Rail Freight Systems", is one of the first reports from the project and will gather together some basic facts for the coming work.

The report has been worked out within a project team consisting of the following organizations and persons:

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All these organizations and people have contributed to the work on the report in some way, but other people from the organizations involved have contributed text and facts. Please see the list of authors on the next page.

The project team held four live meetings and four telecom meetings up to September 2014 when the report was finalized.

Bo-Lennart Nelldal, KTH, has been project leader for this WP and was responsible for editing the report. The work has been very interesting with many fruitful discussions. I wish to thank all members of the project team and those who have made other contributions for their excellent cooperation.

Stockholm in November 2014

Bo-Lennart Nelldal

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Executive summary

The total demand for freight in Europe has increased rapidly in recent decades, but rail freight has lost market share and most of the increase has been handled by trucks. In the last decade, rail markets share has increased in some countries because of deregulation, investments in rail and truck fees, but is still very low in many countries. In the new member states the markets have decreased rapidly when rail monopoly has been taken away.

Rail deregulation has not been implemented in practice in all countries while at the same time truck deregulation has been implemented fully and resulted in a low-cost truck market. Moreover, the cost of external effects has not yet been implemented.

Most forecasts show an increase of 60% in total freight demand by 2050 and an approximately constant market share with a business-as-usual scenario. To fulfil the targets in the EU white paper, it is necessary to roughly double rails' market share from 18% in 2011 to at least 36% in 2050. This means that the tonne-kilometres will be 3.6 times as much as today and 2.4 times as much as in a business-as-usual scenario in 2050.

To reach the white paper target, it is necessary to both increase quality and capacity and lower the cost of rail freight. The customers must be able to trust the delivery time to meet the requirements of their logistic chain and the cost must be competitive with road freight. A system approach is therefore needed and the critical development lines must be identified. From the customer's transportation needs that put demands on the wagons – the wagons are coupled together into trains where available tractive power is taken into account – the train utilises the infrastructure with a certain performance along a link and ultimately in a network from origin to destination.

Much of today's freight train system and infrastructure is based on an old standard 3-4 MW locomotive that means trains of approximately 1,500 gross tonnes and a train length of 650-750 metres. But modern locomotives have a tractive power of 5-6 MW capable of hauling 2,000-2,500 tonne trains of up to 1,000m in length. In Europe, train lengths up to 850m already exist and experiments have been made with 2x750m=1,500m long trains with radio-controlled locomotives in the middle of the train. Not only the tractive power but also the locomotives' axle load is critical for optimal traction. To increase the axle load from normally around 20 tonnes to 22.5 or for heavy haul, 25-30 tonnes is a possibility to operate heavier trains but must be combined with track-friendly bogies.

Concerning the wagons, one important question is whether development will be incremental, as it has been so far, or if it is possible to make a system change. An incremental change means successively higher axle loads, wider gauge, higher payload and less tare weight per wagon, better brakes like more silent brake-blocks, end of train devices and some electronic sensors. A system change will include electro-pneumatic brakes, disc-brakes, full electronic control of the wagons and load and automatic central couplers. The automatic couplers is the most critical component but important not only because it will make shunting and marshalling safer and cheaper but also because it will make it possible to operate longer trains without problems and introduce electronic braking systems. It will be easier to feed the train with electricity and signals and to build lighter wagons and lower the floor.

Today, most rail operators use electric locos for long haul and diesel locos for feeder transport and terminal shunting. But the duo-loco has now been introduced into the markets, equipped with both normal electric traction and diesel traction, either for shunting or for line haul. This means that a duo-loco can shunt the wagons itself at a marshalling yard or stop at an un-electrified siding at an industry and change wagons directly. The operators thus need only one loco instead of two and it will also make it possible to introduce new operation principles like liner trains which can stop along the line and change wagons. It will also decrease vulnerability in case of current interruptions. In the long term, it will also make it possible to avoid catenaries at marshalling yards and sidings, which will save money for the IM.

Also for intermodal it is an advantage to introduce liner trains. If the terminals are located on an electrified side track where the train can drive straight in and out onto the line again, there is no need for a diesel loco to be switched in. This in turn requires a horizontal transfer technology that can function under the overhead contact wires. The train must be able to be loaded and unloaded during a stop of 15-30 minutes. This also obviates the need to park wagons. The terminals can also be made more compact and require less space. This will reduce the costs which is critical for intermodal.

Most trailers today are not designed to be lifted onto a railway wagon. The trailer market is in practice therefore very limited even at conventional intermodal terminals that have lifting equipment. Solutions where trailers do not need to be lifted but can be rolled on and off along a ramp can thus widen the market considerably. They also mean that simple terminals only need to be dimensioned for the trucks' axle load.

To increase the capacity of the rail system, the following measures can be taken: (1) More efficient timetable planning: On double track: Bundling of trains with the same average speed in timetable channels to harmonize speeds. During the day faster freight trains are an option. (2) Use of trains and vehicles with higher capacity: For freight: Longer trains, higher and wider gauge, higher axle load and metre load. For passenger trains: Double-decker and wide-body trains. (3) Differentiation of track access charges to avoid peak hours and overloaded links. (4) Better signalling system, shorter block lengths and in the long term introduction of ERTMS level 3. (5) Adaptation of freight corridors for long and heavy freight trains. (6). Investment in HSR to increase capacity for freight trains and regional trains on the conventional network and in some cases dedicated freight railways.

There is a target in the white paper to triple the length of HSR by 2030, which means approx. 18,000 km HSR or 8% of the rail network. According to actual plans, this seems to be realistic. The planned Rail Freight Corridors (RFC) are of approximately the same length. However, there is no common plan to increase the standard in the RFC, which would be desirable. With the measures listed above, longer and heavier trains will make it possible to roughly double the capacity for freight trains without building new railways and in the long term with ERTMS level 3 even more.

It is possible to reduce GHG emissions for all modes but rail will still be the most efficient mode by 2050. An estimation of the effects of a mode shift to rail transport applying the world's 'best practice' shows that such a mode shift to rail can reduce EU transport GHG emissions over land by about 20 %, compared with a baseline scenario. In combination with low-carbon electricity production a reduction of about 30% may be achieved. A developed rail system can thus substantially contribute to the EU target of reducing GHG emissions in the transport sector by 60% compared to 1990 levels.

To enable such a mode shift and to manage the demand for capacity, there is a need for investment. This will also maintain and increase mobility for passengers and freight.

Table: Today´s common standard, incremental change and system change.

Equipment	**Common standard**	**Incremental change***	**System change***
Wagons			
Running gear Brakes Brake control Couplers Max Speed Max Axle load Floor height lowest IT-system	Different Cast brakes Pneumatic Screw couplers 100 km/h 22.5 tonnes 1,200 mm Way-side	50% Track-friendly LL brakes Radio controlled EOT Automatic couplers on some trains 120 km/h 25 tonnes 1,000 mm Some in wagons	All track-friendly Disc brakes Fully electronic Automatic couplers on all trains 120-160 km/h 30 tonnes 800 mm All radio controlled
Locomotives			
Tractive effort kN Axle load Propulsion Fuel Drivers	300 20 tonne Electric Diesel Always drivers	350 22,5 tonne Some duo-locos LNG/Diesel Some driverless	400 25 tonne All duo-locos LNG/electric All driverless
Trains			
Train lengths in RFC Train weight	550-850 m 2,200 tonnes	750-1000 m 4 400 tonnes	1000-2000 m 10 000 tonnes
Infrastructure			
Rail Freight Corridors Signalling systems Standard rail weight Speed. ordinary freight Speed, fast freight	18,000km Different UIC 60 kg/m 100 km/h 100 km/h	25,000km ERTMS L2 in RFC 70 kg/m 100-120 km/h 120-160 km/h	50,000km ERTMS L3 in RFC 70 kg/m 120 km/h 120-160 km/h
Traffic system			
Wagonload	Marshalling - feeder	Marshalling – feeder Some liner trains	Automatic marshalling Liner trains – duo-loco
Trainload		Remote controlled	All remote controlled
Intermodal	Endpoint-trains	Endpoint-trains Liner trains with stops at siding	Endpoint-trains Liner trains fully automated loading
High Speed Freight	National post trains	International post and parcel trains	International post and parcel train network
IT /monitoring systems			
	Some different	Standardized	Full control of all trains and consignments

*) Adapted to market needs in each product and line

1. Introduction

1.1. Background

On 28 March 2011 the European Commission published a white paper entitled "Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system". The EC has a vision of a long-term-sustainable transport system with the aim of attaining the goals set for reducing the transport sector's emissions. Important goals and measures for the rail mode are:

- 30% of road freight over 300 km should shift to other modes such as rail or waterborne transport by 2030, and more than 50% by 2050, facilitated by efficient, green freight corridors.
- By 2050, a European high-speed rail network should be completed. Triple the length of the existing high-speed rail network by 2030 and maintain a dense railway network in all Member States. By 2050, the majority of medium-distance passenger transport should go by rail.

The consequences for the transport sector and especially for rail of this target are important and we will try to quantify the demand for rail when this is implemented. There are at least two critical questions for the rail sector:

- How can rail offer the quality that is needed to attract customers to fulfil the targets?
- How can rail offer the capacity to meet the demand from a modal shift?

In this report, we will try to determine how to develop the rail system from a technical and operational point of view to fulfil the targets from today and beyond state of the art.

1.2. Objectives

The main objective of this work package WP2.1 is:

- To describe today's and future demand for rail freight through existing forecasts and describe scenarios for freight flows up to 2050
- Analyse existing and expected future customer requirements for different goods segments
- Analyse beyond state of the art for vehicles, intermodal systems and operation principles and identify gaps that remain to be successively bridged up to 2030/2050.
- To specify the requirements an efficient freight rail freight system by 2050 that can fulfil the EU targets

1.3. Scope

The scope of this work has been to report the most important trends in freight rail demand, customer requirements and technical and operational development. Then we intend to evaluate these trends and conclude what is the most important development and if something is missing to reach the EU target by 2030 and 2050. This will be input to the other projects.

1.4. Methodology

The principal working method has been to gather facts from scientific papers and reports, mostly investigations and working documents that have already been published or where the results are available. There is therefore a fairly long reference list at the end of the report. Much has already been done and the problem is to choose the most adequate information and also information about on-going development that has not yet been approved.

In some cases we have also done our own research to complement the report with missing figures that we could not find in existing publications. It has also been necessary to restructure information from different sources to make it comparable and consistent.

For many chapters we have acquired much more material than is published in this report. This is a condensed report and it has therefore been necessary to keep the whole text within approximately 100 pages. Some original full documents which could not be published in this report are listed at the end of the report and are available from the authors.

With a time perspective to 2050 it is necessary to not only investigate what is on the market today, but also what may come onto the market from a world-wide best practice point of view, not only for railways but also for other modes and the industry.

At the end we have also made an evaluation of what the most important development trends are and whether something is missing that will prevent the EU targets being fulfilled. This means that there is no final and correct answer to all questions because the market’s development can change and crises may also occur that interrupt development. But we have tried to make the best evaluation possible from the standpoint of where we are today and what we can foresee for the future.

2. Demand for rail and trends for freight flows in Europe towards 2030/2050

2.1. The development of the total freight market and the modes

Total demand for freight transport 1970-2011

The total demand for EU15 has been analysed from 1970-2011 and for EU27 from 1995-2011 more detailed statistics are also available. Total demand and rail market share have been calculated according to the sum of rail, truck and inland waterways because statistics for these modes are mostly available and comparable, see 2.1, 2.3 and 2.4.

The total demand for freight transport in EU15 increased by 2.5% per year rather constantly between 1970 and 2007 and then decreased until 2011. Most of the increase has been handled by road transportation so the market share for road transportation has increased from 52% in 1970 to 78% in 2007. The rail freight volume has been constant or decreased at the same time and the market share for rail has decreased from 36% in 1970 to 15% in 1995. The rail market share has since then stabilized and slightly increased.

The total demand for freight transport in Europe (EU27) increased by 2.8% per year between 1995 and 2007, and then decreased, mostly due to the economic development. The total market share for rail in EU27 decreased from 21% in 1995 to 17% in 2009 and then increased to 18%.

The modes and their markets

For land transport, truck, rail and inland waterways are available. The truck dominates with 76% of the tonne-kilometres, rail has 18% and inland waterways have 6% of the market, see figure 2.2. Road transport is available in all countries and totally dominates short-haul transportation over less than approx. 100 km. Here it is also used for feeder transport to rail and waterborne services. But truck is also used in very long-distance transportation, especially in international transportation, so it has the most diversified market.

Rail is available in most EU countries but its market share varies widely. The highest transport volumes are in Germany and Poland but rail's market share is highest in Switzerland and Austria.

Inland waterways are restricted to rivers and canals and are therefore used in countries like Germany, France and the Netherlands. They are used for bulk transports as well as feeder transport of containers to and from big international ports like Rotterdam.

Besides the land transport modes, there are also sea, pipeline and air transport. Pipelines are used for oil and gas from specific production fields. Air freight is restricted to very fast transport of post, parcels and spare parts. These modes are not an alternative to truck.

Maritime transport (intra EU 27) refers to transport by sea between and inside EU countries. There is also transoceanic transport between the EU and other continents, but here there is a natural monopoly for maritime transport. Maritime transport consists partly of bulk transportation of oil, coal and ore, where it has its own market, and partly of more refined goods where it also competes with truck and rail in specific relations. There is therefore a possibility to shift from truck or rail to maritime transport, i.e. from Scandinavia to northern Europe. However, maritime transport will also be affected by the sulphur directive in 2015, so there is some uncertainty about the development just now.

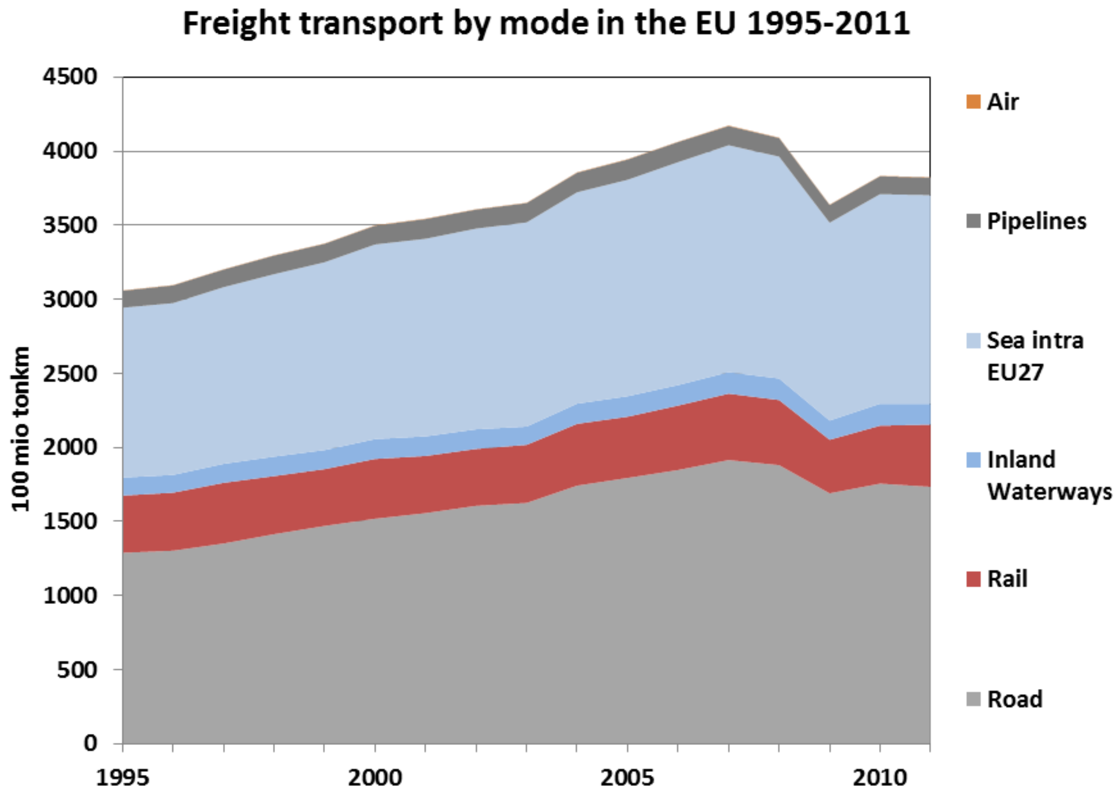


Figure 2.1: Development of modes in EU 27. Source: EC (2013) statistics, processed by KTH.

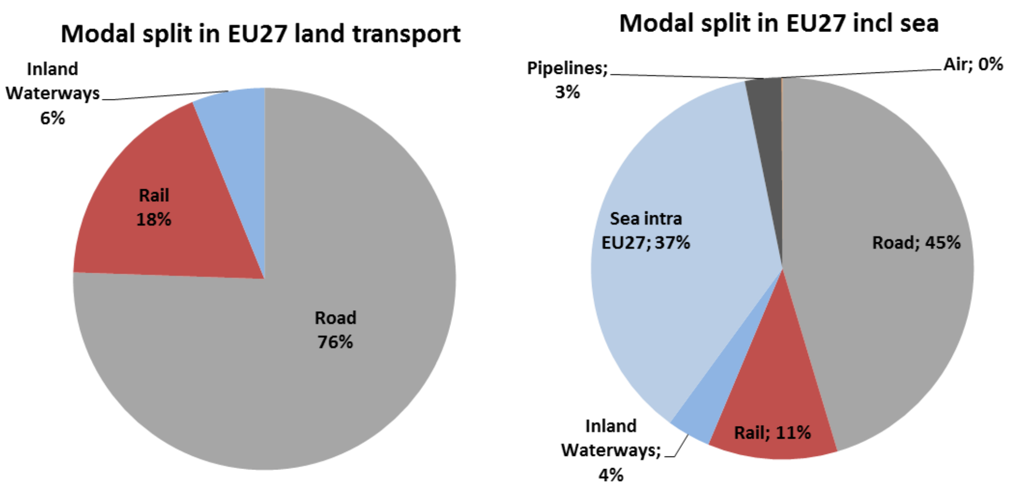


Figure 2.2: Modal split in EU 27 for land transportation and all modes in 2011. Source: EC (2013) statistics, processed by KTH.

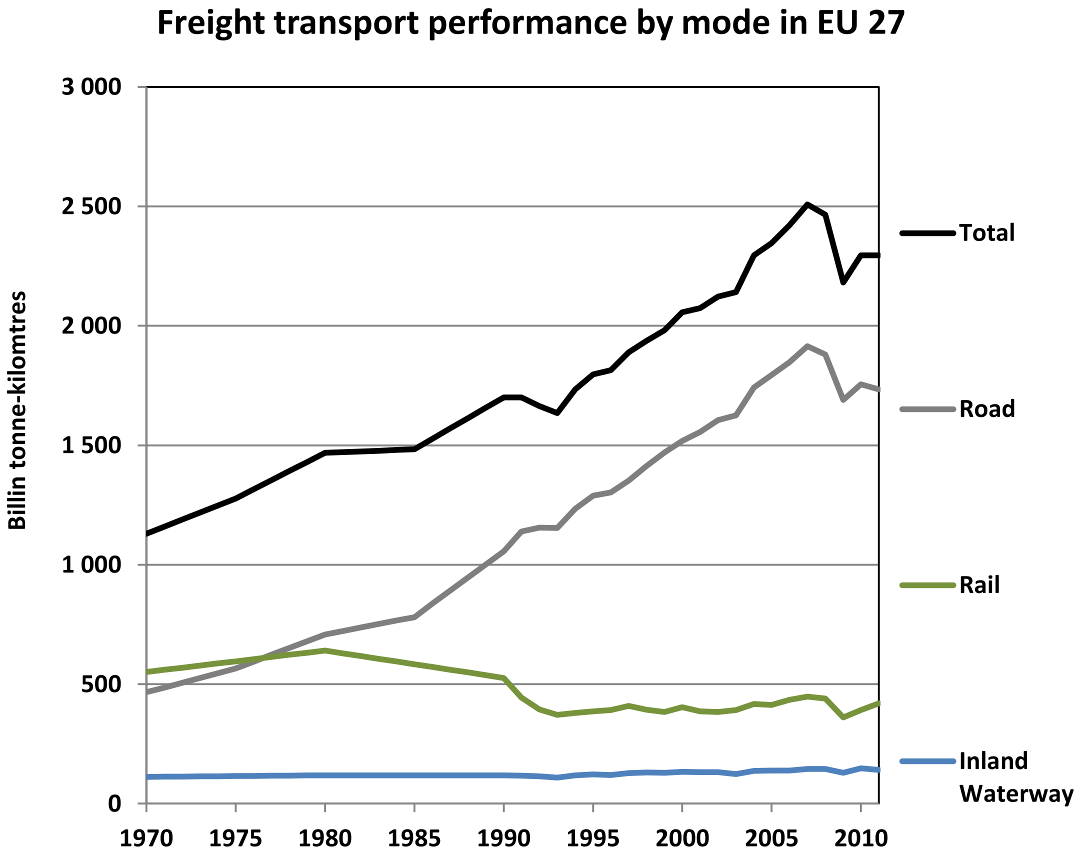


Figure 2.3: Development of the total demand and the modes in EU 27. Source: EC (2013) statistics, processed by KTH.

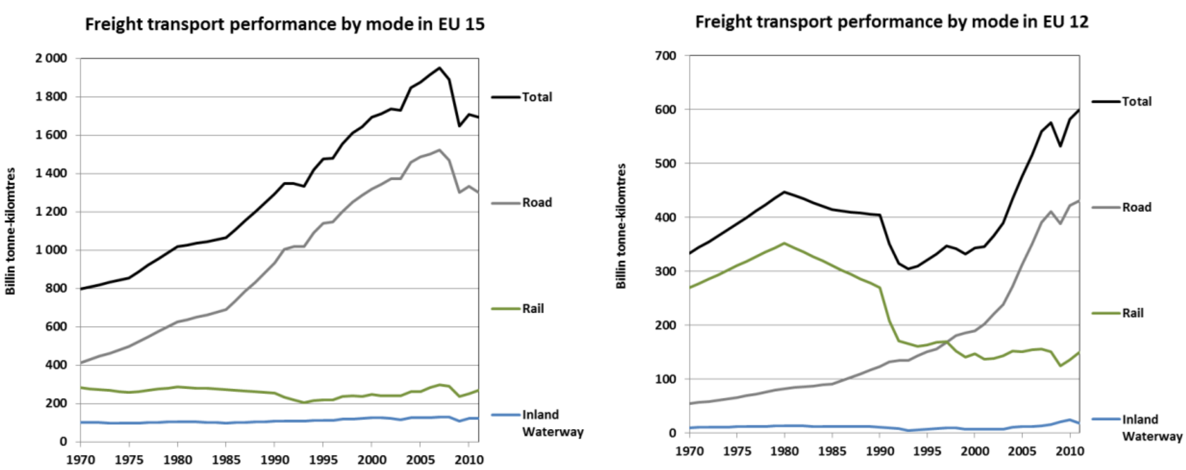


Figure 2.4: Development of the total demand and the modes in EU 15, western Europe, and in EU 12, eastern Europe. Source: EC (2013) statistics, processed by KTH. Statistics for road transport in EU12 before 1990 are incomplete and have been estimated by the author.

2.2. Development of the different modes

Road transport

Network

The total road network in EU27 is approx. 5,000,000 km. Of this figure, 70,000 km are motorways.

The motorway network increased from about 15,000 km in 1970 to about 70,000 km in 2011. Moreover, an increase in the length of state highways and provincial and municipal roads has been recorded in most countries.

Road	1990	2000	2008	2011	1990-2000	2000-2008	2008-2011
Total road network km				5 000 000			
Motorways							
EU15	39 616	51 490	61 635	64 144	30%	20%	4%
EU12	2 269	3 229	5 179	6 007	42%	60%	16%
Total	41 885	54 719	69 468	69 468	31%	27%	0%
Tonne-km (billions)							
EU15	933	1 329	1 470	1 303	42%	11%	-11%
EU12		190	410	431		116%	5%
Total		1 519	1 881	1 734		24%	-8%

Traffic

Freight transport by road more than doubled between 1970 and 1990. From 1990 to 2000 it continue to increase in EU15 but decreased to 2011 because of the economic crisis. In EU12 it more than doubled between 2000 and 2008 and also increased to 2011.

Market structure

International road freight accounts for 33% of all road freight in EU27. It has grown very quickly, especially in EU12 where in 2012 it accounted for 66% of the tonne-kilometres driven by vehicles registered in the reporting countries. Poland had the biggest volumes in international transport, followed by Spain, Germany, the Czech Republic and the Netherlands which together accounted for 57% of international road transport in EU27.

National and international road	2000	2010	2011
Share of international road			
EU15	26%	23%	22%
EU12	48%	66%	66%
Total	28%	33%	33%

The five countries with most road transport in the EU in 2011 are listed in the table below. Germany, Poland, Spain, France and the UK account for 62% of all road transport in the EU. These are also the countries with the highest total demand for transport.

Tonne-km (billions) 2011		Country Code	Road	Rail	Inland waterways	Total	Share of road	Road	Rail	Inland waterways	Total
1	Germany	DE	324	113	55	492	19%	66%	23%	11%	100%
2	Poland	PL	208	54	0	262	12%	79%	21%	0%	100%
3	Spain	ES	207	10	-	217	12%	95%	5%		100%
4	France	FR	186	34	9	229	11%	81%	15%	4%	100%
5	United Kingdom	UK	153	21	0	174	9%	88%	12%	0%	100%
	Sum		1077	232	64	1373	62%	78%	17%	5%	100%
	Other EU		657	188	77	922	38%	71%	20%	8%	100%
	Total EU27		1734	420	141	2295	100%	76%	18%	6%	100%

All types of goods are transported by road. Most of the goods transported are agricultural, industrial and waste products (NST codes 2007).

- GT03: metal ores and other mining and quarrying products; peat; uranium and thorium (31%);
- GT04: food products, beverages and tobacco (10%);
- GT01: products of agriculture, hunting, and forestry; fish and other fishing products (8%);
- GT09: other non-metallic mineral products (14%)
- GT14: secondary raw materials; municipal wastes and other wastes (7%).

Railways

Network

The railway network in EU27 has a length of 213,574 km and has decreased since 1990, especially in EU12. Between 2011 and 2012 there was a slight increase in the total network. Almost 7,000 km of the rail system was high-speed rail in 2012.

Railways	1990	2000	2008	2011	1990-2000	2000-2008	2008-2011
Length in use km							
EU15	162 132	152 446	151 637	152 492	-6%	-1%	1%
EU12	73 110	65 411	61 724	61 082	-11%	-6%	-1%
Total	235 242	217 857	213 361	213 574	-7%	-2%	0%
Tonne-km (billions)							
EU15	257	257	289	270	0%	12%	-7%
EU12	270	147	150	150	-46%	3%	0%
Total	526	404	440	420	-23%	9%	-4%

Traffic

Freight rail in EU27 decreased from 551 to 526 billion of ton kilometres between 1970 and 1990 but was 641 at 1980. Then it decreased to 404 billion to 2000 because the rail monopoly was taken away in EU12 and has then increased to 440 billion 2008. Because of the economic crisis it then decreased to 2011 in EU15.

Train freight kilometres decreased from 838 million in 2000 to 665 in 2010, mostly between 2008 and 2010. These figures do not include all railways in Europe.

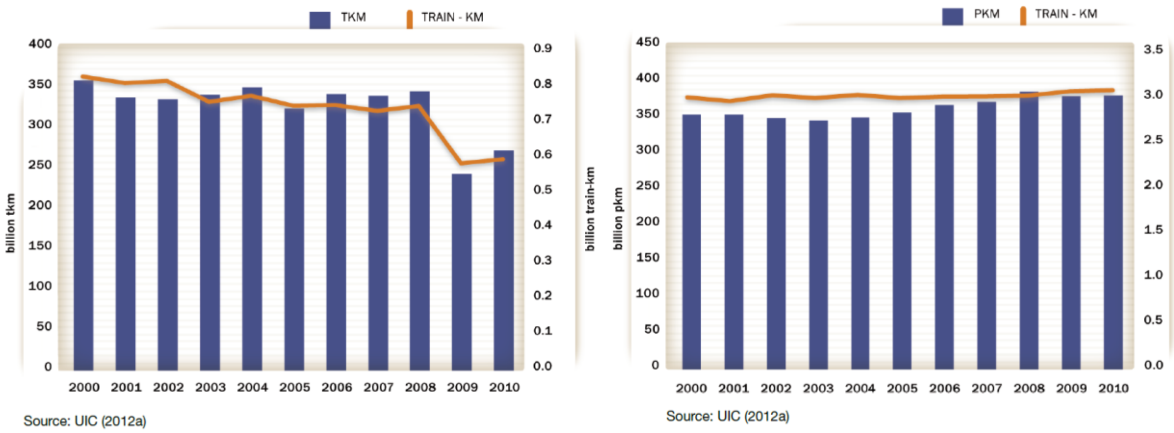


Figure 2.5: Tonne-kilometres and train kilometres for freight trains, and passenger kilometres and train kilometres for passenger trains 2000-2010. Source UIC (2013).The figures show UIC member companies and not all rail traffic in Europe.

By comparison, the demand for passenger trains has increased from 371 billion passenger kilometres in 2000 to 404 billion in 2010, with an increase of 17% in EU15 and a decrease of 28% in EU12. The supply of passenger trains was 2,900 million train kilometres in 2000 and increased to 3,100 in 2010. That means that the ratio of passenger train kilometres to freight train kilometres increased from 2.9 to 4.7, see figure 2.5.

Markets

The five countries with most rail transport in EU 2011 are listed in the table below. Germany, Poland, France, Spain, Sweden and Latvia account for 58% of all rail transport in the EU. With the exception of France, these countries also have a relative high market share for rail.

Tonne-km (billions) 2011	Country Code	Road	Rail	Inland waterways	Total	Share of rail	Road	Rail	Inland waterways	Total
1 Germany	DE	323,8	113,3	55,0	492,2	27%	66%	23%	11%	100%
2 Poland	PL	207,7	53,7	0,2	261,6	13%	79%	21%	0%	100%
3 France	FR	185,7	34,2	9,0	228,9	8%	81%	15%	4%	100%
4 Sweden	SE	36,9	22,9	-	59,8	5%	62%	38%		100%
5 Latvia	LV	12,1	21,4	-	33,5	5%	36%	64%		100%
Sum		766	246	64	1076	58%	71%	23%	6%	100%
Other EU		968	174	77	1219	42%	79%	14%	6%	100%
Total EU27		1734	420	141	2295	100%	76%	18%	6%	100%

Most of the freight volume carried by the railways is domestic. In 2012, 59% of the tonnage was domestic, 36% international and 6% transit freight. The share of international transportation has decreased and domestic transportation has increased, see figure 2.6.

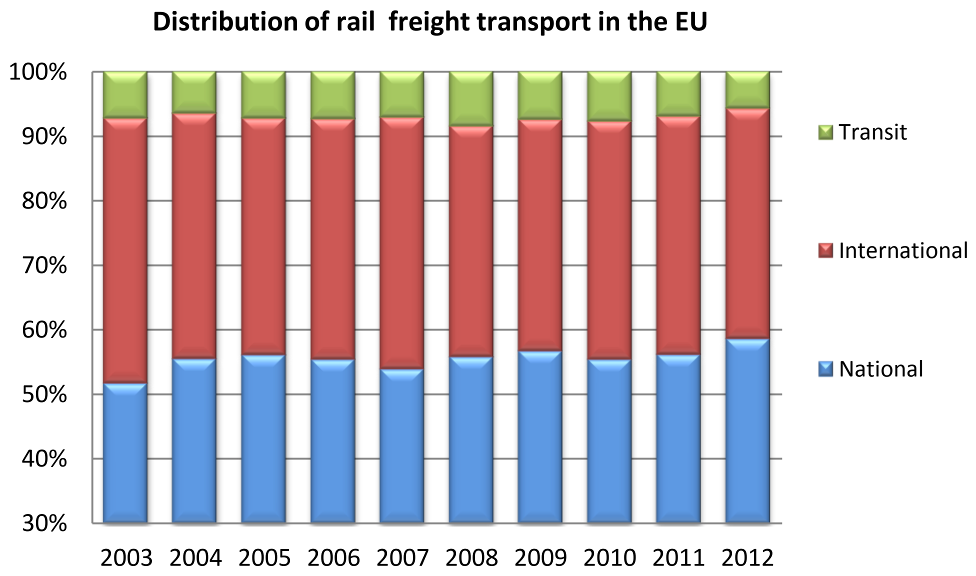


Figure 2.6: Domestic, international and transit transport by rail, distribution of tonnage (DICEA).

Rail transport consists of different products: Trainload, wagonload and intermodal with approx. 50%, 25% and 25% respectively of the tonne-kilometres. Trainload refers to dedicated trains operating for a specific company, e.g. ore, coal and timber trains. Wagonload refers to conventional wagons loaded by the customers and taken by feeder transport to a marshalling yard and from there by long-distance trains and feeder trains to the destination. Intermodal refers to containers, swap-bodies and trailers used for feeder transport that are loaded on trains at terminals for long-distance transportation. Conventional wagonload has gradually decreased in favour of trainload and intermodal. For intermodal, container transport to and from ports in particular has increased.

Intermodal transport units by rail

Three main types of intermodal transport units (ITU) are used in Europe: 1) containers and swap bodies, 2) road vehicles, 3) semi-trailers.

In 2012, about 203 million tonnes were moved by containers or swap bodies in Europe compared with 157 million tonnes in 2004. The share of this type of unit has also increased from 70% to 80% of the total.

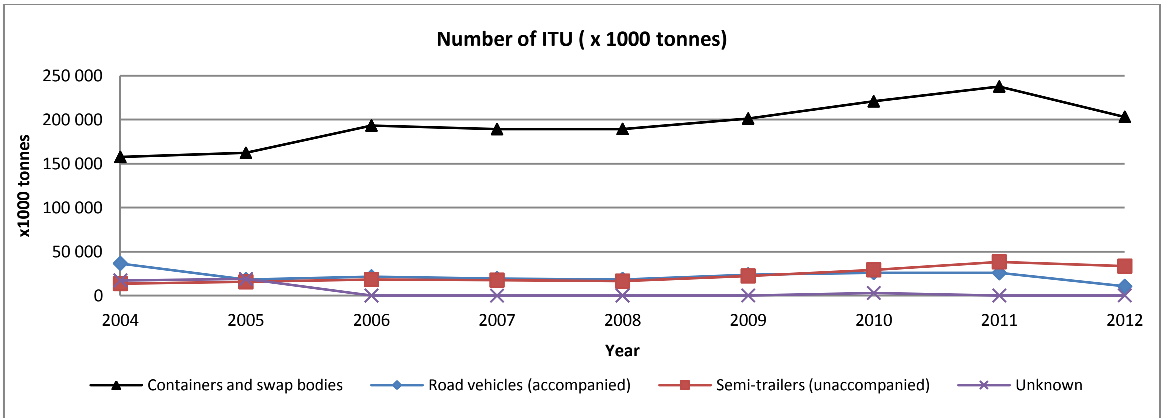


Fig. 2.7: Trend of ITU traffic in Europe, by type (DICEA).

Despite the economic crisis, in comparison with 2004 containers, swap bodies and unaccompanied semi-trailers has increased but accompanied road-vehicles has decreased, see figure 2.7.

In 2012 the empty/loaded distribution of ITUs was as follows:

- container: 73%;
- road vehicles: 93%;
- semi-trailers: 97%

Inland waterways

Network

In Europe, inland waterways (iww) networks are mainly fluvial with a total of 40,590 km in 2010. Between 1990 and 2000 iww increased by 17% in EU15 but has then remained relatively unchanged in both EU15 and EU12.

Inland waterway	1990	2000	2008	2011	1990-2000	2000-2008	2008-2011
Length in use							
EU15	26 565	31 120	31 366	31 380	17%	1%	0%
EU12		8 971	9 108	9 130		2%	0%
Total		40 091	40 474	40 510		1%	0%
Tonne-km (billions)							
EU15	107	127	130	122	19%	2%	-6%
EU12	11	6	15	19	-43%	135%	23%
Total	118	134	145	141	13%	9%	-3%

Traffic

Between 1970 and 1990 transport by iww was fairly stable at 110-120 billion tonne-kilometres. Between 1990 and 2000 the use of inland waterway increased in EU15 and remained at the same level in 2010 and 2011. In EU12, the use of inland waterways decreased between 1990 and 2002 and then increased fourfold between 2000 and 2010.

Markets

The five countries with most inland waterway transport in the EU in 2011 are listed in the table below. Germany, the Netherlands, Romania, Belgium and France account for 93% of iww transportation in the EU. Inland waterways are restricted to rivers and canals and are therefore mainly used these countries. They are used for bulk transport as well as feeder transport of containers to and from big international ports like Rotterdam.

	Tonne-km (billions) 2011	Country Code	Road	Rail	Inland waterways	Total	Share of inl waterway	Road	Rail	Inland waterways	Total
1	Germany	DE	323,8	113,3	55,0	492,2	39%	66%	23%	11%	100%
2	Netherlands	NL	73,4	6,4	46,3	126,1	33%	58%	5%	37%	100%
3	Romania	RO	26,3	14,7	11,4	52,5	8%	50%	28%	22%	100%
4	Belgium	BE	33,1	7,6	9,3	50,0	7%	66%	15%	19%	100%
5	France	FR	185,7	34,2	9,0	228,9	6%	81%	15%	4%	100%
	Sum		642	176	131	950	93%	68%	19%	14%	100%
	Other EU		1092	244	10	1346	7%	81%	18%	1%	100%
	Total EU27		1734	420	141	2295	100%	76%	18%	6%	100%

Maritime

In Europe, sea is the best way of freight exchange for overseas transport to North and South America, Africa and the Far East. Most freight carried to and from these areas is transported by sea.

Currently the total amount of freight transported by sea is about 4.3 billion tonnes. It increased by 30% between 2000 and 2011, see figure 2.8. There are 1,540 commercial ports in EU28.

The major European ports are Rotterdam, Antwerp and Hamburg, all located on the North Sea coast. They consolidated their positions as Europe's top 3 ports in 2010, both for the gross weight of goods and the volume of handled containers.

Europe’s largest port, Rotterdam, experienced a fall of 6.4% in the gross weight of handled goods from 2010 to 2011 (mainly due to reduced volumes of liquid bulk), while Antwerp and Hamburg both reported an increase in the total volume of handled goods over the same period.

Most of the cargo handled in Rotterdam consists of liquid and dry bulk goods such as oil, chemicals, coal and ores. However, Rotterdam is also Europe’s largest container port, handling almost 15 million TEU in 2011, a substantial increase compared with 2010.

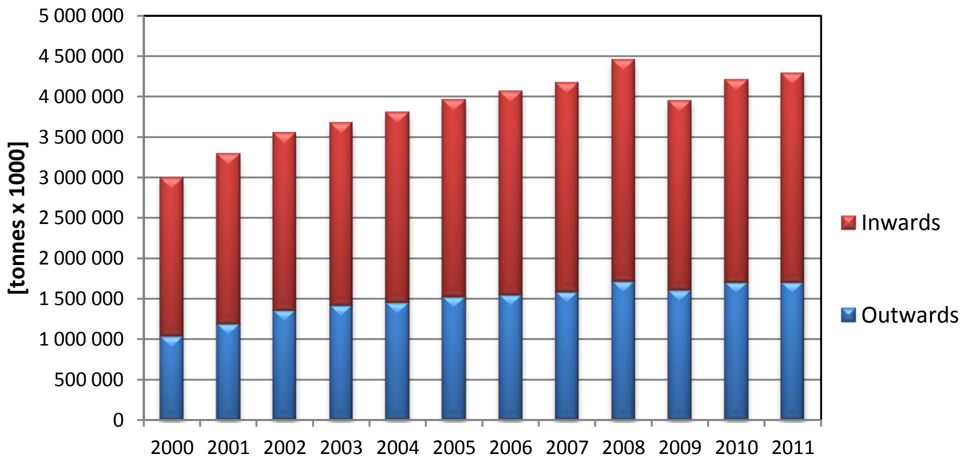


Figure 2.8: Inwards/Outwards distribution of maritime freight traffic (DICEA).

Pipelines

The length of pipelines in Europe was 37,226 km in 2011. The length increased by 10% since 2000.

Pipelines km	1990	2000	2008	2011	1990-2000	2000-2008	2008-2011
Length in use							
EU15	18 309	22 162	24 238	26 099	21%	9%	8%
EU12		11 796	11 169	11 127		-5%	0%
Total		33 958	35 407	37 226		4%	5%
Tonne-km (billions)							
EU15	72	86	89	78	20%	3%	-12%
EU12		41	37	36		-10%	-2%
Total		127	125	114		-1%	-9%

Air

Air transport is used for high-value goods and express deliveries of spare parts, post and parcels. It therefore accounts for only 0.1% of the total tonne-km in the EU but is nonetheless an important mode for the industry and service sectors.

The total demand has remained relatively unchanged at about 2.5 billion tonne-km over the last 10 years.

Air	1995	2000	2010	2011	1995-2000	2000-2010	2010-2011
Tonne-km (billions)							
Total	2,0	2,5	2,5	2,5	23%	4%	-1%

2.3. Rail market share in different countries

The decrease in rail market share since 1995 has been influenced very much by development in the new member states (EU12) in Eastern Europe. In EU12, rail's market share decreased rapidly from 51% to 23% between 1995 and 2009, mainly because the railways' monopoly was abolished. In Western Europe, EU15, the market share has remained fairly stable at about 15% since 1995. In recent years, however, the market share has increased slightly both in EU12 and EU15, see figure 2.9.

To analyse the development, different countries have been arranged by western or eastern Europe and then by market share from highest to lowest, see figure 1.7. Non-EU-members in Europe are also included. In western Europe, some countries have had high market shares for a long time: Switzerland (not an EU member) 45-50% and Austria 30-40%, see figure 1.3. These countries also have considerable transit traffic. Sweden and Finland also have higher market shares than average with 25-35%.

The market share in Germany has increased from 19% in 1995 to 23% in 2011. The market shares in the United Kingdom, Denmark and the Netherlands has also increased but from a very low level of less than 10% in 1995. Rail's market share in Sweden is 38% and has remained stable at a high level.

In most of these countries, rail has lost market share every year since the end of World War II but it has increased over the last decade. This is probably partly due to new private companies entering the market after deregulation but also to a more efficient state railway as a result of deregulation. In some countries, truck-fees may also have affected the modal split. The development is not dramatic but in a historical perspective with a continuously decreasing market share this may represent a reversal of the earlier trend.

By contrast, in some countries in western Europe the market share has decreased during almost the whole period. In France and Norway it has decreased from a relatively high level of more than 20% to 15%. From an already low level of approximately 10%, it has decreased to less than 5% in Spain, Luxemburg and Ireland. Also in these countries, rail's market shares has stabilized or slightly increased in recent years, see figures 2.10 and 2.11 to the left.

In eastern Europe, there are many countries with a very high market share in 1995. Latvia, Lithuania and Estonia had 70-95%, which has now decreased to 55-65%. Poland, Slovakia and the Czech Republic had 40-50%, which had decreased to 20-30% in 2011. In all these countries, rail's market share seems to have stabilized over the past 5 years, even if it fluctuates at times, see figures 2.10 and 2.11 to the right.

In some other countries like Bulgaria, Slovenia, Croatia and Hungary, with a market share of 35-60% in 1995, rail's market share has decreased to approximately 20% or less. In Macedonia it has fluctuated by about 10% and in Turkey it has remained stable at approximately 5%. For these countries, it not so easy to see a reversal of the trend towards stabilization or increased share even if there are exceptions. Sometimes there may also be an uncertainty in the statistics so it is not so easy to draw proper conclusions.

In international transportation in particular, there is a great potential for rail freight because the market share is lower than in domestic transportation because of management and interoperability problems. In Sweden, the market share for international transportation is only half of the share

(12%) of domestic transportation (25%), despite there being substantial volumes of long-distance freight that are suitable for rail because of economies of scale.

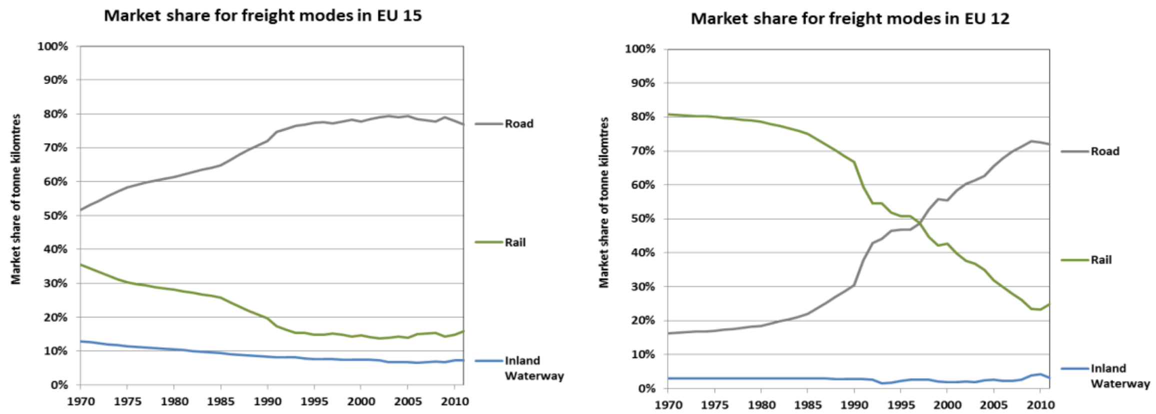


Figure 2.9: Development of the modal split in EU 15, western Europe, and in EU 12, eastern Europe. Source: EC (2013) statistics, processed by KTH. Statistics for road transport in EU12 before 1990 are incomplete and have been estimated by the author.

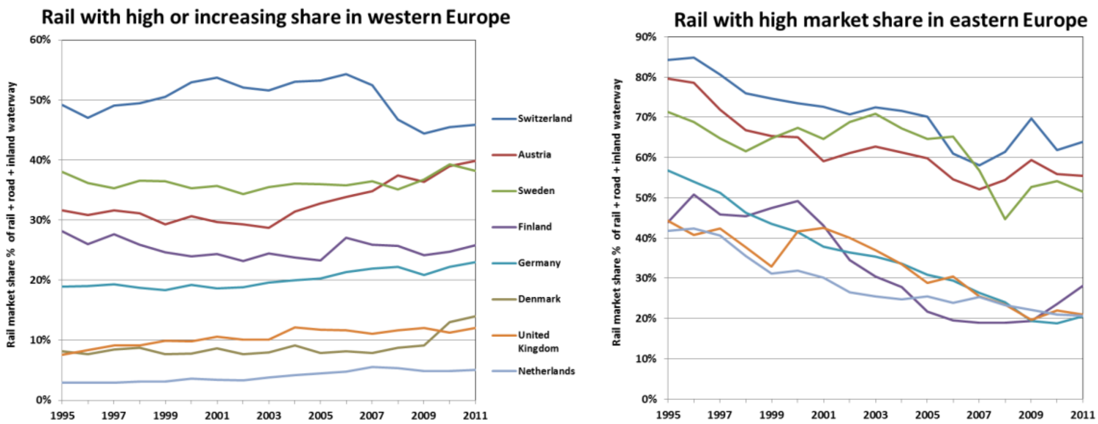


Figure 2.10: Left: Development of rail freight market share in tonne-kilometres in countries with high or increasing market share in western Europe. Right: Development of rail freight market share in tonne-kilometres in countries with high market share in eastern Europe. Source: Author's own evaluation of EU energy and transport in figures 2013.

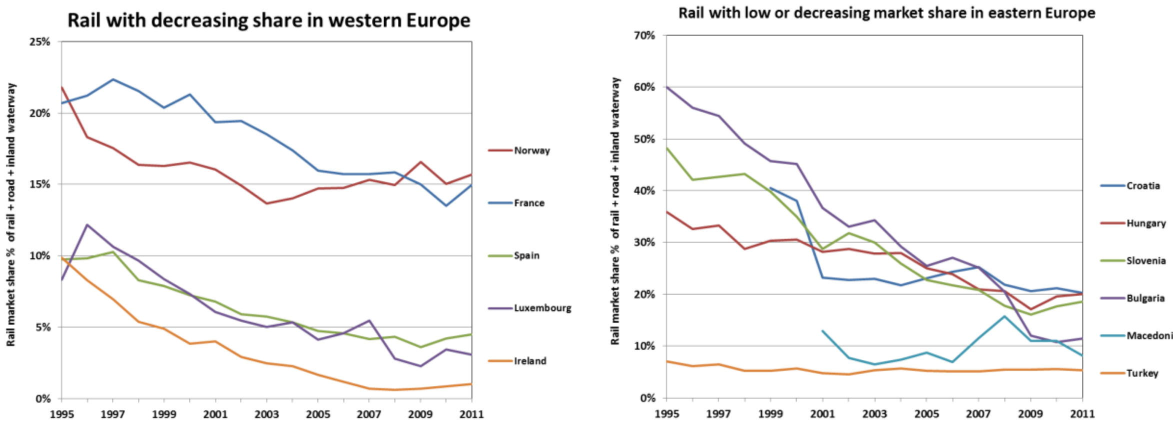


Figure 2.11: Left: Development of rail freight market share in tonne-kilometres in countries with high or increasing market share in western Europe. Right: Development of rail freight market share in tonne-kilometres in countries with high market share in eastern Europe. Source: Author's own evaluation of EU energy and transport in figures 2013.

