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Rail and multi-modal transport

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A B S T R A C T

This paper elaborates on the definitions of inter and multi-modal transport, as well as their differences in terms of performance. A survey of the barriers, both internal and external, to an efficient intermodal transport is included followed by an analysis of the advantages and disadvantages of combining rail transport with the other transport modes. Transhipment technologies for efficient freight service and some examples of freight rail corridors between sea and inland terminals are presented. The integration between air and rail transport is discussed and the potential synergies between air and high-speed rail services are emphasised. The paper concludes with a discussion on energy use for sustainable rail performance.

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1. Intermodal and multi-modal transport

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1.1. Definitions

The association of two or more modes of transport in a transport chain is a well-established and regular practice in the freight transport business (Lowe, 2005; pp 3). Yet, so far no overall consensus on a universal definition has been reached. The most common terms are *multi-modal transport*, *combined transport*, *intermodal transport* and *co-modality*. Over the years many definitions have been proposed. One of the first attempts was by the United Nations in 1980 with a definition on multi-modal transport (United Nations, 1980, pp 5): "International multi-modal is the carriage of goods by at least two different modes of transport on the basis of a multi-modal transport contract from a place in one country at which the goods are taken in charge by the multi-modal transport operator to a designated place for delivery in a different country".

Some years later, in 1997, the European Commission (1997) proposed a definition for intermodal transport:

> "Intermodality is a characteristic of a transport system that allows at least two different modes to be used in an integrated manner in a door-to-door transport chain. In addition, intermodal transportation is a quality factor of the level of integration between different transport modes. In that respect more intermodality means more integration and complementarity between modes, which provides scope for a more efficient use of the transport system"

In 2001, three bodies including the European Conference of Transport Ministers, recently renamed International Transport Forum, the United Nations Economic Commission for Europe and the European Commission, agreed on the definition of the three terms: multi-modal, intermodal and combined transport (European Conference of Ministers of Transport, 2005; United Nations, 2001). The definitions being:

> Multimodal Transport is the "*carriage of goods by two or more modes of transport*" (United Nations, 2001, pp 16);

> Intermodal Transport is the "*movement of goods in one and the same loading unit or road vehicle, which uses successively two or more modes of transport without handling the goods themselves in changing modes*" (United Nations, 2001, pp 17);

> Combined Transport is the "*intermodal transport where the major part of the European journey is by rail, inland waterways or sea and any initial and/or final legs carried out by road are as short as possible*" (United Nations, 2001, pp 18).

Recently the European Commission, in the mid-term review of the European Commission's 2001 Transport White Paper (European Commission, 2001b, 2006), have proposed the term co-modality as

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being the "*efficient use of different modes on their own and in combination*" (European Commission, 2006, pp. 4).

In the body of literature, the emphasis has been placed on the concept of intermodality (Bontekoning, Macharis, & Trip, 2004; Janic & Reggiani, 2001; Lowe, 2005; Panayides, 2002; Zografos & Regan, 2004), although definitions for the other terms do exist (e.g. Lowe, 2005, pp 7 for multi-modal transport, or Lowe, 2005, pp 7 for combined transport). Table 1 presents some of the proposed definitions (Bontekoning et al., 2004).

1.2. Performance of an intermodal transport service

By definition, an intermodal freight transport service is an integrated chain of transport agents. There is a Freight Forwarder (FF) that organises and manages the various agents, aiming to get the most out of each party in favour of the overall performance of the transport service. The role of freight forwarding thus generates synergies that are added to the overall performance and reduces the waste that decreases the overall performance. Thus, it can be concluded that the overall performance is more than the sum of each individual transport service's performance. Considering multi-modal transport, which by definition is made by a set of independent and non-integrated single-modal transport services; therefore, the overall performance is the simple summation of the various individual transport services' performances.

Fig. 1 shows the performance of a multi-modal and an intermodal freight transport services. The vertical axis represents the performance (measure in any unit; note that the unit depends on the specific case, but it could be: time, reliability, flexibility or capacity). It is considered a transport service with three transport agents, TA1 (blue), TA2 (red) and TA3 (green), and one FF (orange). If transport agents are involved in a multi-modal transport service then, accordingly to the above assumption, the overall performance is the summation of each individual performance (left bar in Fig. 1). If those transport agents are now involved in an intermodal freight transport service, then the overall performance will be higher due to the synergies created by and the reduction of waste obtained by the freight forwarder.