Analysis of rail freight in Spain

During 2011 freight trains ran on a total of 10,963 kilometres of line managed by Adif, of which 708 were used only for freight services. The company Feve had 1,057 kilometres for freight and ETS, FGC and CMC maintained service on 242 kilometres in 2011

Logistics facilities, which allow loading, unloading and management of freight trains, are important elements in freight rail transport. In 2011, Adif had 99 main logistics facilities, 66 secondary facilities and 63 technical facilities. In addition, Feve and ETS networks added 13 logistics facilities. There are 23 state-owned ports with rail access, 6 dry ports and only one regional port.

In 2011, the volume of goods transported by rail totalled 24 million net tonnes, which represents an increase of 12% over 2010, but is still far from the 31 million net tonnes in 2007. Net tonne-km also increased by 12%. Revenues per tonne have decreased to 10.99 Euro per tonnes, which is the lowest figure of the last seven years, see table 2.12.

Table 2.12: Basic data in freight services between 2005 and 2011 (FFE)

Concept	Unit	2005	%	2006	%	2007	%	2008	%	2009	%	2010	%	2011
Net tonnes	Thousands of net tonnes	30,890.29	0.4	31,003.49	0.9	31,271.59	-9.0	28,447.65	-22.9	21,922.41	-2.2	21,438.39	12.3	24,072.52
Ton average travel	km/gross tonne	376.66	-0.7	373.91	-3.6	360.53	3.7	373.99	-6.7	348.87	14.7	400.09	-0.5	398.25
Net tonne.kilometer	Thousands of net tonne.km	11,635.24	-0.4	11,592.50	-3.3	11,211.99	-5.0	10,653.00	-28.0	7,675.00	11.8	8,577.30	11.8	9,586.85
Revenue per tonne	Euro/ net tonne	11.03	0.0	11.03	3.0	11.36	5.9	12.03	-6.2	11.29	2.2	11.54	-4.8	10.99
Revenue per tonne in 2011 Euro	Euro/ net tonne	12.35	-3.3	11.94	0.7	12.03	3.7	12.48	-6.4	11.59	-0.4	11.54	-4.8	10.99
Average perception per tonne.km of current Euro	Current Euro cent/net tonne.km	2.93	0.8	2.95	7.4	3.17	1.4	3.21	0.4	3.23	-10.6	2.88	-2.2	2.82
Average perception per tonne.km in 2011 Euro	2011 Euro cent/net tonne.km	3.42	-2.6	3.31	4.5	3.48	0.0	3.38	0.4	3.36	-13.1	2.98	-5.4	2.82
Revenue per traffic(without taxes)	Current million Euro	340.59	0.4	341.97	3.9	355.36	-3.7	342.34	-27.7	247.58	-0.1	247.38	-8.8	225.50
Trains in average day	Trains/day (2 directions)	211.42	-7.6	195.37	-4.9	185.86	40.0	260.27	-23.0	200.38	-0.9	198.60	-1.3	196.05
Average train travel	km/train	512.07	6.6	545.75	0.7	549.56	-31.2	378.00	-4.5	361.00	3.7	374.38	-3.4	361.84
Trains.kilometer per year	Million	41.24	-2.0	40.40	-3.3	39.07	-8.0	35.94	-26.5	26.43	2.7	27.14	-4.6	25.89
Use (tn.km/tb.km)	%	39.80	-0.4	40.28	1.7	40.83	-3.3	40.34	-3.1	39.85	2.2	40.45	9.6	44.34
Average speed	km/hour	54.21	0.5	54.50	-0.3	54.33	0.0	54.34	0.9	54.84	2.2	54.81	1.5	55.60
Tow gross tonnes	Million	29,231.00	-1.5	28,779.30	-4.6	27,459.23	-3.8	26,409.02	-27.1	19,260.54	10.1	21,202.80	2.0	21,623.19
Gross tonnes	Thousand	66,314.72	-3.3	64,148.43	19.2	76,479.69	-6.9	71,203.12	-21.7	55,770.83	0.5	56,028.19	1.0	56,596.27

The distribution per product of the goods transported, measured in net tonne-km is shown in the figure below. Intermodal accounts for 42% and wagonload for 58% where Iron and steel are the most important products with 22% of the net tonne-kilometres, see figure 2.13.

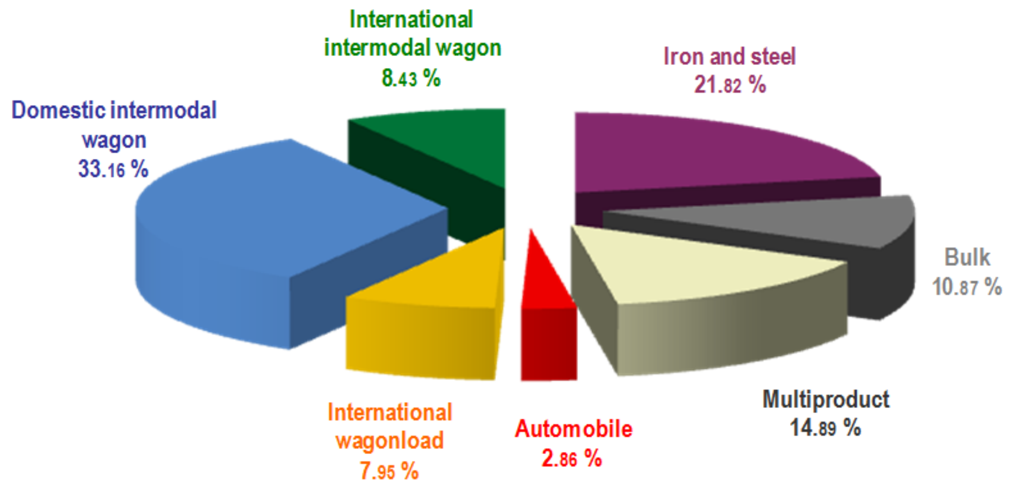


Figure 2:13: Distribution of goods transported by rail in Spain (FFE)

The long-term development of rail freight in Spain from 1963-2011 is shown in figure 2.14. The total tonne-km has fluctuated around 10 billion but the number of tonnes has at the same time decreased from 40-50 million to 20 million tonnes. This means that the average transport distance has increased rather much, i.e. from 210 to 376 km.

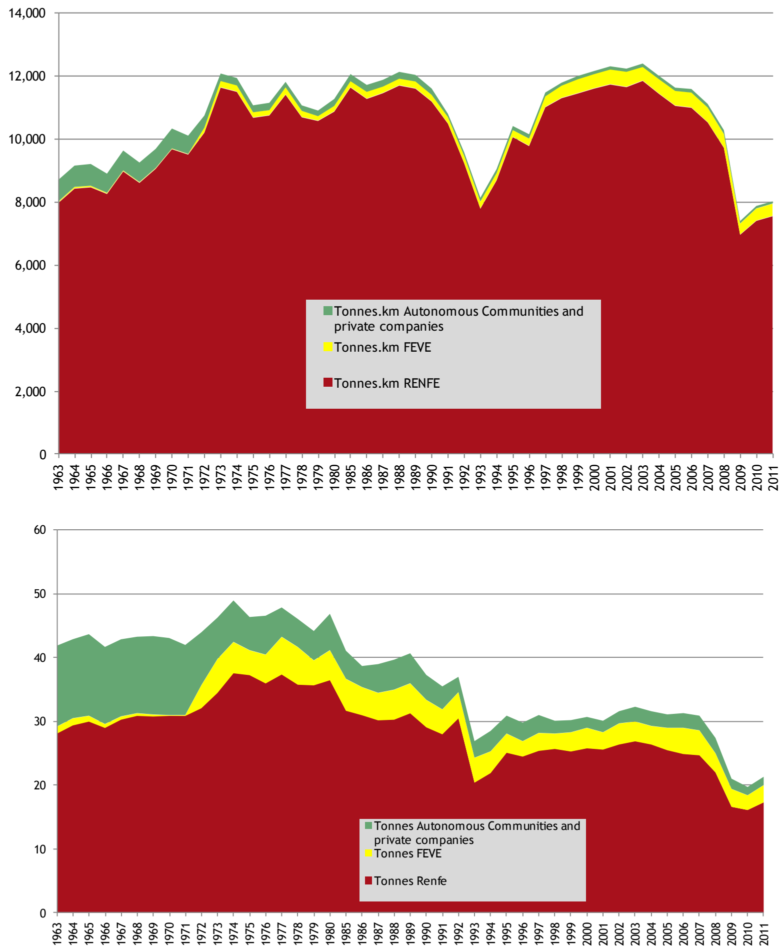


Figure 2:14: Long term development of freight transport by rail in Spain 1963-2011 in millions of tonne-kilometres (above) and tonnes. Source: independently produced with data from the Ministerio de Foment.

As stated in the precious section, rail's market share in Spain has decreased from 10% in 1995 to 4.5% in 2011 (to be compared with 18.4% in EU27. Road transport dominates in Spain with a market share of 95.5%. However, there was an increase in both volume and market share of rail freight in Spain from 3.6% in 2009 to 4.5% in 2011 and at the same time a decrease for road transport.

The main reason for this is the financial crisis. Freight transport in general suffered a significant decrease, which in particular affected road transport. Less total freight transported and more by rail is the explanation for the increase in market share. Going ore deeply, one of the reasons why road transport suffered such a substantial decrease was the bursting of the housing bubble, where most transportation (building materials) was done by road. On the other hand, rail did not lose too extensively, probably for two main reasons:

- Rail market share is so low that the influence of factors like the financial crisis is lower than in other sectors.
- New private companies appear and establish new routes and they have increased their transportation in recent years.

Rail freight in Spain may perhaps develop more positively in the future because the total market is the fourth in EU27, and a big potential for international transportation over long distances.

2.4. Rail freight market share for different commodities

The most important market segments for rail

In order to estimate the rail vocation of different goods, a *Vocation Indicator* has been introduced that shows the preferential transport mode for each type of goods.

$$I_{road} = \left(\frac{Q_i}{Q_{tot}}\right)_{Road}$$

$$I_{rail} = \left(\frac{Q_i}{Q_{tot}}\right)_{rail}$$

where:

- Q_i is the transported amount of a considered goods type;
- Q_{tot} is the total of all goods categories.

In Europe the highest vocations for rail transport are for the following types of goods, see figure 2.15 and supplement.

- GT02: coal and lignite; crude petroleum and natural gas;
- GT07: coke and refined petroleum products;
- GT08: chemicals, chemical products, man-made fibers; rubber and plastic products; nuclear fuel;
- GT10: basic metals; fabricated metal products, except machinery and equipment;
- GT12: transport equipment;
- GT19: unidentifiable goods: for any reason cannot be identified and therefore cannot be assigned to groups 01-16.

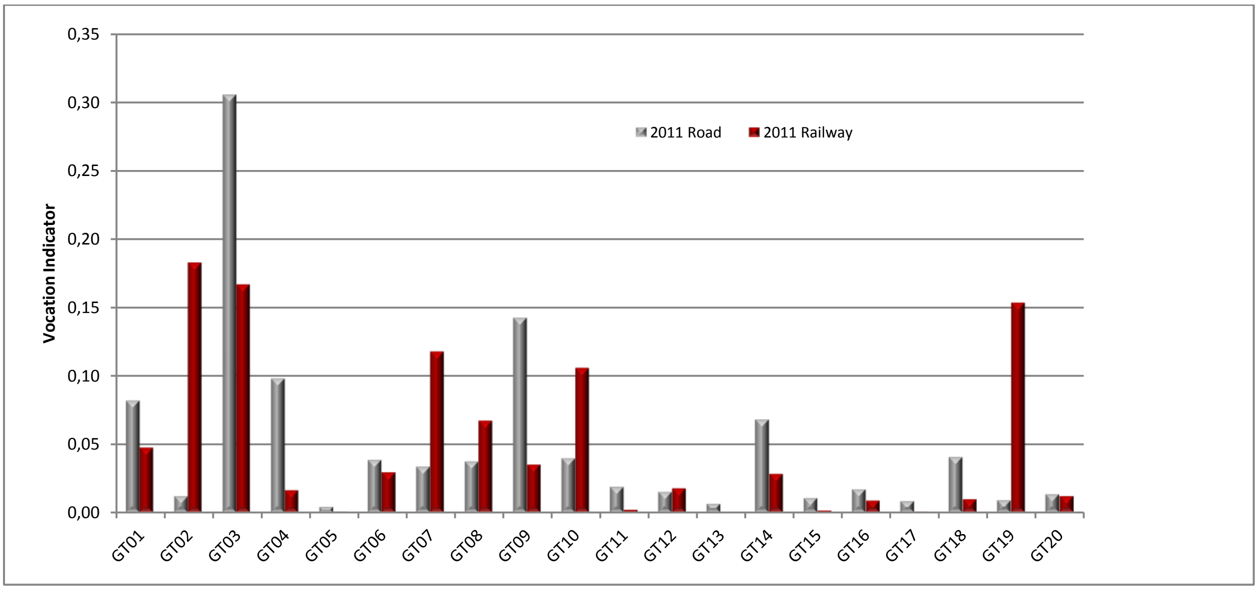


Fig. 2.15: Vocation Indicators for road and railway by NST goods typology. The goods categories are explained in the annex.

2.5. Best practice rail in a global perspective

Some facts about passenger transport around the world are shown in Table 2.17. In Europe, the structure is different between EU 15 and EU 12. Car ownership in particular is lower in EU 12, as is also travel consumption per inhabitant. In the USA, car ownership is extremely high and travel consumption per inhabitant is more than twice that in Europe.

In Japan, car ownership and travel consumption are of the same order as in Europe. At 30%, rail's market share is very high in Japan. This can be compared with 0.4% in the US and 6.5% in Europe, excluding metro and trams. Despite a normal car ownership level, the private car's market share in Japan is only 54%, compared to 74% in Europe and 85% in the USA. One explanation is that Japan has a high-speed rail system over large parts of the country, with both direct trains for longer distances and stopping trains for short and medium distances. Japan has also a lower share of motorways than Europe and the USA.

For freight, however, the situation is different, see figure 2.16. There are no big differences in GNP per inhabitant except for EU 12, where it is much lower. Tonne-kilometres per inhabitant are three times as high in the USA as in Europe. One explanation for this is that the USA is a big continent with substantial natural recourses moved over long distances to the users. Rail's market share is extremely high in the USA; 53% compared to 18% in Europe, excluding sea transport and pipelines. The long-distance freight railways in the USA are very efficient and market-oriented with long trains, high axle load and a large loading gauge. One reason is that the rail freight companies own most railways and have adapted the infrastructure to freight operation and there are very few passenger trains.

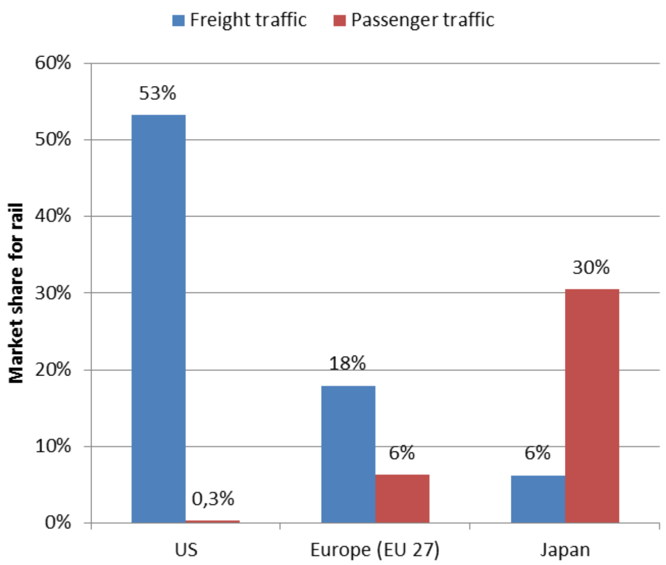


Figure 2.16: Rail's market share in passenger (red) and freight traffic (blue). Comparison of USA, EU and Japan (Figure: Gerhard Troche, KTH).

Table 2.17: Some facts about transport and infrastructure in Europe, USA and Japan. Source: Calculations from EC (2009).

2007	Europe EU 15	Europe EU 12	Europe EU 27	US	Japan
Population density					
Millions of inhabitants	392	103	495	301	128
Number of inhabitants/km2	121	95	115	31	340
Passenger transports					
Passengerkm/inhabitant/year	13 954	7 864	12 770	28 530	10 147
Cars/1000 inhabitants	500	326	464	781	539
Market shares					
Privat car	75%	70%	74%	85%	56%
Bus and coach	8%	13%	9%	3%	7%
Rail	6%	6%	6%	0%	30%
Metro and tram	1%	3%	1%	0%	**
Air	9%	7%	9%	11%	7%
Sea	0%	0%	1%	0%	0%
Total	100%	100%	100%	100%	100%
Infrastructur					
Roads metre/1000 inhabitants			10 101	21 472	9 297
Motorways mere/1000 inhatbitants	151	41	128	316	58
Railways metre/1000 inhabitants	384	598	429	678	219
High-speed rail m/1000 inhabitants	16	0	12	1	19
High-speed rail/Motorways %	10%	0%	10%	0%	33%
Freight transports*					
Gross national product (GNP)/inhabitant	29 281	8 398	24 935	33 472	28 227
Tonne-kilometres/inhabitant	5 000	5 437	5 091	16 880	2 891
Market shares					
Road	78%	70%	76%	37%	94%
Rail	15%	28%	18%	53%	6%
Inland waterway	7%	2%	6%	10%	0%
Total	100%	100%	100%	100%	100%
*) Exkl sea and pipe-lines					**)Incl in rail

2.6. Forecasts of total demand in the EU and rail´s market share

Total Demand for Freight Transport

Many different forecasts for transportation in Europe have been made at different times and with different perspectives. Some of them will be presented in summarized form here: Primes, TREMOVE, iTREN, TRANS-visions and TOSCA. This is followed by a more detailed description of D-rail, which includes both commodities and network assignments, and SPECTRUM because it describes a new market for rail freight. Most of the forecasts include road, rail and inland waterway but few include maritime transport.

The total growth for freight transport demand is of the same order. Due to the economic growth, which for all forecasts is assumed to be positive in the long term, the growth of the total transport effort will be 1.5-1.7% per year or 50-60% from 2010-2050. Overall, the total freight transport forecast scenarios compare well.

Freight Transport Demand per Mode

Most forecasts show small differences and small changes in the market shares for the modes in business-as-usual scenarios. Few of the forecasts have taken a development in line with the EU white paper into account.

Figure 2.18 highlights the overall rise in freight demand and the augmented rate of trucks in 2050 towards overall demand. The modal split also shows that the truck and train modes remain relatively constant, while ship decreases by almost 3% (ADAM, 2009). In the ADAM and TREMOVE scenarios, the road demand should double by 2050. All other modes show a more moderate upward slope.

Rail shows significant differences within the scenarios. Even though the prices are comparable to begin with, the growth rates diverge substantially, implying that modal splits differ between scenarios. The ADAM (2009) scenario forecasts that rail demand also doubles by 2050. Until 2030, all scenarios, including ADAM, agree on the fact that rail demand is moderate, but after 2030 ADAM, iTREN and TRANSvision depict an increasing growth rate. In general, all scenarios incorporate a declining trend in inland navigation demand, see figure 2.19.

In the TOSCA forecasts, the total demand increases by 50% measured in tonne-kilometres. The market shares will be rather stable with 81% for truck in 2010 and 82% in 2050 and 19% for rail in 2010 and 18% in 2050. Trucks will grow a little bit faster than rail; the shift is probably a consequence of different economic development for various sectors and commodities and the actual mix for different modes.

As a matter of fact, the Trans-tools model seems to be very static; most changes will be in total demand because of different economic development. The market shares are almost constant from 2010 to 2050.

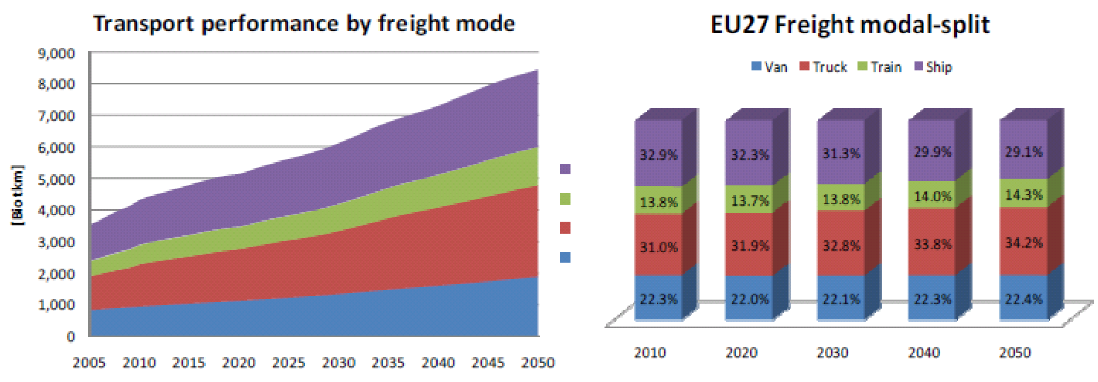


Figure 2.18: Freight Transport Performance and Modal Split (Source: Fraunhofer-ISI, ASTRA Calculations)

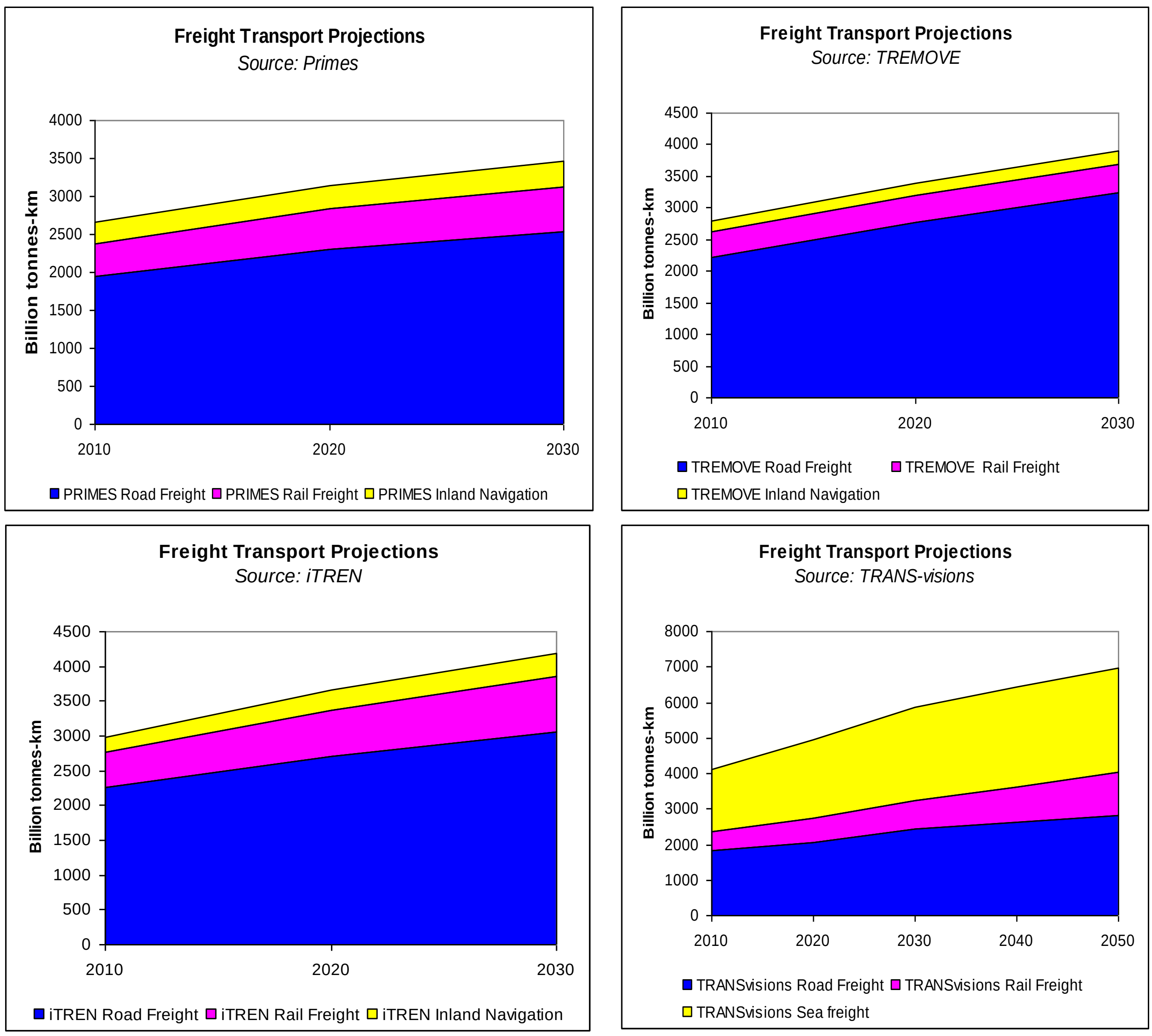


Figure 2.19: Freight Demand per mode of Transportation for each Scenario

Forecasts for white paper scenarios from D-RAIL

The D-RAIL (2012) project forecasted the future levels of rail freight demand assuming three different scenarios: 1) Reference scenario with no change from the current rail system in infrastructure, policies and other trends; 2) White Paper High Scenario and 3) White Paper Low Scenario. The High and Low Scenarios assumed that a full (50% by 2050) and partial (30% by 2030) modal shift of cargo from road for distances over 300 km to rail will occur according to the targets set by the European Union Transport White Paper (2011).

The TRANS-TOOLS model is applied for the forecast. Given the long-term time horizon (up to 2050), model results were mainly used as input for a meta-analysis model which, where possible, combined the TRANS-TOOLS results with the findings of the relevant studies. For this, the study identified trends (for example, transport and logistics trends, e.g. responsiveness, transit time, and reliability, and rail sector relevant trends, e.g. further rail liberalisation) that serve as input to different scenarios in the form of a consistent set of variables that describe the future development of the system. The main scenario parameters are identified through a study of different existing studies (e.g. FREIGHTVISION 2010, TEN-CONNECT 2011) on transport in general and rail freight transport in particular. The White Paper policy options are then applied on the reference scenario as meta-models, deriving the freight demand for all three scenarios.

Based on the transport estimates from the base year 2010, forecasts were made towards 2030 using the Integrated Scenario developed by the EU project iTREN-2030. The basic objective of iTREN was to extend the forecast and measurement capabilities of TRANS-TOOLS. The iTREN project adds multiple modules to TRANS-TOOLS that provide specific input types. These input types are: transport types, vehicle technology, transport policy, TEN-investments, resource prices, energy technology and energy policy. For these inputs, comparable assumptions were made to create a common base. When reviewing the results of previous studies, the iTREN 2030 scenario seems most appropriate for the D-RAIL project as it takes the most relevant input factors into account, for example multiple input, economic downturn, policy measures, network (infrastructure) and detailed output.

For these reasons, the D-RAIL (2012) study considered iTREN (integrated/reference) to be the best source of a reference scenario up to 2030. For 2010 to 2030 there are annual growth factors available at commodity level (per region). The method in the iTREN integrated/reference scenario demand from 2030 and onward is the extrapolation of growth factors.

Forecasts for rail in EU15 and EU12 from D-rail

Figure 1 shows the rail freight demand in tonne-km for different EU segments for the two white paper scenarios, for comparison reasons. It can be seen that the total demand is higher for the second version, where the total shift is allocated entirely to rail. There is also a difference in slope regarding the two white paper scenarios. In the Low scenario, the growth rate from 2030-2050 for EU12 is higher than for EU15. However, in the High scenario the slopes are reversed. This shows that in a more realistic scenario, growth in EU12 will be higher, even if there is a shift from road. On the other hand, in a more optimistic scenario, the road shift mainly occurs in EU15, increasing the slope value, see figure 2.20.

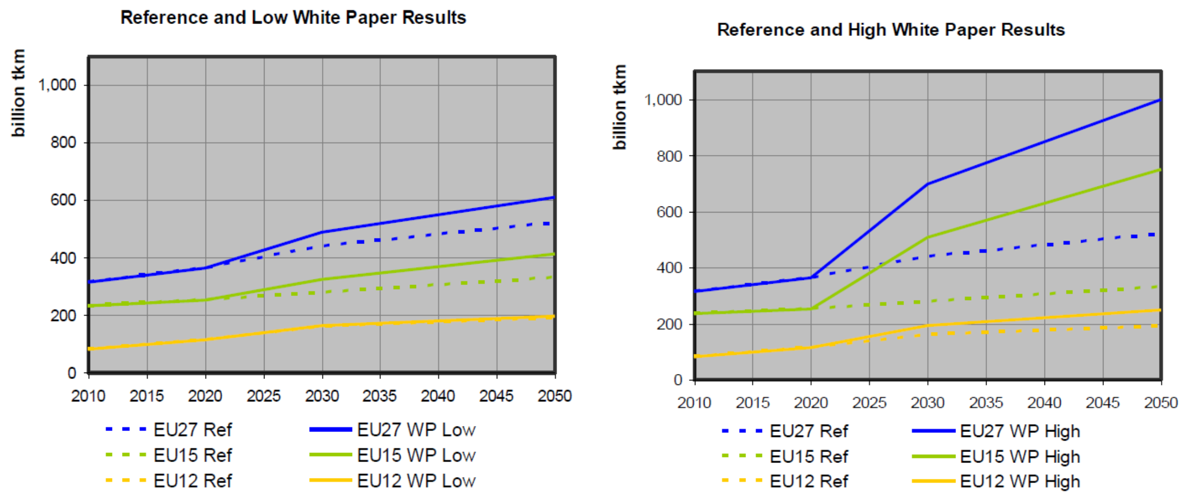


Figure 2:20: Rail demand for EU27, EU15 and EU12 in billions of tonne-km (D-RAIL, 2012 p. 39).

Forecasts for commodities from D-rail

The forecast suggests that the main volume of goods stems from the EU15 countries. We noted before that the particularity of the white paper scenarios is to incorporate a percentage of road goods for distances over 300 km, effects on the total demand, and its distribution as depicted below. The differences between the Low scenario and the Reference scenario are not significant, similar to the results in tonnes, as discussed before.

In contrast to the Low scenario in figure 2.21, in figure 2.22 the High scenario shows some changes. The main flows are for manufacturing materials, transport equipment and coal. The commodities whose share has shrunk are coal (8.3%) and metal waste (3.6%). But the actual demand for these commodities has either remained the same or increased slightly. This indicates that the shift in road demand does not concern these commodities. The main increase is observed for (containerised) transport equipment and foodstuffs, followed by chemicals and agricultural products. Hence, these commodities to a certain extent represent the demand transferred from road to rail.

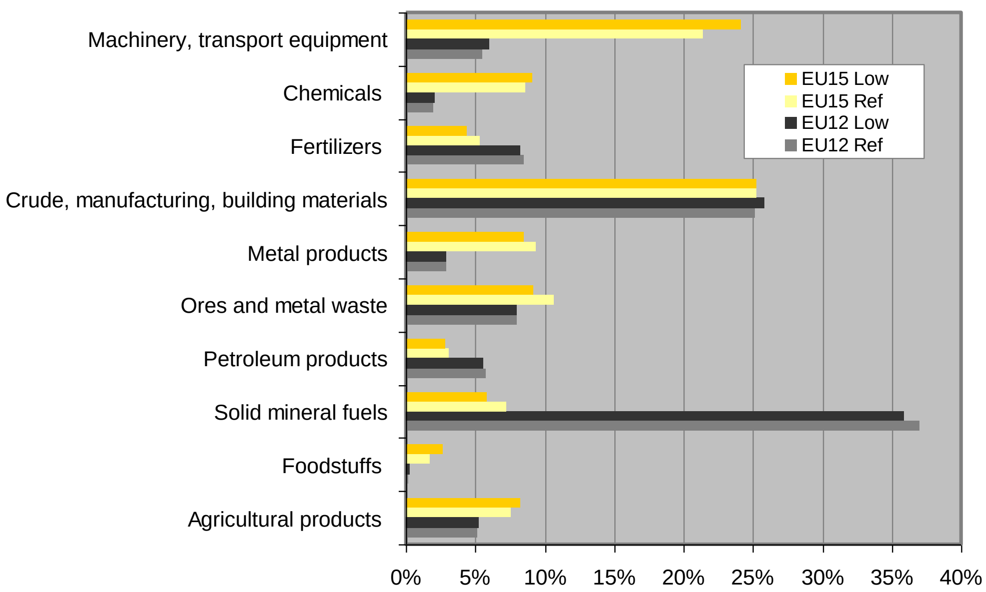


Figure 2:21: Commodities distribution for 2050 for White Paper Low Scenario in tonne-km (D-RAIL, 2012 p. 45).

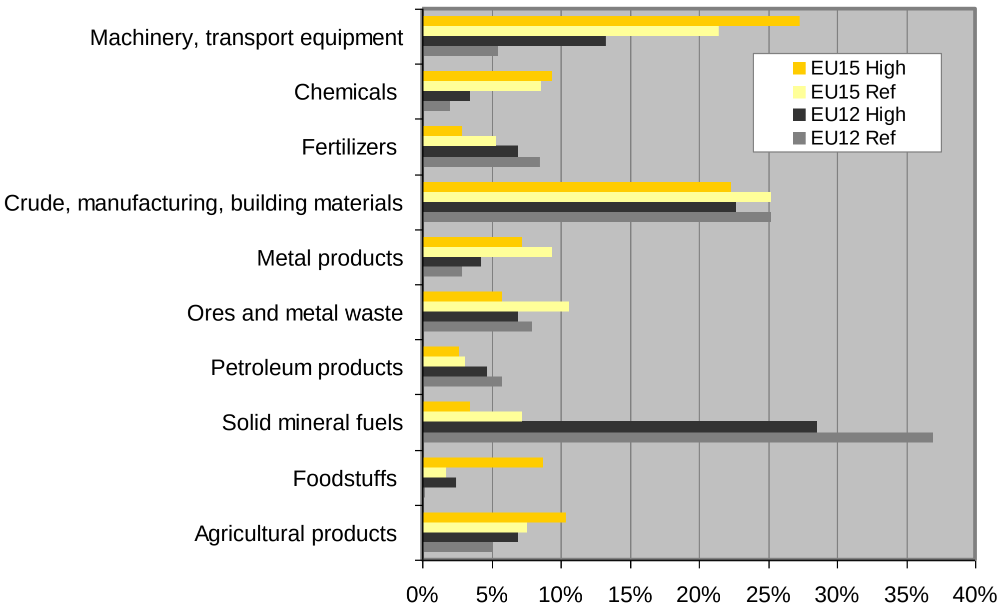


Figure 2:22: Commodities distribution for 2050 for White Paper High Scenario in tonne-km (D-RAIL, 2012 p. 47).

An important observed change is the share between EU15 and EU12. For both the Reference and the Low scenario, the split between the two clusters was 60% to 40%. The High scenario results in a split of 70% (for EU15) to 30% (for EU12). Therefore, the countries that mainly contribute to the modal shift in future demand are within EU15. On the other hand, the EU12 countries do not increase their traffic by more than 24%, with the exception of Slovenia (45%) which is strongly characterised by transit demand.

Forecasts of main rail flows on maps from D-rail

The D-rail forecasts are also assigned on the rail network on maps with flows in tonne-km and flows in tonnes. The maps with tonne-km have a structure which is easier to overview compared to the maps with tonnes, which are more detailed and contain much information.

Table 2.23 illustrates projections from the scenarios. The results in tonne-km do not include Denmark, Estonia, Ireland, Latvia, Lithuania, Luxembourg and Slovenia but include Switzerland and Norway. This explains why the rail tonne-km in 2010 is lower than in EU statistics; 316 compared to 391. This will be taken into account when comparing with other forecasts.

In the Reference and Low scenarios, growth is 65% and 99% from 2010-2050. Growth for the High scenario is more than double, 216%, that in the Reference scenario. The countries that show the highest relative growth are in EU15, with Germany and Italy still maintaining the highest positions. In EU12, the higher flows originate from Poland, the Czech Republic and Romania, representing 60% of the total EU12 demand.

However, the average distance in km by rail decreases in both the Reference and the Low scenario and only shows a slow increase in the High scenario. One explanation is modelling limitations.

Otherwise, a shift to rail for distances over 300 km should expect an increase in the average distance. Compare with the scenario in chapter 2.7.

The flows with highest demand are easiest to see in the tonne-km map for the High scenario in figure 2.25 to the right (in red). They mostly follow the planned RFC, which is not a surprise. There are big flows north-south in corridors from the middle of Sweden, Denmark and Germany to France, Spain and Italy. West-east, there are corridors from the Netherlands and Germany to Poland, Austria and Hungary and also from France via Italy to Austria and Hungary. Most of the corridors pass through Germany. Looking at the maps of tonnes in figure 2.27, the picture is not as clear, most rail lines in Europe seem to have a high load factor.

Table 2.23: Rail demand in tonnes and tonne-km for the scenarios in D-RAIL. Figures from the D-rail report (2012) calculated by KTH.

EU27 with some excptions	2010	2020	2030	2050	Increase 2010-2050	Growth per year	Shift from reference 2030	Shift from reference 2050
Rail demand in mtonnes								
Reference	1,040	1,260	1,590	1,902	83%	1.52%	0,000	0,000
Low White paper scenario*	1,040	1,260	1,650	2,067	99%	1.73%	0,060	0,165
High white paper scenario	1,040	1,260	2,307	3,224	210%	2.87%	0,717	1,322
Rail demand in btonne-km								
Reference	316	365	439	521	65%	1.26%	0	0
Low White paper scenario	316	365	488	611	93%	1.66%	49	90
High white paper scenario	316	365	699	1000	216%	2.92%	260	479
Average transport length								
Reference	304	290	276	274	-10%		0	0
Low White paper scenario	304	290	296	296	-3%		20	22
High white paper scenario	304	290	303	310	2%		27	36

*) This figure for tonnes 2030 is wrong in the report and has been estimated from the diagram

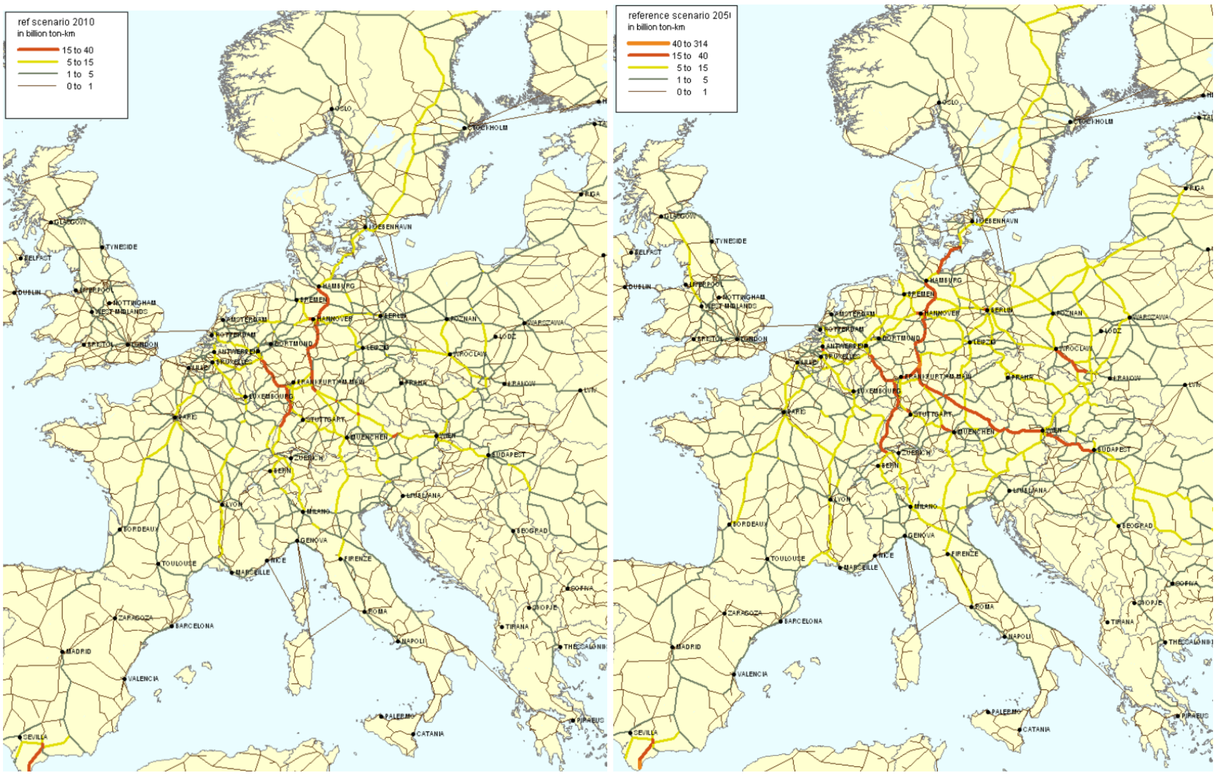


Figure 2:24: D-rail forecasts in billion tonne-km; Left: Reference scenario 2010 (4A), Right: Reference scenario 2050 (4D).

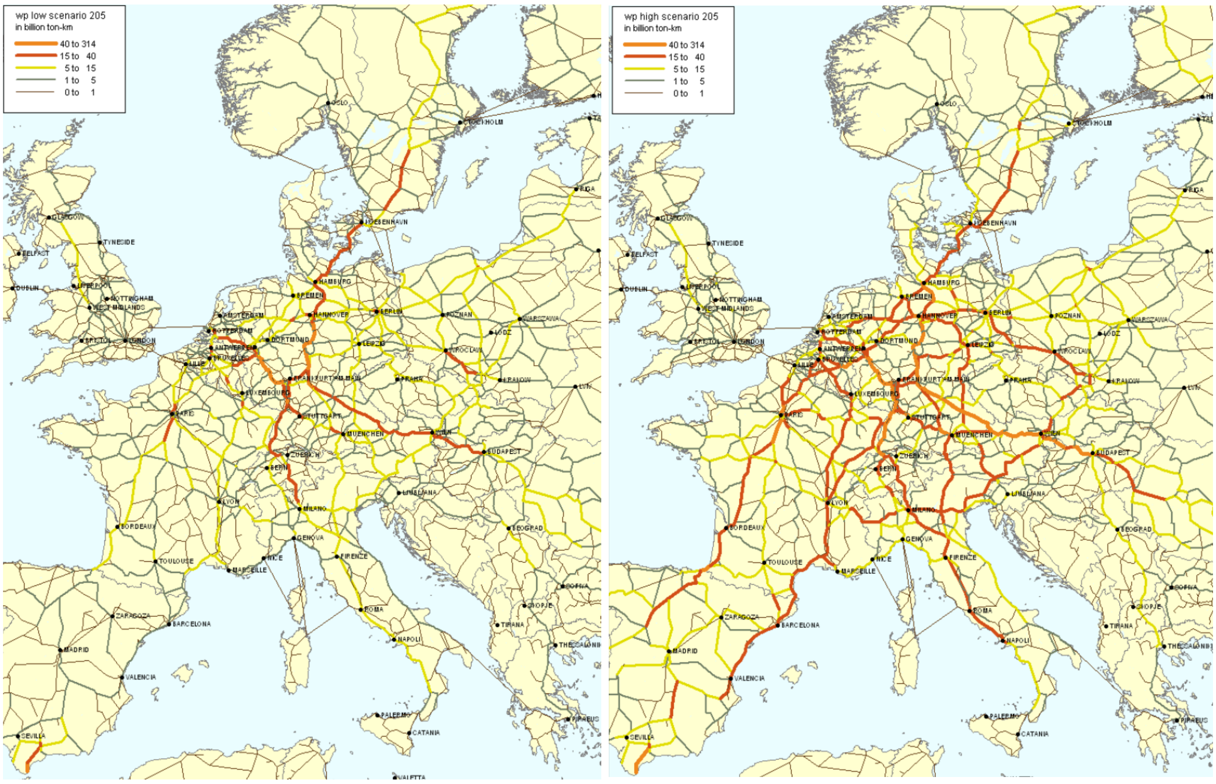


Figure 2.25: D-rail forecasts in billion tonne-km; Left: White paper low shift scenario 2050 (4F), Right: White paper high shift scenario 2050 (4I).

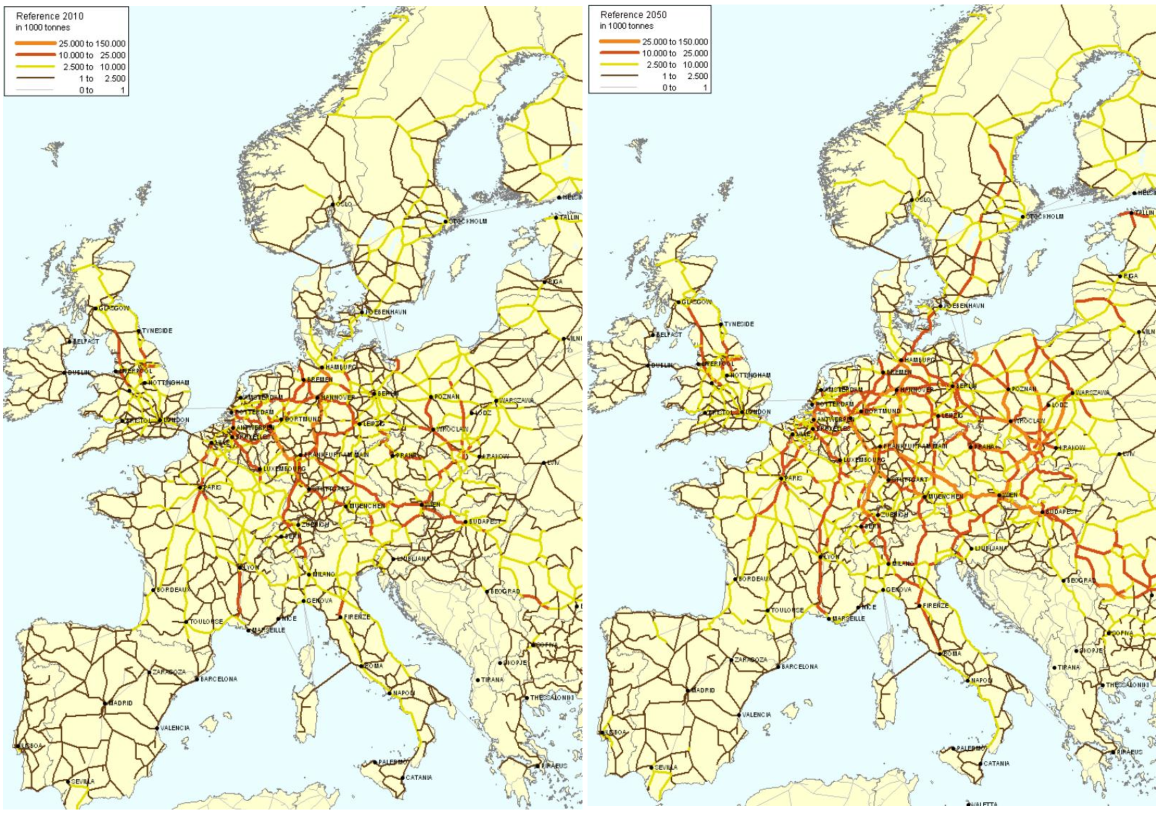


Figure 2:26: D-rail forecasts in tonnes; Left: Reference scenario 2010 (5A), Right: Reference scenario 2050 (5D).

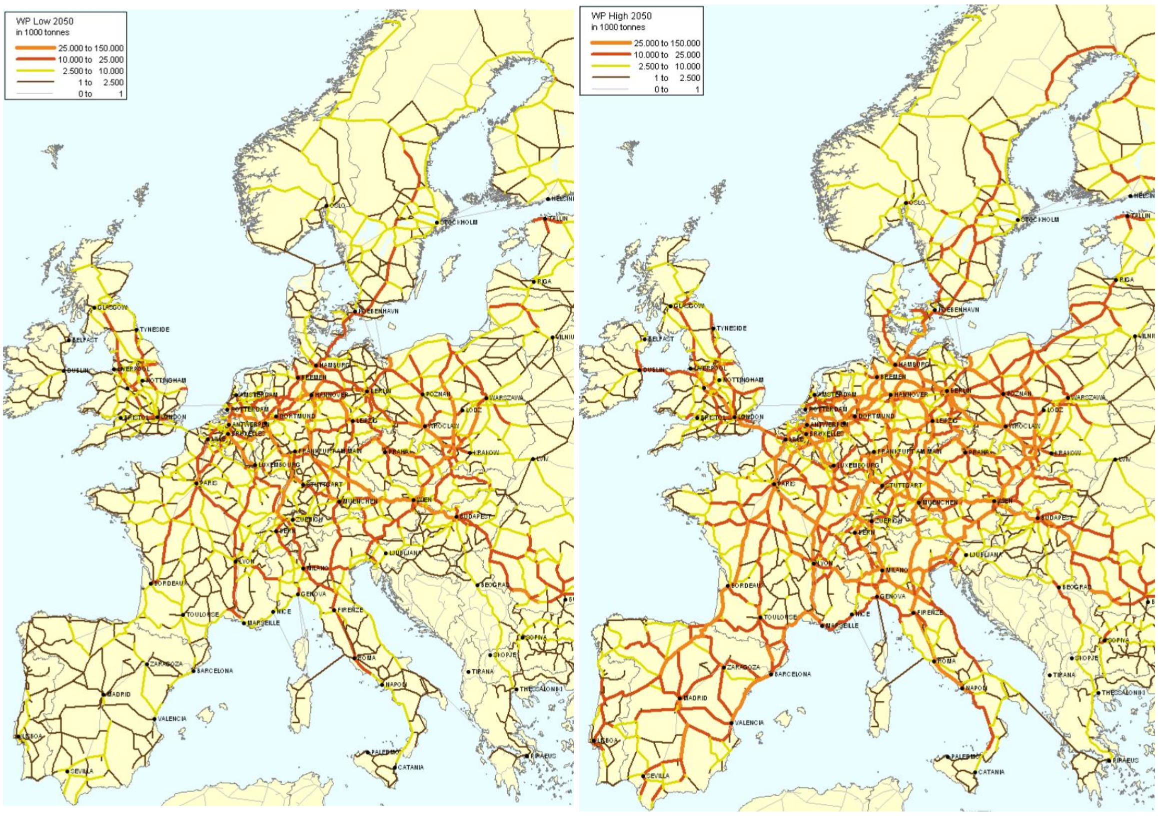


Figure 2:27: D-rail forecasts in tonnes; Left: White paper low shift scenario 2050 (5F), Right: White paper high shift scenario 2050 (5I).

Forecast for low density, high value goods (LDHV) from SPECTRUM

The SPECTRUM (2012) study aims to develop a rail freight train that provides a faster service for low density, high value (LDHV) and time sensitive goods with the performance characteristics of a passenger train. SPECTRUM takes a longer term, radical and first principles approach to deliver a new rail freight offering that can compete with road and air in the growing sectors of logistics where rail freight has traditionally had little to offer.

The transport demand analysis aimed to estimate the potential demand for LDHV goods in EU-27 and Switzerland. This has been done using freight transport statistics and existing macro models. The transport demand analysis was focused especially on road transport. This is the sector that currently transports the majority of the LDHV goods and from where the shift to rail transport could take place. The findings suggest the potential market for LDHV goods that are currently being transported by road over distances of 200 km or greater and that have the potential to be shifted to rail transport (it can be noted that the lower limit of the transport in the D-RAIL study is 300 km). The potential LDHV market in EU-27 and Switzerland was about 12% of total freight in 2009. This is almost 1.9 billion tonnes.

In 2009 a total of approximately 15 billion tonnes was transported by road in the EU-27 countries and Switzerland. Around 46% of these goods fall under the main NST/R categories relevant for this study (i.e. NST/R levels 0, 1, 5, 8 and 9) that can be characterised as LDHV. Figure 2.28 presents the share of transported LDHV goods per selected main NST/R category and as a total. The average share of LDHV goods within the total tonnage of the selected groups is approximately 56%. Most of the LDHV goods fall under the other type of products category, followed by foodstuffs. These are generally goods closer to the end consumers.

The most important countries/regions where the selected goods are transported by road are given in table 2.29. It shows a specialty pattern of specific industries found in each country. For example, for metal products, amongst others the automotive industries in Italy. Also for agricultural products, the agricultural sector in France. France is one of the world's leading producers and exporters of agricultural products and the leading agricultural power in the EU, accounting for about one third of all agricultural land within the EU.

LDHV goods transported by road totalled 3.9 million tonnes 2009 and this is expected to grow by 53% in 2030, reaching a volume of 5.9 million tonnes. This is a growth of about 2% per year on average. The transport by road of metal products and other types of products is expected to have the highest increase.

The total volume of rail freight transport in EU27 and Switzerland is estimated to increase from 1.1 billion tonnes in 2009 to 1.5 billion tonnes in 2030 with LDHV. It is expected that with the structural changes in the economy and demography, the transport of bulk commodities will decrease. The share of NST/R 9 in total rail transport will increase to a maximum of 7.3% in 2030, se table 2.30.

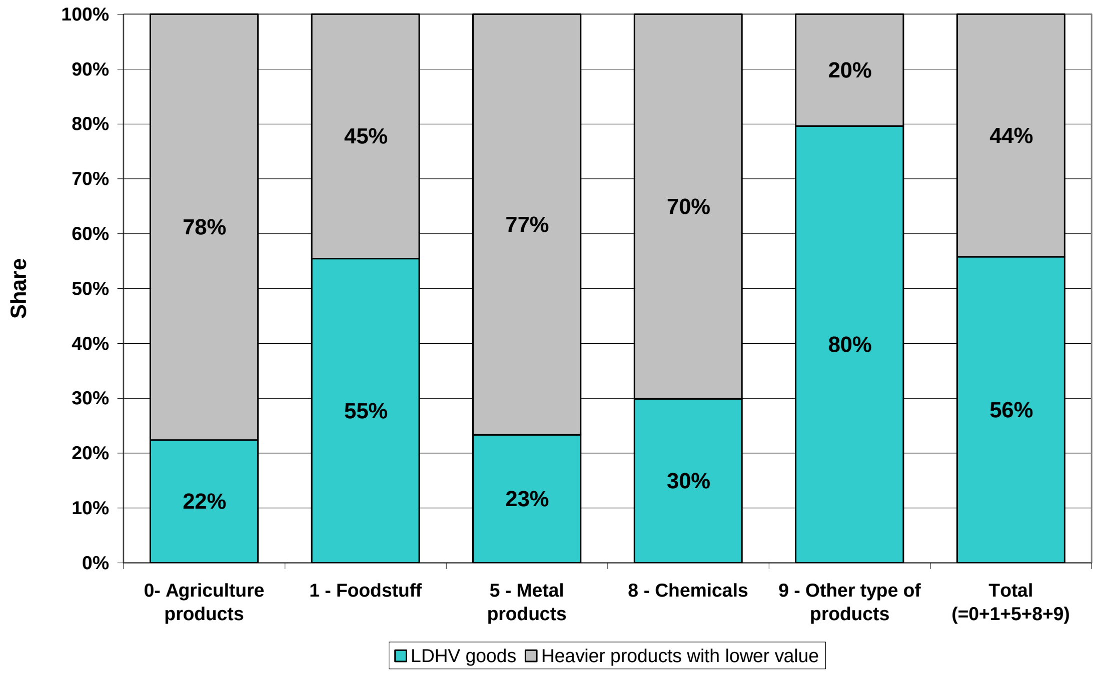


Figure 2:28: Share of selected NST/R categories of LDHV goods in 2009 (SPECTRUM, 2012)

Table 2:29: Most important countries/regions for LDHV cargoes (in 2009) (SPECTRUM, 2012).

Selected LDHV goods per NST/R category	Most important countries/regions where transport of selected goods takes place
0: Agricultural products	France, Finland, Sweden, Poland and Spain
1: Foodstuffs	Spain, France, Poland, UK and Germany
5: Metals	(Northern) Italy, Spain and Germany (around the Ruhr area)
8: Chemicals	The Netherlands, Germany, Poland and Italy
9: Other type of products	UK, the Netherlands, France and Italy

Table 2:30: Volume of total rail transport volume in EU27+CH in 2009, 2020 and 2030 in millions of tonnes. Source: SPECTRUM 2012

Millions of tonnes	**2009**	**%**	**2020**	**%**	**2030**	**%**
Total	1,078	100.0%	1,390	100.0%	1,487	100.0%
Index Total	100		129		138	
NST/R 9	54	5.0%	75	5.4%	108	7.3%
Index NST/R 9	100		140		201	

2.7. A mode shift scenario according to the EU white paper

The European Commission published a white paper in 2011 entitled Important goals and measures for the rail mode as follows:

- 30% of road freight over 300 km should shift to other modes such as rail or waterborne transport by 2030, and more than 50% by 2050, facilitated by efficient, green freight corridors.

The consequences for the transport sector and especially for rail of this target are important and in this chapter we will try to quantify the demand for rail when this is implemented.

A techno-economic analysis of opportunities and strategies towards climate-friendly transport is made in the EU-funded project TOSCA (Technology Opportunities and Strategies toward Climate-friendly transport, 2011). The conclusion is that technology improvements are essential, but cannot alone meet the EU targets for GHG reductions. Behavioral measures are also needed, such as reducing the need for transport and shifts towards low-emission transport modes.

A study by Boer et al (2011) deals with a shift from road to rail of freight transportation in the EU up to 2020. One conclusion is that there is a potential to increase the market share for rail from 18 to 31-36% and reduce GHG emissions by 19% of the emissions where road and rail compete.

In Nelldal-Andersson (2012) the consequences of a higher market share according to the EU target are calculated. The result is presented in next section.

Demand forecasts

The TOSCA total demand forecasts with modal split have been used. The redistribution and the resulting mode shift to rail are made under the assumption of a “best practice” rail system, with influences from the USA, Japan and Switzerland. The data used for mode shift calculation is the distribution by distance classes between rail and truck. Shipping was not included in this study.

The mode split has then been adjusted in different distance classes to what we have assumed to be a realistic share in the future according to the EU target with extended freight corridors with high capacity and seamless rail transport in combination with an improved intermodal transport system, see figure 2.31.

The result of the forecast is that the total transportation effort in EU27 will increase by 50%. With constant market share road transport will increase from 1,940 to 2,910 billion tonne-kilometres and rail transport will increase from 460 to 680 billion tonne-kilometres.

With increased market shares for rail from 19% to 46% for rail, road transportation will remain at the same level as 2007 with 1,940 billion tonne-kilometres. With a decrease in road market share from 81% to 54% at the same time, rail transportation will increase to 1,650 billion tonne-kilometres, which is 3.6 times as much as today and 2.4 times as much as the basic forecast, see table 2.32.

The average transport distance for rail in this forecast increases for from 304 to 499 km. This seems to be realistic according to the white paper ambition when most of the shift to rail from truck is on distances longer than 300 km. The tonnes transported by truck are still increasing substantially even if the tonne-km shows almost no increase. In this case, a rather simple method taking transport distances into account seems to give realistic results. Compare with the D-RAIL forecast in the previous chapter, which is made using more complex models but with decreasing or slightly increasing average transport distances by rail. On the other hand, D-RAIL has the advantage of being the only forecast that can present proper forecasts assigned to the railway lines on a map.

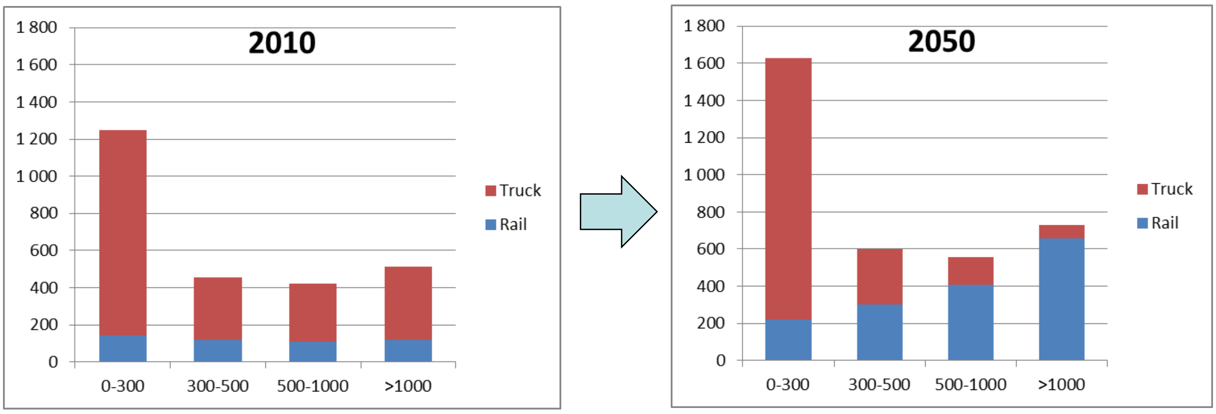


Figure 2:31: Mode shift according to the EU white paper. The market share for rail of the rail-truck market increases on distances more than 300 km. Source: Processing of data from TOSCA forecasts with Transtools at KTH.

Table 2.32: Freight market, baseline forecast and rail best practice scenario (KTH).

Freight tonne-kilometres billions	2010	Increase 2010-2050 Baseline	Increase 2010-2050 Mode shift	Difference Mode shift/ Baseline	Market shares 2010	Market shares 2050 Baseline	Market shares 2050 Mode shift
Trucks	1 881	1,53	1,03	0,67	81%	82%	55%
Rail freight	441	1,43	3,59	2,50	19%	18%	45%
Sum	2 322	1,51	1,51	1,00	100%	100%	100%

Are the EU targets realistic?

The total road-rail market is the same as in the basic forecast but the modal split between the two modes has been taken from “best practice”. As have been shown in chapter 2, rail’s market share is higher in the US than in Europe. There are of course differences in the US and the EU markets. The US market is a market without borders and the US railways can cross borders without any difficulties and they are very efficient. This is not the situation today in the EU but that is what EU policies are looking for, so this can be a future scenario.

There are heavy unit trains moving for example fracking gas and coal long distances in the US. They account for about 25% of the tonne-kilometres of the railways. But also in Europe, there are unit trains, mostly for coal and iron ore, and they account for 27% of the tonne-kilometres in Europe. This is a kind of de facto monopoly. Trucks also have a de facto monopoly on shorter distances (less than 100 km) which account for approximately 10% of the tonne-kilometres by truck. It would have been desirable to take this into account but it was not possible at this stage.

The average transport distance by rail in Europe is only 257 km compared to over 1,470 km for Class 1 in the US in 2010 (Furtado 2013). This is to some extent a statistical failure because international transportation is calculated inside each country. Looking in more detail at Sweden, where we have much data, we can see that the market shares for international transportation are only half of the market share for domestic transportation, despite very long distances and large volumes. This means that with a deregulated railway the market share for international transportation will increase, as will the average distance calculated from origin to destination, even if it will not be as long as in the US.

The modal split between road and rail freight in the US is 41% road and 59% rail. This may seem to be a very high market share for rail. The same modal split in EU-27 was 81% road and 19% rail. The highest market share in the EU was in Sweden with 64% road and 36% rail in 2007. However, in Switzerland, outside the EU but inside Europe, the road-rail market share was 46% road and 54% rail. In this case, the market share also is affected by road charges.

For Sweden we have produced a very detailed forecast for a deregulated railway with high capacity. This has been done by changes in costs and transportation times for different commodities and OD-pairs. The forecast resulted in a 54% road and 46% rail share. We have used this market share as a best practice for Europe for 2050. We think this is the most appropriate estimate at this stage, also taking into account differences between the US and Europe.

The increase in rail transportation with mode shift is 3.0% per year. Between 1995 and 2007 road freight transport in Europe increased by 3.4% per year on average, and before this the increase was even higher. So, in a long-term perspective this kind of development is not impossible.

Regarding the capacity, construction of a high-speed network will free capacity so it will be possible to operate twice as many freight trains on the conventional network as today. With longer freight trains, a doubled length from 750 to 1,500 metres as in the Marathon project, capacity will be doubled again (in the US, freight trains today are 3,000 metres). Higher axle loads, from today's normal 22.5 tonnes in Europe to 25 tonnes will increase capacity by 15% and 30 tonnes by 30% (in the US, the axle load today is 35 tonnes). Capacity measures will be described in more detail in chapter 5.

A three to four-fold increase in capacity is thus not impossible but assumes investment in rail infrastructure. On the other hand, there will not be so much need for investment in the road system for heavy trucks.

2.8. Rail freight corridors and network

There are many kinds of rail freight corridors in Europe; time-table corridors with "one stop shop", the TEN-T-network, the planned ERTMS corridors, The Rail Net Europe corridors and the New Opera corridors. The aim is to prioritise slots for freight trains in the short term and build a network with high capacity, long trains and high axle load in the future.

TEN-T Network

The new EU infrastructure policy will put in place a powerful European transport network across 28 Member States to promote growth and competitiveness. It will connect East with West and replace today's transport patchwork with a network that is genuinely European. The core network will be established by 2030.

The new policy establishes, for the first time, a core transport network built on 9 major corridors: 2 north-south corridors, 3 east-west corridors and 4 diagonal corridors. The core network will transform east-west connections, remove bottlenecks, upgrade infrastructure and streamline cross-border transport operations for passengers and businesses throughout the EU. It will improve connections between different modes of transport and contribute to the EU's climate change objectives.

Financing for transport infrastructure will triple over the period 2014-2020 to €26 billion. This EU funding will be tightly focused on the core transport network where there is most EU added value. To prioritise east-west connections, almost half the total EC transport infrastructure funding (€11.3 billion from the Connecting Europe Facility, CEF) will be ring-fenced only for cohesion countries.

Rail Freight Corridors – RFC and Rail Net Europe - RNE

Six international rail freight corridors became operational on 10 November 2013 and three more in 2015. These will foster international freight transport by rail, making this transport mode more competitive. Within the six corridors, rail infrastructure managers (IMs) cooperate across borders in order to markedly improve service quality and reliability. Freight trains will benefit from high-quality train paths with attractive journey times and common punctuality targets.

In the Rail Freight Corridors (RFCs), railway undertakings and applicants such as shippers, freight forwarders and combined transport operators can request pre-arranged, cross-border train paths at a single contact point, instead of having to submit individual requests to several national infrastructure managers (IMs) – this will lighten their administrative burden and speed up proceedings.

The six corridors are the Rhine–Alp Corridor, the North Sea-Mediterranean Corridor, the Atlantic Corridor, the Mediterranean Corridor, the Orient Corridor and the Eastern Corridor, see figure 2.33. Since there is much overlap between RNE's own corridors – of which the first eight were launched as early as 2005 – a transition phase has begun. During this phase, some RNE Corridors are being merged into the future network of Rail Freight Corridors: where an RFC matches an RNE Corridor, the function of the RNE Corridor Manager will be integrated in the RFC organisations' tasks in order to avoid any work duplication. In other cases, RNE Corridors will continue as they are. Current RNE Corridors 2, 5, 6, 8, 9 as well as parts of 10, are being replaced by RFCs 1, 2, 4, 6, 7 and 9.

Yet for parts of the European rail network where no new corridor organisation is planned yet, RNE is maintaining its RNE Corridors for the benefit of both the Infrastructure Managers and their customers. RNE Corridors bring quick wins, for example a tried-and-tested service portfolio that can be adopted with little effort by the involved parties. They may also help Infrastructure Managers to get acquainted with the requirements of any future RFC membership.

The six new corridors will be complemented by three other RFCs (Scandinavian-Mediterranean, Baltic-Adriatic and North Sea-Baltic) ¬– set to become operational by 10 November 2015.

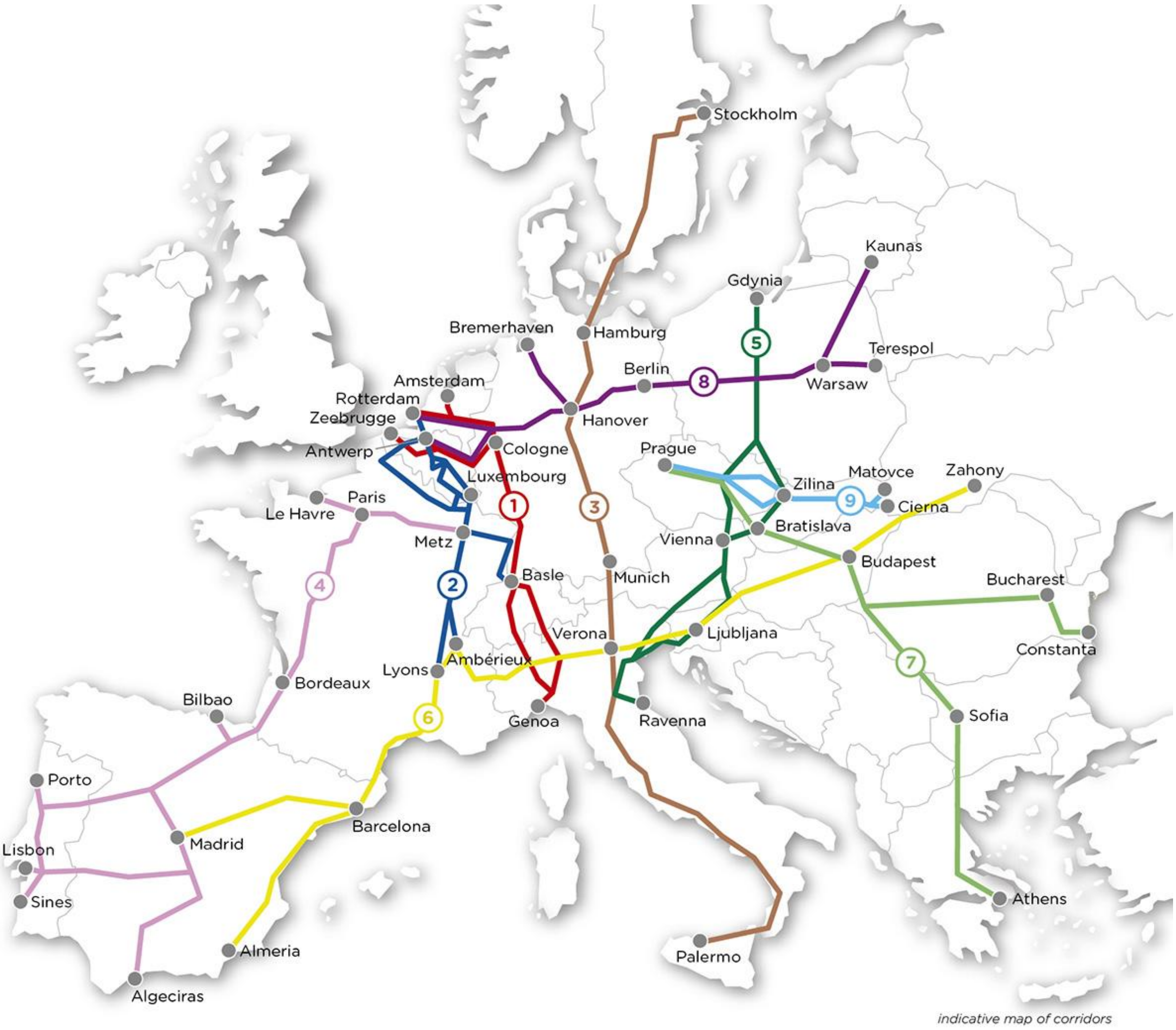


Figure 2:33: Rail Net Europe Rail Freight Corridors. Source: RNE, 25 November 2013.

ERTMS corridors

The European Rail Traffic Management System (ERTMS) is intended to replace more than 20 different national train control and command systems in Europe, which are a major technical barrier to international rail traffic. ERTMS introduces considerable benefits in terms of interoperability, maintenance cost savings, increased safety and increased traffic capacity. By making the rail sector more competitive, ERTMS helps to level the playing field against road transport and ultimately provides significant environmental gains. There is an estimated 33,000 km of railway tracks contracted to be equipped or are already operating with ERTMS in the world, nearly 50% of which are outside the EU.

Together with railway stakeholders, the European Commission has established a list of six priority corridors for the deployment of ERTMS, see figure 2.34. These are major European rail freight axes, where the deployment of ERTMS will bring considerable benefits:

– Corridor A runs from Rotterdam to Genoa;

– Corridor B: Stockholm-Naples;

– Corridor C: Antwerp-Basel;

– Corridor D: Budapest-Valencia;

– Corridor E: Dresden-Constanta;

– Corridor F: Aachen-Terespol.

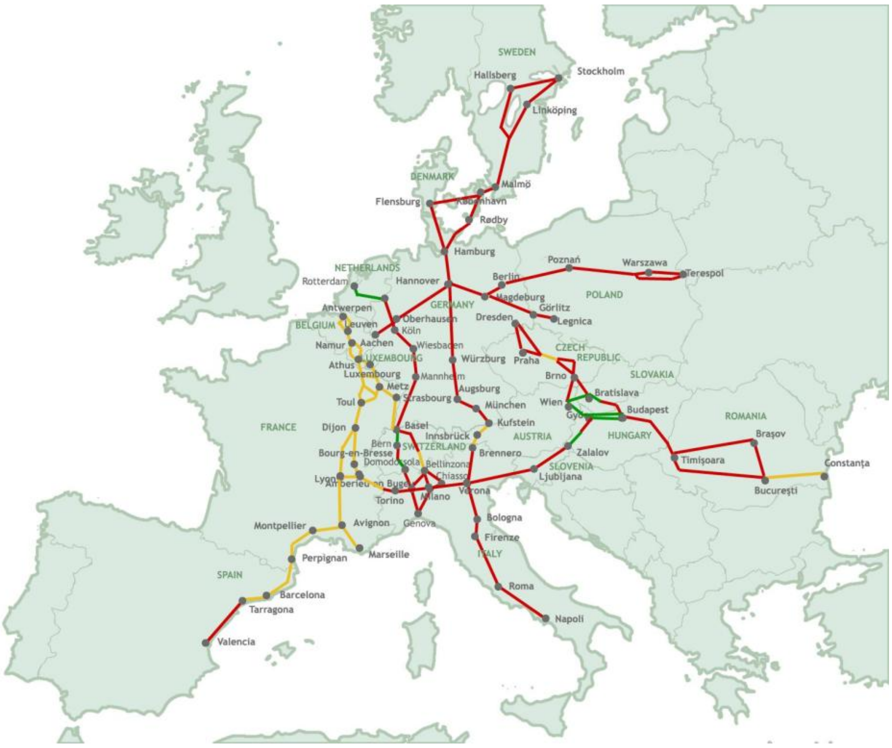


Figure 2:34: ERTMS corridors in Europe. Source: Unife, ERTMS news.

3. Customer requirements for different goods segments

3.1. Customer requirements and mode choice

The role of rail freight transport in the door-to-door services

Rail freight transport is not expected to develop in the EU to the extent necessary to be in line with the sustainable development targets fixed by the Commission. Various reasons explain this evolution. The market has changed from large quantities of bulk being transported by block trains to smaller shipments, more frequently and with a higher value. The development of the single market, regularly extended to new member states joining the EU, has boosted international traffic facing a lack of interoperability at the borders very slowly overcome by technical and administrative harmonization and standardization. The development of regional traffic is associated to a lack of investment in rail infrastructure but for passenger trains high-speed lines have created bottlenecks inducing uncertainty about the reliability of ETA impacting supply chains. Relatively few freight villages have emerged allowing industrialization of rail transport, more collaborative approaches and thus more competitiveness to face an ever more efficient road transport. Lack of innovation, delay in introduction of ICT facilitating access to the rail mode have also hindered development. But the lack of coordinated urban planning to create powerful industrial clusters shows that authorities in certain countries are not very conscious of the importance of rail freight transport for the future.

Rail freight service industry structure

Largely developed on a domestic basis with powerful incumbent railway undertakings, the industry has not developed the necessary collaborative or integrated approach at European level because of the multiplicity of actors in the multimodal supply chains having at times opposing interests. This situation coupled with high barriers faced by new entrants has not boosted the development of industrialized trans-European services answering market needs. Moreover, no modern studies of this market to anticipate its evolution have been introduced on a large scale in this rail world dominated by incumbents more preoccupied by the protection of their market share than introducing new business models to face the changes in demand.

The bundling of the various categories of traffic (bulk, wagonload and combined transport), the creation of efficient nodes to face the bottlenecks by optimizing the use of all existing infrastructure, the development of fully interoperable trans-European corridors with a powerful governance and a coordination with national infrastructure managers progress too slowly. Overcoming the patchwork of national safety rules through powerful action by the ERA is progressively arriving at an urgent need to increase the pace. A multi-channel distribution strategy and logistics engineering must enter this very conservative rail world. **All these elements have hindered the introduction of rail links in supply chains which are as weak as their weakest link**.

The nodes concept

The nodes concept encompasses various types of terminals like hubs, marshalling yards, freight villages, sea ports, dry ports, intermodal, conventional, multimodal terminals and industrial and logistics zones. They have to be close to a production and/or large consumption area and at corridors' crossing points. They have to transform transit round the clock into value-added transit by quick transfer between modes or from train to train, allowing through its efficiency a high filling coefficient of the trains or of the last mile transport, a high degree of reliability for the end customer a capacity to find the best connection to reach the end terminal through their integration in the whole network. They are key elements in network management efficiency. They can also increase their added value by offering ancillary services and through good synchronization between the arrival of the transport vectors (long and short haul trains, truck, barge, airplane) the operations on the node and the departure on the next transport vector which can be the last mile delivery. Their function for ICT integrators, for customs clearance and for information dissemination to interested actors is paramount. Their financing may be more related to private funding or PPPs, thus alleviating national budgets. The design of the node is essential to avoid useless and high costs for transfere between terminals.

The Freight Dimension- the long distance freight competitive profile.

Long distance freight classically favourable to rail is usually segmented according to traffic aggregation and types of wagons but cargo characteristics and customer needs are not fully considered. Industrialized shuttle trains can be relevant for short, medium or long distances if operations are properly planned and synchronized. For long distance traffic across Europe, interoperability and removal of bottlenecks on the routes are paramount. Along the corridors, unified governance is essential with a close coordination with local infrastructure managers. Through the nodes and with ICT integration and a unified management of the network, efficient co-modality can be implemented. Efficient train management to preserve efficient freight paths in-between faster passenger trains is fundamental for the competitiveness of rail freight and a desired modal shift for sustainable transportation. Capacity management on the trains could also enhance competitiveness, specifically by developing a cooperative approach between the sector's key actors. As regards the assets, their utilization could be largely increased through progress in standardization and modularity across all modes where intermodal units are concerned.

The freight dimension – Short distance freight, city logistics, role and competition with other modes

Short distance transport represents a challenge for rail freight transport. However, if large quantities are concentrated, as at ports, shuttle services are for example very competitive towards dry ports.

For city logistics, the evolution of the needs of the urban population in development and the congestion and pollution problems are favourable factors for rail. If logistics areas for distribution are preserved in city centres, very silent trains should reach them for a last mile delivery by electric road vehicles (even at night with high productivity) or using the underground network or even tramways or inland waterways. This will create innovative business models instead of the overwhelming solution of delivery by truck, which is being increasingly subjected to stringent constraints.

Information and Communication Technology and services

The rail mode is not a leader in term of introduction of ICT. Its development has mainly taken place on a national basis with a great lack of interoperability. At the same time, ICT is based on huge infrastructure investments and the operators have developed proprietary systems that are not easy to interconnect efficiently. Moreover, the high safety priority in rail is leading to the development of a European positioning system (Galileo) but which is slow to be developed. Furthermore, some governments have not considered ICT development to be a top priority. Accessibility to the rail mode is very poor as regards freight offerings and in any case longer than accessibility to the road mode. These developments have been hindered by the conservative attitude of incumbents protecting their markets, by the low profitability of rail freight transport, and by the necessary training in the use of ICT. These gaps must therefore be bridged if rail wants to participate efficiently in the necessary modal shift. A unified train management of the corridors with a one-stop shop and good coordination with national IMs will be based on ICT. Its development must therefore become the first priority of the rail mode's actors and the authorities.

Summary of the findings

Customer needs can be summarized in a few points: a competitive cost for a reliable service easy to access giving accurate information in real time on the Estimated Time of Arrival (ETA) adaptable in a short time to the variations in volume that now occur quite suddenly.

They also want to reduce inventories, which means just-in-time and short transit times. In a European world where road is predominant, the target KPIs are given by the road modality. Of course it is possible in the long term that more external effects will be integrated in road costs and that congestion in the road network will increase with growing difficulties in creating new infrastructures with the development of the NIMBYs. But these evolutions will be slow in order not to deteriorate European competitiveness. In cities, the evolution may be quicker with rapid climate change and some heavy pollution, compelling the authorities to impose restrictions on road movements in cities.

So rail has opportunities and the system proposed in the findings relies on very clear actions:

- Serve the long-distance traffic with a network of corridors and nodes, with a unified traffic management giving sufficient priority to freight trains to respect the reliability criteria, development of interoperability, standardization of the rolling stock, efficient management of train capacity based on the bundling of traffic, a collaborative approach on the part of decision makers (shippers, forwarders, ship owners, etc) and managed with an efficient information tool working across various modalities to ensure good synchronization of operations and give accurate ETAs. The best use of the infrastructure capacity being paramount, lengthening of the trains is an interim solution until the implementation of ERTMS level3.
- Serve the short-distance and medium-distance traffic with shuttle trains to offer industrialized services to nodes where transfers are fully optimized and synchronized with train arrivals and departures. Increase in added value services will enhance competitiveness. Growth of intermodal traffic with more standardized intermodal units will be strong and automation at terminals will have to be developed. Innovative transfer technologies from rail to rail or rail to road and vice versa will be necessary, as will new wagons capable of carrying P400 trailers which can be lifted by grabs or rolled on and off to be inserted in classical combined transport trains.
- Serve city logistics through the development of very silent wagons reaching platforms inside cities for a short, efficient last mile service by environmentally friendly trucking.
- All these services will require technological progress on the wagon, its braking systems, its couplings, its sensors, and the train positioning and information systems for the

management of the traffic, of the train capacity and of the information required by the clients.

A gap analysis is presented in table 3.1.

Table 3.1: Gap impact analysis for passenger and freight trains. Source: Spider Plus Project.

			Passengers			Freight		
Action area	Issue category	Issue sub category	relevance to door to door	impact - medium/long distance	impact - local mobility	impact - door to door	impact - long distance	impact - medium/short distance
ACCESS	Bottlenecks	limits of capacity						
		congestion in urban areas						
	Interconnections	rail infrastructure in traffic nodes						
		urban/territory planning						
	Interoperability	technological standards						
		cross border acceptability						
	Regulatory frame & governance	single country - single mode regulatory frame						
		co modal governance						
SHIFT	Offering structure	service integration						
		unsegmented service model						
	Loading factor	marketing						
		capacity management						
	Sustainable solutions/ Renewable sources	investments supporting changes						
		awareness for sustainable solutions						
IMPROVE	Effectiveness	industrialization						
		business model						
	Service quality	flexibility & reliability						
		competition/ liberalization						

3.2. Customer requirements in different market segments

Generally speaking, rail freight transport becomes favourable for high volume low value (HVLV) cargo such as coal and ores. One important reason for this is that the shippers look for lower transport cost rather than faster and reliable transit times. These types of cargo can also generally use a less-reliable transport service. By contrast, the shippers' requirements for non-traditional cargo, e.g. high value low density (LDHV) cargo, differ significantly. Apart from the transport cost, the transit time is very important for this type of cargo. Some of the goods carried are also time-sensitive and require temperature control, for example fish, fruit and vegetables. SPECTRUM (2012) suggests that a delay in delivery and distribution of goods is a serious weakness in some market segments such as the food retail sector. If these goods are not delivered on time, there is a bigger chance that they cannot be sold at all. A new rail freight service should therefore focus on these issues and be able as a minimum to match the service and product offerings of the road transport sector.

SPECTRUM (2012) suggests that for intermodal door-to-door rail freight transport, there is often a lack of technical, operational and administrative interoperability and coordination between countries (such as different energy and signalling systems, time-consuming paperwork at border-crossings and lack of or inadequate communication with the border staff). This increases the chance of experiencing delays, resulting in unreliability.

The SPECTRUM study (2012) identified the following most important shipper's requirements for LDHV cargo (in order of importance):

- ***Reliability of service:*** intermodal rail transit time has to be competitive with road. However, consistently and unfailingly reliable transport (i.e. arriving at the agreed time) is for many shippers even more important than the transit time itself. This is especially the case in the automotive industry, which is the industry with the largest share of 'just-in-time' (JIT) and 'just-in-sequence' (JIS) deliveries. The electronics industry (especially end products) is also highly organised with JIT production structures. The critical issue with these types of deliveries is not the speed of the delivery, but the reliability of the transport.
- ***Costs of door-to-door delivery:*** rail transport is often, but not always, more expensive than road transport, especially for relatively short distances. In general, low overall costs can be reached when combining rail volumes in a corridor and more intensive use of the rolling stock and traction assets.
- ***Service availability:*** service availability at the origin point seems to be just only slightly more important than at the destination point.
- ***Safety and security:*** reducing the chance of losses, theft and damage. This is especially important for the transport of high value goods. In general, rail freight transport has a competitive advantage over road transport with regard to safety (less chance of shifting in wagons) and security (less chance of theft).

The SPECTRUM study (2012) also suggests that potential customers (those who are not currently using rail freight transport) want to see more flexibility in logistics processes in order to meet changes in demand (e.g. re-route and/or create additional capacity). However, rail transport operators at present offer limited flexibility in reserving additional or reduced train capacity in a short time frame. For such additional service the operators will have to get very short-term train path allocation that can be costly and uncertain due to already congest network capacity and is likely to be an increasing service requirement. Shippers want to **reduce the complexity** of their transport chain. Intermodal rail transport creates additional complexity from an operational point of view, if the rail freight is not integrated with the transport chain as a partner of the supply chain. This complexity can be resolved by involving freight operators or system integrators who use intermodal rail transport and guarantee a certain service level. The use of more "friendly" service arrangement packages (e.g. Freight Arranger) to identify available services, space availability, schedules and pricing should help to ease this concern and also bring rail into line with competing modes (SPECTRUM, 2012).

Other customer requirements include more ***regular rail freight services***. SPECTRUM (2012) suggests that there is often no ***track-and-trace*** equipment available on trains, resulting in trains that cannot be found (when necessary) and difficult real-time communication with the rail service providers. Clients want to be informed quickly when there are delays in the service and the actions to respond to the disruption that are taken. This can be done using tracking and tracing and other real-time communication equipment. Tracking and tracing are vitally important for the transport of containers and swap bodies. In addition to track and trace, condition monitoring and security issues need to be addressed to position rail at a level where it can compete on product and service grounds with the road transport sector.

3.3. Rail products for different markets

Market requirements vary for different commodities and rail has to meet the demand with different products. The demands for some different commodity groups are specified in the form of transport time requirements, frequency and rail's main products in table 3.2.

For commodities transported between different industries and warehouses, these are normally produced during the day and shipped overnight, preferably with daily departures. In international traffic, however, the daily rhythm is somewhat different. Prices must generally be low because these goods are not normally highly refined. This means that substantial capacity is needed as regards weight or volume. Capacity requirements vary.

For freight transported to the process industry, continuous departures are often more important than overnight transportation. This is high volume system transportation, which means that prices are low. The capacity required is at least as high as for the basic products. On the other hand, precision must also be high.

Distribution shipments of finished goods to warehouses or direct to the consumer can be divided into two groups. One group has the same transportation time requirements as the basic products but demands higher quality, for example in terms of handling, cargo securement, temperature, etc. and has a more disparate structure. The requirement for overnight transport is more precise and often concerns the period between 5 pm and 7 am.

Lastly, there is an express freight market, e.g. for spare parts, where the requirements coincide with those of the passenger trains, i.e. high average speed, high accessibility during most of the day (high frequency of service) and broad geographical coverage of the market. Compared to normal freight transportation, the price levels in this market are relatively high.

The freight transport system can be divided into the following main products with regard to market and production system: Wagonload traffic, Unit trains, Intermodal traffic and High-speed freight trains, see table 3.2.

Wagonload traffic

Wagonload traffic is the oldest product and has for a long time been the basis of the railways' freight traffic system. Principally, it meets the base market's need to transport raw materials and semi-manufactures. It comprises the transportation of whole wagons that are loaded and unloaded by the customers at industrial sidings or on team track platforms. Wagonload traffic may consist either of single wagons or groups of wagons. The wagons are often marshalled twice or more during their journey. Where the sender or the recipient has no industrial spur, the goods transported by rail can be reloaded to road haulage.

Unit trains

Unit trains are freight trains that form part of customised logistics systems where the railway functions as a conveyor belt for industry. Each unit train is operated for a specific customer with dedicated wagons and according to their own timetable. Unit trains use basically the same technologies as wagonload traffic, but unit trains allow the railway's economy of scale to be exploited to the full. Typical loads are iron ore, raw timber, steel, wood chips, peat, oil, and paper.

Intermodal traffic

In inter modal traffic, rail is used for the long-distance haul between the terminals and trucks for the short-distance feeder transport. For easy handling unit loads are used as containers, swap-bodies or semi-trailers are used. The wagons mostly travel directly in separate trains directly between the intermodal terminals. Shipping container traffic to ports and trailer traffic to ferry berths is extensive. Intermodal transportation also means that several small shipments can be consolidated.

Express freight

Express freight can consist of time-sensitive goods such as post or parcels and small consignments up to a pallet in size. Transportation is generally 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. Some trains make scheduled stops along the way for loading and unloading. The trains generally consist of freight cars based on passenger rolling stock

Development

The general development in Europe in recent decades has been that wagonload has decreased and unit trains and inter modal have increased. In some countries, wagonload has been abandoned, and in other countries it has been concentrated to fewer customers and more groups of wagons instead of single wagons. Intermodal has increased, especially to and from ports in line with containerization and increased world trade. Express freight is a marginal product and only exists in some countries.

Table 3.2: Different market segments, customer requirements and main rail products. Source: KTH.

Market segment	*Time requirement*	*Frequency*	*Rail main product*	*Cooperate with*
Bulk freight - raw materials	less than 24 hours	continous	unit trains	shipping
Basic market - raw materials - semi manufactures	Domestic: 0-1 days International: 1-3 days	daily several/week	wagon load	shipping
Product market - semi manufactures - finished products	over night 17:00-07:00	daily	Inter modal	truck
Service market - mail, parcels - Express freight	over night same day	daily several/day	Express freight train	air cargo truck delivery

3.4. Rail and intermodal competitiveness compared with other modes

There has always been an effort to make all modes more efficient by incremental changes to gain customers. Sometimes big steps are taken that affect the market substantially. In this chapter the effect of longer trucks will be analysed because there are suggestions for longer and heavier trucks in Europe.

- In Germany and other countries from 18 m truck to a longest 25,25m mega truck
- In Sweden from 25.25 m to at longest 32 m DuO2 truck, se figure 3.5.

The cost per TEU with a standard train and the three different wagons including terminal handling and feeder transports has been calculated. The wagons are Sgns (4 axle 60 ft wagon), Sgrss (6-axle 40+40 ft wagon) and the VEL wagon (80 ft 4-axle wagon). The result is shown in the form of diagrams with cost according to distance at 0-1000 km. Distance is important for two reasons:

1. There is a rank-size rule about transport distances and transport volume that means that the shorter the distance the bigger the volumes in tonnes that are available on the market.
2. It is also possible to identify the break-even-point according to distance compared with direct trucking or other modes.

With this it is also possible to analyse the consequences of more efficient wagons as well as more efficient trucks for competition and cooperation between modes.

The total market in tonnes for different distances in Sweden shows that on the distance 300-400 km there are approximately 4 times as many tonnes on the market as on the distance 600-700 km. So the distance where intermodal is competitive is important to get enough volumes to fill the trains and achieve sufficient frequency.

Between 1987 and 2008 trucks in Sweden increased their market share by about 10 percentage points on most distances up to 900 km. One reason for this is that the gross weight for trucks in Sweden was increased from 51.4 to 60 tonnes around 1990 and the payload increased from approx. 30 tonnes to 40 tonnes. This means that the cost of transporting heavy goods by truck decreased by approximately 20% and because customers are price-sensitive they choose truck instead of rail in some cases.

Figure 3.3 show the transport cost per tonne for an intermodal transport chain with 20 ft containers compared with an 18 m EU truck and a 25.25 m truck calculated with Swedish costs. The 25.25 m truck can load 3 TEU instead of 2 as on the 18 m truck, which makes it much more efficient. In this case, the longer truck will push the break-even point for intermodal from approximately 350 km to 500 km. The effect of more efficient freight wagons is approximately 50 km in this case.

Figure 3.3 also shows the transport cost per tonne for an intermodal transport chain with a 25.25 m truck with 3 TEU compared with a 32 m experimental truck in Sweden with 4 TEU. The longer truck will push the break-even point for intermodal from approximately 500 km to 600 km. The VEL wagon in itself can increase the available market by reducing the break-even point for intermodal from 550 km to 500 km compared to transport with the normal wagon types.

However, the situation is not exactly the same in Europe as in Sweden. For example, Germany has road tolls and track access charges are higher. It is also a question of the weight and not only the length of the trucks, so in reality the situation is more complex.

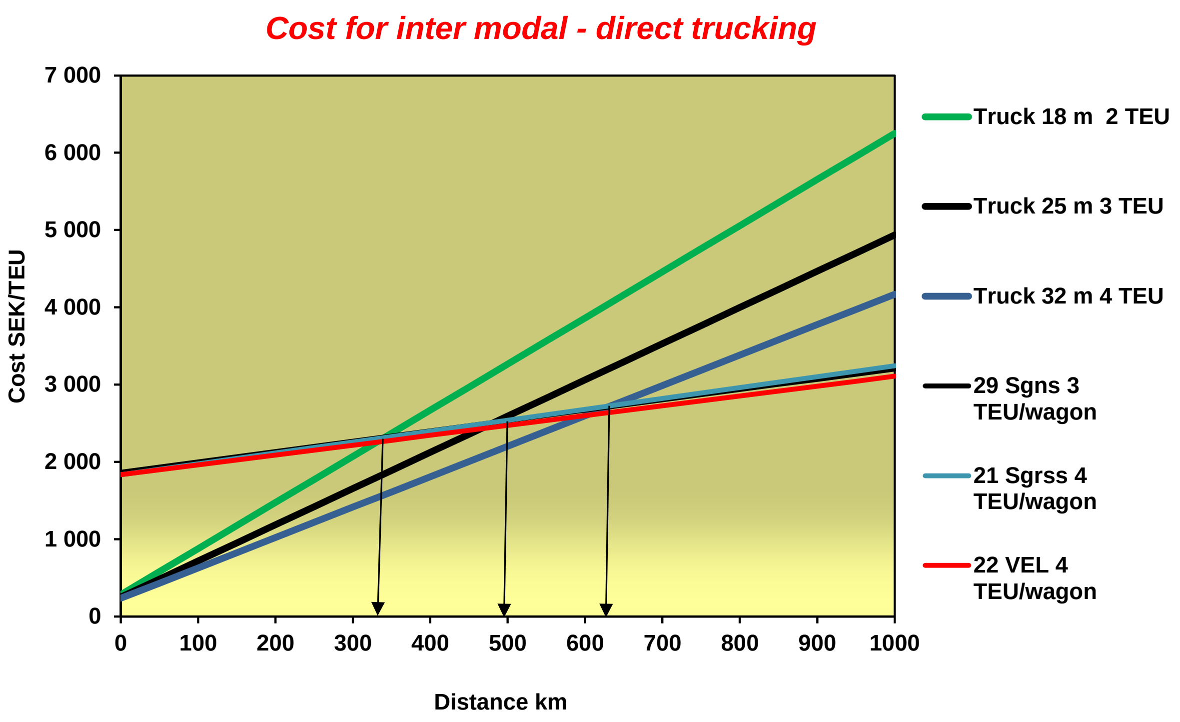
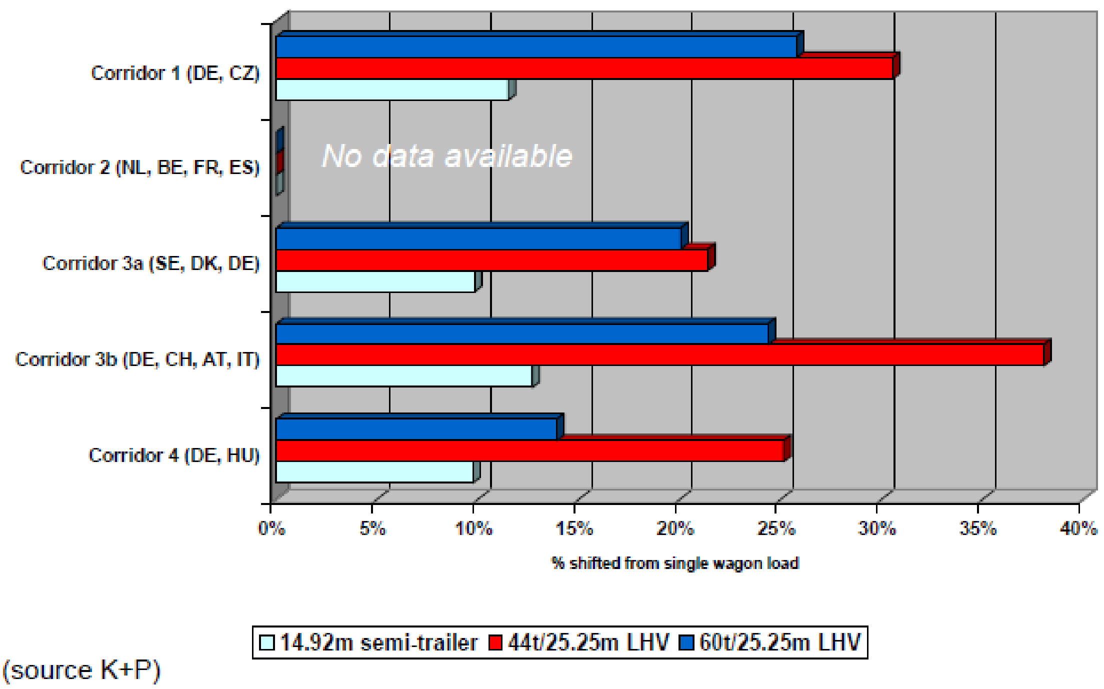


Figure 3.3: Transport cost per tonne for an intermodal transport with 20 ft containers on different wagons compared with an 18 m EU truck, a 25.25 m Swedish truck and a 32 m Swedish experimental truck, calculated in Swedish costs. Source: KTH calculations in VEL-wagon 2012.