Assuming that first, each transport agent is being deployed at their maximum performance, second, that synergies are maximised and, third, that waste (inefficiencies) is reduced to zero (or to the minimum), then such assumptions would con-substantiate a situation where transport agents would be delivering the maximum possible overall performance. This performance is called the *theoretical performance* (right bar in Fig. 1), where the theoretical performance corresponds to the maximum performance attainable by an intermodal freight transport service.

However, diverse factors, further explanations are provided in later on, may create losses of synergies or waste between the transport agents and, in this way, may preclude the achievement of the *theoretical performance*. Hence the maximum performance attainable in the real world is always inferior to the *theoretical performance*. This performance shall be known as the *best possible in the real world performance* (second right bar in Fig. 1). This gap between the *theoretical performance* and the *best possible in the real world performance* (Gap 1 in Fig. 1) is called *Friction Gap* that corresponds to the level of friction. The Friction Gap cannot be eliminated by the freight forwarder because it is generated by properties that are intrinsic to the transport agents and, thus, outside the scope of the FF's area of influence. In order to reduce the friction gap the transport agents should work together to eliminate the sources of friction, for example, investment in interoperable equipment, alignment of processes, and the like.

Calling upon the freight forwarders, it should be noted that they all are not equally skilled. Different freight forwarders follow different processes of production of intermodal freight transport services and as such, they are likely to obtain different performances from the same set of dual systems. The *actual performance*

Table 1
Intermodal transport definitions.

Author (date)	Proposed definition
Jones et al. (2000)	The shipment of cargo and the movement of people involving more than one mode of transport during a single, seamless journey
Southworth & Peterson (2000)	Movement in which two or more different transport modes are linked end-to-end in order to move freight and/or people from point to origin to point of destination
Min (1991)	The movement of products from origin to destination using a mixture of various transport modes such as air, ocean lines, barge, rail, and truck
Van Schijndel & Dinwoodie (2000)	The movement of cargo from shipper to consignee using two or more different modes under a single rate, with through billing and through liability (Hayuth, 1987)
D'Este (1995)	A technical, legal, commercial, and management framework for moving goods door-to-door using more than one mode of transport
TRB (1998)	Transport of goods in containers that can be moved on land by rail or truck and on water by ship or barge. In addition, intermodal freight usually is understood to include bulk commodity shipments that involve transfer and air freight (truck–air)
Ludvigsen (1999)	The movement of goods in the same load-carrying unit, which successively use several transport modes without handling of goods under transit
Tsamboulas & Kapros (2000)	The movement of goods in one and the same loading unit or vehicle, which uses successively several modes of transport without handling the goods themselves in changing modes (European Commission, 1997a)
Van Duin & Van Ham (1998)	The movement of goods in one and the same loading unit or vehicle, which uses successively several modes of transport without handling the goods themselves in changing modes (European Conference of Ministers of Transport, 1993)
Murphy & Daley (1998)	A container or other device which can be transferred from one vehicle or mode to another without the contents of said device being reloaded or disturbed (Jennings & Holcomb, 1996)
Newman & Yano (2000a,b)	The combination of modes, usually ship, truck or rail to transport freight
Taylor & Jackson (2000)	The co-ordinated transport of goods in containers or trailers by a combination of truck and rail, with or without an ocean-going link (Muller, 1995)
Slack (1996)	Unitised loads (containers, trailers) that are transferred from one mode to another
Spasovic & Morlok (1993)	The movement of highway trailers or containers by rail in line-haul between rail terminals and by tractor-trailers from the terminal to receivers (termed consignees) and from shippers to the terminal in the service area
Niérat (1997)	A service in which rail and truck services are combined to complete a door-to-door movement
Harper & Evers (1993)	One or more motor carriers provide the short-haul pick-up and delivery service (drayage) segment of the trip and one or more railroads provide the long-haul or line-haul segment
Evers (1994)	The movement of truck trailers/containers by both railroads and motor carriers during a single shipment
Nozick & Morlok (1997)	The movement of trucks and containers on railcars between terminals, with transport by truck at each end

Source: Bontekoning et al. (2004).