(source K+P)

Figure 3.4: Relative modal back-shift from single wagonload to road per corridor and LHV scenario in 2020 (base: tonne-kilometres). Source: KP Transport Consultants/Fraunhofer, 2011.

KP Transport Consultants and Fraunhofer have analyzed the effects of different Long Heavy Vehicles (LHV) on combined transport as well as single wagonload in Germany. Their conclusions are that:

- The 44t/25.25m LHV causes the highest back shift for combined transport as well as for single wagonload due to its cost advantage.
- Single wagonload is more affected than combined transport as a result of the high share of fixed costs.

The backshift differs between corridors. Corridor 2 is the most affected for combined transport with more than 13% losses. In corridor 3b, more than 35% of its single wagonload traffic is transferred to road, despite the LHV ban in Switzerland, see figure 3.4. For the effects of longer trains see chapter 5.1.

The study has found much stronger effects for single wagonload transport than for combined transport services. Although both are considerable, the intensity of the downward spiral in single wagonload markets could lead to their complete or partial breakdown in specific regions or countries. The introduction of LHVs would then sharpen the discussion on single wagonload services that is already now ongoing in some EU Member States.

Figure 3:5: In Sweden 32 m long trucks for two 40 ft containers and a possible maximum weight of 90 tonnes are being tested at the same time as an extension of 18 m trucks to 25 metres is being discussed within the EU.

3.5. Industrial logistics concepts into the picture of future visions till 2050

Introduction

Current logistics trends in international networks of production companies have a huge impact on transport demand. In logistics networks, besides transportation, other activities such as sourcing, production and warehousing are necessary in order to fulfil the requirements of final customers.

This topic was focused by FREIGHTVISION, a project funded by the European Commission - DG Energy and Transport - in the 7th Framework Programme. The project, which was concluded in 2010, was intended to develop long-term visions and robust and adaptive action plans for both transport and technology policies for sustainable long-distance freight transport, which are supported as much as possible by the relevant stakeholders.

This report summarizes the content of the project's deliverables, which should be consulted for more information.

It is structured as follows: in section 2 the current logistics trends are identified and evaluated based on a cost perspective, in section 3 new logistics trends are discussed from an integrated perspective and, finally, section 4 presents some conclusions.

Cost Perspective

Traditionally, the design of a logistics network is based on financial objectives, i.e. minimizing total logistics costs which consist of facility, inventory and transportation costs. In addition to the financial objectives, a wide variety of other factors influence the network design and therewith the location of facilities. There is a basic trade-off between economies of scale and responsiveness by being close to the market. Concerning facility location macroeconomic factors, the quality and cost of workers, availability of infrastructure and manufacturing and logistics technology also have to be considered.

Current logistics trends are **outsourcing**, **offshoring** and **centralization**. The resulting design of the logistics network is mainly based on a cost perspective. **Outsourcing** of production activities means to subcontract a process to a third-party, which can gain economies of scale. **Offshoring** describes the dislocation of a production activity to a far-distant country in order to lower operational costs. Physical **centralization** means that the number of production, procurement or distribution sites is reduced, whereby the main goal is to pool risks, reduce inventory and exploit economies of scale. For instance, offshoring leads to a reduction in total logistics costs by 25%-40%. But important "soft" factors, like delivery time, flexibility and risks of a logistics network can lead to a considerable reduction of this cost advantage. Furthermore, stricter regulations and increased awareness of customers with respect to the environment support a reconsideration of a company's strategy.

The three mentioned trends prove to be advantageous in certain circumstances but usually lead to an increase in transport demand.

New logistics trends: Integrated perspective

Besides efficiency, the environmental impact and the reliability of logistics chains become important. Furthermore, shifts have occurred in the composition of the total costs and further changes are expected. This might lead to a change in existing trends. In the following, we highlight future developments concerning on-/nearshoring, i.e. the relocation of production processes closer to the market, flexible and resilient logistics networks, and green supply chain management initiatives.

The study by Ferreira and Prokopets (2009), which was carried out among European and US-based enterprises shows that 30% of the companies have already reversed their offshoring decision; 59% are willing to change their strategy with respect to offshoring. This means that either offshored activities are relocated or that managers will show an increased awareness in future offshoring decisions. This is due to various concerns of managers with respect to the reliability of supply chains and estimated cost savings that could not be realized. Furthermore, the cost components are about to change; 40% of the manufacturing enterprises have experienced an increase of 25% or more in direct offshoring cost (materials, components, logistics and transportation) over the last three years. Nearly 90% of them expect cost to rise by more than 10% in the next 12 months. This is due to rising labour costs in important offshore countries like China (2005-2008: wages + 44%), an increase in transportation charges for sea freight (2005-2008: + 135%) and an unfavourable development of foreign currencies (Ferreira and Prokopets, 2009, p.22). Details are shown in figure 3.6.

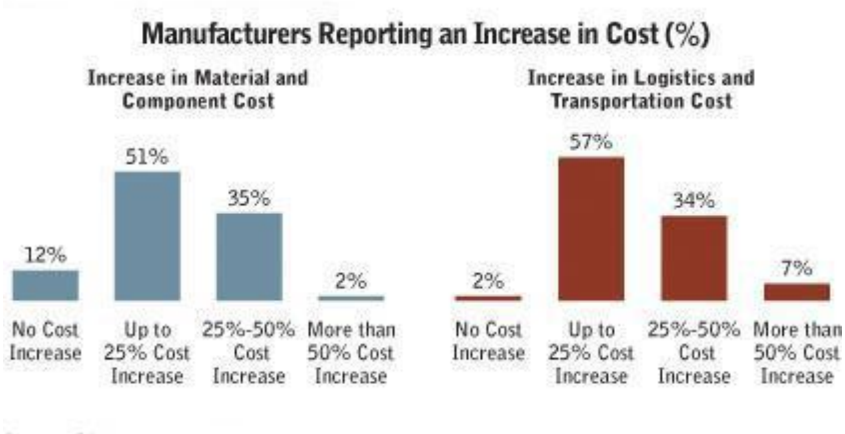


Figure 3.6: Manufacturers reporting an increase in cost (%). Source: Ferreira and Prokopets, 2009, p.22.

Simchi-Levi et al. (2008) expect transportation cost to become more important for future decision-making. When transportation costs become more dominant, a company is willing to transport in large lots to exploit economies of scale and accept higher inventory levels. The annual “State of Logistics Report” shows that logistics costs, which include all costs that are related to the movement of goods, increased by 52% between 2002 and 2007; 47% increase in transportation costs and 62% in inventory costs. Furthermore, a company will try to minimize the distance to its customers and will therefore rely on a more decentralized network or employ logistics service providers who can optimize their shipments better.

The study by Breinbauer et al. (2008) presents results concerning onshoring for Austrian enterprises. Over the last 2 years, almost 20% of them relocated processes back to Austria because of higher productivity in Austria, quality problems and negative development of factor costs abroad. In contrast to this, only 5% plan a relocation of their production processes to Austria in the near future. But this represents no change in the trend as relocations are seldom planned in the long-term but rather considered when foreign investments turn out to be a no longer acceptable error. Figure 3.7

shows the results of the European Manufacturing Survey about relocation activities of companies. The offshoring quota of certain European countries is contrasted with the backsourcing quota of the respective countries.

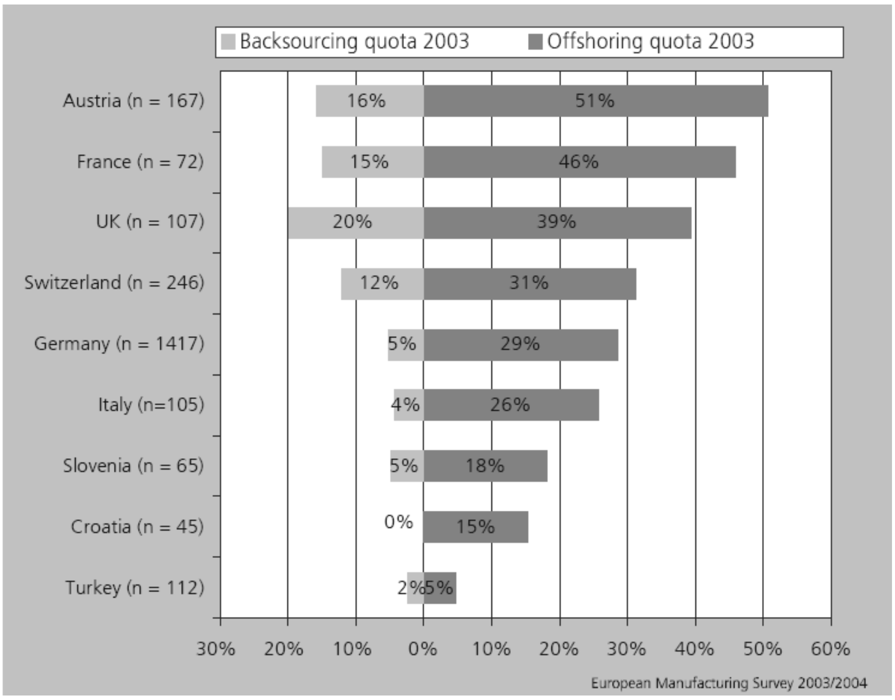


Figure 3.7: Share of companies having offshored parts of production abroad and having backsourced from abroad. Source: Dachs et. al, 2006, p.3.

Kouvelis and Niederhoff (2007) work on the topic of "Globalization of Operations and Supply Chain Strategies" and point out that the importance of certain cost components, especially labour costs, diminishes with advances in technology and production methods. Nowadays, due to these improvements, direct labour costs on average only account for less than 15% of total production costs. Factors like quality, delivery speed and customization also gain more importance in the eyes of the customers. Offshoring therefore no longer provides a significant cost advantage.

As mentioned earlier, centralization, which McKinnon (2007) calls spatial concentration of economic activity, leads to an increase in the average distance goods have to be transported. In the UK, the average length of haul for road freight increased constantly until 1998 with an average rate of 2%-2.5%. Between 1998 and 2003 it stabilized and since then it has begun to fall. This is a clear sign of reduced spatial concentration. One main reason for this may be the increased risk with the longer distances; increased congestion of the road network contributes to this risk. Further, efficiency increases in vehicle routing help to reduce the average distance freight has to be transported (McKinnon, 2007, pp.53). Tendencies towards decentralization in order to reduce transportation distances can be observed in different industries. Besides increased delivery speed and reduced cost, a positive impact on the environment can also usually be achieved.

Tang (2006) points out that supply chains have to become robust, meaning that a supply chain is able to fulfil customer requirements even though a disruption of the supply chain has occurred. This disruption can be of different kinds, either a short one due to congestion or accidents or a long one possibly resulting from a natural disaster or a terrorist attack that destroyed a node in the supply chain. By using a flexible supply base a company can benefit from low costs in an offshore facility and simultaneously be able to respond quickly to demand fluctuations by serving the market also from an onshore site. In this way, the amount of long-distant freight transport can be reduced, thereby mitigating transportation risks such as accidents and congestion.

The use of a single mode is mainly due to cost considerations and the aim to reduce complexity in supply chains but this increases the vulnerability of the chains. Multi-modal transportation makes the supply chain more flexible and better able to handle disruptions. Especially in the case of congestion, an alternative route could increase both time- and cost-efficiency. Improvements in transportation efficiency can be achieved through better vehicle utilization, the reduction of empty trips and less frequent shipments with larger lot sizes. This leads to a reduction in the number of trips.

Conclusions

In general, it can be said that these new logistics trends and others will certainly gain importance in the future as companies' focus will also shift away from a pure cost perspective to a more integrated one that includes cost, risks and the environment.

In particular, considering that offshoring no longer offers a significant cost advantage and that, furthermore, some companies are reducing spatial concentration, a future network should be a more decentralised one in which the amount of long-distance transport can be reduced. Improvements in transportation efficiency can be achieved through better vehicle utilization, the reduction of empty trips and less frequent shipments with larger lot sizes. This leads to a reduction in the number of trips. Multi-modal transportation makes the supply chain more flexible.

Nevertheless, there was a common understanding that from a myopic perspective the current logistics trends (outsourcing, offshoring and centralization) are still of relevance and due to the economic crisis cost will remain the most important key indicator in the near future.

4. Technical and development of the rail system

4.1. Rolling stock systems

System capacity

Rolling stock comprises all vehicles including locomotives, coaches, and wagons that move on a railway system. From a train operator's point of view, we can consider two aspects: train capacity and wagon capacity. Train capacity is dependent among other things on the length of the train. The loading capacity (i.e. how much cargo can be carried) of a train can be broken down into two parts: volume (cubic) and mass (tonnage) loading capacity (Boysen, 2012b). The cubic and tonnage capacity per train together with high average speed drive efficiency and capacity since high fixed or 'stiff' costs per train are very important (Boysen, 2012a).

For the railway system as a whole, the loading capacity per train multiplied by train frequency determines the overall system transportation capacity. Also loading capacity per train can be linked to axle load. The loading capacity per wagon is dependent on the number of axles, axle load, wagon tare mass as well as the volume (cubic) and density (tonnage) of the cargo. Boysen (2012b, p. 6) suggests that the loading capacity per train can be limited by its useful volume, for example in the case of low-density voluminous commodities, or by its load (mass) limit, for example in the case of high-density heavy commodities.

Axle load

The axle load of a wagon is the total weight felt by the railway for all wheels connected to a given axle. It is the part of the total wagon weight (empty wagon weight + load on the wagon) resting on the axle. Higher axle load means fewer requirements, which is good from the operator's point of view. Axle load is therefore an important design factor in the engineering of railways, designed to tolerate a maximum weight-per-axle (axle load). If it exceeds the maximum rated axle load, it will cause more damage to the track. So from the infrastructure manager's (or network manager's) point of view, a lower or safer axle load limit is desirable. In this regard, Kalay et al. (2011) remind us that 'the negative impacts of increased axle loads occur primarily in the areas of track and bridge maintenance and renewal, and freight car maintenance'.

Speed

The typical axle load limit on European networks is 22.5 tonnes and the maximum freight speed is 100 km/h. Many wagons and locos are designed for 120 km/h and this is used for some special trains. A higher freight train speed will mean that more cargo can be transported per unit of time (e.g. hour or year) and this will improve the asset (in this case rolling stock) utilisation per unit of time. The SUSTRAIL study (2013) suggests, as a high priority for the improvement of the rail system as a whole, optimising axle load limits (17-20t / 22.5t / 25t) depending on different operational scenarios. Some infrastructures, usually ore lines, are designed and maintained for even higher axle loads (than those suggested above). For example, in Sweden heavy haul transport with axle loads up to 30t is well developed, although for specific circumstances and may not be copied to other railways in general.

From the operational point of view, much attention is being increasingly paid to the operation of freight wagons with higher axle loads, for example for bulk traffic up to 30 t (D-RAIL, 2013). This is not a widespread upper limit but has implications for track and structure strength to accommodate this weight level on a routine basis. Existing and commonly used vehicle wagons mean that dynamic properties associated with higher axle loads contribute to significant infrastructure damage. Advances in rail vehicle bogie and general rail vehicle dynamics through better suspension characteristics are expected to reduce direct damage to track and allow increasing high axle loads.

Kalay et al. (2011) suggest that to improve productivity 'there has been a constant pressure in the marketplace to increase train weight and axle loads in order to reduce operating costs and increase capacity' in the USA. They report that 'The capacity of the average freight car has risen by about 80 percent since 1960 and reached 92 tonnes'. D-RAIL 2012 (P. 22) concludes that railways in the USA have significantly higher axle loads than in Europe. Standard "free interchange" axle loading in the USA (and in North America in general) is 33 tonnes (36 tons) on 914 mm (36") diameter wheels. This higher axle load combined with longer trains results in a significantly high level of rail loading (12,000+ tonnes per train) capacity.

Loading gauge

Boysen (2013) suggests that high cubic and tonnage capacity per wagon are important aspects of freight train efficiency and capacity, which can be limited by, among other things, permissible loading gauge and axle load. A loading gauge can be defined as the maximum height and width of railway vehicles and their loads to ensure safe passage through bridges, tunnels and other structures.

A larger loading gauge is at least as important as a higher axle load/weight per metre and the greatest effect is often 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 proven 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. It is very important to make the loading gauge rectangular by removing the bevelled corners, which is sometimes simpler and important from a market perspective, see figure 4.1.

For trailer transportation, it is very important to have a high but not so wide loading gauge. The loading gauge P/C 450 (4,83x2,60m) is ideal because it makes it possible to transport both 4,5 m high trailers on pocket wagons and 4,0 m high trailers on low flat cars with a height of 0.83 metres, see figure 4.2.

To improve capacity, British Network Rail adopted a strategy in 2004 to guide enhancements of loading gauges and in 2007 the freight route utilisation strategy was published that identified a number of key routes where the loading gauge should be cleared to W10 standard, and where structures are being renewed or new ones built the W12 will be a preferred standard.

Length utilization

The length utilization of wagons and trains can be improved. One example is the VEL wagon which is a 24m long wagon with two bogies that can load two 40 ft containers or other combinations of unit loads on an 80 ft loading area. It implies better loading factors of trains, 10% more TEU per length on fewer axles, and thus lower energy consumption, less maintenance and lower cost per transported unit, see figure 4.3 (VEL wagon 2012). Other measures are short-coupled wagons with draw-bars or automatic couplers without buffers.

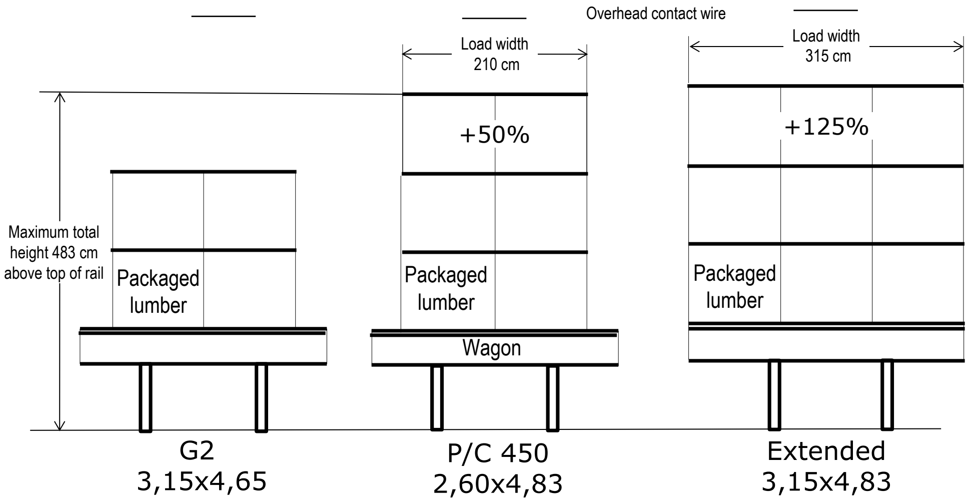


Figure 4.1: Possibilities to load more freight on existing wagons. A= Today's loading, B=It is possible to load two more rows already today in most of Sweden, C= with the C loading gauge and new wagons, three more stacks can be loaded abreast.

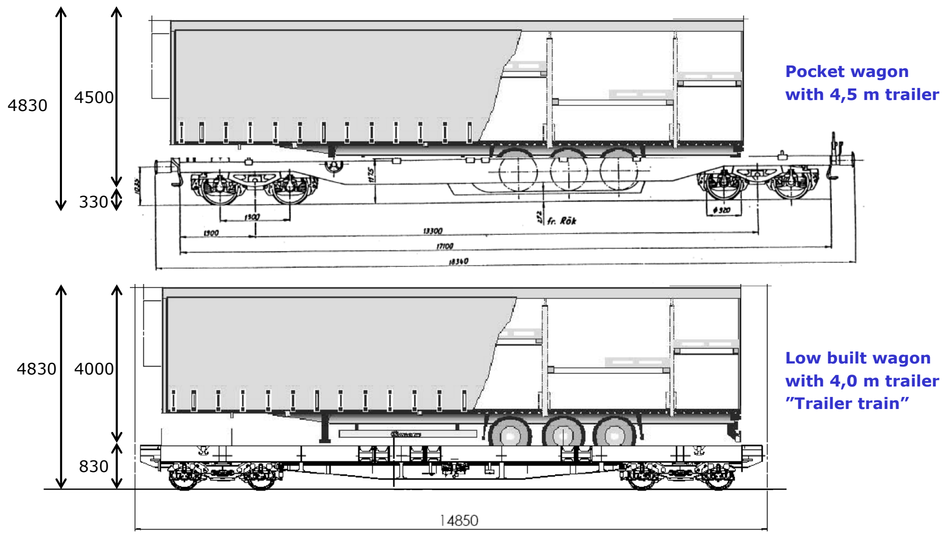


Figure 4.2: For intermodal, the total possible height is important. Here two possible combinations of trailers and wagons with the P/C 450 gauge are shown.

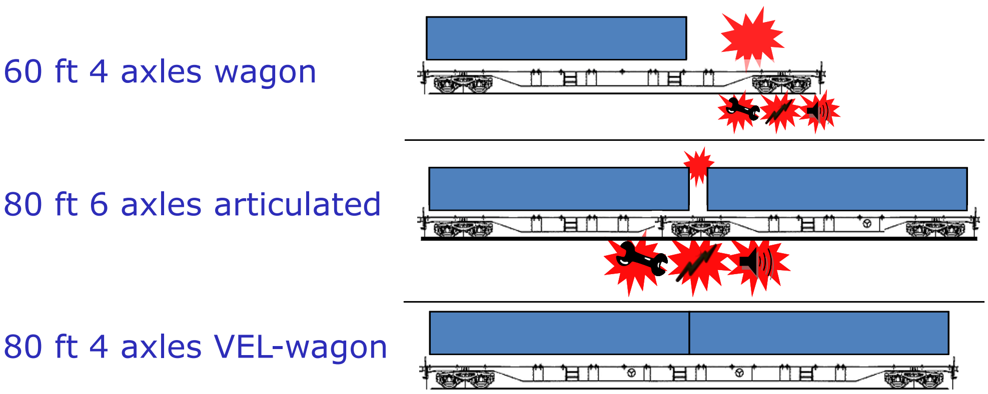


Figure 4.3: The 80 ft 4-axle VEL wagon is more efficient than 60 ft 4-axle and 80 ft 6-axle wagons due to their high capacity, more flexible loading schemes and lower maintenance costs. Source: VEL (2012).

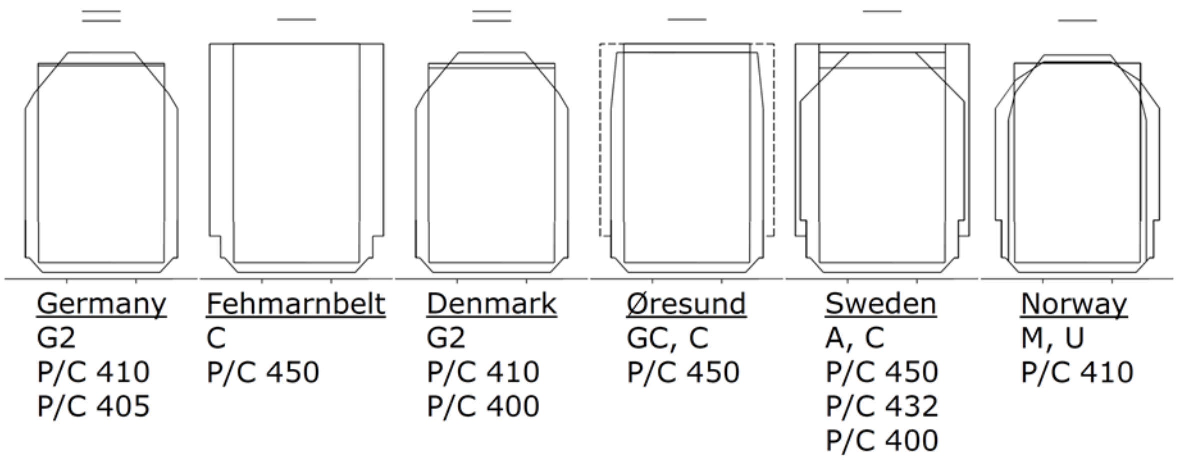


Figure 4.4: Loading gauge for wagons and intermodal transport in Germany, Fehmarnbelt, Denmark, the Öresund Link, Sweden and Norway. Source: Boysen, H., 2013.

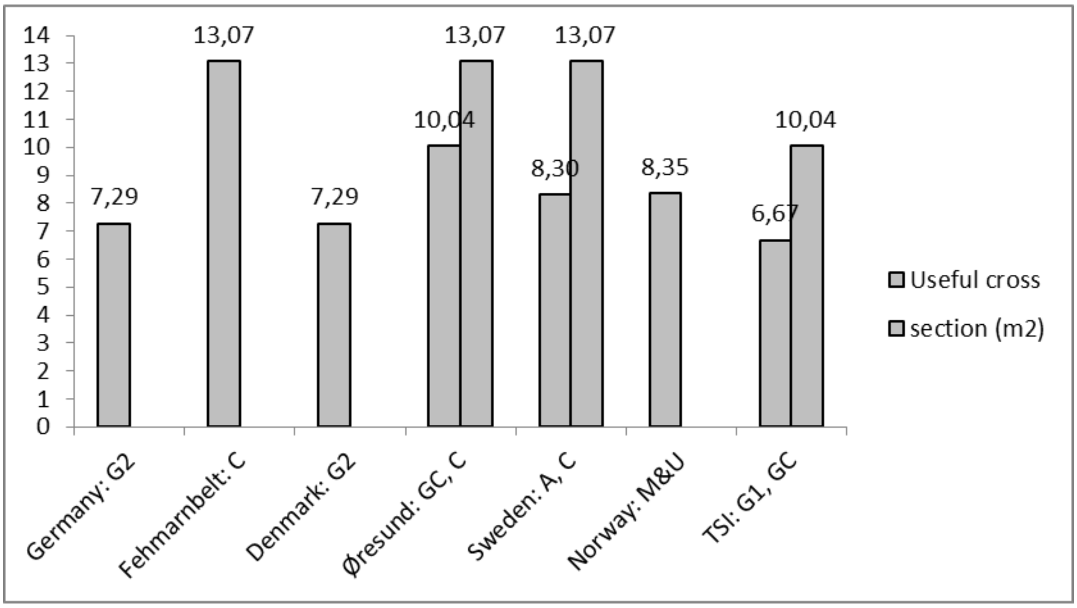


Figure 4.5: Possible rectangular area within loading gauge over floor level (1.2 m above top of rail) today and in planned services. Source: Boysen, H., 2013.

4.2. Best practices and future development of wagons and coordination with WP 2.2.

Quality

Customers' requirement mainly concern competitiveness and reliability. Competitiveness is achieved through a better path that leads to efficient use of all resources (network capacity, driving force, asset utilization, energy consumption), through full use of the wagon and train capacity (volume and weight), through reduction of track wear and tear and through lower costs for maintaining rolling stock. Reliability is achieved through a robust path and emergency solutions in case of incidents. At the same time, the customer wants to know the ETA adjusted according to the various events occurring during the journey. And the question of transit time is naturally always present in the competition with road transport.

Speed

All these requirements have to be met with technological innovations. Getting a better path on a track used by passenger and freight traffic means that you either increase the speed of your train or you have to obtain better manoeuvrability of the train. In the first option, the challenge is to increase the speed of your train without losing payload. This is today unresolved at an acceptable cost because of the relation between axle load, speed and maintenance cost. Research could certainly progress here.

Brakes

The second option is related to the behaviour of a freight train when braking. The normal braking system on freight trains is based on depression of a single brake pipe and its slow propagation towards the end of the train, successively putting all distributors into service when they detect the pressure drop. For that reason, the last wagons are still busy running while the first wagons are trying to stop. This creates longitudinal compression forces that increase the risk of derailment. The time taken to brake the train is therefore quite long. At the same time as releasing the brakes, it is necessary to refill the brake pipe until nominal pressure for each wagon to release the brakes is reached. The time to release the brakes is also quite long.

For these reasons, the time in-between passenger and freight paths is quite large (some minutes), the reaction of a freight train being slower than the reaction of a passenger train. It is also very penalizing to stop a freight train as it recovers its nominal speed much more slowly than a passenger train due to its weight compared to the maximum force that the locomotive can produce. It is thus essential to be able to give a freight train manoeuvrability to modulate its speed with predictive train management and good communication with the train driver and with a braking system that reacts much quicker. These concepts must be validated in WP2.2.

Gauge

At the same time, other elements for increasing competitiveness have to be analysed, for example the design of the wagon to make full use of the axle load capacity in relation to the track capacity, the optimal use of the profile clearance for low density cargo, the filling coefficient of the train which can be advanced with better, computerized management of clients' orders, the introduction of predictive maintenance to reduce unexpected stops for faults on wagons in combination with sensors equipping the various components.

Finally, competitiveness is also a matter for the whole supply chain to avoid waste of resources, which means that the dynamic information on the evolution of the journey based on the position of the wagons and the train coupled to train management in case of incidents inducing certain delays has to be transferred in real time to the next links in the supply chain in order to allow good reorganization of the resources. All these concepts need to be analysed and their impact assessed in WP2.2.

4.3. Development of wagons and wagon technology

Running gear

The running gear design is crucial in most rail transportation systems. Trends towards higher axle loads and/or higher top speeds to increase transport capacity challenge the running gear designers, in particular since international standardization of running gear also means that it may be difficult to implement more innovative design solutions.

A review of freight wagon running gear designs can be found in [Jönsson, 2002]. For low-density goods, single-axle running gear designs are common, whereas (two-axle) bogies are needed for heavier products. Three-piece bogies are most common worldwide, but in western Europe such bogies are rare. Instead, link suspension bogies and Y25 bogies are common. The most common bogie configuration is for each wagon to have two two-axle bogies, but for intermodal transport units three bogies with the middle one supporting two wagon frames are frequent.

Higher axle loads to increase the payload capacity per metre of train is a trend also seen in Europe although the loads are currently limited to 25-30 metric tonnes. Efforts are also being made to reduce the tare weight of the wagons, including the running gear weight through lighter bogie frames. See for instance [TU Dresden & TU Berlin, 2012] and [Iwnicki et al., 2013]. Higher (static) axle loads should, at least partly, be compensated for by lower quasi-static (curving) and dynamic track force contributions to mitigate the impact on and deterioration of the track and the running gear themselves. Improved radial steering of the bogies during curving would give a positive contribution in this respect, see the Y25 bogie example in [Iwnicki et al., 2013]. More resilience in the secondary suspension is of interest, as is lowered wagon centre of gravity.

Higher top speeds, say up to 120-140 km/h, increase the average speed and thus reduce transport times. For mixed traffic lines, faster freight trains can also fit into the timetables better. Each freight wagon can in principle increase its weekly transport capacity in this way. However, increased top speeds typically lead to increased risk of ride instability and larger track impact. The running gear suspension design is again crucial to compensate for the effects of higher speeds, see [Iwnicki et al., 2013]. For instance, the traditional friction damping devices may have to be accompanied by rubber elements and/or hydraulic dampers. The classical trade-off between ride stability on straight track and track-friendly performance in curves must be studied as well as both empty and fully laden wagons. For delicate goods, ride comfort (carbody vibrations) is also an issue. Reducing the unsprung (wheelset) mass is of interest, but may require a smaller wheel diameter than the standard 920 mm. An advantage of higher speeds in curves is that the cant excess becomes smaller, likely leading to less settlement of the inner (lower) rails.

Today there is often a lack of incentives to develop freight wagon running gear with improved performance such as allowing higher axle loads and higher speeds as well as causing less track deterioration and wheel damage. For special transport applications, business cases can be found but usually running gear design development is incremental, starting from existing and internationally standardized design solutions. However, one important step forward is that rail infrastructure managers should have knowledge about the benefits of track-friendly running gear and in the future have the possibility to adapt the track access charges more closely to track deterioration.

Some quite different freight running gear designs than indicated above are presented in [Jönsson, 2002] and in the ongoing European research project SUSTRAIL [SUSTRAIL].

Braking

Although freight trains usually do not make frequent stops for unloading/loading goods, train braking is common to accommodate reduced line speeds and stop at sidings for more prioritized (passenger) trains. Also stops at red signals along the railway lines are quite common. From a freight transport capacity perspective this is of course a disadvantage. However, efficient braking through significant retardation can increase average speed and reduce transport time (but is not the most energy-efficient braking in case the locomotive has regenerative braking).

Unfortunately, the retardation is usually less than 0.5 m/s^2. This is mainly due to the slow pneumatic braking systems that dominate among freight trains, in particular in Europe. The most well-known braking system in this class is the pneumatic (P) braking system as defined and standardized by UIC. Other limiting factors are the use of cast iron brake blocks, with strongly speed-dependent friction, and lack of wheel-slide protection system. The devices for payload-dependent braking capacity also typically give less retardation at higher loads (in Europe usually above 18 tonnes axle load).

An increase in transport capacity by allowing higher axle loads thus often means lower retardation, mainly to avoid wheel tread damage, and extended transport times. Alternative brake block materials, like composites or sinter, and modified wheel steel types may mitigate this situation. A more drastic remedy is to abolish block braking and go for disc braking, but the business case is probably questionable for high axle load and low speed operation.

Increasing transport capacity by means of higher top speeds certainly raises the demands on braking. For top speeds of 140 km/h and more this usually calls for disc braking. But the increased speed is usually motivated by high-value, and fairly low-weight, goods and the additional cost associated with implementing disc braking may be justifiable.

Another way to increase transport capacity is to run longer trains. This option is also strongly related to train braking performance. Today, the maximum freight train length in Europe is typically 650-850 m, and the traditional UIC P-braking system does not really allow for longer trains. Since the braking signal in this system only relies on the air pressure drop propagation down the train braking pipe, with a typical propagation speed of less than 100 m/s, the braking synchronization along the train will be poor and result in significant compressive forces between wagons that may cause train derailment. The brake application time in the freight train locomotive is therefore long (20-30 s) and the maximum brake cylinder pressure limited.

Longer freight trains than indicated above therefore call for some kind of improved braking system. One way is to introduce an end-of-train (EOT) valve that will release air from the braking pipe at the end of the train, thus also giving an air pressure drop signal propagating forwards along the train. A relatively inexpensive approach to quickly activate the EOT valve when braking is to use radio communication, although loss of such communication for a few seconds may occasionally ocuur.

In the ongoing European project Marathon [Marathon], radio communication is used to allow two 750 m long trains to be merged into one 1,500 m long train. In this way the master locomotive at the front of the train will communicate by radio link with the slave locomotive in the middle of the train. By means of simulations many braking scenarios for such trains have been studied, including loss of radio communication and braking immediately following significant locomotive traction, to evaluate the longitudinal compressive forces and the derailment risk. Varying payloads along the train and thus different wagon buffer heights are also investigated as well as different track geometries (straight horizontal, straight uphill/downhill, curves, turnouts). In general the risk of train derailment has been shown to be very small. Successful field tests have recently been carried out in France.

The main alternative to radio (wireless) communication is to introduce an electric cable (wire) along the train to virtually guarantee synchronous braking along the train and thus, for an ideal payload-dependent braking, very small longitudinal compressive forces between wagons as well as shorter braking distances and higher average speeds. This concept is used on modern passenger trains and many long freight trains outside Europe. However, this electronically controlled pneumatic (ECP) braking system is difficult to introduce in the traditional draw gear design of freight wagons with screw couplers and side buffers. On the other hand, an electric supply can also be used for wheel-slide protection systems, condition monitoring and other purposes.

When it comes to braking and draw gear, (automatic) centre couplers transfer both compressive and tensile forces and typically allow higher longitudinal forces and also longer and heavier freight trains.

It should be pointed out that braking is also closely related to the railway signalling system and its speed reduction supervision with advance warnings at certain distances.

For further references on freight wagon/train braking, see for instance UIC540 [UIC, 2002], KTH [KTH Railway Group et al., 2005 & 2013], Marathon [Marathon] and SUSTRAIL [SUSTRAIL].

Noise

Noise from passing freight trains is a serious issue that jeopardizes the entire rail transport capacity. Legislation, not least in Europe [EC, 2011], today enforces strict noise limits on the dB sound pressure scale and more restrictions on the design of new freight wagons. In densely populated areas, speed restrictions may be required, in particular at night.

For typical top speeds of around 100 km/h, the major source of freight train noise is from the wheels rolling on the rails, not least in tight curves, and is worsened due to the typical lack of non-metallic components in the running gears. However, the main concern is usually associated with the noise emitted during braking. The situation can be particularly annoying for freight trains equipped with cast iron block brakes. In Europe, this has led to new freight wagons not being allowed to use cast iron blocks [EC, 2011]. Existing wagons may have to be retrofitted.

Alternative and less noisy block materials are composites and sinter. A list of approved K-composite brake blocks is given in [ERA, 2011]. Disc braking, in particular with wheel-mounted discs, may be another option to reduce noise levels. However, the discs will increase the unsprung mass.

Resilient rubber components in the running gear suspension and wheels can reduce the noise to some extent. For reduced rolling noise, smooth wheel and rail running surfaces are important. In tight curves, typically with less than 600-700 m radius, trackside lubricants often have to be applied to reduce rolling noise as well as wheel and rail damage such as wear. Another traditional infrastructure action to reduce the railway noise experienced by residents etc is to introduce noise-reducing screens along the railways, but the associated costs are high and future development should focus on the sources of rolling noise and braking noise.

For further references on noise from freight trains, see for instance KTH [KTH Railway Group et al., 2005 & 2013] and SUSTRAIL [SUSTRAIL]. The review paper by Thompson and Gautier [Thompson & Gautier, 2006] should also be mentioned.

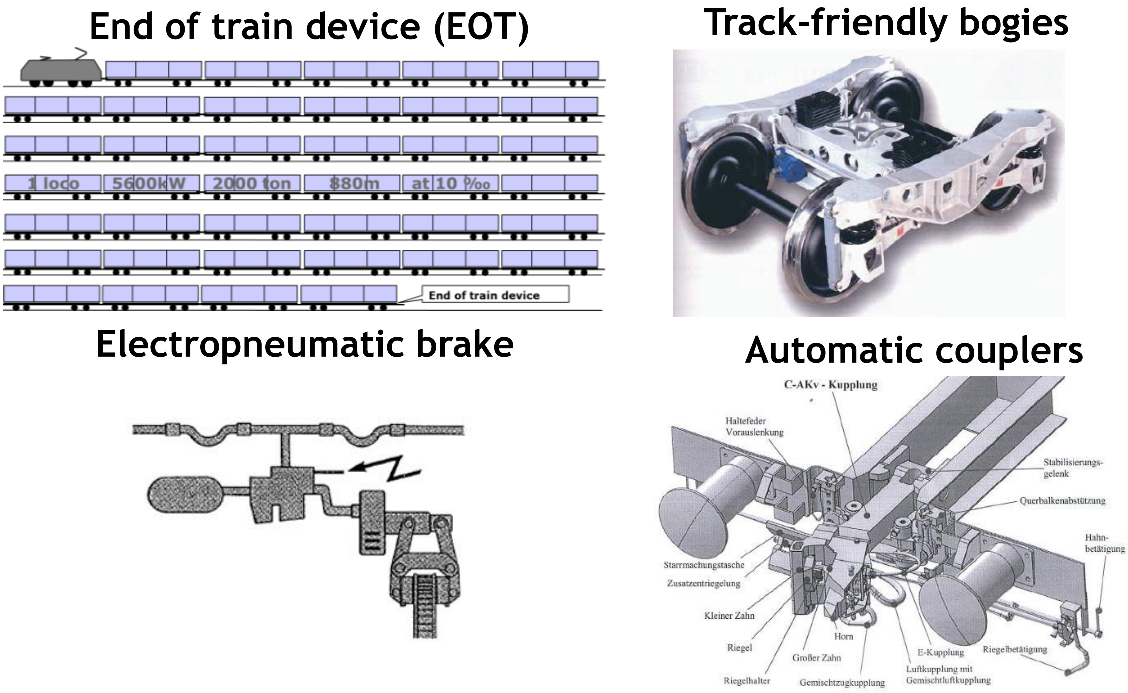


Figure 4.6: Examples of different components for future freight wagons.

4.4. Development of traction

Electric traction

In contrast to most modern passenger trains, virtually all freight trains rely on only one or a few vehicles for their traction performance. These locomotives are thus key vehicles and they are decisive for the maximum speed and acceleration of the trains, and thus their average speeds and running times.

Key characteristics of locomotives are maximum (continuous) traction power and maximum traction force as well as locomotive (adhesion) weight. The available wheel-rail adhesion is also critical to performance and not only depends on how "slippery" the track is but also on the locomotive's slip control and overall dynamic behaviour. The maximum power is important for the maximum speed whereas the (adhesion) weight, maximum force and available adhesion are important for the maximum acceleration.

The maximum train acceleration is of course also dependent on the gross weight the locomotive(s) should haul and also on track gradients (uphill/downhill). For maximum train speed, the aerodynamic resistance of the train also plays a role. For efficient rail freight transportation, the locomotive(s) should be appropriate for the operational task in question. The trend is towards more powerful locomotives that can haul even greater train weights.

An example of a powerful modern freight locomotive is shown in Figure 4.7. The locomotive can provide a maximum (continuous) output of 6,500 kW and has the capacity to run at a top speed of 140 km/h. The (adhesion) weight is 132 tonnes distributed over six axles (22 tonnes axle load) and the maximum traction force is 400 kN. The locomotive can haul trains of 2,000 tonnes at an initial acceleration of almost 0.2 m/s^2 on horizontal track, provided the available adhesion is at least 0.3, but also on uphill gradients of about 15 permille at constant speed. The electric supply can be either 15 kV & 16.7 Hz or 25 kV & 50 Hz.

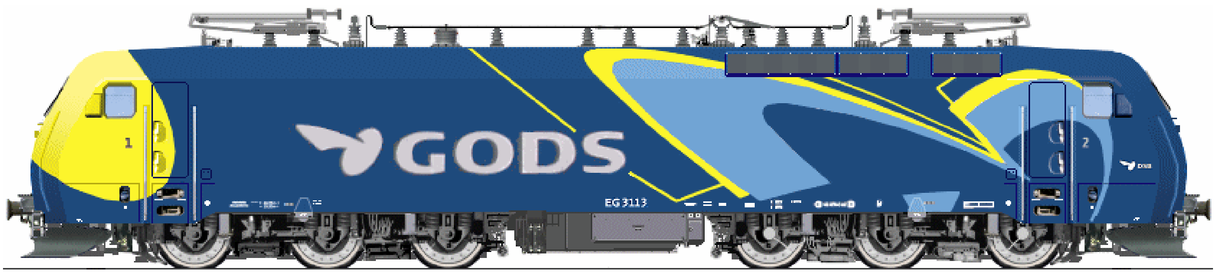


Figure 4.7: EG3100 electric locomotive for freight transport Sweden-Denmark-Germany.

For demanding freight transportation in terms of train weight, track gradients and/or train speed, multiple locomotives are probably needed. The same applies to operations that include many stops calling for many and fairly high accelerations. These locomotives are often directly connected to each other through draw gears, but in particular on long trains locomotives can also be found at the train's rear and in the middle.

One of the world's most high-performing twin locomotive is shown in Figure 4.8. It has a maximum (continuous) output of 10,800 kW and can run at up to 80 km/h. The (adhesion) weight is 360 tonnes spread over 12 axles (30 tonnes axle load) and the maximum traction force is 1,200 kN. The locomotive can haul trains of 8,500 tonnes on uphill gradients of up to about 10 permille. At this train weight and at a speed of 60 km/h, the locomotive can cope with long uphill gradients of about 6 permille.

Figure 4.8: IORE electric twin locomotive for iron ore transport in northern Sweden.

A modern four-axle locomotive common in Europe is shown in Figure 4.9. These TRAXX electric locomotives are used for both freight and passenger transport. Compared to the six-axle EG1000 locomotive above, the TRAXX locomotives are lighter and provide less traction force but they can still haul substantial train weights. Cf. Table 4.11 below.

Figure 4.9: TRAXX electric locomotive for freight and passenger transport (example)

In the EU, about 85% of the total rail freight transport volume is based on (straight) electric traction, with large variations between countries and within countries, calling for continuous electric supply through catenary systems along the tracks. In this way, the energy efficiency in the railway infrastructure plus locomotive traction may be 70-80%, thus more than twice the efficiency of locomotive traction relying on on-board combustion. However, the ratio for GHG efficiency is less than two due to as much as 50% of the electricity production in EU being based on fossil fuels

[Eurostat, 2009]. When it comes to improving the energy and GHG efficiency of rail freight transportation, extensive work was done in the EU project TOSCA [TOSCA, 2011]. It can be mentioned that the three locomotives shown above are equipped with regenerative electric braking that gives savings in energy usage of about 20%.

Diesel locomotives

Traffic on non-electrified railway lines calls for locomotives hosting combustion engines, usually supplied by diesel. A modern powerful diesel-electric locomotive is shown in Figure 4.10. This six-axle Euro 4000 locomotive can be utilized for both freight and passenger transport. Comparing the freight version of Euro 4000 with the EG1000 locomotive above, the Euro 4000 has similar performance except for significantly lower traction power and somewhat lower top speed. In recent field tests within the EU project Marathon, two of the Euro 4000 locomotives were used to haul a 1,500 m long train weighing about 4,000 tonnes.

Figure 4.10: Euro 4000 diesel-electric locomotive for freight and passenger transport.

In Table 1 performance parameters of the four locomotives above are summarized. For the TRAXX and Euro 4000 locomotives, their freight versions are used. Even more powerful freight locomotives are being developed worldwide, promoting high-capacity freight transport by rail.

Table 4.11: Performance of some modern locomotives (KTH).

Locomotive	**EG1000**	**IORE**	**TRAXX**	**Euro 4000**
Power supply	Electric	Electric	Electric	Diesel-electric
Number of axles	6	12	4	6
Weight (tonne)	132	360	84	123
Axle load (tonne)	22	30	21	20.5
Max speed (km/h)	140	80	140	120
Max traction force (kN)	400	1200	300	400

Max cont. traction power (kW)	6,500	10,800	5,600	3,200*
Max train weight at 10‰ (tonnes)	2,000	8,500	2,000-2,500	2,000

*) At diesel motor shaft, 20% less at wheel

Duo-locomotives

In the freight transport chain electric locomotives are often used for long distance transport between the marshalling yards and diesel locos are needed to distribute the wagons to the customers because their tracks are not often electrified. However, today dual-mode locomotives are being developed with both electric and diesel traction that can be used to run on non-electrified lines or in areas like terminals and industries. Operators then often only need one locomotive instead of two and can save costs and also make operations more flexible by shunting wagons along the line.

There are two types of duo-locomotive: a regular electric loco with a small diesel engine for shunting wagons in yards or on shorter distances like "TRAXX last-mile", see figure 4.12. There are also locos capable of line haul with both electric and diesel traction like the Vossloh six-axle Euro Dual locomotive with a 5,000 kW electric motor and a diesel engine of 700-2,800 kW.

For further references on traction for freight trains, see for instance KTH [KTH Railway Group et al., 2005 & 2013] and SUSTRAIL [SUSTRAIL].

Figure 4.12: Duo-locomotive with both electric and diesel traction, Traxx "Last mile".

4.5. Energy consumption and CO2 emissions from rail

Electrified an non electrified railways

Considering the source of energy supply, a locomotive can be diesel or electric or combined. A KTH (2013, p. 13) study suggests that there are differences in energy efficiency in the rail system: Diesel traction is less efficient than electric traction. The electrical locomotives are the best choice from an environmental point of view, although it depends on how the electricity is produced. It may come from a coal-fired power plant that produces substantial emissions or hydropower with almost no emissions. The energy efficiency of an electric locomotive can be improved by optimising its operational efficiency. The energy supply to the rolling stock can be improved by electrification of existing diesel-operated railway lines as well as production of low greenhouse gas (GHG) producing electricity.

Approximately 55% of the European rail network is electrified, see figure 4.13, and 85% of the traffic is handled by electric traction. As can be seen from the figure below, the share of railways which are electrified has increased successively. Electricity can be produced without GHG but today it is also produced with carbon-emitting fuels such as oil and coal.

There are some fundamental technical prerequisites that make rail energy-efficient: The steel wheel-steel rail concept has very low running resistance, coupling many wagons in a train reduces air drag, not so steep gradients that reduce the need for tractive effort and the possibility to regenerate braking current back to the grid. All these aspects make trains very energy-efficient, especially if the transport flows are large and the distances long.

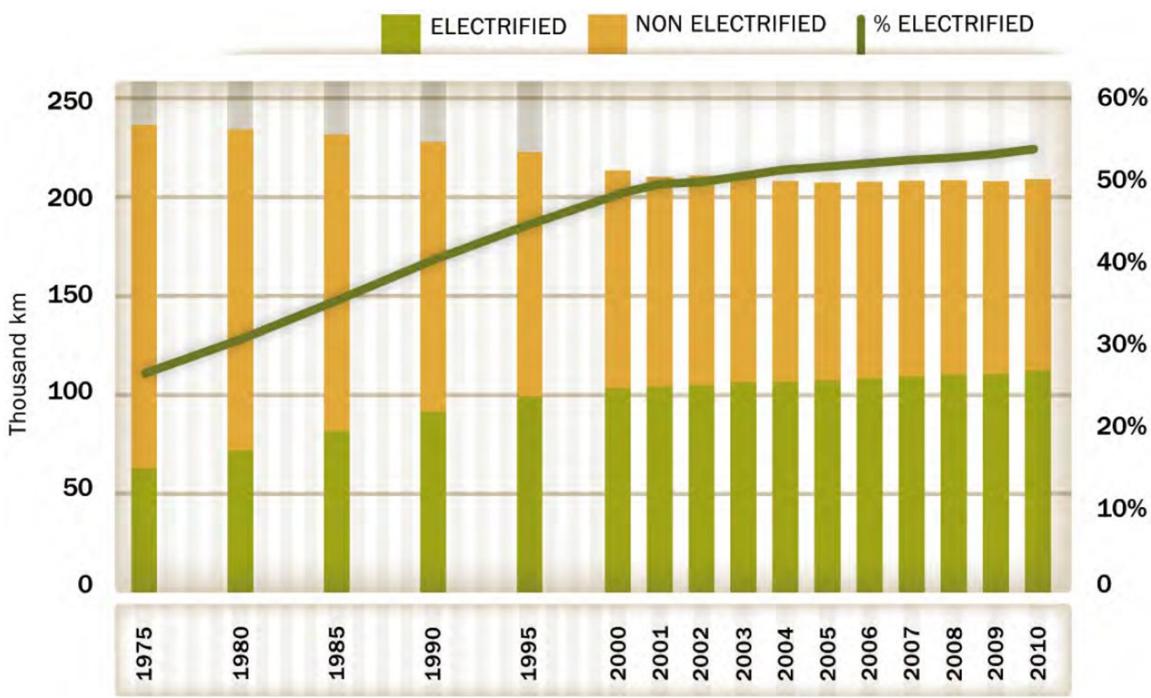


Figure 4.13: Length and share of electrified and non-electrified railways in EU27 1975-2010. Source: IEA/UIC (2013).

Comparison of profiles, type of freight and scale effect

In this section, energy consumption and CO_2 emissions are calculated in relation to the load. The transported tonnes have been modified and a different train composition for each case has been obtained. Finally, equations for energy consumption and CO_2 emissions have been obtained.

Figure 4.14 shows in a simple manner what the most efficient composition is and the differences between them for each of the four products and type of traction and for each value of transported load (net load). The upper curves for each train type are diesel traction trains (blue and yellow in the upper diagrams, green and yellow in the lower diagrams), the lower curves are electric traction trains.

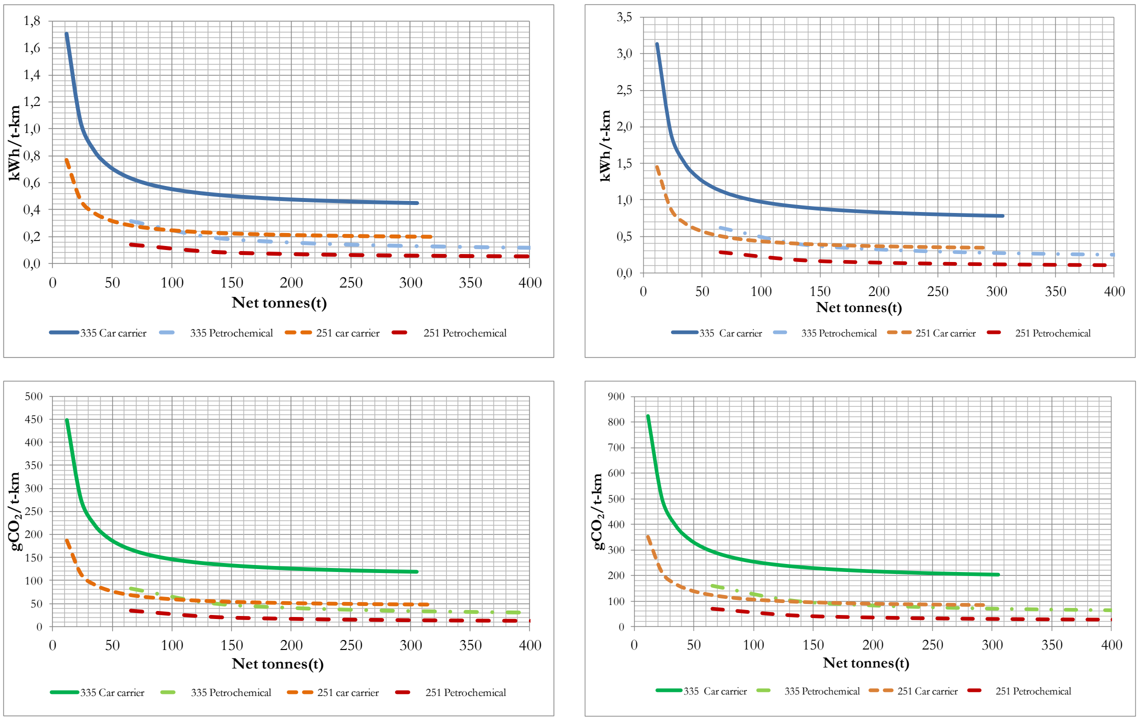


Figure 4:14: Energy consumption in kW per tonne-km (upper) emissions in g CO2 per tonne-km (lower) to the left: on a smooth profile, to the right: on a mountainous profile. Source: FFE

After the calculations, the conclusions reached are diverse and complex. For this reason, they will be divided into four sections.

Difference between diesel and electric traffic

Figure 4.14 shows that trains hauled by diesel locomotives have CO_2 emissions and energy consumption approximately between 2.15 and 2.6 times greater than electric traction for the same train size (and thus of net tonnes loaded) and on a smooth profile.

Table 4.15 shows the relationship between diesel and electric compositions in terms of their smooth profile. This difference between diesel and electric traction is the same as has been noted in (García Álvarez & Martín Cañizares, 2009).

	Consumption
	kWh Diesel/ kWh Electric
Car carrier	2.15-2.3
Petrochemical	2.3-2.6

Table 4.15: Comparison between diesel and electric traction for the transport of different goods. Source: Independently produced

Train size effect

For the same product and the same type of traction, emissions and consumption are reduced while the train load increases. For example, it is observed, for loads of 131 net tonnes in transport of petrochemicals and diesel traction, the energy consumption is about 20 kWh per net tonne per 100 km on a smooth profile and 40 kWh per net tonne per 100 km on mountainous profile; while transporting 300 net tonnes on the same trains, consumption falls to 12 kWh per net tonne per 100 km on smooth profile and about 27 kWh per net tonne per 100 km on a mountainous profile. It is observed that from 300 net tonnes, consumption and emissions are independent of train size, load transported and traction, figure 4.14.

The high sensitivity of energy consumption and emissions to the size of the train is characteristic of freight trains because they are always hauled by locomotives, and the energy required to move the locomotive is therefore “diluted” between the load while the size of the train increases. This leads us to say that long freight trains are more efficient.

Differences per products

The difference between “dense” and “light” products is shown table 4.16:

		Car carrier/petrochemical	
		Electric	Diesel
Mountainous profile	Maxum difference	1.87	1.92
	Minimum difference	2.74	2.79
	Average	**2.33**	**2.38**
Smooth profile	Maxum difference	2.08	2.12
	Minimum difference	3.30	3.34
	Average	**2.71**	**2.75**

Table 4.16: Difference between “dense” and “light” products. Source: Independently produced

The results presented in figure 4.14 show that the case of car carrier transport is different from others. This is due to the small load carrier for the same length than other products. The limitation on the number of vehicles that it is possible to transport in each wagon is not due to the weight, but the volume of the load (in this case, it is due to the length of the vehicles), which leads to the relationship between the tare of the wagon or truck and the net load transported being very high. For example, an MA5 double-decker car carrier platform wagon, for an average car length of 4 metres, can hold 12 vehicles, which is roughly equivalent to 11.75 tonnes. For each net tonne, 2.36 tonnes of wagon tare are therefore moved. Conversely, in the transport of petrochemical products 0.37 tonnes of wagon tare are carried per net tonne.

It is confirmed that for the same net tonnes transported and equal size of the train, consumption per net tonne transported by car carrier is about 3 times higher.

Comparison between consumption and emissions depending on the line profile

Table 4.17 below shows the relationship between energy consumption between mountainous profile and smooth profile. It can be seen that there are big differences between both profiles, in the order of 2 (i.e. the consumption in mountainous profiles is double that in smooth profiles), in all cases analysed.

		Mountainous profile/smooth profile	
		Electric	Diesel
Car carrier	Maxum difference	1.88	1.84
	Minimum difference	1.73	1.73
	Average	**1.77**	**1.75**
Petrochemical	Maxum difference	2.15	2.14
	Minimum difference	1.73	1.73
	Average	**1.95**	**1.90**

Table 4:17: Comparison of consumption and emissions in a smooth and mountainous profile for different types of products. Source: Independently produced

It can be seen that the difference between the two extreme types of line is very significant, with ratios of between 1.90 and 1.95 for petrochemical trains, and a difference of about 1.80 for car carrier trains. Arguably, the energy consumption and CO_2 emissions of a train, whatever the product transported, are approximately twice as high if it runs over a mountainous profile than over a smooth profile.

Conclusions

As demonstrated in this research, affirming that the energy consumption of a freight train is a certain value without having any thoughts about it, leads us to make a big mistake. High variability has been shown in consumption and emissions that represent the exploitation of freight trains, showing the variables that most strongly impact the calculations and differences between them.

The use of an equation for unit energy consumption is important to allow a better understanding and improvement of energy consumption. Empirical evidence is needed to ensure better calibration of the equation.

Unit energy consumption per tonne-kilometre was estimated for two types of profile (smooth and mountainous) in different railway vehicles. The results show that the operating parameters that depend on the type of profile, such as speed, number of stops and braking, have a great influence on the total energy consumption of vehicles and consequent consumption per unit of transport tonne-kilometre. Parameters depending on the type of vehicle and independent of the type of profile, such as vehicle mass, rolling resistance and drag, also have a significant impact on energy consumption. In any case, unit energy consumption and the consequent CO_2 emissions presented in this study correspond to a special case in the Spanish railway environment, and therefore may be different in others.

The results show that energy consumption per equivalent tonne-kilometre is strongly related to the maximum net tonnes carried so that the correlation between unit consumption and total consumption, in loaded and empty vehicles, is high in trains. Total consumption relates to the vehicle's mass since almost all the vehicle’s energy losses (rolling resistance, aerodynamics, gravity and kinetic energy) depend on its tare. According to the results of this research, a combination of vehicles with a high ratio of net tonnes carried with respect to tare, with low rolling and drag coefficients, operating in constant speed profiles with few stops leads to lower energy consumption per equivalent tonne-kilometre.

Finally, from the energy consumption and emissions generated by the transport of a "dense" reference product (petrochemicals), for a given load, with electric traction and on a smooth line profile, it is possible to approximately estimate the energy consumption and emissions of different compositions by multiplying the reference composition for the following values:

- To determine the consumption of a composition with diesel traction, the consumption of the reference product is multiplied by a value between 2.15 and 2.60.
- To determine the consumption of a car carrier (“light”) train with electric traction, the consumption of the reference product (“dense”) is multiplied by a value between 2.08 and 2.33.
- To determine the energy consumption in a mountainous profile, based on the emissions in a smooth line profile, emissions are multiplied in the case of “dense” trains by a factor between 1.7 and 2.1 and in the case of “light” trains by a factor between 1.7 and 1.9.

It can also be said that from 300 net tonnes (when the load carried is increased, the train length increases) transported in all compositions, consumption and emissions have an asymptotic trend that remains fairly constant.

Future savings in energy and GHG

Regarding improved energy and GHG efficiency of rail freight transport, extensive work was carried out in the EU project TOSCA [TOSCA, 2011]. Ten general actions were identified and most of them are also linked to the economic efficiency of rail freight transport. Below follows a summary of the ten actions, see also figure 4.18. Savings are given in percent per unit load (tonne-km) by 2050 in comparison with the reference system of 2009. A likely increase in top speed of 0.3-0.5% per year is not considered below.

Low-drag freight train

Technologies are available for reducing air drag by 20–25 % compared with the reference trains. A transition from open towards covered wagons is already under way but not all freight wagons can be covered for practical and operational reasons. For example, in intermodal transport different load carriers are loaded on open railway wagons with some 2–10 m longitudinal intermediate gaps. The low-drag freight train is at this stage estimated to have an energy-saving potential of up to 10 %. There is a large potential for improvement in the loading of intermodal units where the intermediate gaps should be minimized by appropriate loading strategies and flexible wagons.

Low-mass freight wagon

Lower tare mass of freight wagons can allow more loading of heavy goods in each unit, while maintaining limits for permissible total mass and axle load. This will reduce energy and related GHG emissions (per tonne-km) in cases where total wagon mass is a limiting factor. The potential for energy savings is estimated to be 5–8 % in heavy haul freight trains and about half of this in other trains. Both design changes and material substitutions are needed.

Energy recovery

Most modern European electric locomotives for freight haulage use their motors as generators when braking, thus feeding back electric energy to other trains on the line. This technology is already in use but may be further improved and introduced. At this stage, a further 4–8 % reduction in net energy use per tonne-km is expected in the medium term until 2025. About the same savings can be achieved by using electric recovery brakes as the normal braking mode, which will however delay the train by 40-60 seconds per braking – which can be accepted if the train is not running late. Such braking will also reduce the maintenance of the mechanical brakes.

Heavier freight (axle load + loading gauge + longer trains)

European freight trains are usually fairly light, with a limited length, axle load and loading gauge. This makes rail freight services less efficient on cost and energy usage than technically necessary. This is obvious in comparison with North America, where an average long-distance freight train is 5–10 times heavier, while the permissible axle load is almost 50 % higher. In addition, the standard loading gauge is about twice as large in North America than the most commonly used loading gauge (G1) in Europe. In the long term (until 2050), a 20 % increase in axle load (from normally 22.5 tonnes to 27 tonnes) and an enlarged European loading gauge - from gauge G1 or G2 to at least gauge GC – would lead to 15–20 % energy savings relative to the reference trains. Increased axle load is useful for heavy high-density freight and improved loading gauge for low-density items. Some further improvement in energy performance can also be achieved by increasing the train length.

High-efficiency machinery

Electric power technology is continuously improving both for high-powered electric motors and their feeding converters. This opens the way for improved energy efficiency of new freight train locomotives, both straight electric and diesel-electric. Improvements in the electric power supply system of the rail infrastructure are also anticipated. In all, losses in these systems are anticipated to be reduced by about 30% in the long term relative to the reference trains. For example, losses in locomotives are anticipated to be reduced from 18% to about 13% and in electric power supply from 9% to 6%. Diesel locomotives can take advantage of the continuously improving diesel engine technology, with fuel consumption assumed to be reduced by 8% in the long term.

Eco-driving

Optimization of driving style means, for example, coasting before braking and downhill approach, use of regenerative brakes as the ordinary brake, running slowly when time allows, etc. In the short and medium term, such optimization is estimated to have a saving potential of 8–10% compared with the reference case of average manual driving. To some extent, these technologies have already been commercially introduced, but are estimated to be improved and can be fully implemented on modern freight trains within the next 5–10 years. In the long term, this technology may be co-ordinated with rail traffic control, which would lead to further improvement and also enhance railway transport capacity to some extent. The potential of total energy savings by 2050 is expected to be at least 12–15%.

Dual mode and hybrid locomotives

Today, many freight trains running on both electrified and non-electrified sections use diesel power only, in order to avoid changing locomotives. In dual mode locomotives, electricity is used on electrified railways while diesel or bio-fuels are used in combustion engines on non-electrified sections, including industrial sites. Depending on the share of electrified sections in the actual operation and the carbon-intensity of the electrical supply, emission reductions may be in the order of 20–50 %, compared with the reference pure diesel operation. Another possibility is hybrid diesel-electric propulsion with on-board energy storage, which in diesel operation can reduce energy and emissions by 10–15%. This technology is partly available today, but is sparsely used. Applications are limited to diesel-hauled operations, i.e. a theoretical maximum of 15% of total rail freight in Europe.

Bio-fuels in diesel engines

As with road vehicles diesel, fuel can be substituted by liquid or gaseous bio-fuels. The maximum market penetration is 15%, i.e. the market share of diesel-hauled rail freight. But it is anticipated that bio-fuels will be reserved mainly for use in airplanes and long-distance road transport.

Electrification of non-electrified lines

Electric rail operations are usually much more energy- and GHG-efficient than diesel operations. Some European countries have today a very limited part of their rail networks electrified. In these countries, substantial reductions in GHG emissions are expected, in particular if 'Low-GHG electric power' is used in the future (see below). Massive electrification to cover, say, 95% of all European rail transport (instead of the present-day 85%) would reduce GHG emissions on non-electrified lines. However, the overall effect would be limited and the GHG reduction is again dependent on the GHG emissions of energy conversion into electricity. The limited overall impact - because of the low additional market penetration - and the associated cost of electrification are a matter of optimization.

Low-GHG electric power

Electric power in Europe is essentially produced by fossil fuels, renewable energy sources and nuclear power. In 2009, fossil fuels had about a 50% share of the total. Tomorrow's long-term electric power mix must have substantially diminishing dependence on fossil fuels if GHG emission targets are to be met. At the consumer level, GHG emissions in 2009 were estimated to be 460 gCO_2-eqivalent per kWh electricity from the public grid with the EU27 electric production mix (128 gCO_2-eq per MJ). Substantially reduced GHG emissions from electric power generation will be one of the most effective means of reducing emissions from the European transport sector, not only for railways but probably also for passenger cars in the road sector. Reduction of the GHG content by 80% will reduce specific emissions of electric trains by the same amount. Market penetration in the rail sector is as high as 85% (i.e. diesel operations are excluded).

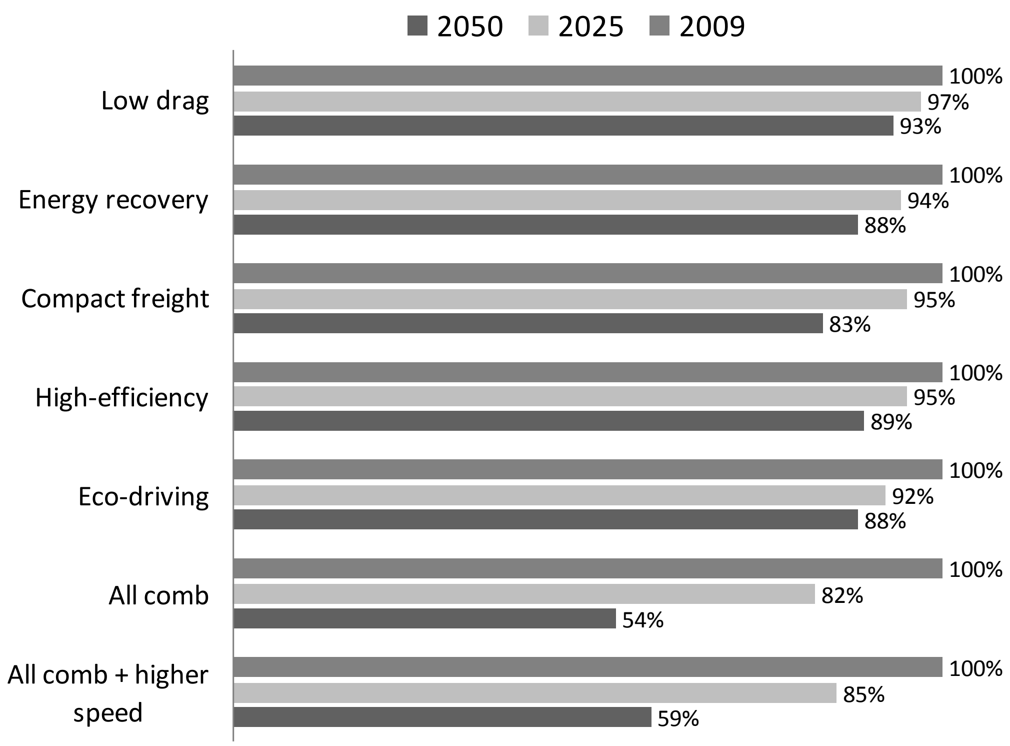


Figure 4.18: Estimated trends of energy use (per tkm) by technology over time, including all combinations and higher speeds, aggregated and weighted over all types of electric rail freight services. Source: TOSCA (2011).

In table 4.19 are listed measures to reduce GHG in the rail system and in the transport sector as a whole by making rail more efficient and increase market share on behalf of modes with higher relative GHG-emissions.

Table 4.19: Overview of measures to reduce GHG and make rail more efficient. Source: STTP 2012.

	System development	**Technical development**
To reduce GHG in the rail system		
In the rail system	Eco-driving Improved load factor	Space-efficient & compact trains Energy recovery Low drag trains
In the energy supply	Electrification of diesel-operated lines Production of low-GHG electricity	Dual-mode locomotives Hybrid trains Biofuels in diesel engines
To reduce GHG in the transport sector		
Passenger transport	Extension of High Speed Rail network Investments in EU 12 Market liberalization for lower prices Development of customer-oriented intra-modal and intermodal network	Technology for higher speeds Running gear for smoother ride and lower dynamic forces Space-efficient trains Modular trains More efficient trains at reduced cost
Freight transport	Implementation of deregulation in practice to improve supply Seamless rail freight corridors through borders Investments in EU12 Development of dense inter-modal network	Lighter wagons with less noise Running gear for higher axle loads and speed Higher axle load and larger loading gauge Electro-pneumatic braking Distributed radio-controlled power Automatic couplers Intelligent freight wagons and trains Terminal technology for horizontal automatic transhipment
Infrastructure	Implementation of longer freight trains Higher axle loads and wider loading gauge Faster freight trains	Cost-efficient slab track Long-life cross-ties Low-cost track
Traffic management and IT	Implementation of ERTMS	ERTMS level 3 Automatic operation
New modes		Magnetic levitation trains Vacuum tunnel trains Personal rapid transit (PRT)

4.6. Intermodal terminal technology

New concepts for intermodality and co-modality

With the dominant and ever increasing share of road freight transport growth over the last over thirty years, the EU aims to disconnect mobility from its negative effects, for example through promoting technical innovations and a shift towards the least polluting and most energy-efficient modes of transport — especially in the case of long distance. In this context, the European Commission adopted a policy of 'co-modality', i.e. the efficient use of different modes on their own and in combination, will result in an optimal and sustainable utilisation of resources.

Rail freight has been supported in different EU transport policy documents (for example EU, 2001; EC, 2006; EC, 2007; EC 2011) to promote a modal shift from road. In some cases, an explicit state interventionist approach was also proposed to achieve higher rail freight share and demand changes and an active promotion of intermodality (Zunder et al., 2013). Intermodal freight transport is defined as the movement of goods in one and the same loading unit by successive modes of transport without stuffing/un-stuffing of the goods themselves when changing modes (European Conference of Ministers of Transport et al., 1997). Bontekoning et al. (2004) observed that the intermodal transport cab be a competing mode and can be used as an alternative to unimodal, for example road transport.

Rail freight transport normally offers terminal-to-terminal transport service for typical voluminous cargo such as raw materials for manufacturing industries, coal for power plants, iron ore for steel manufacturers, for a limited number of customers. In a comparative scenario, the customers of these types of cargoes look for cheaper transport options and as such rail and waterways fit well for these customer requirements. These cargoes are also less time-sensitive and less reliable time schedules can be accommodated for them. As the European manufacturing industry has become less cost-effective, due among other things to higher labour and other input cost in general, the manufacturers have moved towards the east to look for cheaper industrial inputs. The citizens of European have also formed a consumer society, meaning that the consumables are produced outside Europe and then imported for consumption. This type of cargo, possibly in containers, requires among other things faster and door–to-door (or point-to-point) delivery of service. Rail freight transport is increasingly carrying containerised cargo. For example, the share of containerised cargo has increased significantly in the UK, although mostly terminal (e.g. Felixstowe port) to terminal (a terminal in the Midlands) service.

Considering the definition of intermodal transport we can argue that rail freight transport needs the pick and delivery service at the origin and destination sides of the total transport haul. In other words, there is a need to tranship cargo or cargo units at the modal transfer points, i.e. terminals. Traditionally, building a modal transfer point is costly due the need for a vast amount of space with suitable concretisation to bear the movement of heavy vehicles including trains, trucks, wagons, swap bodies and containers as well as container handling equipment. The transhipment is traditionally performed vertically with a variety of equipment including Transtainer - operating on rails or rubbers over stack yards (stocking areas), tracks and road; Straddle carrier - operating in stack yards; Fork lift operating in or to stack yards with high manoeuvrability; Reach stacker - operating in or to stack yard with high visibility; and Semitrailer, operating in/to storage areas for transport only, but at higher speed (Marinov, et al., 2012, p. 8). With this type of equipment, a container is lifted from a train, for example, and moved to a stack yard either for storage or loading onto a truck, for example. Comparatively speaking, this vertical transhipment is time consuming and incurs higher risk of loss/damage to cargo.

The European Commission (2007) suggests that the efficiency and effectiveness of intermodal transport is largely dependent on the efficiency and effectiveness of terminals, including ports and airports along the transport chain. Within the European context, a set of generic European benchmarks (both static and dynamic) should be developed allowing performance measure of these terminals. Modal transfer points also need methods and technologies that cost less and are less time-consuming. Along these lines, the SPECTRUM (2012) project suggests horizontal transfer of the cargo unit with comparatively cheaper transshipment equipment. Another advantage of this type of transshipment method is that it requires less space for trucks and trains. Virtually the truck with cargo-to-be-loaded on a wagon can be placed parallel to the railway line with a small space, see Figure 4.20. This type of transshipment, that can be classified as a small terminal, will allow train operators to stop at comparatively shorter intervals for picking up or delivering a smaller number of containers or swap bodies. The terminal will require a small staff. This will allow faster picking up of cargo from origin (shippers) and delivery to destination (consignee).

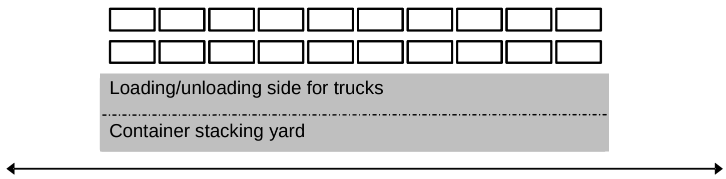


Figure 4.20: Typical trackside low-cost loading/unloading facility Source: UNEW,

4.7. Analysis of transshipment technology and traffic systems

The terminal is a critical component in intermodal traffic

The analysis shows that the terminal cost constitutes approx. 40% of the total cost in a typical intermodal chain while feeder transportation by truck accounts for 30% and long-haul by rail also approx. 30%. It is thus important to make the terminals more efficient. A low terminal cost is crucial to intermodal traffic's competitiveness.

Conventional end-point terminals are relatively expensive in both investment and operation but can handle all types of unit load, for example with a reach-stacker. However, they cover a relatively large area and must be dimensioned for very high axle loads. The fact that the terminal tracks cannot be electrified means that trains must be switched in with a diesel locomotive. And several tracks are needed to be able to park the wagons while they wait to be loaded and unloaded. All of this contributes to the terminals being cost- and space-intensive and it is difficult to bring the cost per unit handled down even with large freight volumes.

Intermodal traffic is traditionally operated as end-point traffic but there is a possibility to also operate intermodal traffic as liner traffic but these possibilities are presently limited, due mainly to the terminal technology. The terminals are often built without through tracks.

A liner traffic terminal is located on a side track where the train can drive straight in and out onto the line again. This track could be electrified so that the train does not need to be switched in. This in turn requires a handling technology that can function under the overhead contact wires. The train must be able to be loaded and unloaded during a stop of 15-30 minutes. This also obviates the need to park wagons. The terminals can also be made more compact and with the right handling technology will not need to be dimensioned for higher axle loads. They will also require less space and will be more cost-effective than conventional terminals.

Most trailers today are not designed to be lifted onto a railway wagon. The trailer market is in practice therefore very limited even at conventional intermodal terminals that have lifting equipment. It is therefore a great advantage if trailers can be rolled onto the wagons. A traditional solution is the “rolling highway” commonly used for example in alpine passes. This solution is extremely costly, partly because the entire truck including the driver has to be loaded and partly because the railway wagon itself is expensive to buy and maintain.

Solutions where trailers do not need to be lifted but can be rolled on and off along a ramp can thus widen the market considerably. They also mean that the terminals only need to be dimensioned for the trucks’ axle load. Megaswing has the advantage that it is relatively small-scale but it is relatively complicated. The system can be used in terminals with liner services and in end-point terminals. It has been tried and tested and is available on the market, see figure 4.23.

Trailertrain is a simpler low-built wagon that is loaded by “circus loading” by means of end ramps. It is therefore most suitable for end-point traffic. This system is used in the USA but is not on the market in Europe yet. The trailer height is restricted by the wagon height and the gauge and full-height trailers therefore cannot be loaded on most lines in Europe.

If a transportation system that is sustainable in the long term is desired, the principle should be that the freight is transported as far as possible into conurbations by rail and then distributed by road for as short a distance as possible. This is also economically advantageous since feeder transport by road often constitutes a major portion of the cost, often as much as long-distance transportation by rail.

A small scale intermodal system has been implemented in Switzerland, Innovatrain, a liner train with stops at many terminals over short distances. It is a push-pull train, capable of operating in either direction. It can either run on the electrical main track at speeds up to 120 km/h, or drive into a private railway siding by using its diesel power, see figure 4.21.

Figure 4:21: Railcare push-pull train. Source: Railcare 2013

For horizontal transshipment, the ContainersMover system is used between the train and the truck. The device is mounted on the truck, which makes transshipment possible at every terminal or siding.

Another system for horizontal transfer of unit loads is the CarConTrain (CCT). The system consists of a wagon that travels parallel with the track, equipped with arms for transferring freight horizontally.

The system can transfer unit loads fitted with corner castings of any width and length; they can be 2.5 or 3.6 metres wide and 3 or 12 metres long. Since it can be fully automated, it could be used in unmanned terminals and warehouses. The train can be unloaded regardless of whether the truck is available and can arrive at any since no personnel are required, se figure 4.24.

The cost of handling units with a reach stacker at conventional end-point terminals is approx. 30 €/unit. At a liner traffic terminal with forklifts, this may be reduced to 15€/unit if the train driver drives the forklift but is restricted to 20 ft containers or swap-bodies. Approximately the same cost can be calculated for the ContainerMover system with the transfer system on the truck. With a horizontal transfer system like CCT the cost is estimated to be around 10 €/unit. Handling a trailer with Megaswing or Trailertrain that do not require a special terminal costs roughly the same.

The lower cost for terminal handling also means that the break-even point for intermodal compared with direct trucking will shift to shorter distances and widen the market, as can be seen from figures 4.25 and 4.26. With a liner train with more stops at terminals, see figure 4.22, more customers can be reached along the way and the average feeder distance will be shorter, which also reduces the cost.

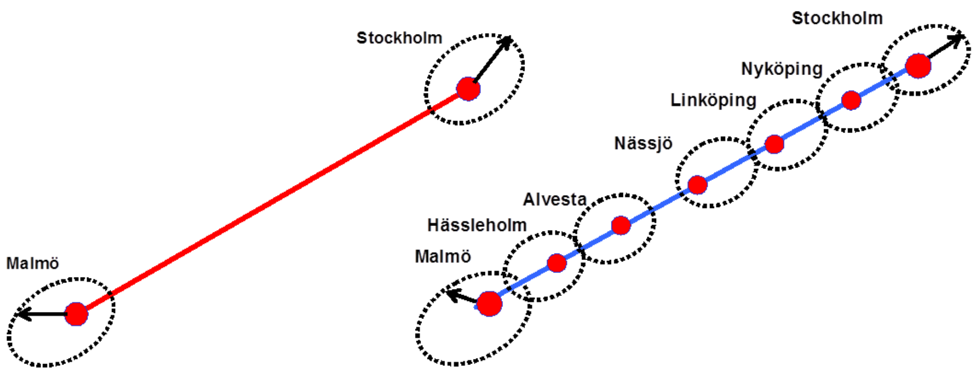


Figure 4.22: Left: Two places at the end-points and the trading area can be covered with conventional inter-modal traffic. Right: With liner train traffic with more terminals, more relations and a larger geographical area can be covered.

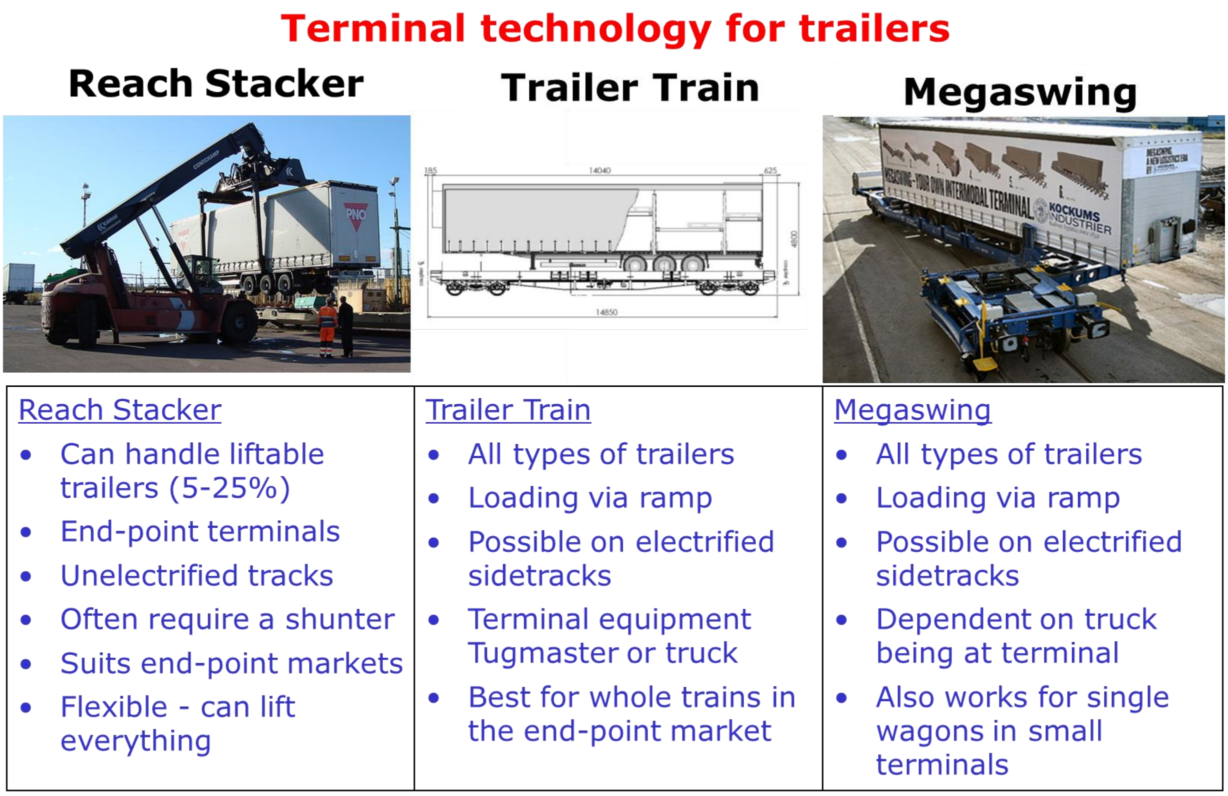


Figure 4.23: Development possibilities for trailer traffic

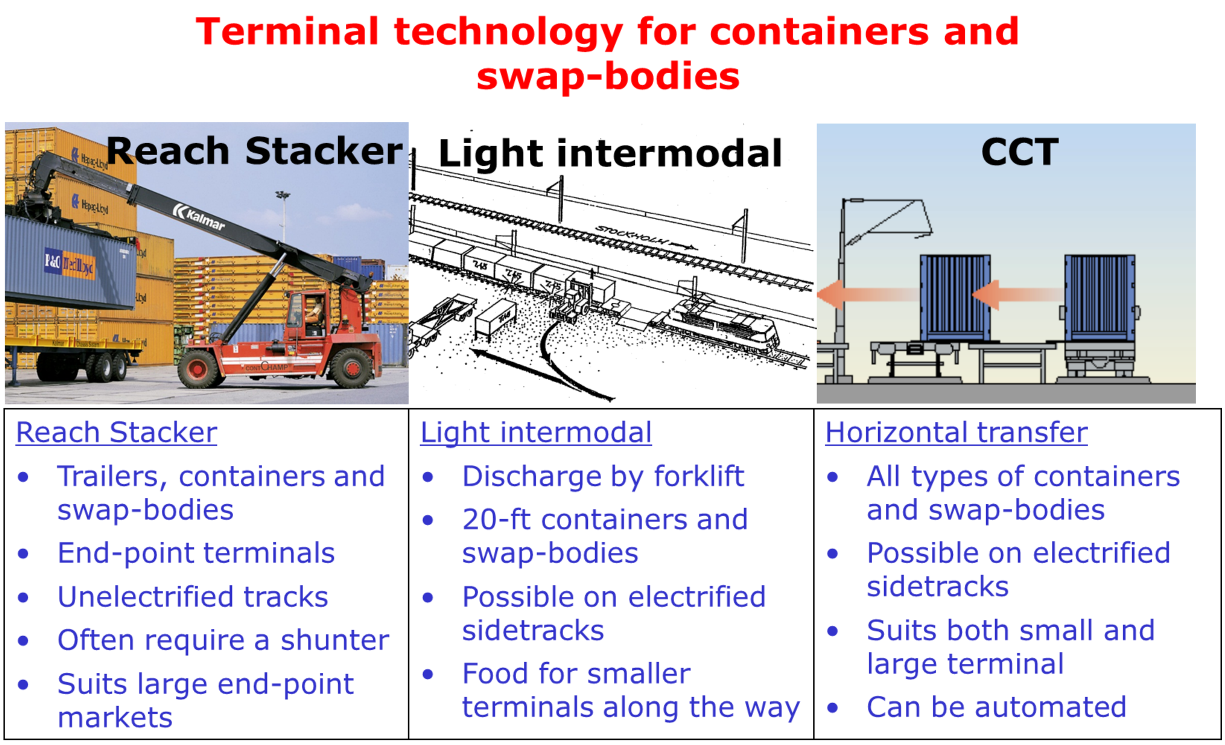


Figure 4.24: Development possibilities for containers and swap-bodies

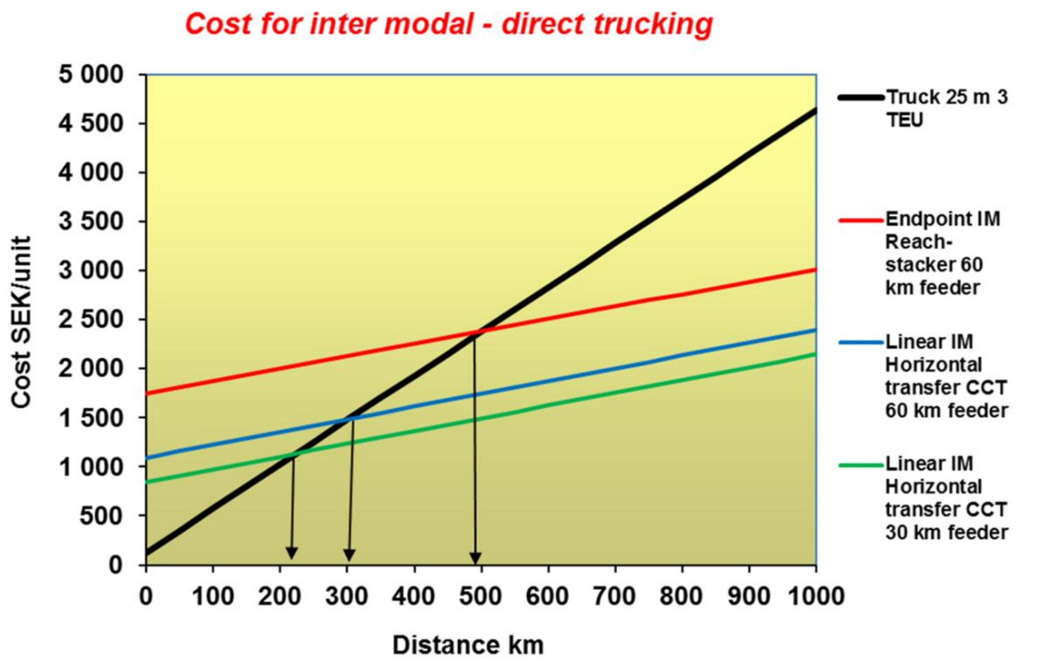


Figure 4.25: Cost of conventional intermodal traffic and intermodal traffic with horizontal transfer of CCT type and with regular traffic with shorter feeder distances

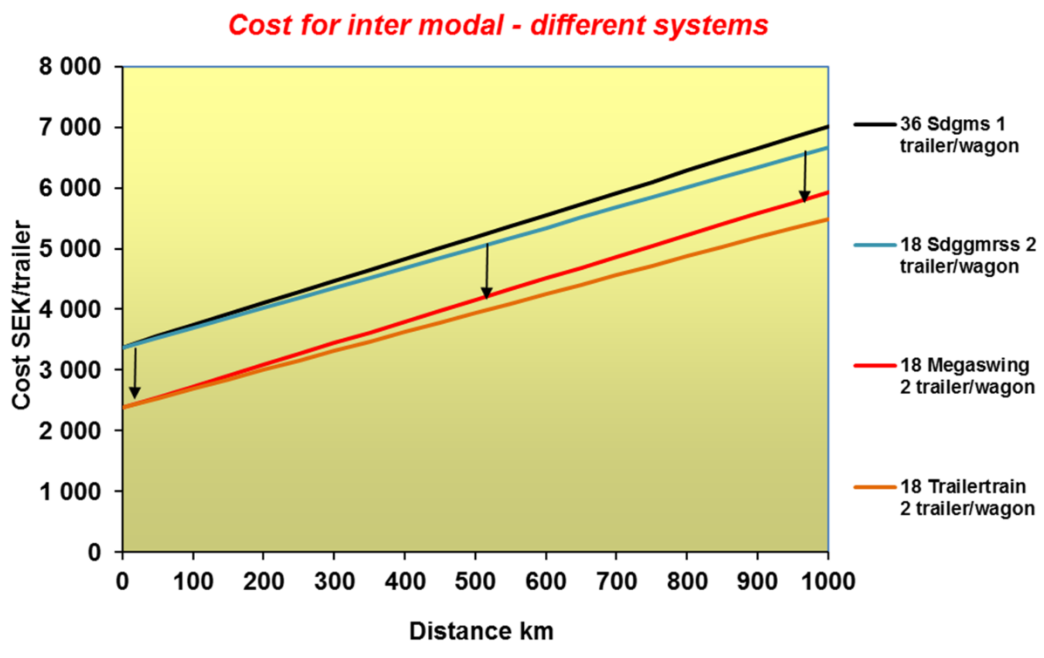


Figure 4.26: Cost of conventional intermodal traffic with trailers and traffic with Megaswing and Trailertrain that do not require any special terminal

5. Traffic and operational development

5.1. Effects of longer, heavier and faster trains with higher and wider wagons

The development of the future rail transport system must have as its starting point optimised freight transportation on the basis of a system view of the railways: from the customer's transportation needs that put demands on the wagons – the wagons are coupled together into trains where available tractive power is taken into account – the train utilises the infrastructure with a certain performance along a link and ultimately in a network from origin to destination. The intention is to analyse the railway system from its actual performance today to what is planned for the future and what is optimal from the point of view of markets if the entire system is considered. The principle of the optimisation is shown in Figure 5.1.

Optimization of wagons for different types of product

Wagons have typically been constructed to satisfy today's infrastructure standard. But different lines in Europe have different standards already today. With different types of products and customer needs as the starting point, the wagons' design can be analysed with current praxis and future best infrastructure performance. Some products are heavy and need as much cargo weight as possible; others are volume goods and need space. There are limitations as regards axle loads, load per metre and loading gauges today but these can also be changed to a certain extent, at least in a long-term perspective.

Optimisation of trains for different transportation needs

As regards the freight transportation system, development has technically speaking always been incremental. Performance has gradually improved from the first steam locomotives, but it is the tractive power – the locomotives – that has often determined the standard of the trains and the infrastructure. The trains in Europe are dimensioned according to tractive power, the braking system and the infrastructure standard depending on inclines, track length at stations and other physical limitations. Much of today's freight train system and technology is based on a normal 3-4 MW locomotive, in Sweden, the Rc locomotive, that was introduced in 1968. This means trains of approximately 1,650 gross tonnes and a length of 630 metres.

But modern locomotives have a tractive power of 5-6 MW and there is technology available to operate longer, heavier trains. The USA, for example, has trains of between 2,000 and 3,000 metres in length with radio-controlled locomotives distributed along the train. One important question is what the standard tractive power in Europe will be in the future with the next generation of locomotives – and what trade and industry will need.

Optimisation of the infrastructure for different types of train

The infrastructure's performance decides how long trains can be in the network. But axle loads and speeds have increased by stages as the track has been improved with heavier and continuously welded rails and better wagons. Many new wagons are designed for 25 tonnes axle load and 120 km/h top speed but are normally used for 22.5 tonnes axle load and 100 km/h.

The loading gauge is also interesting since it can sometimes be very simply and relatively cheaply widened while in other cases this can be rather difficult. The same applies if longer trains than normal are desired. In this case, the capacity of the railway network must be analysed since there may sometimes be alternative routes for freight trains.