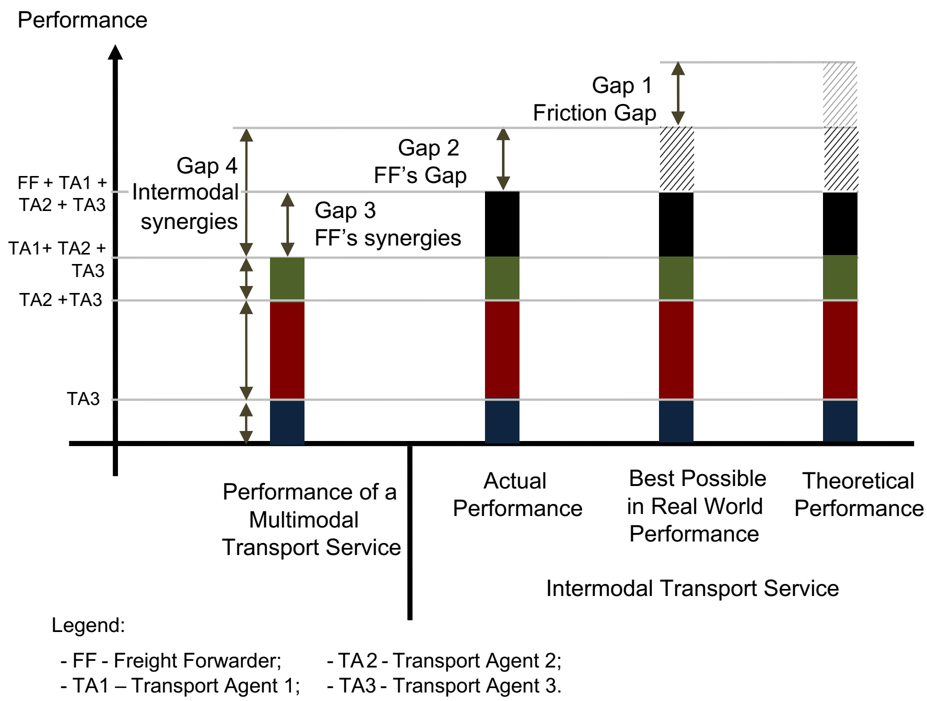

Fig. 1. Showing the performance of intermodal freight transport services.

(second left bar in Fig. 1) achieved by the transport agents ultimately depends on the capabilities of the freight forwarder and it is below the best *possible in real world performance*. The *actual performance* is higher than the performance of a multi-modal transport service because of the synergies created by the presence of the freight forwarder. A second gap may thus occur between the real world performance and the actual performance known as the so-called, *Freight Forwarder's Gap* (Gap 2 in Fig. 1) and corresponds to the inability of the freight forwarder in extracting the most from the dual systems and, ultimately, the transport service.

A third gap may also be identifiable between the actual performance and the performance of the multi-modal transport service, known as the *Freight Forwarder's synergies Gap* (Gap 3 in Fig. 1) and corresponds to the added valued brought by the freight forwarder.

A final gap can be identified and corresponds to the difference between the real world performance and the performance of the multi-modal transport service. This is known as the *Intermodal synergies Gap* (Gap 4 in Fig. 1) and corresponds to the full potential of intermodality over multimodality (that may not be entirely explored due to the incapacity of the freight forwarder).

In conclusion, the performance of an intermodal freight transport service is a function of three key factors:

- Performance of the dual system: transport agent – mode of transport;
- Freight forwarders' capabilities of managing;
- Friction gap.