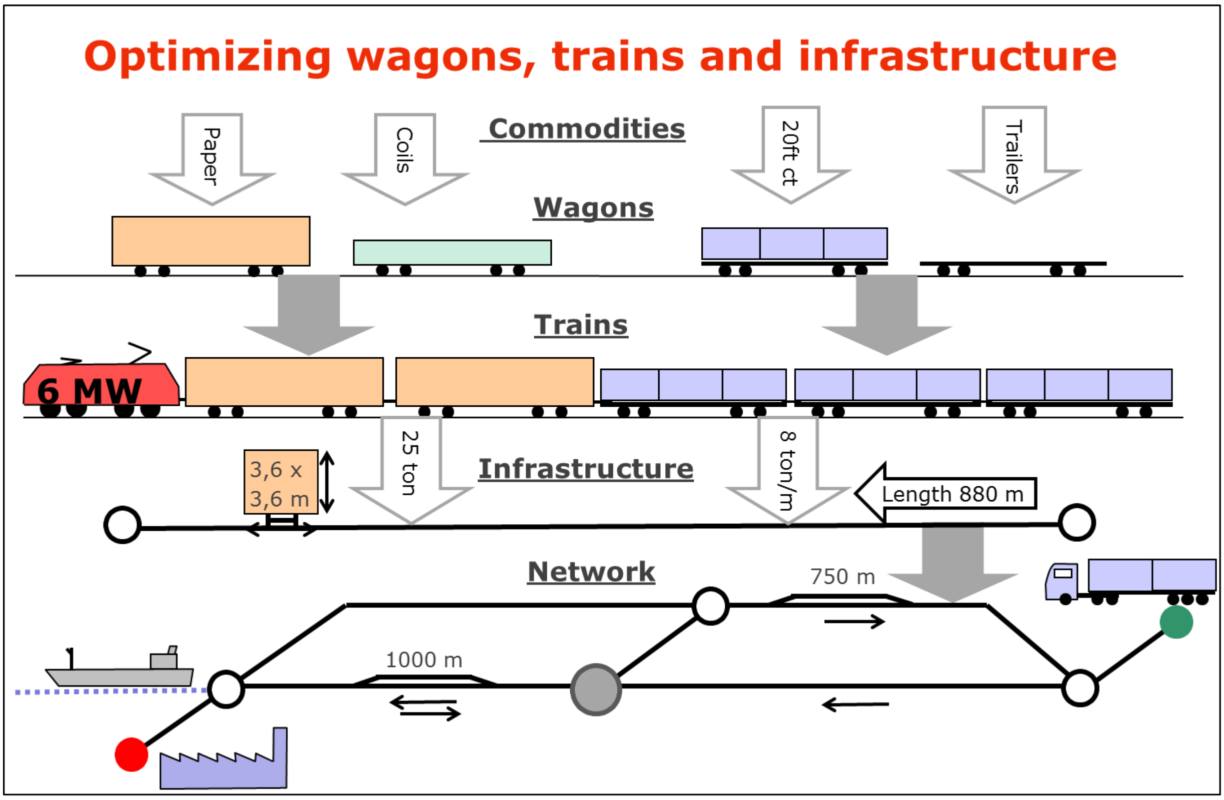


Figure 5.1: Principles for optimising wagons, trains and infrastructure

Short-term measures

In the short term, there are a number of measures where the aim is to use existing infrastructure and vehicles better without any major investment, for example:

- Load more freight on existing wagons by using a higher loading gauge.
- Operate heavier trains by utilising the tractive power of modern locomotives
- Standardise braking rules and tables that make better use of possible performance
- Operate faster freight trains at 120 km/h during the day to obtain more train paths
- Operate longer trains in special corridors and at special times where possible
- Establish a freight database for groupage to utilise capacity better
- Secure quality in international freight corridors

Medium- and long-term measures

In the medium term there are further measures that need closer analysis and sometimes investment:

- Secure high quality and capacity in international freight corridors
- Optimisation of wagons for different customers' needs with larger loading gauges and higher axle loads
- Heavier trains with locomotives that have higher static adhesive weight

- Longer trains according to the market's needs on special freight routes after careful planning and additional investment
- Lighter wagons with lower tare and higher payload
- End-of-train device or electro-pneumatic brakes and disc brakes for freight trains
- Introduce incentives for track-friendly running gear and for better brakes and improved braking performance
- Introduce automatic couplers to reduce shunting costs and widen the market

Evaluation of different measures

With a model developed at KTH the cost and capacity of a typical freight train have been calculated. The model has been used to evaluate different measures. The cost has been calculated for a Swedish freight train on a 600 km line with an average speed of 75 km/h. The result shown here is the difference in percent of cost per payload in tonne-kilometre and capacity in tonnes for the train. The changes are calculated in comparison with a 650 m long freight train of 1,650 gross tons with 22.5 tonnes axle load. Some examples are shown in Figure 5.2 and are explained below.

Heavier trains: If the gross weight of the train is increased from 1,650 to 2,000 tonnes the loading capacity in net tonnes will increase by 22%. At the same time, the cost per net tonne-kilometre will decrease by 9% if this can be handled with one loco. At 4,000 tonnes gross weight, two locos are needed and the cost will decrease by 18% at the same time as capacity will increase by 58%.

Longer trains: If the train is extended from 650 to 750 m with one loco, capacity will increase by 16% and the cost will increase by 6%. If the length is 835 m with one loco, as today between Hamburg and Copenhagen, capacity will increase by 29% and the cost will decrease by 10%. These are effective measures if you calculate the train cost and capacity but the infrastructure cost is not taken into account.

Higher axle load: An increase from 22.5 to 25.0 tonnes axle load will increase the capacity of a train by 1,650 tonnes, gross weight by 5% and decrease the cost by 7%, not taking the infrastructure cost into account, due to fewer wagons for the same payload. If the train length is constant at 650 m, the train can be extended with more wagons and capacity will increase by 15% and the cost will decrease by 10% with 25.0 instead of 22.5 tonnes axle load.

Lighter wagons: If the tare weight of the 4-axle freight wagon will decrease from 26 to 24 tons, the cost per ton kilometre will decrease by 3.5% and the capacity of the train will increase by 3.1% in a 2000 ton train with one loco.

Faster trains: In principle, faster freight trains will cost more because of higher energy consumption and maintenance costs and more expensive equipment. But in many cases it is also possible to increase productivity with more trips per day and to get more slots between faster passenger trains. Taking this into account, it might be cheaper with faster freight trains. Many locos and wagons are equipped for 120 km/h already today but to go faster more sophisticated running gear and braking systems are needed, which means there is an need for system change. The figure shows some examples of different productivity.

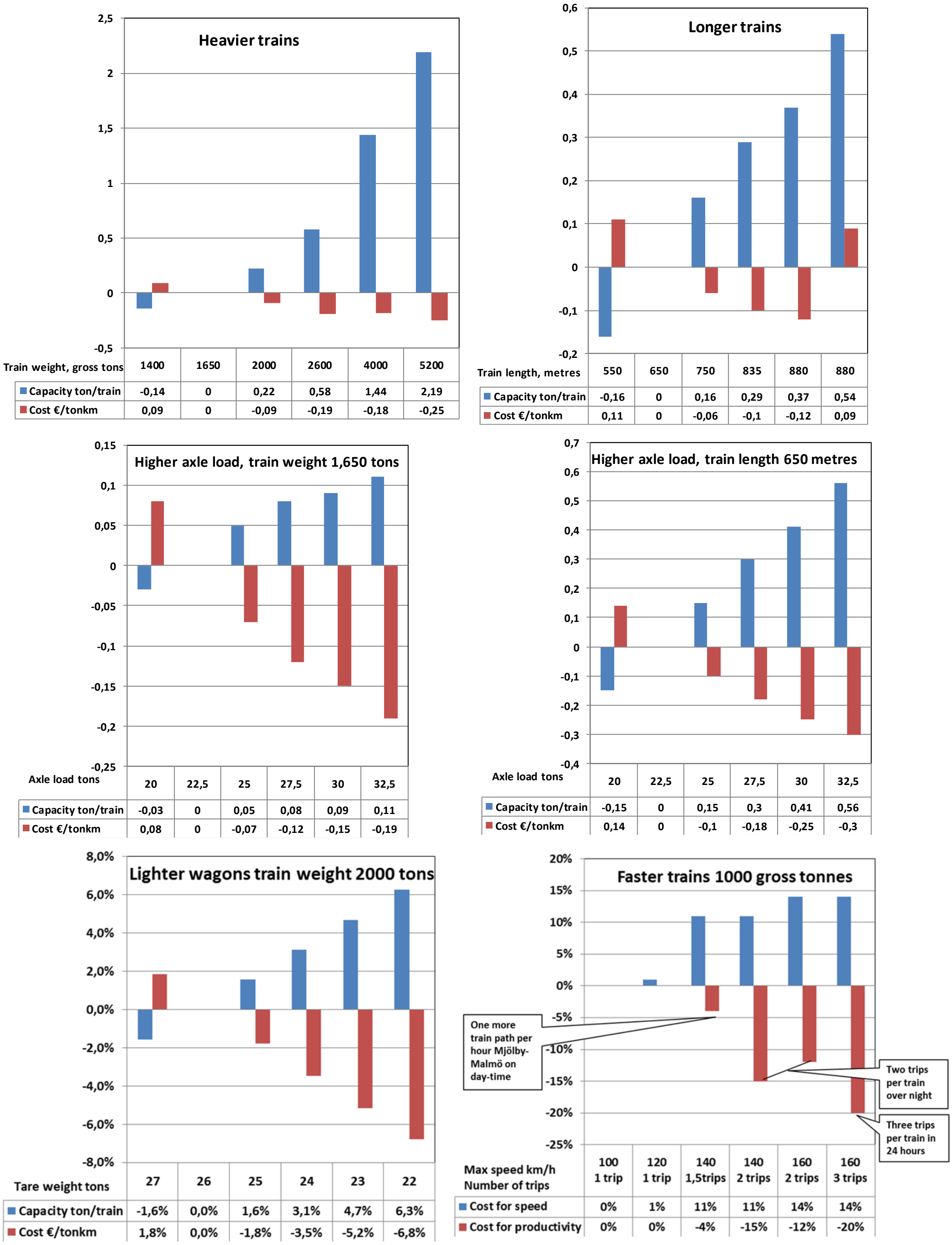


Figure 5.2: Evaluation of measures taking capacity and cost into account. Note that the scales are different. Source: Nelldal 2013.

Mass and volume load capacity per wagon and per train

The mass and volume load capacity per wagon are constrained by the infrastructure's limits on axle load and loading gauge, respectively. Raising these will raise the load capacity per wagon. The mass load capacity per train is constrained by the absolute trailing mass limit per train, which in all the cases studied is more restrictive than the product of train length and linear load. Raising the trailing mass limit per train, including the electric power feeding capacity, will thus result in a higher mass load capacity per train.

The volume loading capacity per train is constrained by the limit on train length and the loading gauge useful cross section. Raising either or both of these will result in a higher volume loading capacity per train. Using a model for volume loading capacity per train (Boysen, 2013) this can now be calculated, deducting the locomotive length and applying a length utilization of approximately 0.95 (depending on wagon length).

As an example, the attainable volume loading capacity in the German-Scandinavian corridor with each set of standards in this corridor is compared in Table 5.3 and Figure 5.4. As can be seen, the volume loading capacity can almost be doubled if the TSI standard could be applied and be three times higher if the Öresund and Fehmarnbelt standard was applied in the corridor.

Table 5.3: Overview of constraining standards in the German-Scandinavian rail corridor (Boysen 2013)

	Constraining limits Hamburg – Oslo, 2014	Constraining limits Hamburg – Hallsberg, 2014	TSI minimum standards (new freight lines)	Øresund and Fehmarnbelt
Loading gauge	7,285 m^2 (DE, DK)	7,285 m^2 (DE, DK)	10,0395 m^2	13.068 m^2
Intermodal gauge	P/C 400 (SE)	P/C 410 (DE, DK)	P/C 432	P/C 450
Train length	580 m (NO)	630 m (SE)	740 m-1050 m 1)	1000 m 1)
Axle load	22.5 t	22.5 t	25 t	25 t
Linear load	6.4 t/m (DE, SE)	6.4 t/m (DE, SE)	8.0 t/m	8.3 t/m
Trailing mass 2)	1,010 t (NO) 3)	2,500 t (DK)	n.a.	4,000 t
Gradient	25 ‰ (NO)	15.6 ‰ (DK, ØSB)	12.5 ‰	EB 15.6 ‰ (ØSB) WB 15.4 ‰ (ØSB)
Distant signals	800 m (NO)	1,000 m (DE, SE)		2000 m (ØSB)

Notes: 1) Wagon rake length 1,000 m per UIC 544-1. 2) W.r.t. mechanical limitations. 3) On a 25 ‰ gradient with head end power only.

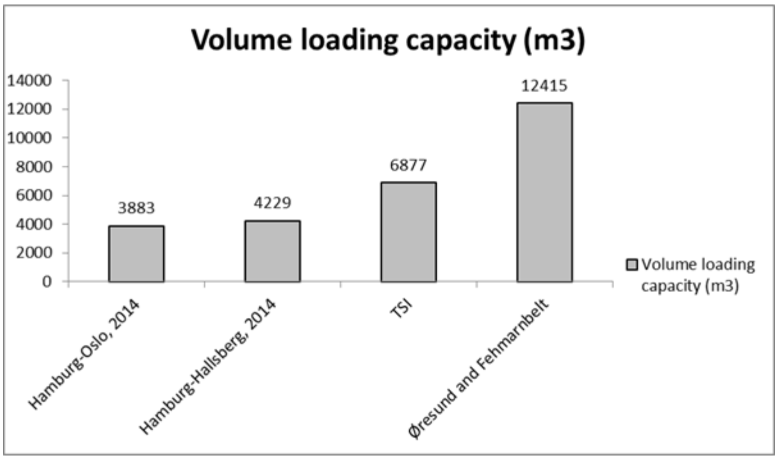


Figure 5.4: Volume load capacity per train in the German-Scandinavian rail corridor (Boysen 2013).

5.2. Intelligent systems for planning and dispatching trains

This section aims to provide a picture of the state of the art related to intelligent systems for planning trains, traffic monitoring, tracking, tracing and real time information management to support operators and customers. Existing solutions for dispatching trains with ERTMS are dealt with in chapter 2.8 and 5.6.

Existing solutions for freight trains monitoring and real time information management

This chapter presents the main existing solutions, at European level, for freight train monitoring and real time information management.

1. Hermes VPN

Hermes VPN is a pan-European, secure, and fully managed IP network interconnecting European railway companies and applications. Hermes VPN connects 34 locations across 23 countries. Hermes Open Services is a middleware cloud solution enabling railway related companies to interconnect applications. HEROS takes care of the channel conversion and the format translation.

2. COTIF/CIM and CIM/SMGS (Consignment notes for rail transport)

The CIM is Appendix B of COTIF (Convention concerning International Carriage by Rail), which concerns "Uniform Rules concerning the Contract of International Carriage of Goods by Rail". These rules allow consignment notes and their duplicates to be established electronically, performing the same function of "evidence" as the paper notes in international traffic. The CIM Consignment Note Manual (GLV-VM)21 provides for the possibility of electronic consignment notes. These rules allow for electronic data records that can be transformed into legible written symbols, where the procedures for storage and processing are functionally equivalent to the paper system, particularly in so far as the evidential value of the consignment is concerned. In 2011, the COTIF rules (without appendices) have been ratified in 24 EU countries. Within the EU, only Ireland, Italy and Sweden have not yet ratified the rules (in addition to Malta and Cyprus, where no railway infrastructure exists). Outside the EU, 17 countries have ratified the COTIF rules with appendices and one country (Norway) without appendices.

The CIM/SMGS consignment note has been elaborated as part of a joint project of the International Rail Transport Committee (CIT) and the Organisation for Co-operation between Railways (OSJD) to simplify cross-bordering procedures. The note especially simplifies and speeds up traffic on the west-east and east-west axes. It is also recognised as a customs and bank document.

CIM/SMGS is also based on the United Nations Layout Key for Trade Documents. EDIFACT infrastructure and Internet based technologies have been integrated. The CIM/SMGS consignment note covers mainly the same aspects as the CIM Consignment Note, in addition to which it also includes more detailed information, for example on transshipment procedures and charges. In practice, the CIM/SMGS consignment note could be used on over 20 railway transport routes. Examples of routes include the following: Germany–Russia (via Poland and Belarus), Germany–Ukraine, Czech Republic–Russia/Ukraine, and Romania–Russia. The CIM/SGMS consignment note has been estimated to save both time (16 hours per train) and money (40 euros per wagon) in addition to improving the overall legal certainty related to railway transport between Eastern and Western Europe.

3. ORFEUS (Open Railway Freight EDI System)

ORFEUS is a central international information exchange system. It was designed to ensure exchange of the railway CIM consignment note data between the co-operating railway undertakings. It also allows the exchange of CUV (Appendix D of COTIF, which concerns “Uniform Rules concerning Contracts of Use of Vehicles in International Rail Traffic”) wagon note data, which makes it unnecessary to collect the consignment or wagon note data at the borders. The data are delivered by the forwarding railway undertaking to ORFEUS and from there distributed to other railway undertakings involved in the transportation.

The main components of the system are CDS (Central Data-management System), which acts as a message broker for collection and distribution of information, including specific logic and verifications) and National Information Systems (NISes, which connect railway undertakings to the information systems of freight railway companies, covering commercial and production functions).

The ORFEUS system is currently used by railway companies in 11 European countries. These countries are Germany, the Netherlands, Austria, Switzerland, Sweden, Denmark, Luxembourg, Spain, Belgium, France, and Italy. In addition, a Serbian railway company is planning to adopt ORFEUS.

4. ISR (International Service Reliability)

ISR is a common tool of the European cargo railway undertakings for concentration and exchange of information about movements of freight wagons in international traffic through a central platform. It makes possible to track both loaded and empty freight wagons and consignments across significant part of Europe. ISR is applied to customer information and for wagon fleet management, as well as enabling visible customer service improvement and significant cost savings.

Besides basic information about actual status and position of wagons, ISR also offers additional information services:

- Records and shows wagon movement history (for about 2 months);
- Estimates time of arrival based on experience of the same transport in the past;
- Calculates estimated wagon mileage (km travelled) based on different sources;
- Integrates transport descriptions from commercial systems (from ORFEUS);
- Monitors wagons during train runs (using train movement information from TIS);
- Offers manual input of information (community cloud for data capturing).

The ISR members use the ISR data for several purposes, but mainly for:

- Customer information;
- Wagon Tracking;
- Trip Analysis;
- Transport tracking (as forwarding, transit or destination railway undertaking);
- Wagon Usage Planning;
- Wagon performance measurement (estimated km travelled);
- Single wagon performance analysis (via X-Rail).

5. Use-IT - Uniform System for European Intermodal Tracking and Tracing

Use-IT is a central information integration and distribution system, developed on request of the UICs Combined Transport Group (CTG). CTG stated a strong need for monitoring of combined transport block trains. The railway undertakings and mainly their intermodal customers requested a system to trace their (mainly container) trains in real time over the Internet or by directly tapping into their own IT tracking systems. Use-IT makes it possible to identify where the train is, if it is on time and a y deviation from its schedule.

The present Use-IT tool is based on:

- train reference data (mainly timetable data captured by railway companies via a web application);
- train movement information (reported in real time by railway undertakings' systems);
- web application for consultation of actual train position and situation over the Internet;
- interface for distribution of train position reports to customers' and railways' systems.

Use-IT is an information system developed, maintained and operated by RAILDATA. Its Special Assembly Use-IT provides management of the project. Technical issues are handled and coordinated by the Use-IT Experts group meetings. The User Support Centre in Basel provides support for the production. LUSIS' computer centres in Aubervilliers and Paris are responsible for production of the central application. The following railway undertakings take part in the operation of the system: DB Schenker Rail Deutschland, Rail Cargo Austria and Trenitalia Cargo.

The decision was taken to build up a completely new application (New Use-IT) with generally the same functionality. Currently used functionality and interfaces are covered, but the data source for train movements is RTIS (the train database). The user interface will be given a new design. Less invention is needed on the RU side. RUs no longer sends massages with real-time data to the system. The real time data are received automatically from TIS. TIS stands for Train Information System (formerly Europtirails), operated by Rail Net Europe (RNE). RNE automatically sends train movement reports from TIS to RAILDATA over the common interface. These data originate from particular infrastructure managers (IMs). Train position data received from TIS are stored in RAILDATA's train database (RTIS). These data are matched with the pre-defined combined transport trains. Train positions can be viewed over the real time Train Overview web forms and displays. A contract manager (railway undertaking responsible for a train) configures the train data with all its related information. These data are used for the access rules definition. At the same time he/she can also define the customers entitled to consult the train information.

Railway undertaking users can see all the relevant information for trains they are assigned to and have the right to see. Customers can gather information about the actual position and deviation from the schedule of his/her train(s) and to have a detailed view of the history of the trains concerned.

The new USE-IT system will also deliver information (outgoing) via FTP or SMTP. Standard FTP is currently used with active file download from partners. The message format is a specific XML based Use-It message.

6**. Rolling Stock reference Database (RSRD²)**

One of the most important requirements of the ECM certification to ensure safe operation of the European freight railway is the exchange of information/data between the actors, i.e. RU and ECM/keeper.

A freight wagon is mainly operated all over Europe by many different RUs, sometimes across borders. It is easy to understand how difficult it is to fulfil this requirement in such a business framework.

In parallel with the drafting of the ECM certification by ERA, the International Union of Wagon Keepers (UIP), which represents owners and users of private rail freight wagons, is developing a Rolling Stock Reference Database ($RSRD^2$) in order to respond to the TAF TSI requirements (Telematic Application Freight). This $RSRD^2$ is planned to provide technical information to the RUs, including maintenance information. and should allow RUs to provide information to the keepers and ECMs. The $RSRD^2$ also complies with the GCU requirements.

This is why this $RSRD^2$ will be able to be used by the ECMs and RUs in order to fulfil the ECM requirements and the RUs' obligation to provide operational information.

$RSRD^2$ also includes a solution for collecting mileage data from multiple data service providers, to be selected by UIP.

7. Train Information System (TIS)

The Train Information System (TIS) is a web-based application that supports international train management by delivering real-time train data concerning international passenger and freight trains. The relevant data is processed directly from the Infrastructure Managers' systems.

The application was developed by a consortium of 6 Infrastructure Managers (DB Netz, ÖBB, ProRail, RFF, RFI and SBB) and was co-financed by the European Commission. In 2007, RailNetEurope (RNE) took over the management of TIS and since then has been developing and improving the application. Nowadays, 16 Infrastructure Managers are involved in the project and 5 more could participate in the future.

The Train Information System (TIS) monitors international trains from origin to destination on the involved IMs' networks. It serves as an information source for international performance reports and quality analysis and standardises the exchange of data between different players. TIS also allows the identification of problems due to different national processes (for international trains) and triggers appropriate corrective action.

The main goals of the Train Information System (TIS) are to help RUs and Terminals with their own production system and to support IMs in the field of train running management. RUs have unlimited access to their own trains and to those operated in cooperation with an existing data exchange agreement. Terminals have access only to trains running to/from the terminal with an existing data exchange agreement. The main TIS functions are as follows.

TIS Real-Time Information function

- Real-time train traffic data, e.g. contracted timetable, forecasts, running advice, delays.
- Real-time information is visualised in the TIS graphical interface.
- Accessible with standard web browsers.

TIS Reporting function

- Predefined reports and graphs (punctuality, delay causes, etc.).
- Customisable reports and graphs.
- Information source for international Train Performance Management (TPM).

TIS Data Exchange function

- Raw data exchange based on UIC messages – and since 2012 TAF TSI messages.
- Filtering function to select the required information.
- TAF TSI pilot for the Common Interface (TAF TSI message exchange via Common Interface).

TIS Real-Time Information function features

- Real-time train traffic data via the internet (contracted timetable, forecasts, running advice, delays).
- Real-time train information in the TIS graphical interface shows a real-time visualisation of International
- Trains (network overview, space-time diagrams, train run reports, etc.).
- Collection and exchange of railway traffic data from/with European traffic management systems.

8. X-rail

X-rail is a production alliance this aims to render international wagonload traffic by rail more customer-friendly and efficient. The alliance aims to increase the competitiveness of wagonload traffic in Europe, protecting the environment by offering a more sustainable alternative to road.

The alliance consists of seven members (CD Cargo, CFL cargo, DB Schenker Rail, Green Cargo, Rail Cargo Austria, SBB Cargo and SNCB Logistics) and currently covers 10 major European wagonload networks throughout 11 European countries.

Whereas in the past systematic international schedules and delay alerts did not exist, X-rail has developed an IT tool that closely monitors all X-rail transportation by comparing the planned transport times against the actual wagon runs for a specific origin/destination (customer departure siding / customer arrival siding) along the entire transportation route.

The partners automatically receive relevant information before, during and after the transport. In case of delay (meaning that the actual wagon run is behind its pre-defined schedule), the X-rail IT tool automatically alerts the partners and provides a new ETA (estimated time of arrival).

In addition to the delay alert message, the X-rail IT tool also provides a “next day arrival message”. This means that, each day, the alliance partners receive information regarding which wagons will arrive the following day at the customer’s destination. Finally, customers can also track their international transport produced in the X-rail system via the alliance’s track & trace tool.

5.3. Development of traffic systems and products

Safe operation is at the heart of the development of traffic systems in European railways incorporating both passenger and freight trains. At present, infrastructure managers in the European rail network typically assign train paths on the basis that passenger trains have priority. Like passenger services, freight trains have a number of operational models, each of them with a different implication for safety. Freight service operations are typically characterised as trainload, single wagonload and intermodal, typically using the conventional network although increasing attention is being paid to the transportation of freight on the high-speed network. Like passenger trains, freight trains can be categorised as local, intercity, international and high speed. It should also be noted that European railways incorporate both incumbent and new entrant operators who are in many cases SMEs. Symonds Group Ltd (2001, p. 115) notes that the development of traffic systems can be more complex when dealing with wagonload (discussed in detail in section 5.5), which is found to marginally underperform compared to other types of rail in terms of price/cost, image, transit time, provision of advance information about changes to planned services and quality management systems. Symonds Group Ltd (2001, p. 115) also notes that "the current organisational structure of operators means that delays are more likely to affect wagonload than other types of rail services, in view of its usual position 'at the back of the queue'". It is clear, however, that nobody, be it operational personnel, passengers or train assets, should be exposed to unnecessary hazards and risks.

In the European context, the traffic systems should be developed for mixed traffic (freight and passenger services operating on the same network) ensuring that all service types have safe passage and this it is not an easy task for the traffic manager. From the freight train operational perspective, there is an increasing amount of low density, high value cargo generally transported in containers known as intermodal traffic. This type of traffic demands a lower transit time and unfailing reliability. This type of freight offers the operators higher commercial rates. Traditional rail freight traffic such as bulk goods such as coal and aggregates can accept longer transit time with a view to reducing the overall cost. Traditionally, rail freight services operate at a lower speed than their passenger train counterparts.

The SPECTRUM project is working on a train concept that can be characterised as a passenger train. It is proposed that the vehicle will have similar performance characteristics (in terms of acceleration, braking and speed) to a passenger service with the intention of enabling the service to run between passenger services. This type of operation is required to meet the demands of customers with LDHV goods, which typically consist of finished and semi-finished goods.

The principal objective of developing a suitable traffic system would be to improve infrastructure capacity usage so that railways become more efficient with reduced operational costs benefiting operators in the form of lower rates and customers in terms of improved service. In developing the traffic systems, the focus of the mixed train concept can be broken down into traditional operational divisions or be proactive to meet the operational needs for different types of passenger trains and freight trains operated by incumbent or private operators to improve their profitability by achieving for example higher load factors, higher asset utilisation, increasing flexibility to meet the changing demands of the final customers, i.e. shippers/consignees, and introducing strategic control including minimising wagon handling and yard operations in the case of LDHV services.

Li and Mitchell (2003, p. 2-13) suggest that tracks can be divided into 'main tracks' and 'other than main tracks' depending on the level of control required for trains, single wagons, or engine movements. The main track is the track extending through yards and between stations, upon which trainloads or engines are authorized and governed by one or more methods of traffic control system. Here, it is very important to note that the main track must not be occupied without authorisation or protection. Li and Mitchell (2003, p. 2-13) also suggest that the term 'mainline' is not defined in the rulebooks and generally refers to the series of sub-divisions on which most of the traffic is carried, as opposed to secondary lines and branch lines. A portion of the main track can be designated by limit signs in the field and/or by timetables or special instructions that permit certain types of movements without specific authorisation. Certain speed restrictions normally apply which are generally known as 'Yard Limits'.

A trainload is also known as a block train, meaning that all the wagons and/or cars are shipped from the same origin to the same destination, without being loaded or unloaded en route to achieve operational efficiency in terms of time and money. This aims to mitigate the delays and confusion associated with assembling and disassembling trains at rail yards near the origin and destination as associated with single wagonload traffic. It also enables railways to compete more effectively with road and inland waterway transport systems. Block or unit trains, as they are also known, are typically more economical for larger volumes of cargo. Unit trains often carry only one commodity and wagons are of the same type. This might for instance be a hopper wagon on a unit train carrying grain.

5.4. Network organisations and innovative operational models

The EU 1991 Directive and subsequent three Railway Packages attempted to make provisions for the private (as well as incumbent) rail freight operators to enter/exit the market with no or minimum hurdles and do business in a fair competitive market with similar treatment in terms of licensing, path allocation and charging. In the deregulated rail transport operating environment, we can discern at least three types of organisation: organisation responsible for network development, maintenance and traffic management (e.g. Network Rail in the UK); independent and government regulatory authority responsible for access and market regulation, e.g. issuing licences, path allocation, charging (e.g. Office of Rail Regulation (ORR) in the UK); and the operators (both freight and passenger) responsible for offering transport (commercial) services. There may also be other types of organisations, such as the RSSB in the UK, responsible for example for safety performance and risk related issues. Once an operator is granted a licence by the ORR, they have to operate on the network that is maintained by network manager Network Rail. There are some issues that cross boundaries of their responsibilities. For example, the ORR has to consult with Network Rail in granting licences as well as path allocation. These organisations thus need to work closely together to do business both in freight and passenger rail transport safely and efficiently.

Getting fair treatment from a national network manager (infrastructure manager) or regulatory body, for example Network Rail or ORR in the UK, is not without controversy, as some network managers are brothers/sisters of the incumbent operators (e.g. DB Netze and DB Schenker in Germany). There have been complaints that the incumbent companies receive unfair advantage from the network manager over new entrants. Some experts suggest that if there were one functioning network manager responsible for path allocation, licensing and charging for all European countries, then all operators (irrespective of new entrant or incumbent) would be given equal and unbiased treatment. To this end, the fourth railway package, waiting to receive approval from the Commission, was issued in January 2011. Critics of this central and one-stop-shop network management approach argue that it will hamper the safety of the network and also create problems for development and maintenance of the network.

Some also think that if all TEN-T rail freight corridors are put under one company with joint responsibility for network management and service operation as in US Railways, then the rail freight operation would be efficient, effective and safe. Critics of this approach raise complex issues of maintaining links (hub and spoke train or mother and feeder train concepts) with local national lines, network managements and local freight and passenger service operators. More research is needed to find an innovative solution suitable for the European context.

5.5. Future single wagon systems and alternatives

Why wagonload traffic?

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 other countries. In the USA, wagonload traffic still has a strong position, and is an important source of the revenue. Wagonload traffic in Europe has decreased but still accounted for 30% of the total transportation effort 2012.

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 the EU, a normal truck can be 18 m long and 4.0 m high and weigh 40 tonnes, which in practice means a loading height of 3.0 m, a payload of approx. 26 tonnes, and a volume of approx. 100 m^3.

If the freight is to be transported by a 40 ft container, volume is limited to 80 m^3 because the height of the container is normally 2.5 m. An 18 m long bogie wagon can accommodate three 20-foot containers. Given a container's payload of 20 tonnes, 60 tonnes can be loaded on a railway wagon but only 26 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. The difference is even greater if the axle load is increased to more than 22.5 tonnes and the loading gauge extended.

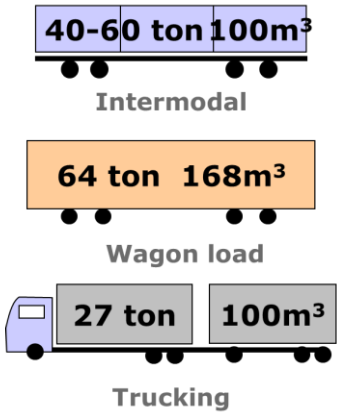


Figure 5.5: Comparison between capacity for intermodal, wagonload and truck transportation.

There are many transport concepts where intermodal transportation has logistic advantages, but if wagonload traffic were to be generally discontinued in Europe, 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.

Developing today´s system

Shuttle freight trains, direct by nature, generally run between hubs (i.e. major rail terminals) where multiple wagons (loaded or unloaded) are consolidated or unbundled for different destination terminals (i.e. freight train stations). The shuttle trains generally run with scheduled path allocations. The rail terminals may be linked with services such as marshalling yards for consolidating single wagonloads. In fact, an efficient and effective operation of marshalling yards is at the heart of the future single wagonload (SWL) freight service in Europe, as the average rail transport haul is short compared to that in the USA. In such cases, a group of single wagonloads can form a direct train to run between rail terminals (adjacent to a marshalling yard) and rail hubs.

Clausen and Voll (2013, p. 130) discussed the issues of transporting wagonload as follows: 'A customer wants to transport a small group of wagons from A to B by train. The number of wagons is too small to justify direct transport. Therefore, it is necessary to bundle them with wagons from other origin-destination-pairs (relations) for certain parts of their routes. Trains can be separated and sorted to new trains in classification and marshalling yards which are distributed all over the railway network. The sorting process (called reclassification) is very expensive and time-consuming. Hence, it is necessary to balance reclassifications and transport distance'. Figure 5.6 illustrates such train formation with SWLs.

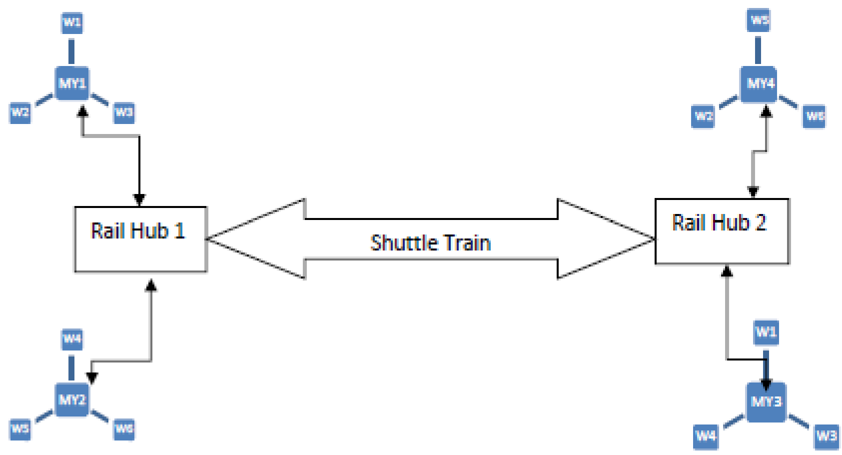


Figure 5.6: Single wagonload, group of single wagonload, hub and shuttle train concept. Islam, DMZ, 2014.

The transport of SWLs forms an important part of total supply and transport chains in Europe. Consolidation or unbundling of SWLs and wagon groups is conducted from the feeder line to the rail hub, for the formation of full train loads between hubs, for block and shuttle trains. The SWLs were an important source for the regular shuttle trains. Marinov, et al. (2013) suggest that the share of SWL in the global rail freight traffic is gradually decreasing from 40% in 2005 to approximately 30% in 2010. Clausen and Voll (2013, p. 129) suggest that the situation is such that some European countries have begun to abolish wagonload traffic. The CER (2012 p.4) reports that SWL has only 10.6% of the total market share, while full truckloads hold the remaining 89.4% in the European rail freight market. UIC (2013) reports that most of the European railway undertakings are losing money on their SWL activities, although it is claimed that the RETRACK, partly funded under EU FP6, rail freight operators successfully operate such SWLs and wagon groups by applying a hub and spoke model (Zunder et al., 2012; Islam, et al., 2010) without consolidating the cargoes of SMEs and other major customers. One important reason for the decline in SWL's share is strong competition from trucking companies who offer door-to-door services to all types of customers (big companies and SMEs) whereas the rail operators focus on the big customers due to operational limitations. The situation is getting even worse with the introduction of bigger containers (e.g. 45 ft) and longer and heavier trucks in different European countries. UIC et al. (2008, p. 9) suggest that an introduction of longer and heavier road vehicles will shift about 55% of the combined transport (that includes rail freight transport for longer parts of the total transport chains with road for shorter) and the SWLs will also be hit hard.

A more recent study echoed a similar effect on SWL (K+P Transport Consultants, 2011). CHRISTIDIS and LEDUC (2009 p. 4) found that rail freight demand (including SWL) will decrease by about 3.8% with the introduction of longer and heavier vehicle in Europe. Closing down this SWL business segment is not a sensible option. Woroniuk et al (2012, p. 83) suggest that block and shuttle trains be employed in some major European rail corridors that will lead to an average freight growth of 5% to 10%. They suggest that the operation of these trains is less complex than the operation of SWLs. An appropriate solution needs to be put in place; for example, the feeder line operators can consolidate the cargoes of SME customers at consolidation centres at rail terminals on some of the major and longer corridors. In other words, the traditional rail terminals have to be the centre of value adding services, instead of only marshalling yard facilities.

Liner trains instead of node systems

Instead of a conventional hub and spoke system, a system of liner trains has been proposed (Nelldal et al 2005), 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 can handle many non-standard relations.

The upper diagram in figure 5.7 shows 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 diagram in figure 5.7 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.

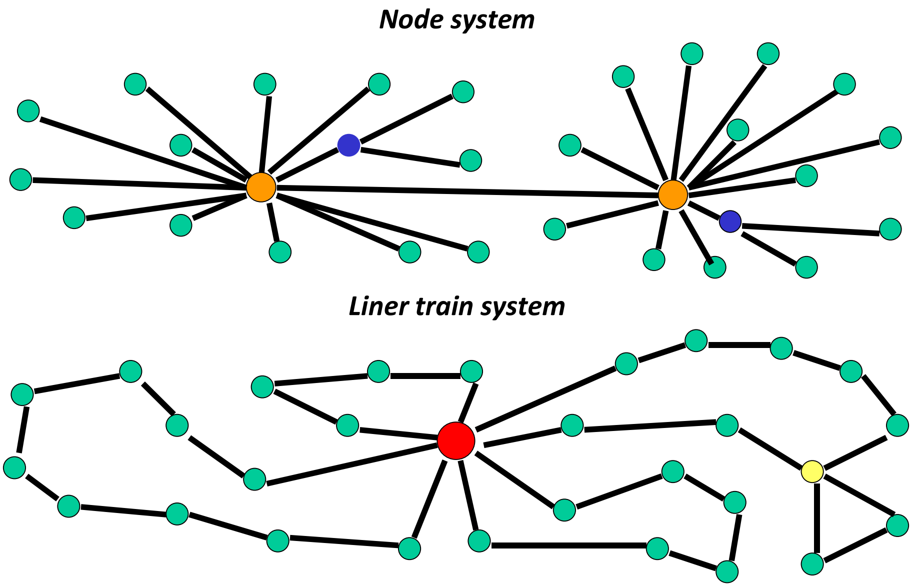


Figure 5.7: Conventional hub and spoke system (top) and liner system with the same market (bottom).

A calculation shows that transportation costs are reduced by 17% in the case of wagonload traffic. If duo locomotives are used, the transportation costs can be reduced by a further 5%. With a duo locomotive, the same locomotive can be used for shunting and for long-haul traffic. The trains do not then need to change locomotives to enter a terminal.

Automation of marshalling yards

There are many possibilities for further automation of marshalling yards, i.e. radio-controlled hump-locomotives, primary hump and secondary-retarders, piston retarders in the sorting tracks, wagon-movers, movable stopping devices and automatic brake test equipment. Complemented with an IT system to control all movements and an advanced planning system, marshalling can almost be done automatically.

The ultimate solution is to introduce automatic couplers so the wagons can be coupled and decupled automatically. The process will demand a minimum of staff and not be so dangerous for the workers. If this is also radio-controlled there will be further cost savings in the operations and it will also widen the market for wagonloads through more efficient operations on sidings and stations.

There are also new network strategies, which mix full train loads and single wagonloads to achieve a unified system based on the blocking principle. This system looks at the conventional traffic as dynamic wagon blocks that are susceptible to being coupled and decoupled. The new system is meant to increase the capacity of the trains and the frequency of the service by coordinating the timetable and the booking system better by using sophisticated IT systems.

5.6. How a new signalling system such as ERTMS will affect freight capacity

The effect of a better signalling system

UNIFE (2012) reports that there are more than 20 signalling systems in Europe inherited from the past. The use of such significantly varying systems can in itself be a critical factor in running pan-European rail freight services because each train used by a national rail operator has to be equipped with at least one signalling system, and in some cases more than one, to be able to run safely within even one country. Having multiple signalling systems on board is costly and significantly increases the technical and operational complexity of train sets. To remove these barriers, the European Rail Traffic Management System (ERTMS) has been introduced. The ERTMS is a major industrial project at the forefront of the EU agenda for an interoperable railway system and the progressive establishment of an open market in the EU sector (2013, p.29).

ERTMS/ETCS L-1 is as an add-on designed for conventional lines already equipped with trackside signals and train detectors. Balises are installed on the trackside adjacent to the signals to transmit information to the control centre and the train. The information from the balises is used to calculate the maximum speed of the train by the on-board ETCS equipment, which helps to determine when and where to brake the train (Railway-technology.com, 2014). ERTMS/ETCS L-2 does not require trackside signals. The movement authorisation communication occurs directly from a Radio Block Centre (RBC) to the on-board unit using a GSM-R. The continuous communication system of the L2 allows the train to reach its optimum or maximum speed while maintaining a safe braking distance (Railway-technology.com, 2014). ERTMS/ETCS L-3 is still at the conceptual stage. It is based on moving block technology and involves the use of special equipment inside the train to continuously supply data about the train's position to the control centre, rather than by track based detection equipment. The train thus continuously monitors its own position (Railway-technology.com, 2014).

The ability to absorb greater demand, as some corridors in Europe are very busy due to more passenger, freight and international train movements, is an important factor in rail transport’s competitiveness. ERTMS enables significant increases in traffic along the railway networks. Once established along the corridors and networks, UNIFE (2012) claims that it is a cost-efficient solution to absorb higher freight and passenger demand. The TOSCA (2011, p. 18) study found that a 35% capacity improvement can be achieved through introduction of ERTMS-L3 by 2030, see figure 5.8. UNIFE (2012) also suggests that a continuous communication-based signalling system, such as ERTMS, reduces the headway between trains, enabling up to 40% more capacity on existing infrastructure. It therefore offers considerable advantages for both infrastructure managers and operators wishing to run competitive freight operations: more capacity means more trains moving, and thus more benefits. This “capacity advantage” partly explains why some countries outside Europe and isolated by the sea, like Taiwan, have opted for ERTMS as the signalling system of choice.

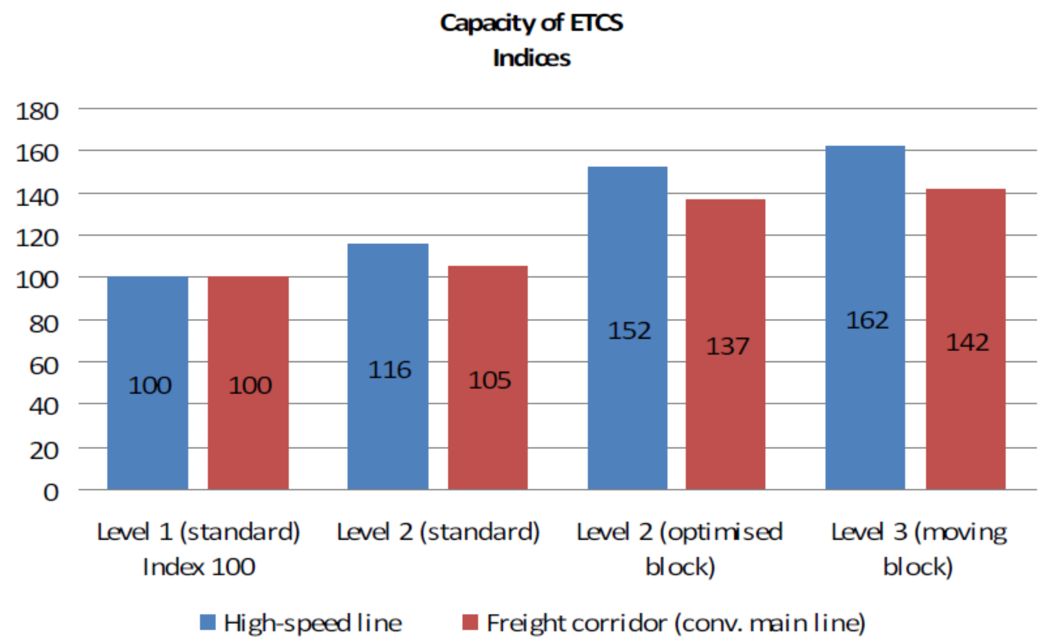


Figure 5.8: Capacity of ERTMS L1, L2 and L3 on a double-track line. Source: TOSCA Capacity report.

The cost for introducing ERTMS

The advantage of introducing ERTMS is increased interoperability and less investment and maintenance when building a new railway line. However, there is also a cost for the operators to equip and test the devices on locomotives. The cost for the equipment in a new standard locomotive is approx. 3,500,000 euro and the ERTMS device costs 100,000 euro, i.e. 3% of the investment. But the investment represents only a part of the operative costs for a freight train, so the transportation cost per TEU will increase by 0.4% for a typical intermodal train with 34 four-axled wagons.

For a small operator, with a second-hand engine bought for 1,000,000 euro, the cost can be much higher because the system must be verified for every type of engine. The cost can be as high as 1,000,000 euro, or as much as the locomotive. The transportation cost will then increase by 4% for the same train. But the problem is that it is not profitable for a small railway company to make an investment like this in an old loco so the operators have to pay a cost which they cannot always get back from the customers until the system has been implemented everywhere to allow them to reach a bigger market and gain capacity.

5.7. How dedicated high speed lines will affect freight capacity

In Sweden the southern main line between Stockholm and Malmö/Copenhagen and the western main line between Stockholm and Gothenburg are the most congested routes. There is a mix of trains with different speeds, high-speed trains with a maximum speed of 200 km/h, regional trains with 160 km/h and freight trains with 100 km/h. There are therefore plans to build a dedicated high-speed line between Stockholm-Jönköping-Gothenburg/Malmö-Copenhagen.

The total effect on different sections of todays´ main lines is shown in figure 5.9. If dedicated high sped lines are built, most of the express trains can be removed from the Western and Southern main lines. In addition to extremely short travelling times and greater capacity and punctuality in passenger traffic, capacity is also freed up on the main lines for freight traffic and regional trains. Simulations show that it is possible to operate 2-3 times more freight trains during the day. Freight trains that operate at night will not be affected so much.

The figure also contains another alternative with upgraded main lines from 200 to 250 km/h with three or four extended track sections and overtaking stations. The increase in speed differences will decrease capacity that will hardly be compensated for by the infrastructure investments. The total capacity will on most sections be approximately the same as today, and the gain in journey times will not be of the same order as with dedicated high speed lines. The conclusion is that in the long term it is more socioeconomically profitable to build dedicated high-speed lines than to upgrade the conventional lines. The Swedish government has also decided to build the first part of the high-speed lines.

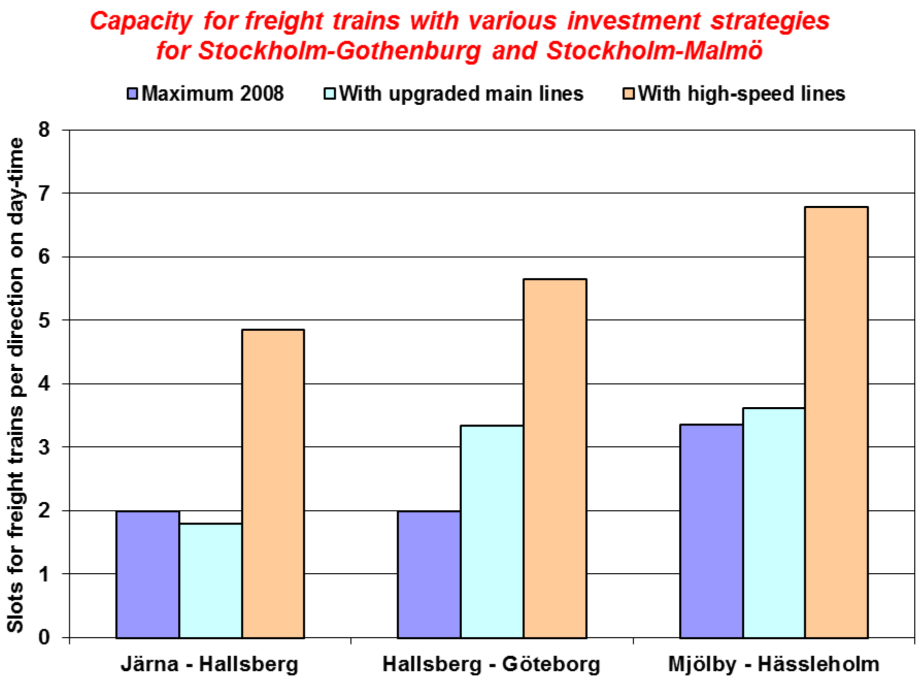


Figure 5.9: Number of possible train slots for freight trains during daytime 2008, with upgraded main lines and with real high-speed lines.

5.8. Capacity by building dedicated freight lines

The question of capacity on a line is a very complex problem because the capacity of a double-track line is extremely dependent on the signalling system, the existence of a capacity of running on each track in two opposite directions safely, having points that allow trains to switch from one track to another at certain distances (which is also a parameter), the speed distribution of the trains, and the barking capacity of the trains. With all these parameters, the indication of the capacity of a line makes it imperative to define a simple schedule of assumptions to allow comparisons. As reference we can use the statistical results of train management on normally equipped tracks with an automatic block light system placed at 1500 m average interval with passenger trains running at up to 160 km/h with long-distance trains, with other regional passenger trains stopping at every station and with freight trains running at between 100 km/h and 120 km/h as their maximum speed. In this scenario, the traffic flows normally if it does not exceed 220 trains in both directions per day, which means 110 trains per direction.

For a dedicated freight track with an automatic block light system placed every 1500 m as the signalling system, the safety movement of the trains is preserved if two blocks are empty for a train to enter, which means that the head of the first train is 3 km+750 m = 3,750 m in front of the head of the train behind. This interval will be covered by the second train running at 100 km/h in 2.25 min, which should theoretically allow 26.6 trains per hour during a 20 hour-period (4 hours being allocated to maintenance), which amounts to 532 trains per track per day. Unfortunately, we should use a random distribution of trains over this period, reducing the volume by 50% to 266 trains per track compared to 110 with real traffic. This very rough calculation should even be reduced a little by the difference in speed of 20km/h and by the difference in traction capacity as the profile of the track may introduce some slopes to climb. It is quite difficult to take that factor into account but with sidings enabling an overtake every 100 km, you can see that the distance between a more rapid series of trains at 120 km/h and the last train in a series of 100 km/h would be 20 min, meaning that you have to reduce your capacity by 33%, leaving you with 190 trains per day compared to 110, which is still 70% more than a track with mixed traffic.

This calculation is a little pessimistic as we have already reduced the overall volume by 50% because of random arrivals of trains on the section considered. My conclusion is that the increase in capacity with a dedicated network is considerable and it is even more important if you take into account the 1,500-metre Marathon trains that are being tested. Of course, on certain sections you have to take into account that the signalling blocks need to be 800 m apart. In that case, you would have a train every 2.35 km, which are covered in 1,41 min or 42.5 trains per hour and 850 trains in 20 hours, leading to 425 trains after a 50% reduction and 280 trains taking into account the speed difference between 100 km/h and 120 km/h. This is a huge capacity increase compared to 110 trains, which is considered reasonable today. This is a very theoretical approach as concentrating so many trains needs terminals to be able to dispatch and handle them properly. This is why such block-shortening is only installed in very congested areas near big cities. So we have to be cautious with these theoretical figures.

In conclusion, it is clear that dedicated lines are safely able to accommodate twice the number of trains classically accommodated on mixed traffic lines and if high-speed traffic is introduced on mixed traffic lines, capacity is largely reduced due to the speed difference.

5.9. Tracking, tracing and monitoring information systems for operation and management

For years, the competitiveness of combined road-rail freight transport (CT) has been high on the European transport policy and research and technological development (RTD) policy agenda. One of the problems that the CT community faces is the introduction of information and communication technology (ICT) based services: Shippers and forwarders (the ultimate clients of CT) require real-time tracking & tracing (T&T) information about the position of their consignments while on an intermodal journey. In addition to track and trace, condition monitoring and security issues need to be addressed to position rail at a level where it can compete with the road transport sector on product and service grounds. T&T and monitoring technologies constitute the core of such automated real-time information systems. While a range of different technologies for the tracking, tracing and monitoring of mobile resources is provided, only limited systematically compiled information is available about their performance and suitability for CT. In this respect, the best-known T&T technologies are the Global Positioning System (GPS) and Automatic Equipment Identification (AEI) and their localization within the Global System for Mobile Communication (GSM). The focus of this study is location technologies likely to be found in past, current and future T&T systems in CT based on the automatic generation of location information.

Conventional Location Technologies

1 Location through video surveillance and optical recognition

Video surveillance is basically an extension of manual location monitoring. Closed circuit video cameras are primarily installed at combined transport terminals to cover the roadside gates and the loading area. Road-gate surveillance allows visual capture and recording of all incoming and departing trucks and ITUs. Surveillance of the transshipment area with adjustable cameras allows the terminal management to follow all operational processes from a central control terminal. Video surveillance is therefore mainly a means to support the terminal and transshipment management. For tracking & tracing purposes, transport equipment identity marks could be taken from the video screens instead of from the actual location, allowing manual monitoring activities to be removed from the location of physical activity and to be centralised, at least on terminal level. A logical extension of video surveillance towards a more automated system is its use together with optical recognition techniques, a process by which the images taken by the video cameras are scanned and resolved into a systematically organised grid, in which contrast points are either present or absent. In this way, identity marks such as truck or semi-trailer number plates, swap-body code plates, and painted container or wagon numbers could be transformed automatically into usable electronic information.

2 Manual location

Used especially on the railways, each locomotive and wagon has a unique identification number that should be visible from the outside. Railway rolling stock can therefore be detected and unambiguously identified by human beings. Trains are stored in the database in a data structure that logically relates timetables to trains, trains to the wagons they are made up of (wagon consist) and ITUs to the wagons they are loaded on. When a train is spotted, e. g. when it passes a certain station, the time of passage, arrival or departure is entered into the database and the system automatically associates the time to all the wagons and ITUs that are supposed to be on the train.

Advanced Location Base Technologies

1 Location through Automatic Equipment Identification (AEI)

AEI systems are based on short-distance radio frequency (RF) transmission and consist of an RF-tag which is attached to a vehicle or equipment and a reader which is stationary or can be carried around by a person or mounted on a vehicle. Mostly incorporated into the reader are an RF module, one or more antennas and an interrogator. Tags contain an identification code and related information for the specific vehicle or equipment. When a tag on a vehicle or piece of equipment enters the read zone of the antenna, the RF tag detects the radiated signal, modulates it with the coded information and sends it back to the antenna via reflection. They contain circuits that modulate the broadcast signal according to the stored identification code and other related information and reflect a small part of the modulated signal back to the antenna. The reflected radio waves thus denote the tag's unique identification code and related information. The antenna receives the reflected, modulated signal and transfers it to the RF module which demodulates it, pre-amplifies it and sends it to the interrogator, which can add information such as date/time to the tag's identification code, and stores it in a buffer. The reader can transmit this information to a local or remote host computer via data communication services. In Europe, AEI applications have so far been implemented for locomotives and wagons by the French and Swiss national railway companies. For swap-bodies, Kombiverkehr and a number of German swap-body operators have implemented an application at the Köln-Eifeltor terminal and CNC between Le Havre and Valenton.

2 Location through satellites

Satellite-based location of unaccompanied units has to fulfil two functions: the location of the mobile unit and the transmission of the location information to the user at a remote monitoring site. Three satellite-based location technologies are presented below:

• The GPS/GLONASS/GNSS system, which is the most accurate real-time location service but which only provides the location function and therefore needs to be combined with a space or terrestrial data communication technology.

• Qualcomm's Automatic Satellite Positioning Reporting (QASPR), with location function and a very versatile two-way communication function but which requires large transceiver devices.

• The Advanced Global Research and Observation Satellite (ARGOS) system with non-real-time location function and limited one-way data communication function. GPS can be integrated in both QASPR and ARGOS to enhance the location accuracy of these systems.

3 Location within the global system for mobile communication

Cellular mobile communication systems can potentially be used to supply information about the location of a mobile station (e.g. a mobile phone or a mobile data station) using it. The cellular system exploits the nature of the dissemination of electromagnetic waves in open space: Because of the limited range of these waves, several base stations that are placed at some distance from each other can transmit with the same frequency without the signals interfering with each other at the receiver.

Basically, three location techniques can be used within GSM networks:

• Base station or cell identification and possible hand-over/change-over recording;

• Base station triangulation;

• The CURSOR technique;

Location accuracy increases from a theoretical minimum of +/- 70 km for base station or cell identification to about +/- 75 m for the CURSOR technique.

The Internet of Things in Solutions for Monitoring

1 RFID technologies for the Internet of Things in the supply chain

Concerning monitoring and re-planning to achieve on-time train departures and deliveries, there has to be a tracking & tracing system that includes the terminals. This involves the positioning of loading units on the ground at the terminal, the communication with actors along the chain, especially information with feedback on status to the customers (shippers, freight forwarding companies). One solution is the instalment of RFID (Radio Frequency Identification) on wagons where a radio transmission of data between a reader by the track and a tag/transponder will provide real-time information. RFID is the technology that is most often referred to in relation to the Internet of Things. RFID allows objects to be identified at several metres' reading range without visual contact.

The most important identification techniques in freight transport are barcodes and RFID (Radio Frequency Identification), see figure 5.11. Barcodes are currently the most widely used method for the identification of parcels, but RFID is more suitable for automated identification since it allows larger reading distances, has the possibility to identify multiple items in a single reading, and can identify a target in motion.

There is a wide range of RFID techniques: from small passive inductive tags for animal identification with a few centimetres' reading range to active microwave or UHF active transponders with over 100 metres' reading range. The introduction of standards, especially EPC Gen 2 (ISO 18000-6c) has solved the interoperability problems in many areas of RFID identification. RFID technology uses either inductive or electric linkage between tag and reader. The lower frequency systems (125 kHz and 13.56 MHz) use inductive technology, higher frequency systems (433 MHz and up) mainly radio linkage. Higher frequency systems can use inductive linking for short range communication, e.g. for printing or for item identification in which tags have to be uniquely identified. The information given by the RFID is what vehicle (EPC (Electronic Product Code)), when the event took place, where the event took place, and train direction.

The memory part of the tag may contain information about the condition of the wagon, i.e. its technical wellbeing including bearing temperatures. It is thus possible to combine the information and have logistics to track and trace vehicles and vehicle maintenance.

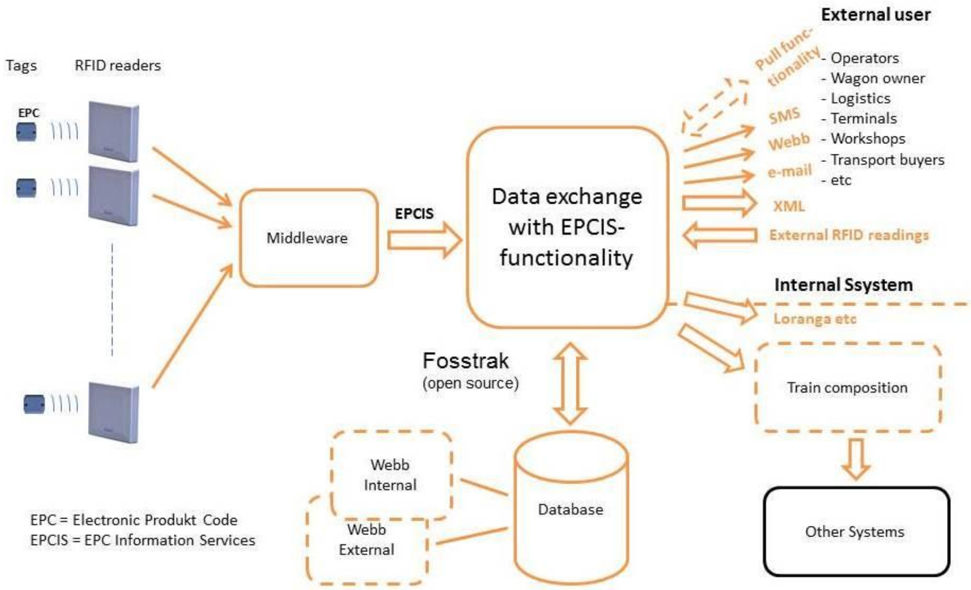


Figure 5.10: Structure of database for transports.

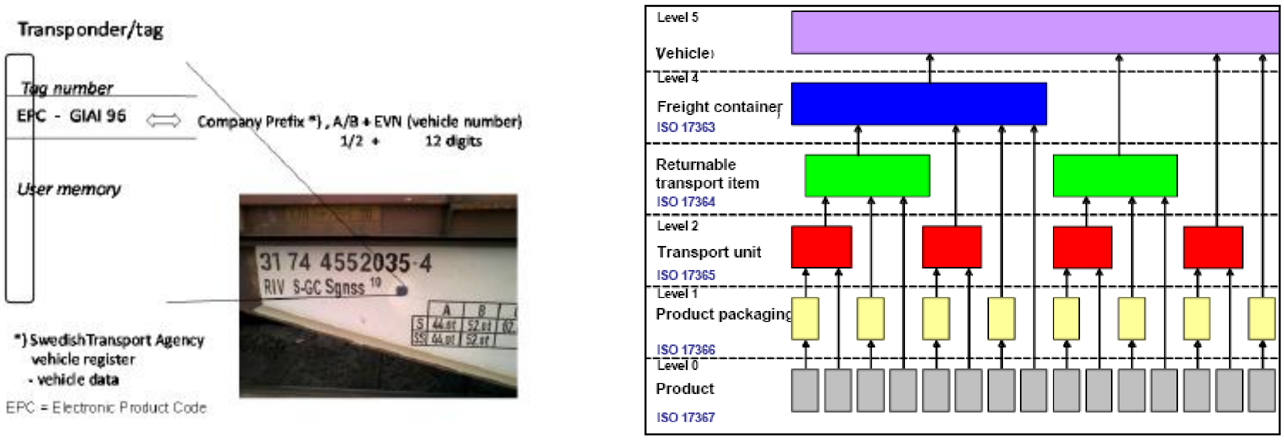


Figure 5.11: Left: Example of RFID tag on freight wagon. Right: Standardized information structure.

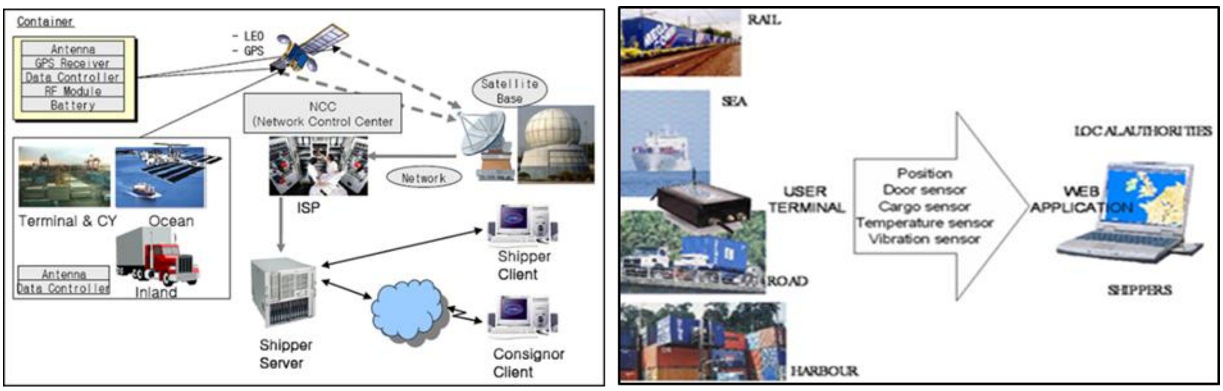


Figure 5.12: Example of Technology. Left: Container Tracking, Right: GPS Application

2 Smart containers

Smart containers are containers with built-in sensors and communication possibilities. A control centre can track the status and integrity of the container during transport in real-time or at regular intervals, see figure 5.12. Properties of the smart container include:

- location (e.g. GPS)
- identification (RFID)
- door sensor
- alarm if the container deviates from the projected route or moves outside the allowed area (geofencing)
- monitoring of the load (acceleration, temperature, etc.)
- communication (GSM/GPRS, satellite)
- power source (vehicle, battery, solar cells).

and evaluation of performance over time.

3 Intelligent unit

Wireless data transfer techniques and sensor technology enable significant development of the supply chain. An intelligent transport unit or package is a package that monitors its own condition, draws intelligent conclusions and communicates wirelessly in the supply chain. The system is based on an active package and automated, interactive communication. The package (e.g. a pallet or roller cage) is able to perform measurements, transmit the data, operate independently and manage the sensors. In addition to the package, a transport unit or warehouse module is needed. This module transmits and saves data and also keeps a record of packages. The package communicates with the transport unit, warehouse or control centre. The package sends a message to the control centre if alarm limits (e.g. temperature is not within given limits) are exceeded.

Monitoring and real-time information

1 On monitoring providing real-time information

The monitoring system needs to decide what information is important and what information is not, which can be done using signal processing to compare with normal results, including deviations. There is thus a need for a threshold for all information where a customer or operator needs to access real-time updates on where the cargo is or a factory to plan for just-in-time operation, or for the operator to improve their customer service. In normal cases particularly concerning structural health monitoring, the information on the train-set can be collected on board the wagons or by sensors beside the track. If the information does not differ from what is expected, old data can be erased and new data uploaded in conjunction with the trains passing or if the sensor is on board the train sensors will be monitored at regular intervals. Too much information being transmitted will create congestion that can be difficult for the network operator to handle and may even create unnecessary alerts. There are, however, cases where it might be necessary to access all the information, e.g. accident investigations. The measurement data is also preserved at the sensor node for a fixed time until the next site for measuring the condition of the wagon has been passed.

The data registered by the sensor node sites has to be compared in the case of wayside-mounted detectors in order to watch for trends and use this as the basis for an alert. This implies the necessity for bilateral communication through the system where information can be retrieved from the sensors. In the event of deciding to send an alert signal, it is important that different sensor data has been compared, e.g. if the same trends of increasing temperature and vibration are seen for the same ball bearing. This must be done since an inspection stop induces high costs and delays. It is shown that health and operation management systems coupled with damage prognoses and integrated sensor networks [D.L. Balageas 2008, J.D. Achenbach 2009, A. Tessler 2007] have the distinct advantage of being able to provide better coordinated and planned infrastructure management and maintenance schedules and are able to optimize structural health life cycles into the train operation monitoring systems.

This type of so called tele-maintenance can also provide input for a database on degradation/damage to mechanical parts stored on a central computer. Such databases are being used in many countries to investigate degradation and damage to mechanical parts. It was found in the USA's data base that the wheel-sets (wheel, axles and journal bearings) comprised the largest group, with a 44.7% contribution in terms of total accidents caused [S. Y. Chong 2010]. This result underscores the increasing need for wheel-set damage detection techniques. In the EU project DRAIL, emphasis has been laid on evaluation of Inspection and monitoring techniques where a survey has been made of the current state of the art in monitoring and inspecting systems, including vehicle identification [EU-project DRAIL]. The study includes, along with a selection of case studies:

- track-based inspection and condition monitoring equipment;
- vehicle-based technologies and specific recording cars with on-board systems;
- vehicle identification using video or Radio Frequency Identification (RFID).

Information from a monitoring system can be divided into two sub groups: critical and non-critical. Critical information is information that can cause damage to trains or infrastructure or injury to human beings if not transferred without delay. Types of information that belong to this area include ongoing overheating, leakage from goods, etc. Non-critical information on the other hand is information that can tolerate delays without the risk of not being able to prevent an accident. Prediction of maintenance and similar information belong to this subgroup.

2 On-board versus wayside detection based monitoring

On the railways, there are two options as to where to place the detectors and their sensors: either on board the train or alongside the rails, so-called wayside sensors. Both options introduce their own possibilities and difficulties. Since the energy can easily be transferred to the wayside sites, it is possible to use more complex analyzing tools. On the other hand, wayside monitoring systems have less potential to continuously monitor the rail wagons than an on-board monitoring system.

An on-board system has the drawback that it can be much more difficult to supply with power as well as transfer the information to the end user. To find a durable and economically viable solution, the sensor network on-board the train will most likely need a supporting system to transfer the information from the train to the end user. It is realistic to assume that the sensor network must have either its own system or in parallel with an already existing vehicle-to-vehicle communication system such as GSM-R or RFID-readers. Since the GSM-R transceiver modules consume a relatively large amount of energy, the latter, RFID, is more promising. Since many of the train wagons, e.g. freight wagons, are not powered, one of the larger issues with wireless sensor networks on-board a train wagon is how to power the electronics. Mainly, devices are powered by batteries, but batteries alone are not a viable solution. The batteries have a rather short life time and it is not a viable solution to replace these batteries if each train contains several hundred sensor nodes. Therefore it is necessary to find a solution for charging the batteries on-board the train. This can be solved by means of so-called energy scavenging. A test has been performed to find the most promising solution [M. Grudén 2013]. In this trial, solar cell, vibration- and thermoelectric harvesters were tested.

The most promising way to scavenge energy is to use vibration harvesters. Interference with external signal sources must be investigated as well. Depending on where the railway is located, the immediate environment will look extremely different. For example, railways located in a city have buildings only a few metres away and railways in remote areas may have the nearest civilization several kilometres away. The conditions for having a wireless monitoring system will be different in these environments. Assumptions regarding interference must be dealt with in order to build a system with as little external interference as possible. In most cases, the railway has a buffer zone of at least a few metres to the nearest buildings. Bearing this in mind and the fact that WLAN usually only operates with such output power that the communication distance is only within or near the buildings, interference with WLAN can be seen as a minor problem. Also, if the measurement system on-board the train is of a kind that is critical, the system should use another frequency band than the standard ISM bands.

3 Structural health monitoring in conjunction with real time information

Vehicles in the future will be reliable and designed for extended operations with minimal routine maintenance. The remote condition monitoring will assist with the achievement of this and minimise in-transit failures and failures with no warning. Information and warning systems on-board the wagon can be focused on payload-dependent braking performance, wheel-slide protection for high retardation trains, hotbox detectors, axlebox vibration and bogie frame vibrations. The design, materials, engineering and maintenance regime will reflect a commercial requirement for extended periods in operation with limited time allowed for this activity. The vehicles/trains will need to maximise their in-service time. Maintenance and checks where required will be undertaken as the trains/wagons are being loaded or stripped. This could also apply to any fuel replenishment for any train requiring diesel fuel. Both maintenance and re-fuelling will come to the train rather than losing production time.

Among the logistics requirements, reliability can be considered the most important. High reliability of the service can be assured only if there is minimal premature failure of the train’s sub-systems. Today, condition monitoring is applied to minimise the catastrophic failure of systems. In the related EU project SPECTRUM, two design aspects were identified for condition monitoring, namely the railway vehicle itself and in some cases the goods being transported. For the railway vehicles, key parameters to be monitored may include ride quality to ensure that the goods are not subjected to excessive accelerations which may damage them. Other potential vehicle components to be monitored are the wheels and/or wheel bearings. This would feed into the preventive maintenance programme, thus avoiding premature component failures that may cause shipment delays and goods being damaged as a result of extreme events such as accidents. It should be observed that currently, no technical standards exist for the condition monitoring of running gear, suspension and braking systems.

A few examples exist of condition monitoring of freight-trains using wireless sensor networks (WSN) in conjunction with RFID systems for transferring condition information. One such example is the monitoring of ball bearing temperature using a WSN. During the autumn of 2011, a trial headed by Uppsala University and the Swedish Transport Administration was performed applying a wireless sensor network (WSN) aboard a train wagon with the objective of demonstrating a proof of concept for monitoring the temperature of ball bearings aboard, see figure 5.10. This trial investigated several key aspects when applying sensor networks such as radio wave propagation, energy scavenging and the performance of the WSN aboard the wagon [M. Grudén 2013].

Figure 5.10: Left: One of the sensors mounted on the ball bearing cap. The electronics are located inside the white box and the temperature sensor is located inside the bolt. The cable from the sensor to the node is covered by metal. Right: The setup aboard the wagon with gateway (GW) and RFID reader.

The condition monitoring of the train can also be done using track-based detectors. Examples of sensors located along the track are hotbox detectors, wheel impact load detectors, weigh-in-motion detectors, and detectors for lateral loads in curves. Acoustic detectors can also be used and has been able also to detect vibrations from ball bearings [J.E. Cline 1998].

4 Monitoring of the railroad infrastructure

Structural monitoring of rail infrastructure, including the rails, track, overhead power distribution and associated trackside structures, is essential for safe and efficient railway operation. The results from inspections are typically used to prioritise short-term maintenance interventions and to plan more long-term maintenance programmes. Intelligent infrastructure has the potential to transform rail management by enabling a greater understanding of the interconnectivity of systems and the implications of events, resulting in improved reliability, safety and efficiency. Monitoring infrastructure like bridges and building which are part of the railway is of great importance in order to understand, for example, the dynamic characteristics of a bridge. In order to do this, several different types of sensors have to be embedded in the concrete to measure accelerations, displacements, strains, hanger forces, temperatures, and wind speed and wind direction. [J. Wiberg 2009].

EDI for multimodal transport chain management (MTCM)

The EDI (Electronic, Data Interchange) standards were originally designed for use over Value Added Networks. “Web EDI”, i.e. the interchange of EDI formatted messages using Internet messaging protocols, principally SMTP (the e-mail protocol) or HTTP (the Web protocol) is being increasingly used, although sometimes FTP (the file exchange protocol) is also used. Recent advances in ICT systems have opened the way for the delivery of personalised real-time traffic information to drivers.

Events are stored as event data-objects (e.g. Accident), which have associated phrases (e.g. chemical spillage accident) and attributes (e.g. delay time). Due to the fact that it provides a standard, non-proprietary means of data-exchange, DATEX has gained widespread implementation within Europe. XML is being adopted universally as a means of automatically publishing, storing and exchanging data on the Internet. XML describes data in a human-readable format with no indication of how the data is to be displayed. Because the data is structured it can easily be searched, aggregated, transformed or interpreted by other systems.

A model for a multimodal transport chain management system (MTCMS)

1 FTMS - Freight Transport Monitoring System (D2D project)

An FTMS will gather information about the movement of cargo through a position data network utilising a number of different sensors. This will ensure that information is available in the appropriate formats in all transport chains. The system will be used to monitor the actual transport operations and to provide feedback if schedules are not adhered to. The FTMS system will be designed to be a European global commercial service that will be able to provide status information to a number of subscribers, i.e. by many TCMS installations and other systems used for intermodal transport chain management. By being generic, the FTMS should be envisioned as a service that could be used by anyone transporting cargo in the physical infrastructure monitored by the FTMS. The FTMS should also be an open system and should have the capability to receive status information from a number of sensor technologies such as Automatic Equipment Identification, position sensors for cargo and load units, and transport means.

2 TCMS - Transport Chain Management System (D2D project)

The Transport Chain Management System will be provided with transport status information by the FTMS to be used for managing multimodal door-to-door transport operations. The main functions of the TCMS are:

- Organize and initiate transport
- Monitor and control operations
- Visualize the transport status (including position of cargo, ETA, etc.).
- Exchange product- and transport documentation (product certificates, quotations, proof of delivery, invoicing information, etc.).

TCMS handles all types of information related to managing such operations efficiently and handles all types of documents that are necessary to perform the transport and to evaluate the performance over time.

6. The prerequisites for an efficient rail freight system 2030/2050

6.1. Future demand and the market's requirements

Rail and the market's development

The total demand for freight transport in EU15 increased by 2.5% per year rather constantly between 1970 and 2007 and then decreased until 2011. Rail has lost market share to truck and the market share for rail decreased from 36% in 1970 to 15% in 1995. Rail's market share then stabilized and increased slightly. The total market share for rail in EU27 has decreased from 21% in 1995 to 18% 2011. In EU12, rail's market share decreased rapidly from 51% to 23% between 1995 and 2009, mainly because rail's monopoly had been abolished.

In western Europe, some countries have for a long time had a high market share: Switzerland (not an EU member) with 45-50%, and Austria and Sweden with 30-40% of the road-rail-IWW-market. Rail's market share in Germany has increased from 19% in 1995 to 23% in 2011. Rail's market share in the United Kingdom, Denmark and the Netherlands has also increased but from a very low level.

In many other countries in western Europe, on the other hand, rail's market share has decreased over almost the whole period, and also in eastern Europe from a very high level. In recent years, rail's market share has increased slightly in most countries in both EU12 and EU15. If this is a break in the trend is too early to say.

It seems that countries with high investment in the rail system and also with a developed deregulated freight market have a high market share for both freight and passenger rail. One conclusion is that transport policy is very important if rail is to have the higher share of the freight market that is stipulated in the EU white paper

In an international perspective, the USA's rail freight market share of approx. 50% is very high, and rail's passenger market share with approx. 30% is very high in Japan. In the USA, there is a huge market without borders, the railways are privately owned, and the rail system is adapted to freight with very high capacity. Japan, with its high population density, has had a high-speed rail system for a long time.

The customer's requirements

Customer needs can be summarized in a few points: a competitive cost for a reliable service that is easy to access and gives accurate information about the Estimated Time of Arrival (ETA) in real time, and can react quickly to variations in volume, more precisely (Spectrum 2012 and others):

- ***Reliability of service:*** rail transit time and frequency have to be competitive with road. However, consistently and unfailingly reliable transport (i.e. arriving at the agreed time) is for many shippers even more important than the transit time itself.
- ***Costs of door-to-door delivery:*** if the quality targets are fulfilled there is often tough competition on lowest cost. Rail must be competitive with road transport throughout the transport chain.
- ***Service availability:*** service availability at the origin point seems to be only slightly more important than at the destination point.

- ***Safety and security:*** reducing the chance of losses, theft and damage. This is especially important for the transport of high value goods.
- ***Environmentally friendly transport:*** Many customers want environmentally friendly transportation but are unwilling to pay so much more for it, but here rail has an advantage.

Logistic trends

Current logistics trends are **outsourcing, offshoring** and **centralisation**. The resulting design of the logistics network is mainly based on a cost perspective. **Outsourcing** of production activities means to subcontract a process to a third-party who can take advantage of economies of scale. **Offshoring** describes the dislocation of a production activity to a far-distant country in order to reduce operational costs. Physical **centralisation** means that the number of production, procurement or distribution sites is reduced, whereby the main goal is to pool risk, reduce inventory and exploit economies of scale. For instance, offshoring leads to a reduction of total logistics costs by 25-40%. But important "soft" factors, like delivery time, flexibility and risks of a logistics network can lead to a considerable reduction of this cost advantage. Furthermore, stricter regulations and increased awareness of customers with respect to the environment support a reconsideration of a company's strategy.

In the case of city logistics, the evolution of the needs of the urban population in development and congestion and pollution problems are favourable factors for rail. If logistics areas for distribution are preserved in city centres, very silent trains should reach them for a last mile delivery by electric road vehicles (also at night with high productivity) or using the underground network or even tramways or inland waterways. This will create innovative business models instead of the overwhelming solution of delivery by truck which is being increasingly subjected to stringent constraints.

In general, it can be said that these new logistics trends and others will certainly gain importance in the future as companies' focus shifts away from a purely cost perspective to a more integrated approach that includes cost, risks and the environment.

In particular, considering that offshoring no longer offers a significant cost advantage and that, furthermore, some companies are reducing spatial concentration, any future network should be a more decentralised one in which the amount of long-distance transport can be reduced. Improvements in transportation efficiency can be achieved through better vehicle utilization, the reduction of empty trips as well as less frequent shipments with larger lot sizes. This will lead to a reduction in the number of trips. Moreover, using multi-modal transportation will make the supply chain more flexible.

6.2. Core network and capacity for freight

The future demand for freight will be very much dependent on whether the white paper targets will be fulfilled. If so, the demand for freight will de 3-4 times as great as today and at the same time passenger demand will also increase in the same order.

Figure 6.2 shows the demand for freight assigned to the rail network. It is made up of the forecasts from D-rail (se chapter 3.5), the scenarios for 2050 where the white paper scenarios have been implemented. It is evident that freight demand will increase and be very high mostly in the same corridors where the passenger demand is high today and will be even higher tomorrow. This is natural because the demand for passenger and freight transport is generated by the population, except for some transportation of raw materials.

Figure 6.3 shows the planned rail freight corridors to the left and the planned High Speed Rail lines and other fast connections to the right. As can be seen, there are great similarities between the freight and passenger networks, because demand for both passenger and freight is high in these corridors.

There were 7,378 km of high-speed lines in service in 2013 (UIC 2013). 2.565 km were under construction and 8,321 km were indicated as planned to be in service by 2025. This means that if the plans are realized there will be 18,264 km of HSL in 2025.

The EU's target in the 2011 white paper was to triple the HSL network by 2030. If we take the HSL lines in 2010, figures that were available when the white paper was published, we get 18,483 km. From that point of view, the EU target seems to be realistic. However, all HSL lines that are planned may not be built for economic or other reasons. On the other hand, there are already today some new projects planned or under discussion in some countries.

If the planning and building of HSL continues at the same yearly rate between 2025 and 2050 as between 2013 and 2025, there will be another 22,679 km of HSL in Europe by 2050 and a total of 40,943 km. This is only a simple calculation but if it is fulfilled, the network will be almost 6 times as long as today and double compared to 2030. If this is implemented it is also positive for freight because removing the fastest trains from the conventional lines will free capacity for freight trains and regional trains. It is however important that capacity be reserved for future demand for freight trains and not from the beginning be fully occupied by regional trains even if this is possible at present.

The six first rail freight corridors have a length of 13,505 km and together with the three that have also been proposed, the length of the RFCs will be approximately the same as the planned HSR in 2025 (approx. 18,000 km, table 6.1). However, no common investment programme exists for the rail freight corridors and no common target to increase the standard.

Table 6.1: Today´s and future transport networks in Europe.

Infrastructure	At year	Km	% of tot	Infrastructure	At year	Km	% of tot
Railways				**Roads**			
Total km in EU 28	2012	215 734	100%	All roads	2010	5 000 000	100%
Electrified	2012	115 508	54%	Motorways	2011	71 405	1,4%
High-speed Rail							
High-speed in service	2013	7 378	3%				
Incl. under construction	2013	10 886	5%	EU-target in white paper: Triple HSR to 2030			
Incl. planned to	2025	18 264	8%	=3*6 160 km (length 2010)=18 483 km o.k.			
Projection to	2050	40 943	19%				
Rail freight Corridors				**Inland waterways and pipelines**			
The 6 first RFC	2013	13 505	6%	Inland waterways	2011	41 527	
The 9 RFC estimated	2015	18 000	8%	Pipelines	2011	37 836	

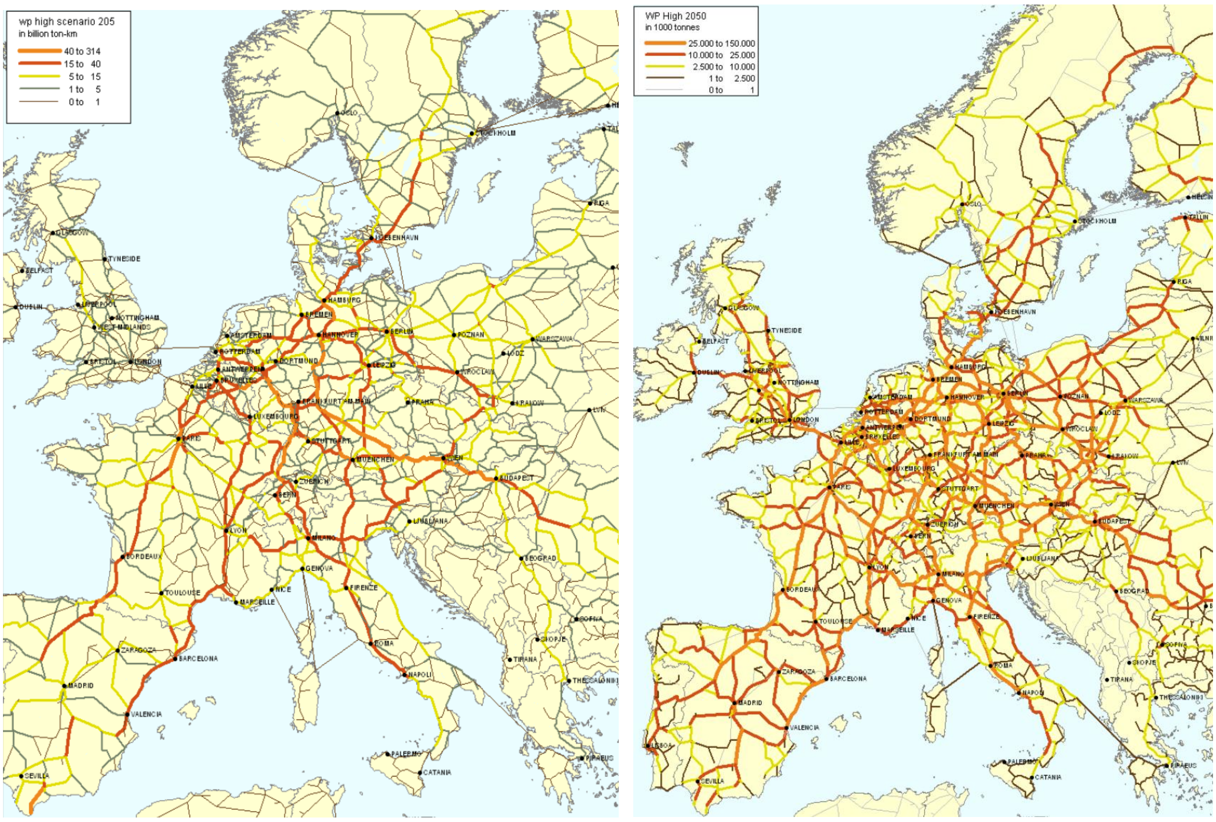


Figure 6.2: Demand for freight rail: D-rail white paper high-shift scenario 2050. Left in tonne-km, right in tonnes.

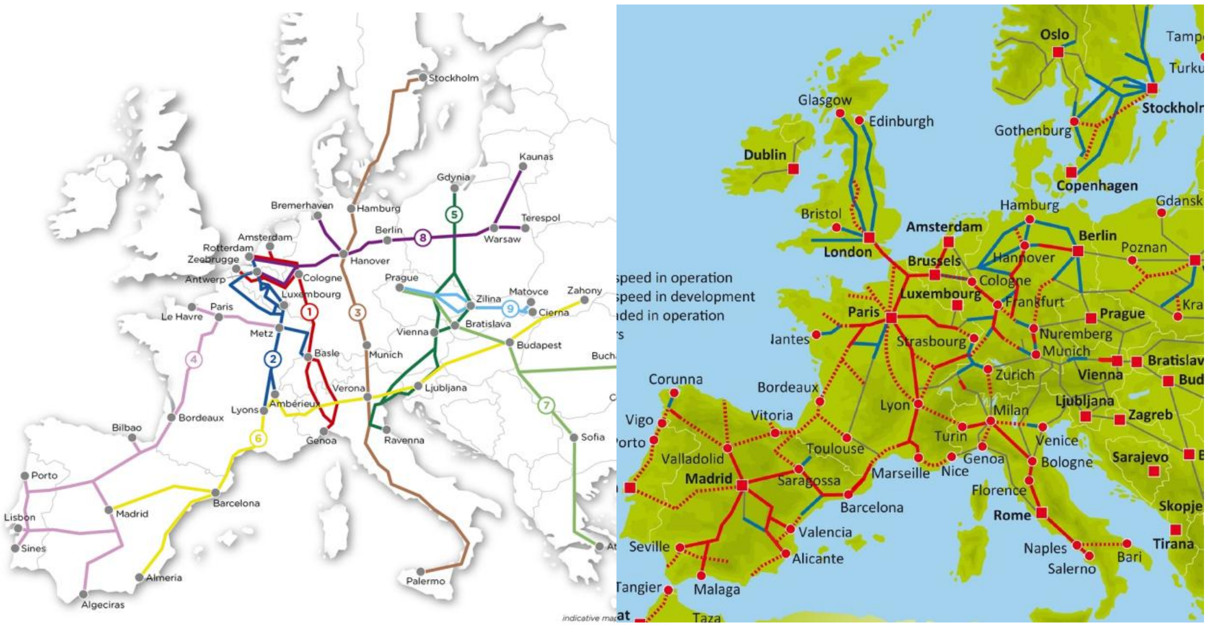


Figure 6.3: Left: Rail Freight Corridors in Europe. Right: High Speed Rail network in Europe.

6.3. The most important needs for technical development

The most important customer needs are sufficient quality and low cost. Then it is also an advantage if the transport solution is environmentally friendly. The technical development must therefore lead to lower cost and higher capacity. Higher capacity often also leads to lower cost, energy consumption and GHG emissions in the rail system. But it is also important that the rail system can increase market share and by this reduce energy consumption in the transport system as a whole.

Regarding rolling stock, better use of train and waggon capacity in terms of weight and volume, reduction of track wear and low maintenance cost for wagons as well as more efficient transshipment techniques and enhanced accessibility are key factors to enhance competitiveness. Technological innovations in the field of rolling stock design that are expected lead to increased axle load (see figure 6.4), top speed and train length and also ensure lower noise emissions from freight trains are also important.

The running gear design is crucial in most rail transportation systems. Trends towards higher axle loads and/or higher top speeds to increase transport capacity challenge the running gear designers, in particular since international standardization of running gear also means that it may be difficult to implement more innovative design solutions.

More efficient braking is important to reduce maintenance costs for wheel and rail, reduce noise and operate longer trains. Better block brakes or disc brakes and different kinds of electronic brake control are measures that must be taken into account.

Innovations which address energy efficiency and lower GHG emissions are for example low-mass freight wagons, low-drag freight trains, energy recovery, high-efficiency machinery, eco-driving and dual mode and hybrid locomotives.

Much of today's freight train system and infrastructure is based on an old standard 3-4 MW locomotive that means trains of approximately 1,500 gross tonnes and a train length of 650-750 metres. But modern locomotives have a tractive power of 5-6 MW and are capable of hauling 2,000-2,500-tonne trains of up to 1,000 m. In Europe, train lengths up to 850 m already exist and experiments have been made with 2x750 m = 1,500 m long trains with radio-controlled locomotives in the middle of the train. Not only the tractive power but also the axle load on the locomotives is critical for optimal traction. To increase the axle load from normally around 20 tonnes to 22.5 or for heavy haul 25-30 tonnes is a possibility to operate heavier trains but must be combined with track-friendly bogies.

Concerning the wagons, one important question is if the development will be incremental, as it has been so far, or if it is possible to make a system change. An incremental change means successively higher axle loads, wider gauge, higher payload and less tare weight per wagon, better brakes through for example more silent LL-blocks, end of train devices and electronic sensors. A system change will include electro-pneumatic brakes, disc brakes, full electronic control of the wagons and load and automatic central couplers. The automatic coupler is the most critical component but important not only because it will make shunting and marshalling safer and cheaper but also because it will make it possible to operate longer trains without problems and introduce electronic braking systems. It will be easier to feed the train with electricity and signals and to build lighter wagons and lower the floor.

Today, most rail operators use electric locos for long haul and diesel locos for feeder transport and terminal shunting. But the duo-loco has now been introduced onto the markets, equipped with both normal electric traction and diesel traction, either for shunting or for line haul. This means that a duo-loco can shunt the wagons itself at a marshalling yard or stop at an unelectrified siding at an industry and change wagons directly. Operators then only need one loco instead of two and it will be possible to introduce new operation principles like liner trains that can stop along the line and change wagons. It will also decrease vulnerability in case of current interruptions. In the long term it will also be possible to avoid catenaries at marshalling yards and sidings, which will save money for the IM.

Also for intermodal there are advantages to introducing liner trains. If the terminals are located on an electrified side track where the train can drive straight in and out onto the line again there is no need for a diesel loco to be switched in. This in turn requires a horizontal transfer technology that can function under the overhead contact wires. The train must be able to be loaded and unloaded during a short stop. This also obviates the need to park wagons and the terminals can be more compact. For inter modal the terminal cost is critical and by this system terminals can be more cost-effective.

Most trailers today are not designed to be lifted onto a railway wagon. The trailer market is in practice therefore very limited even at conventional intermodal terminals that have lifting equipment. Solutions where trailers do not need to be lifted but can be rolled on and off along a ramp can thus widen the market considerably. They also mean simple terminals only need to be dimensioned for the trucks’ axle load. This means lower logistic costs for customers and society. This increases productivity and the trains can operate more services per day, which also increases flexibility.

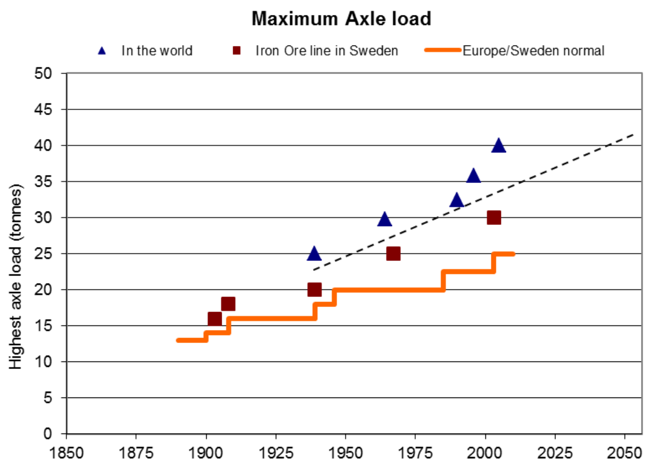


Figure 6.4: Incremental change in axle loads has been implemented since freight rail was established but differs around the world and between lines (KTH).

6.4. The most important needs for operational development

Capacity for rail

Most important for rail capacity are the infrastructure, the vehicles and trains, the timetable and the signalling system. One fundamental factor is the number of tracks, as follows:

1. On single track: The distance between crossing stations is most important. High speed is an advantage because the train will come to the meeting stations quicker. Simultaneous arrival from opposite directions is important for capacity.
2. On double track: The timetable is most important. Mixing trains with different average speed or stopping patterns lowers capacity. Building passing stations will increase punctuality and flexibility in timetabling but cannot increase capacity.
3. Four tracks: The best solution is to build complementary tracks to a double track as separate high-speed lines (HSL) to split slower and faster trains on different lines. Also makes it possible to make the line straighter for higher speeds and to reach new markets.

If we want to increase capacity in the rail system, this can be done in the following steps, beginning with the cheapest measures:

1. More efficient timetable planning: On double track: Bundling of trains with the same average speed in timetable channels. Harmonize speeds. On day-time faster freight trains is an option
2. Use of trains and vehicles with higher capacity:
    a. For freight: Longer trains, higher and wider gauge, higher axle load and metre load
    b. For passenger trains: Double-deck and wide-body trains with efficient seating, i.e. compare TALGO 350 (single deck, 2.9m wide): 1.6 pass/metre train, TGV Duplex (double deck 2.9m wide): 2.7 pass/m and Japanese E4 Max (double deck 3.4m wide): 4.1 pass/m.
3. Differentiation of track access charges to avoid peak hours and over loaded links, i.e. higher train-kilometre fees on overloaded sections and at peak times.
4. Better signalling system, shorter block lengths and in the long term introduction of ERTMS level 3.
5. Investment in infrastructure like longer crossing stations, passing tracks, double track or four tracks on shorter sections.
6. Investment in HSR to speed differentiation – high speed on HSR and freight trains and regional trains on the conventional network
7. Adaption of freight corridors for long and heavy freight trains, in some cases dedicated freight railways like the BETUWE line.

It is noted that some of the rail networks in the EU are highly congested and there is a need to increase capacity and operational efficiency in the short term. Longer trains may offer one of the most promising solutions. Trains longer than the standard 750 m are already in operation in Germany, Denmark and France. The Marathon project conducted a successful operation in 2014 with a roughly 1.5 km long train that gives about 75% operational efficiency without needing extra path allocation. Other options are higher axle loads and extended gauge that can be introduced successively on specific lines according to the market's needs, se figure 6.5.

Signalling systems

The different signalling systems in Europe are a legacy from the past and constitute a barrier to running pan-European rail services. For international operation, the trains often have to be equipped with more than one signalling system. To remove this barrier, the European Rail Traffic Management System (ERTMS) has been introduced. The ERTMS is a contribution to an interoperable railway system and the establishment of an open market in the rail sector in the EU. By introducing ERTMS level 2, capacity can be increased as well, if the block sections are shortened, or with ERTMS level 3 with continuous blocks even more. It is therefore important to develop and implement ERTMS level 3.

Information and communication technologies and services

Accessibility to the rail mode is very poor as regards freight offerings and in any case longer than accessibility to the road mode. Development has been hindered by the conservative attitude of incumbents protecting their markets, by the low profitability of rail freight transport, and by the necessary training to use ICT. It is thus necessary to bridge these gaps if rail wants to participate efficiently in the necessary modal shift. Unified train management in the corridors with a one-stop shop and good coordination with national IMs will be based on ICT so its development must be made the first priority of rail actors and the authorities.

Monitoring and IT systems

Real-time monitoring systems for traffic are vital to today's rail freight service and can be split into on-board and wayside-mounted systems. The on board tracking and tracing system provides real-time information using RFID (Radio Frequency Identification) on wagons where radio transmission of data between a reader by the track and a tag/transponder will provide the real-time information. The RFID systems on-board the wagon can also be used to transfer information related to condition monitoring of payload-dependent braking performance, wheel-slide protection for high retardation trains, hotbox detectors, axlebox vibration and bogie frame vibrations.

The wayside detection systems can be used to detect hot roller bearings and flat-wheel but has less potential to continuously monitor the rail wagons than an on-board monitoring system. Another important area for wayside detectors is to monitor the rail infrastructure, including the rails, track, catenary power distribution and associated trackside structures.

Network management

Getting fair treatment from national network IMs or regulatory bodies is not without controversy, as some network managers are brothers/sisters of the incumbent operators. There have been complaints that the incumbent companies get unfair advantage from the IM over new entrants. To eliminate this, the fourth railway package, awaiting approval from the Commission, was issued in 2011. Critics of this central and one-stop-shop network management approach argue that there is a risk to the safety of the network. It will also create problems for both development and maintenance of the network. Another thought is that the major corridor or TEN-T corridor network management can be established and this will ensure that all modes and all types of services are given fair and competitive access to the network.

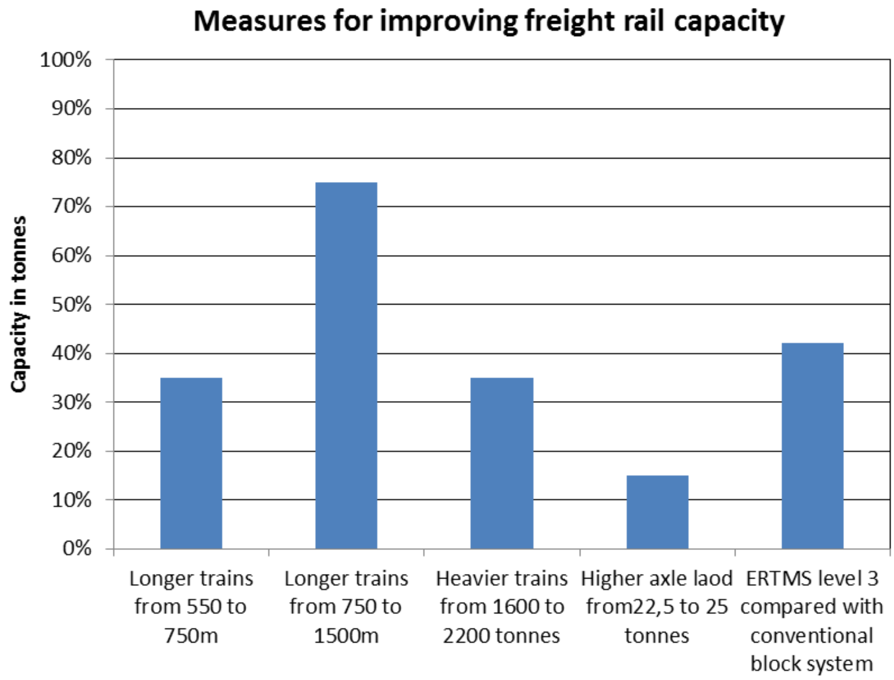


Figure 6.5: Capacity gains for different freight train measures. Source: TRANSFORUM freight road map (Nelldal 2014).

6.5. Possible energy and GHG savings in the transport market

The possible energy and GHG savings have been calculated in the EU project TOSCA (2011) for all modes and both passenger and freight transport. In TOSCA, the savings for each mode through technical development was calculated but the conclusion was that it is not enough to fulfil the EU target so there must also be changes in behaviour and a mode shift. In a paper (Nelldal-Andersson 2012), the effect of mode shift to rail were calculated for both freight and passenger traffic.

In the baseline scenario, freight transport by truck will increase by 53% from 1,900 to 2,900 billion tonne-km from 2010 to 2050 and by rail by 43% from 440 to 630 billion tonne-km. The shift from road to rail over longer distances indicated in the white paper results in 950 billion tonne-kilometres being transferred from road to rail. This means that the truck transport effort will remain at the 2010 level. Rail will increase from 630 to 1,600 billion tonne-km or by a factor of 2.5 compared with the baseline scenario, see table 6.6.

The market share for rail freight will increase to 45% as a result of the mode shift and truck will decrease to 55%. This means that rail and truck each have half of the long-distance market for transport longer than 100 km. At distances longer than 300 km rail has taken over 63% of the tonne-km by road in the baseline scenario by 2050. These figures are in line with the EU target that more than 50% of the road freight should shift to rail or waterborne transport by 2050.

In the baseline scenario, passenger transport by car will increase by 57%, rail will increase by 37% and for air we have assumed 100%. The shift in mode split from road to rail has been adjusted from road to rail over distances mainly over 100 km and from air to rail mainly between 300 and 1,000 km.

The net result is that rail demand will increase from 560 to 2,660 billion passenger kilometres or by a factor of 4.7 compared with the baseline scenario. This means that the private car still will increase by 19% and air by 48%.

The market share for passenger rail will increase to 29%, as a result of the mode shift; for car it will decrease to 62% and for air it will decrease to 8% for the car-rail-air-market. At distances between 100 and 1,000 km, rail has a market share of 61% of the passenger-km, which is in line with the EU target that most medium-distance passenger transport should go by rail.

In the baseline scenario, the GHG emissions for all modes included for passenger and freight transport will increase by 15% between 2010 and 2050 despite technology improvements. In the mode shift scenario, GHG will decrease by 8% and will be 20% lower than in the baseline scenario. The net effect is almost the same in passenger and freight transport.

These estimates have been made using today´s electricity production mix. There is also a scenario with electricity production with lower GHG emissions. This is important both for rail and for electric private cars in 2050. In this scenario, combined with a mode shift to rail, it is estimated to be possible to reduce GHG emissions by almost 30% from 2010 to 2050.

Table 6.6: Total GHG emissions and average emissions per passenger- and tonne-kilometre for a mode-shift scenario compared with baseline (Nelldal-Andersson 2012).

GHG emissions	2010	2050 Baseline	2050 Mode shift	2050 Mode shift low GHG el	2050 Mode shift/ baseline	2010	2050 Baseline	2050 Mode shift	2050 Mode shift low GHG el
Passenger transports	Tonnes CO2, millions					g CO2/passenger kilometre			
Passenger cars	624	727	551	393	-24%	132	98	98	70
Rail passenger	20	12	56	21	374%	48	21	21	8
Aviation (intra-EU27)	78	90	56	56	-38%	140	82	76	76
Sum	721	829	663	471	-20%	127	91	73	52
Index	100	115	92	65	-20%	100	72	58	41
Freight transports	Tonnes CO2, millions					g CO2/tonne-kilometre			
Trucks	245	289	215	215	-25%	130	100	112	112
Rail freight	11	7	17	8	149%	26	11	11	5
Sum	256	296	233	223	-21%	110	84	66	64
Index	100	116	91	87	-21%	100	76	60	58
Total	977	1 124	896	694	-20%	122	89	71	55
Index	100	115	92	71		100	73	59	45

6.6. Vision 2050: The railway – a new transport mode for future needs

Prerequisites: Sustainability and intermodality

A basic prerequisite is long-term development of the transport sector in line with what the natural environment can withstand at the same time as transport needs are satisfied. This means a gradual shift to more environmentally friendly and resource-efficient transport systems. In Europe we now use only 10% as much energy per passenger-km or tonne-km as in 2000 and with only 1% as much harmful contaminants. The following measures were taken for rail to achieve this:

- Developed the railway into a new intermodal transport mode
- Gradually adapted transportation prices by internalising external effects
- Taken advantage of IT's possibilities to be an efficient means of transport control

Through these measures track-bound traffic has increased its share of transportation to more than 50% for freight over 300 km and for passengers over medium distances. At the same time, a common European market has been created through accessibility increasing through shorter transportation times and lower transportation costs for both people and freight.

Freight transportation

A trans-European High Capacity freight Rail (HCR) network has been established in Europe. This was achieved by RFC and freeing up capacity on the conventional lines by building a cohesive high-speed network for passenger traffic. The heavy traffic network permits 30 tonnes axle load and a maximum speed of 120 km/h. Some lines with only freight traffic have 35 tonnes axle load but lower speeds. The load gauge is larger than today. The railway is competitive from 100 kilometres if volumes are large.

The wagons have quiet, track-friendly bogies and automatic couplers. The automatic coupler is an “intelligent coupler”, i.e. it can both couple and uncouple automatically by means of remote control from the locomotive or somewhere else, e.g. a marshalling tower. The freight wagons also have anti-lock protection and also other electronic monitoring systems such as weight and load displacement indicators, “the intelligent freight wagon”.

For small consignments of finished products and semi-manufactures and for customers without a local freight siding, intermodal traffic exists that consists of two systems: heavy intermodal and AutoCombi.

Heavy intermodal is conventional intermodal traffic of heavy containers and trailers over long distances. It offers overnight transportation within three nights in the whole of Europe at an average speed of 70 km/h and is competitive from about 500 kilometres. Heavy intermodal trains operate between ports and “Freight Services Centres” with logistics functions and local deliveries by truck. Heavy intermodal can handle containers up to 53' weighing 40 tonnes (the trucks limit their weight) or 25-metre trucks weighing 60 tonnes on low-built wagons. This is made possible by heavy intermodal using the heavy traffic network.

A completely new type of intermodal traffic has also been introduced: AutoCombi. In this system loading and unloading are done automatically by means of horizontal transfer using a loading robot. This is done at terminals located on sidings or, on lines with little traffic, in the main train path. The load is transferred to a storage area where it is held while waiting to be fetched by a local delivery truck or local freight train. AutoCombi can handle swap-bodies up to 15 metres and containers up to 53' and that are 2.5-3.6 metres wide. Careful, systematic load planning and follow-up are accomplished with the help of a computerised booking system that the “train manager” also has access to.

AutoCombi interacts with heavy intermodal and also calls at Freight Services Centres, which have automated warehouses where the load units are briefly stored to await transshipment between different transport modes, and where there are industrial and distribution warehouses close by. The transport companies can then also provide storage and carry out deliveries for industry.

In the metropolitan areas the railway is used for some distribution traffic with the help of automated unloading at a number of small terminals in the region instead of one large concentrated terminal. By using horizontal transfer technology at certain nodes metros and tramways can also be used for distribution in the cities.

The same system is also used for loading in the heavy intermodal system and for unloading large containers at ports and in warehouses and industry. Automated unloading systems for unit trains where an entire train can be unloaded at once also give completely new possibilities. In wagonload traffic, the system is used partly to marshal the load carriers instead of the wagons and for wide containers that go directly to industry and are not transported on by truck.

The high -speed freight trains transport perishable finished goods, spare parts, parcels and mail at an average speed of up to 225 km/h. They can transport goods overnight in central Europe and go directly to the central parts of towns and cities and special mail and parcel terminals for further distribution by road. The high-speed freight trains also interact with air transport and call at several airports.

Passenger traffic

The market is naturally divided up so that the bicycle dominates for local trips up to 3 km, the car up to 100 km, the train between 100 and 600 km and air for distances above that. This is achieved by the different transport modes being integrated through common terminals where it is easy to change transport mode.

In addition to a gradual development towards higher speeds and lower costs the passenger traffic system is developing towards greater flexibility. The train systems have developed in two directions: large units with a high service level, “luxury cruisers on rails”, and smaller units, “self-propelled modules”. Both can also be combined. A great deal of integration has also taken place between tram and bus systems and railway systems.

The train system consists of an international high-speed network with a top speed of up to 500 km/h and a range of 1,000 kilometres over a day. Active tilting and lateral suspension systems are used to reach higher speeds on existing high-speed lines. The load gauge is wider and wide double-decker trains with five seats across and high comfort can thus be used. The largest double-decker trains can carry up to 2,000 passengers and have passenger compartments of varying size that can be used both day and night, saloons, restaurants, a kiosk and video on demand at seat.

The smallest units used in national and regional traffic are 100-passenger multiple unit modules designed for 300 km/h that can be coupled to and uncoupled from each other and that can also dock while running. Combined with an infrastructure that allows continuous train operation this is very competitive. This means that it is possible to offer high frequency of service on the major routes and direct connections on more unusual routes.

The terminals consist partly of large travel centres integrated with shop and office, mostly centrally located in the major population centres and partly of simple stops to change to another transport mode. Passengers never need to stand outside at these nodes; the vehicles are “docked” for exchanges between nodes or the body is changed.

Infrastructure and traffic operation

In addition to traditional technology development towards higher speeds and greater capacity and reliability, completely new ways of building railways and operating trains have been developed. One example is continuous train operation. The purpose of continuous train operation is to enlarge the railway's market by covering more stations and routes. In its most developed form it means that:

- All stations are located on sidings with side platforms. This means that faster trains can pass slower ones in natural places. The sidings are about 1,500 metres long so trains can brake from 200 km/h on the siding and so that a long freight train can be accommodated.
- There are automatic loading and unloading systems so that freight trains can quickly load and unload unit loads at a freight terminal also located on the siding.
- There is a continuous signalling system with movable blocks that follow the train where the block distance is equal to the braking distance. The trains can be operated fully automatically and sense other trains or objects on the track inside the braking distance.
- There is an Intelligent Train Operation system (ITO) that monitors and controls the traffic to minimise delays and operating costs.

Great advantages can be attained in train operation with this system. Capacity and punctuality increase with more opportunities to overtake. Flexibility also increases since the trains can always overtake one another. Fast and slow trains are mixed more according to the market's needs than the track's capacity. Sensitivity to disruptions is reduced since there are so many opportunities to overtake and active train control.

For passenger traffic this means that product differentiation can be increased with different trains for different markets and thereby also market share. For goods transportation this means that completely new markets can be reached, viz. transportation over relatively short distances and high-value goods between the stations that today go by road.

The main lines have no level crossings with roads and are fenced to enable automatic train operation that can be monitored and controlled from the train control centres. The train then becomes a kind of conveyor belt for external transportation for industry and can offer very high safety and reliability.

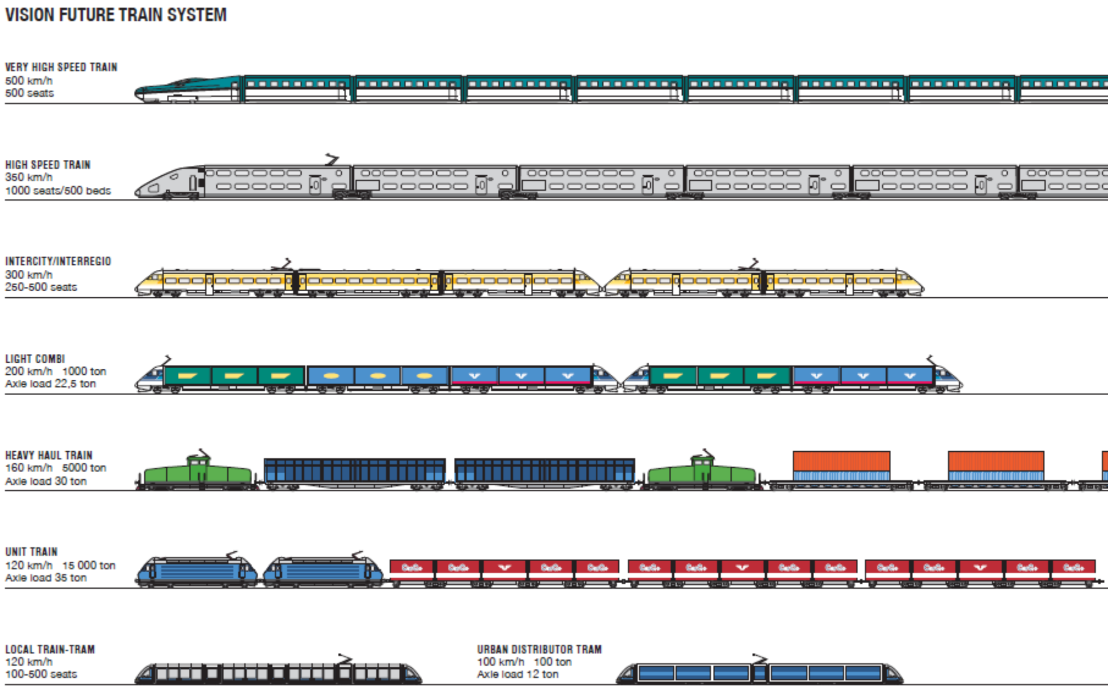


Figure 6.7: Vision of rail systems in 2050.

7. Abbreviations

CO2	Carbon Dioxide
EOT	End of train device
ERTMS	European Rail Traffic Management System
ETA	Estimated Time of Arrival
EU	European Union
EU15	The 15 first member states of the EU in western Europe
EU12	The 12 new member states of the EU in eastern Europe
EU27	The 27 member states of the EU
GHG	Greenhouse Gas
GPS	Global Positioning System
HSR	High Speed Rail
IM	Infrastructure Manager
kW	Kilowatt
kWh	Kilowatt hours
kN	Kilonewton
LDHV	Low Density High Value Goods
RFID	Radio-frequency identification
RFC	Rail Freight Corridors
RNE	Rail Net Europe
TEN-T	Trans-European Transport Networks
TEU	Twenty-foot Equivalent Unit

8. References

2. Demand for rail and trends for freight flows in Europe towards 2030/2050

2.1. The development of rail freight market and the modes

- EU Transports in figures, statistical pocketbook 2013

2.2. Development of the different modes and 2.4 Rail freight market share for different commodities

- Eurostat, transport database.
- European Commission, *Pocketbook*, 2013.
- European Commission, *Handbook on the Regulation concerning a European rail network for competitive freight*, 2011.
- European Intermodal Association (EIA), *Handbook, Innovative Intermodal Transport.*
- ERRAC WORK PACKAGE 02: *Encouraging modal shift (long distance) and decongesting transport corridors*, Freight Roadmap July 2012.
- European Commission, *Study on Freight Integrators,* Berlin, 2003.
- Project - Freight Vision, *Freight Transport 2050 Foresight,* 2009/2010.
- Press4Transport consortium, *Possibilities of intermodality in passenger transport,* 2010.
- United Nations Conference On Trade And Development, Review of Maritime transport, 2012.
- International Union of Railways Combined Transport Group (UIC-GTC), *Study On Infrastructure Capacity Reserves For Combined Transport By 2015,* 2004.
- International Union for Road-Rail Combined Transport (UIRR) *Report*, *European Road-Rail Combined Transport,* 2012/2013.
- Danish Transport Research Institute, *The Future Flow Of Goods In The Enlarged EU,* 2005.
- Trans-European Transport Network, *Priority Projects 2010 A Detailed Analysis, 2010*
- The SoNorA project, *Future of rail and inland waterway freight in Europe*, Proceedings of the 6th, SoNorA University Think Tank Conference, 2010.
- Institute of Transport & Maritime Management Antwerp (ITMMA), University of Antwerp, *Containerized Freight Distribution in North America and Europe.*
- The CER concept, *Towards a Primary European Rail Freight Network,* 2007.
- FERRMED, *Great Axis Rail Freight Network and its area of influence,* 2009.

2.3. Rail market share in different countries

- EU Transports in figures, statistical pocketbook 2013
- Freight Railway Transport in Spain. Fundacion de los Ferrocarriles Espanoles, 2014/01/27
- Data from the Railway Observatory in Spain 2011. Observatorio del Ferrocarril en España 2011.

2.5. Best practice rail in a global perspective

- Nelldal, B-L and Andersson, E, Mode shift as a measure to reduce greenhouse gas emissions. Paper 635 at Transport Research Arena in Athens 2012.

2.6. Forecasts for total demand in EU and rail´s market share

- ADAM (2009), "ADAM 2-degree scenario for Europe – policies and impacts" in Chapter 9
- TREMOVE, 2007. TREMOVE Project Final Report. European Commission DG Environment, Brussels. <http://www.tremove.org/documentation/Final_Report_TREMOVE_9July2007c.pdf
- iTREN, 2009. Intregrated Transport and Energy Baseline Until 2030. iTREN-2030 Deliverable D4, <http://www.tmleuven.be/project/itren2030/D4_Reference_Scenario.pdf>.
- D-RAIL, 2012, Rail Freight Forecast to 2050, Deliverable D2.1, D-RAIL- 'Development of the Future Rail Freight System to Reduce the Occurrences and Impact of Derailment' PROJECT, July.
- SPECTRUM, 2012, Logistics and market analysis, Deliverable D1.1 SPECTRUM – 'Solutions and Processes to Enhance the Competitiveness of Transport by Rail in Unexploited Markets, February.

2.7. A mode shift scenario according to the EU target

- de Boer E, et al (2011): *Potential of modal shift to rail transport - Study on the projected effects on GHG emissions and transport volumes.* CE, publication 11 4255 15, Delft.
- EC (2011): *Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system,* EC White Paper, Brussels, 28.3.2011.
- Nelldal, B-L and Andersson, E (2012): Mode shift as a measure to reduce greenhouse gas emissions. Paper 635 at Transport Research Arena in Athens 2012.
- TOSCA (2011a): www.toscaproject.org
- TOSCA (2011b): Schaefer A, et al: *TOSCA Project Final Report: Description of the Main S&T Results/Foregrounds.* 27 May 2011
- TOSCA (2010). Transport Infrastructure Capacity Assessment – Intelligent Transport Systems and the Impact on Capacity - Rail Transport WP 5 Report, Deliverable D6.3, NTUA, Athens.
- Furtado (2013) Francisco Manuel Bastos Andrade Furtado: U.S. and European Freight Railways: The Differences That Matter. Journal of the Transportation Research Forum, Vol. 52, No. 2 (Summer 2013), pp. 65-84

2.9. Rail freight corridors and network

3. Existing and future customer requirements for different goods segment

3.1. Customer requirements and mode choice

3.2. Customer requirements for different markets segments

- European Commission, 2012, EU Transport in Figure: Statistical pocketbook 2012, Mobility and Transport, Transport Statistics, table 2.2.2; http://ec.europa.eu/transport/facts-fundings/statistics/doc/2012/pocketbook2012.pdf, last accessed 10.04.2013.
- ISLAM, DMZ, 2013, What should be done for European rail freight transport? A logistics perspective, 13th WCTR, July 15-18, 2013 – Rio de Janeiro, Brazil.
- Islam DMZ, Zunder TH and Zomer, G., 2010, The Potential of a Pan European Rail Freight Service Using Hub and Spoke Model, in International Journal of Logistics and Transport (IJLT) Vol. 4, No 2, pp 21-30.
- NEWOPERA, 2008, NEWOPERA - THE RAIL FREIGHT DEDICATED LINES CONCEPT, THE EUROPEAN FREIGHT AND LOGISTICS LEADERS FORUM(F&L), 270 Avenue de Tervueren – 1150 Brussels, Belgium
- SPECTRUM, 2012, Logistics and market analysis, Deliverable D1.1 SPECTRUM – 'Solutions and Processes to Enhance the Competitiveness of Transport by Rail in Unexploited Markets, February 2012.

3.3. Rail products for different markets

- Railway Traffic Planning, Compendium published by KTH Railway Group at the division of Traffic and Logistics, Fourth, revised edited by Bo-Lennart Nelldal, Stockholm 2011-09-28.

3.4. Analysis of truck competition in future

- VEL-Wagon - Versatile, Efficient and Longer Wagon for European Transportation - Implementation and migration strategy. EU Grant agreement no: 265610. Deliverable report 31.12.2012.
- Study on railway business for VEL-wagon and target costs. Armando Carrillo Zanuy, Bo-Lennart Nelldal, Hans Boysen. D3.1 VEL-wagon report 30.4.2012. EU FP7 Grant agreement no: 265610.
- Competition and co-operation between railways and trucking in long distance freight transport - an economic analysis. Bo-Lennart Nelldal. Paper to 3nd KFB-Research conference "Transport Systems – Organisation and Planning" at Stockholm School of Economics 13/14 of June 2000.
- Study on the Effects of the Introduction of LHVs on Combined Road-Rail Transport and Single Wagonload Rail Freight Traffic. KP Transport Consultants in co-operation with Fraunhofer, Freiburg/Karlsruhe, October 5th 2011.

3.5 Industrial logistics concepts into the picture of future visions till 2050

- Jammernegg W., Rosič H., Bauer G. (2009): EU project Freight Vision – Deliverable D 4.2 Logistic trend report.
- Anupindi R, Chopra S, Deshmukh SD, van Mieghem JA and Zemel E (2006): Managing Business Process Flows - Principles of Operations Management, Pearson Prentice Hall.
- AT&S (2008): AT&S celebrates ground breaking of new plant in India, Press Release 05/08/08, URL: http://www.ats.net/inforum/filedb/soz1po0tp7kk0gg8@0000000001c9c09.pdf, 2009/02/26
- Breinbauer A, Haslehner F and Wala T (2008): Internationale Produktionsverlagerung österreichischer Industrieunternehmer - Ergebnisse einer empirischen Untersuchung, FH des bfi Wien, http://www.fh-vie.ac.at/files/2008_Studie_Produktionsverlagerungen.pdf, 2009/02/05
- Chopra S and Meindl P (2007): Supply Chain Management, 3rd ed., Prentice Hall
- Dachs B, Ebersberger B, Kinkel S, Waser BR (2006): Offshoring of production – a European perspective, Bulletin European Manufacturing Survey, URL: http://www.systemsresearch.ac.at/getdownload.php?id=154, 2009/02/26
- ECR (2008): ECR Sustainable Transport Project – Case Studies, URL: http://www.ecrnet.org/05-projects/transport/Combined%20Case%20studies%20_v1%208_220508_pro.pdf, 2009/02/26
- Ferreira J and Prokopets L (2009): Does offshoring still make sense, Supply Chain Management Review 13(1), pp. 20-27
- GCI and Capgemini (2008a): Future Supply Chain 2016, URL: http://www.gci-net.org/gci/content/e29/e5015/Documents5017/item_d5642/2016_Future_Supply_Chain_Report-Contents.pdf, 2009/02/26
- GCI and Capgemini (2008b): Future Supply Chain 2016, URL: www.bem.edu/fr/content/download/2562/66633/file/Appendix%20GCI_Capgemini-future%20Supply%20chain%202016.pdf, 2009/02/26
- ILOG (2009): ILOG Supply Chain Applications - Customer Success Briefs, URL: http://www.ilog.com/products/supplychain/casestudies/, 2008/12/13
- Jahns C, Hartmann E and Bals L (2007): Offshoring: Analyse der Hintergründe und Potenziale, in: Specht D (ed.): Insourcing, Outsourcing, Offshoring, Tagungsband der Herbsttagung 2005 der Wissenschaftlichen Kommission Produktionswirtschaft im VHB, Deutscher Universitäts-Verlag
- Jammernegg W and Reiner G (2007): Performance improvement of supply chain processes by coordinated inventory and capacity management, International Journal of Production Economics 108(1-2), pp. 183-190
- Kouvelis P and Niederhoff J (2007): On the Globalization of Operations and Supply Chain Strategies: A Conceptual Framework and Its Application, in: Lee HL and Lee CY (eds.): Building Supply Chain Excellence in Emerging Economies, New York, pp. 3-36
- Lett E, Banister J (2006): Labor costs of manufacturing employees in China: an update to 2003-04, Monthly Labor Review 129(11), pp. 40-45

- Lewin AY, Peacock M, Peeters C, Russel J and Sutton G (2006): 2nd Bi-annual Offshore Survey Results December2005, URL: https://offshoring.fuqua.duke.edu/pdfs/2nd_highlights.pdf, 2009/02/19
- McKinnon AC (2007): Decoupling of Road Freight Transport and Economic Growth Trends in the UK: An Exploratory Analysis, Transport Reviews 27(1), pp. 37-64
- Murphy S (2008): A Look Ahead: The Supply Chain in 2009, Supply Chain Management Review 12(9), pp.4-10
- NXP (2009): NXP Semiconductors, URL: http://www.nxp.com/acrobat_download/other/profile/factsheet.pdf, 2009/02/26
- Robinson DR, Wilcox S (2008), The greening of supply chains, Supply Chain Management Review, 12(7), pp. 61-66
- Seebauer P (2008): Supply Chain unter der Öko-Lupe, Logistik heute, 2008(10), pp. 54-55
- Simchi-Levi D, Nelson D, Mulani N and Wright J (2008): Crude Calculations, The Wall Street Journal, URL: http://online.wsj.com/article/SB122160061166044841.html, 2009/02/04
- Simchi-Levi D (2008): Green and Supply Chain Strategies in a Volatile World, Fachkonfernez: Grüne Supply Chains, 2008/12/10, Frankfurt/Main, Germany
- Tang (2006): Robust strategies for mitigating supply chain disruptions, International Journal of Logistics: Research and Applications 9(1), pp. 33-45
- Van Mieghem JA (2008): Operations Strategy: Principles and Strategy, Dynamic Ideas.
- Walker H, Di Sisto L and McBain D (2008): Drivers and barriers to environmental supply chain management practices: Lessons from the public and private sectors, Journal of Purchasing & Supply Management 14(2008), pp. 69-58

4. Requirements of technical and operational development of the rail system

4.1. Rolling stock and monitoring systems

- Boysen, H 2013, 'Øresund and Fehmarnbelt high-capacity rail corridor standards', in 10th International Railway Engineering Conference, London, ECS Publications, Edinburgh.
- Boysen, H. (2012 a), More efficient freight transportation through longer trains, Transportforum, Linköping.
- Boysen, H. (2012 b), General model of railway transportation capacity, 13th International Conference on Design and Operation in Railway Engineering (Comprail), New Forest.
- D-RAIL, 2013, Future Rolling Stock breakdown to 2050, D-RAIL Project - Development of the Future Rail Freight System to Reduce the Occurrences and Impact of Derailment, Deliverable D2.2, FP7.
- D-RAIL, 2012, Summary report and database of derailments incidents, D-RAIL Project - Development of the Future Rail Freight System to Reduce the Occurrences and Impact of Derailment, Deliverable 1.1. FP7
- Kalay, S., LoPresti, J. and Davis, D., 2011, Development of Enabling Technologies for Heavy Axle Load Operations in North America, WCRR, Lille, France, May 22-26,

- KT, 2013, Roadmap for development of rail and intermodal freight transportation: HIGH CAPACITY TRANSPORTS FOR RAIL – GREEN FREIGHT TRAIN, KTH Railway Group 16/04/2013, Stockholm, Sweden.
- Rail Safety and Standards Board, 2007, Freight Opportunities Stage 2 Part 3 – Available Space Assessment – ISO Container Routes, September, Report reference number 7481- LR- 009 issue 1.
- SUSTRAIL, 2013, Outline design of an optimised, low impact, sustainable freight bogie, Deliverable 3.1, p.8. FP7
- VEL-Wagon, 2012: Versatile, Efficient and Longer Wagon for European Transportation - Implementation and migration strategy. EU Grant agreement no: 265610. Deliverable report 31.12.2012.

4.2. Best practices and future development for wagons and coordination with WP 2.2.

4.3. Development of wagons and wagon technology

- European Commission: Technical specification for interoperability for the “rolling stock – freight wagons” subsystem, Brussels, April 2013.
- Jönsson P-A: Freight wagon running gear – a review, Report TRITA-FKT 2002:35, Div of Railway Technology, Dep of Vehicle Engineering, KTH Royal Institute of Technology, 2002.
- TU Dresden, TU Berlin: White Paper Innovative Rail Freight Wagon 2030 – The “5 L” future initiative as a basis for growth in rail freight transportation, 1st edition, September 2012.
- Iwnicki S, Bezin Y, Orlova A, Jönsson P-A, Stichel S, Schelle H: The SUSTRAIL high speed freight vehicle – Simulation of novel running gear design, Proc of the 23rd IAVSD Symposium on Dynamics of Vehicles on Roads and Tracks, Qingdao, China, August 2013.
- SUSTRAIL: http://www.sustrail.eu
- Marathon: http://www.marathon-project.eu
- UIC: Sub-section 54 – Brakes, Leaflet No 540, 2002. (also 541-549)
- KTH Railway Group et al.: Efficient train systems for freight transport – A systems study, Principal Report 0505, 2005. (Also Report 0508 on braking systems)
- KTH Railway Group et al.: Roadmap for development of rail and intermodal freight transportation – High capacity transports for rail – Green freight train, Forum för innovation inom transportsektorn, Report, Stockholm, April 2013.
- European Commission: Technical specifications of interoperability relating to the subsystem “rolling stock – noise” of the trans-European conventional rail system, Brussels, April 2011.
- European Railway Agency: List of fully approved K composite brake blocks for international transport, Technical Document, ERA/TD/2009-02/INT, Version 5, 2011.
- Thompson D J and Gautier P-E: Review of research into wheel/rail rolling noise reduction, Proc. IMechE Part F: Journal of Rail and Rapid Transit, Vol 220, pp 385-408, 2006.

4.4. Development of traction

- KTH: Rail vehicle technology, course material, chapter on traction etc.
- Eurostat: http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home

- KTH Railway Group et al.: Efficient train systems for freight transport – A systems study, Principal Report 0505, 2005. (Also Report 0508 on braking systems)
- KTH Railway Group et al.: Roadmap for development of rail and intermodal freight transportation – High capacity transports for rail – Green freight train, Forum för innovation inom transportsektorn, Report, Stockholm, April 2013.
- SUSTRAIL: http://www.sustrail.eu
- TOSCA: http://www.toscaproject.org

4.5. Future savings in energy and GHG

- TOSCA: http://www.toscaproject.org
- IEA/UIC: Railway Handbook 2013 Energy Consumption and CO2 Emissions - Focus on Energy Mix

4.6. Energy consumption and CO2 emissions for rail

- Burgess, S.C. and Choi, J.M.J., (2003). A parametric study of the energy demands of car transportation: a case study of two competing commuter routes in the UK, Transportation Research Part D, 8 (1), 21-36.
- Cillero, A., Bouzada, P., García, A., Martín, M., (2009). Métrica y estandarización de los consumos y emisiones en el transporte, Fundación de los Ferrocarriles Españoles. Madrid.
- García Álvarez, A. (2011). In García González-Román L. (Ed.), Energía y emisiones en el transporte por ferrocarril (Fundación de los Ferrocarriles Españoles ed.). Madrid.
- García Álvarez, A., & Martín Cañizares, M. P. (2009). Comparación medioambiental entre la tracción eléctrica y la tracción diésel en el ferrocarril., 56.
- González Franco, I (2012). Estimación del consumo de energía y emisiones de CO2 en trenes de mercancías y análisis de la variabilidad. Tria Railway R&D.
- González Franco, I; García Alvarez, A; Pérez Martínez, P.J. (2012): “Carbon Dioxide Emissions in Rail and Road Freight Transport in Spain: A Case Study of Car Carriers and Bulk Petrochemicals”. Journal of Intelligent Transportation Systems. Taylor Francis.
- Leonardi,J. y M. Baumgartner (2004). CO2 efficiency in road freight transportation: Status quo, measures and potential. Transportation Research Part D, 9, 451-464.
- López Martínez, J. M., Sánchez Alejo, J., Gómez, Á., & Fernández, Á. (2009). Flujos del petróleo y del gas natural para el transporte. Fundación de los Ferrocarriles Españoles. Madrid.
- Niedzballa, H.A. and Schmitt,D., (2001) Comparison of the specific energy demand of aeroplanes and other vehicle systems, Aircraft Design, 4 (4), 163-178.
- OFE. 2012. Observatorio del Ferrocarril en España. Transporte de mercancías. Fundación Española de los Ferrocarriles. Madrid.
- Observatorio de la electricidad (2012). In WWF España (Ed.),
- Pérez-Martínez, P.J., Sorba, I., (2010). Energy consumption of passenger land transport modes. Energy and Environment 21 (6), 577– 600.
- Pilo de la Source, Eduardo, & Pérez Arriaga, J. I. (2009). Flujos de la energía de la electricidad para el transporte. Fundación de los Ferrocarriles Españoles. Madrid.

- Rallo Guinot, V. (2010). Capacidad de los trenes. Máster Universitario en Sistemas Ferroviarios ICAI.

4.7. Intermodal terminal technology

- Bontekoning, Y. M., Macharis, C., and Trip, J. J., 2004, Is a new applied transportation research field emerging?—A review of intermodal rail–truck freight transport literature Transportation Research Part A: Policy and Practice, Vol., No. 1, January, pp. 1–34
- European Commission (2006), Keep Europe moving — Sustainable mobility for our continent mid-term review of the European Commission's 2001 Transport White Paper, COM (2006) 314 final.
- European Commission (2007), Freight transport logistics action plan, Brussels.
- European Commission (2011), Transport White Paper 2011 - Roadmap to a Single European Transport Area - Towards a competitive and resource efficient transport system, Brussels.
- European Conference of Ministers of Transport, United Nations Economic Commission for Europe Statistical Division and European Union Eurostat, 1997, Glossary for Transport Statistics, second edition.
- Marin Marinov, M., Ismail Sahin, I., Stefano Ricci, S., and Gordana Vasic-Franklin, G., 2012, Railway operations, time-tabling and control, Research in Transportation Economics,
- SPECTRUM, 2012, Logistics and market analysis, Deliverable D1.1 SPECTRUM – 'Solutions and Processes to Enhance the Competitiveness of Transport by Rail in Unexploited Markets, February.
- Zunder, T. H., Islam, D. M. Z., Mortimer, P. N., and Aditjandra, P. T., 2013, How far has open access enabled the growth of cross border pan European rail freight? A case study, Research in Transportation Business and Management, Vol. 6, pp. 71-80.

4.8. Analysis of transhipment technology and traffic systems

- Nelldal, B-L., 2013: Roadmap for development of rail and intermodal freight transportations - High Capacity Transport for rail - The Green Freight Train. KTH Railway Group Report 2013, KTH TRITA-TSC-RR 13-006.
- Kordnejad, B., 2013: Regional Intermodal Transport Systems – Analysis and Case Study in the Stockholm-Mälaren region. Licentiate Thesis, 2013, KTH TRITA-TSC-RR 13-006.
- Nelldal, B-L. et. al., 2005: Efficient train systems for freight transport - A systems study. Principal report 2005. KTH Railway group report 0505.
- Nelldal, B-L., Sommar, R., Troche, G., 2008: Evaluation of intermodal transport chains. Paper at Congress on ITS, New York, 2008
- Sommar, R., 2010: Evaluation of intermodal transport chains, Cost models, Only in Swedish: Utvärdering av intermodala transportkedjor – Kostnadsmodeller. KTH Report 2010-04-12

5. **Traffic and operational development**

5.1. Effects of trains of longer, heavier, faster, higher and wider wagons and trains

- Nelldal, B-L., 2013: Roadmap for development of rail and intermodal freight transportations - High Capacity Transport for rail - Green Freight Train. KTH Railway Group Report 2013, KTH TRITA-TSC-RR 13-006.
- Boysen, H 2013, 'Øresund and Fehmarnbelt high-capacity rail corridor standards', in 10th International Railway Engineering Conference, London, ECS Publications, Edinburgh.

5.2. Intelligent systems for planning and dispatching trains

- www.transport-research.info
- www.uic.org
- www.hitrail.com
- www.cit-rail.org
- www.raildata.coop
- www.tis.rne.eu
- www.uiprail.org
- www.xrail.eu

5.3. Development of traffic systems and products

- Li, P., and Mitchell, M.B., 2003, Chapter 2- Railway Industry Overview, in AMERICAN RAILWAY ENGINEERING AND MAINTENANCE OF WAY ASSOCIATION Practical Guide to Railway Engineering, p. 2-13
- Symonds Group Ltd, 2001, A Study of Single Wagonload Rail Traffic, European Commission Directorate-General for Energy & Transport, 7 August, p. 115.

5.4. Network organisations and innovative operational models

- CER, 2012a. CER Factsheet – Single Wagonload Freight. The Voice of European Railways, 08 November, p. 4.
- CHRISTIDIS, P. and Guillaume LEDUC, G., 2009, Longer and Heavier Vehicles for freight transport, ipts, JRC European Commission
- Clausen, U. and Voll, R., 2013, A comparison of North American and European Railway systems: why Europe needs particular optimisation models for railway freight traffic, European Transport Research Reviews, Vol. 5, pp. 129-133.
- Islam, D.M.Z., Zunder, T. H., Zomer, G., 2010. The potential of a pan European rail freight service using hub and spoke model. International Journal of Logistics and Transport 4, (2), 21–30.
- K+P Transport Consultants, 2011. Study on the Effects of the Introduction of LHVs on Combined Road-Rail Transport and Single Wagonload Rail Freight Traffic, Freiburg/Karlsruhe, 5 October, 83-85.
- Marinov, M; Sahin, I, Ricci, S; and Vasic-Franklin, G, 2013, Railway operations, time-tabling and control, Journal: Research in Transportation Economics, Vol. 41, Issue 1, pp. 59-75
- UIC et al., 2008, Mega-trucks versus Rail freight? What the admission of Mega-Trucks would really mean for Europe, July, UIC Communications Department.

- Woroniuk, C., Marinov M., Zunder, T., Mortimer, P., 2013. Time series analysis of rail freight services by the private sector in Europe. Transport Policy 25, 81–93.
- Zunder, T. H., Islam, D. M. Z., Mortimer, P., 2012. Pan-European Rail Freight Transport; Evidence from a Pilot Demonstration Result, Procedia: Social and Behavioural Sciences 48, 1346-1355.

5.5. Future single wagon systems and alternatives

5.6. How new signalling systems as ERTMS will affect capacity for freight

- European Union, 2013, European Railway Agency Annual Report 2012, Luxembourg, ISBN 978-92-9205-029-0, pp. 29.
- Railway-technology.com (2014) European Rail Traffic Management System (ERTMS), last retrieved on 07/02/2014 from http://www.railway-technology.com/projects/european-rail-traffic-management-system-ertms/
- TOSCA (2011) Transport Infrastructure Capacity Assessment , Technology Opportunities and Strategies towards Climate friendly trAnsport, Deliverable 6.3, p. 18.
- UNIFE, 2012, FACTSHEETS, FROM TRUCKS TO TRAINS - HOW ERTMS HELPS MAKING RAIL FREIGHT MORE COMPETITIVE,

5.7. How dedicated high speed will affect capacity for freight

- Nelldal, B-L., Jansson, K., Halldin, C., 2010: High-speed lines in Sweden - Traffic forecasts and socioeconomic calculations using the Samvips method for expanded main lines and separate high-speed lines - Summary in English. KTH Report TRITA-TEC-RR 10-005.
- Nelldal, B-L., Jansson, K., 2010: High-speed trains in Sweden – a good idea?. Royal Institute of Technology (KTH), Stockholm, Sweden. Paper at WCTR 12th congress in Lisbon, 11-15th July 2010.

5.8. Capacity by building dedicated freight lines

5.9. Monitoring systems for traffic

- J.D. Achenbach, "Structural health monitoring - What is the prescription", Mech. Res. Commun., 36(2), 137-142, 2009.
- D.L. Balageas, "Introduction to structural health monitoring, Structural health monitoring", ISTE Ltd., UK, 2008. http://www.iste.co.uk/data/doc_xqjujdlhnfls.pdf.
- J.E. Cline, J.R. Bilodeau and R.L. Smith, "Acoustic wayside identification of freight car roller bearing defects", Proceedings of the 1998 Railroad Conference, ASME/IEEE Joint, pp:79 – 83, 15-16 Apr 1998.
- S. Y. Chong, J.-R. Lee* and H.-J. Shin, "A review of health and operation monitoring technologies for trains", Smart Structures and Systems, Vol. 6, No. 9, pp. 1079-1105, 2010
- DRAIL, FP7 EU project, website: http://www.d-rail-project.eu/
- M. Grudén, M. Hinnemo, D. Dancila, F. Zherdev, N. Edvinsson, K. Brunberg, L. Andersson, R. Byström and A. Rydberg, "Field Operational Testing for Safety Improvement of Freight Trains

using Wireless Monitoring by Sensor Networks," Wireless Sensor Systems, IET, December 2013.
- Tessler, "Structural analysis methods for structural health management of future aerospace vehicles", NASA/TM-2007-214871, 2007.
- J. Wiberg, and R. Karoumi, "Monitoring dynamic behaviour of a long-span railway bridge",Structure and Infrastructure Engineering, 5:5, pp: 419 — 433, 2009.

5.10. Information systems for planning and management in terminals

- Institute For Prospective Technological Studies, "Tracking & tracing in combined road/rail freight transport", March 1999;
- European Commission, "IMPULSE – Interoperable modular pilot plants underlying the logistic systems in Europe", 2000;
- Department of Logistics University of Incheon, "Container tracking and tracing system to enhance global visibility", 2005;
- European Commission, Thematic Research, "Summary Freight Transport",2010;
- Chalmers University Of Technology, The Value of ITS on Supply Chain Operations", 2010;
- European Commission, "FLAGSHIP – Final Report", 2008;
- Politecnico di Milano, "RFID technology in a container port: an activity-based model to assess costs and benefits";
- European Commission, "E-FREIGHT, D1.2 - Assessment and forecasting of e-Freight technologies", 2011;
- International Transport Forum, "Terminal Study on the Freight Corridor", 2008;
- European Commission, "SECURCRANE, Design of an innovative system for the drive and control of port cranes for safe remote operation", 2006;
- European Commission, "D2D PROJECT, Demonstration of an integrated management and communication system for door-to-door intermodal freight transport operations", 2005;
- European Commission, "PRECISE IT – Precise Automatic Location System for the Management of ITUs and Vehicles inside Intermodal Terminals", 2000;
- UCI ITS Statewide Freight Transportation Research Group, "Intelligent Freight Transportation Systems", 2012;
- European Commission, "FREIGHT INTERMODALITY, Results from the transport research programme", 2001;
- European Commission, MOCONT, Final Report", 2001;
- European Commission, "PROMIT, Promoting Innovative Intermodal Freight Transport", 2008;
- EUROPEAN COMMISSION - EXTR@Web, "Intermodal Freight Terminals, In search of effi ciency to support intermodality growth", 2006;
- EUROPEAN COMMISSION - DG Mobility and Transport, "Intermodal Terminals in an Integrated Transport System of the Baltic Sea Region", 2012;
- TREDIT S.A, "FRETIS, FREight Transport Information Technology Solutions";
- EUROPEAN COMMISSION, "S - CBB PROJECT : Final Report, 2002;
- EUROPEAN COMMISSION, "CESAR: Final Report, 2002;
- GLOBE TRACKER, "Globe Tracker Smart Container Tracking and it's Impact on Global Ocean Freight";

- EUROPEAN COMMISSION - PORT NET, “EDI and Cargo Flows in the Mediterranean Sea”, 2007;
- EUROPEAN COMMISSION, “INTEGRITY, Intermodal Global Door-To-Door Container Supply Chain Visibility, 2008;
- EUROPEAN COMMISSION, “FREIGHT VISION, Deliverable 3.1 Relevance of infrastructure and ITS, vehicle and engine and logistics technologies on long distance freight transport in Europe, 2009;
- JOURNAL OF ADVANCED TRANSPORTATION, “The Importance of New-Generation Freight Terminals For Intermodal Transport, 1999;
- INTERNATIONAL JOURNAT OF MANAGEMENT, “The Impact of Information and Communication Technologies on Logistics Management”, 2006;
- PORTLAND STATE UNIVERSITY, Department of Civil and Environmental Engineering, “Trends in Intermodal Freight Transportation”, 2007;
- EUROPEAN TRANSPORT, “Analysis of Impact of ICT Solutions in Inter

6. The prerequisites for an efficient rail freight system 2030/2050

6.3. The most important needs for technical development

- Tåget till framtiden - järnvägen 200 år 2056. TRITA-TEC-RR 06-004. Oskar Fröidh och Bo-Lennart Nelldal, 2006-2008 . Särtryck ur Järnvägen 150 år.

6.4 The most important needs for operational development

- TRANSFORuM Transport 2050: Long distance freight - Road Map 2014-12-08. http://www.transforum-project.eu/

6.6 Vision 2050: The Railway – a new transport mode for future needs

- Railway Traffic Planning, Compendium published by KTH Railway Group at the division of Traffic and Logistics, Fourth, revised edited by Bo-Lennart Nelldal, Stockholm 2011-09-28.

9. Annex

2.4 Code and definition of goods typologies (NST 2007)

GT01	Products of agriculture, hunting, and forestry; fish and other fishing products
GT02	Coal and lignite; crude petroleum and natural gas
GT03	Metal ores and other mining and quarrying products; peat; uranium and thorium
GT04	Food products, beverages and tobacco
GT05	Textiles and textile products; leather and leather products
GT06	Wood and products of wood and cork (except furniture); articles of straw and plaiting materials; pulp, paper and paper products; printed matter, etc.
GT07	Coke and refined petroleum products
GT08	Chemicals, chemical products, and man-made fibres; rubber and plastic products; nuclear fuel
GT09	Other non-metallic mineral products
GT10	Basic metals; fabricated metal products, except machinery and equipment
GT11	Machinery and equipment n.e.c.; office machinery and computers; electrical machinery and apparatus n.e.c.; radio, television and communication equipment
GT12	Transport equipment
GT13	Furniture; other manufactured goods n.e.c.
GT14	Secondary raw materials; municipal wastes and other wastes
GT15	Mail, parcels
GT16	Equipment and material utilized in the transport of goods
GT17	Goods moved in the course of household and office removals; baggage and articles accompanying travellers; motor vehicles being moved for repair; others.
GT18	Grouped goods: a mixture of types of goods which are transported together
GT19	Unidentifiable goods: goods which for any reason cannot be identified and therefore cannot be assigned to groups 01-16.
GT20	Other goods n.e.c.