1.2.1. Barrier to integration

In an integrated transport network, each mode of transport is expected to be used at its best scale and operation. This will result in the specialisation of the various modes of transport, in accordance with their operational characteristics, that is; high-speed rail, air and sea for the long and medium distances, and conventional rail, metro, bus and cars, for short and medium distances. As a consequence, a transport network's available capacity can be used at maximum efficiency with a rationalisation of the energy consumption. However, achieving stable and efficient intermodal transport services is far from simple. A considerable amount of research was dedicated to study the problems affecting these transport solutions and to propose measures to overcome them. In brief, the problems may be divided into two parts:

- *Internal sources* (Gap 2 in Fig. 1) or friction referring to internal factors to the transport service (i.e.: factors that are related to the transport operators and the production of the transport service).
- *External barriers* (Gap 1 in Fig. 1) referring to the external factors around the transport service system (i.e.: factors that are not related with the transport operators' characteristics).

Fig. 2 shows the *mechanisms of integration in an intermodal transport service* and it can be used to understand the nature of friction in efficiency. The mechanisms of integration can be depicted into five building blocks (Reis, 2010):

Customers' requirements;

1. Customers' requirements;
2. Transport service's properties;

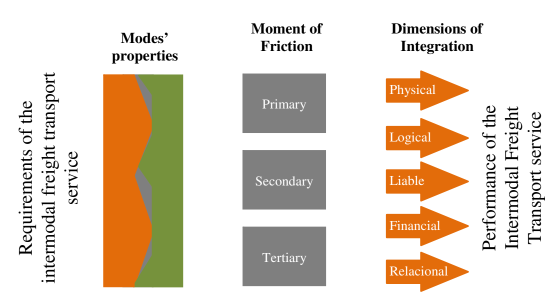

Fig. 2. Mechanisms of integration in a co-modal transport service.

3. Moment of Friction;
4. Dimensions of Integration;
5. Intermodal service's performance.

The *transport service's profile refers to the set of operational and technological properties* of the system; transport operator and transport mode (such as: capacity, tariffs, schedules, etc.). The choice of the properties of the transport service's profile is determined by the *passengers' mobility requirements*.

At a nodal point, an airport for example, two profiles interact. If they are not a good fit (where their properties are not compatible, for instance they have different capacities, different time schedules, different baggage regulations, etc.), then losses of efficiency will occur. These losses or *types of friction* exhibit different nature and occur in different moments and fall under three types:

- Type 1 – friction that provokes losses of efficiency *during the production* of the transport service, including the transfer between transport modes as is the case of an airport, and that undermines the efficiency (such as: delay in one segment resulting in losing the next one, lost baggage, etc.).
- Type 2 – friction that prevents the detection and recovery of a problem (for example: the impossibility of a fast transfer connection for delayed passengers) *during the production* of the transport service.
- Type 3 – friction that prevents the customers to be compensated for the problems that occurred during the transport service, typically this happens *after the production* of the transport service (e.g. non agreement between stakeholders on the compensation to the customers).

The *dimensions of integration* refer to the nature of the interactions that occur during the production of an intermodal or co-modal transport service. Along each dimension, friction may occur and lead to losses in the efficiency of the transport service. It is the existence of the dimensions of integration that make the intermodal or co-modal transport arrangements unstable and prone to failure. Conversely, single-modal transport services do not exhibit such dimensions for which are much more stable. This is the reason that transport operators prefer to operate either on a modal basis or, when they operate more than one mode of transport, prefer to control the transport chain as a way to better control the sources of instability. There are five dimensions of integration:

- Physical interaction – refers to the physical transport of passengers (and their luggage) along the transport chain;
- Logical interaction – refers to the exchange of communication between the transport operators;
- Contractual interaction – refers to the share of responsibilities agreed between the transport operators;
- Financial interaction – refers to the scheme of payments agreed between the transport operators.
- Relational interaction – refers to the nature of the relationships established between the transport operators.

The existence of friction along one or more dimensions of integration will result in losses of *efficiency and performance of the co-modal transport service.*

The sources of friction will impact one or more interaction and thus affect the level of integration of the co-modal transport service. Consequently, producing a stable co-modal or efficient intermodal transport service is inherently complex as it involves streamlining multiple dimensions (or flows) to deliver transport services to customers with different demands.

A significant research effort has been dedicated to external barriers over recent years. The following research projects have analysed the barriers and proposed solutions to overcome them. It should be noted, in particular, that the HERMES project of the EU has recently assessed the main barriers, both institutional and physical to the production of efficient intermodal transport services. Table 2 summarises the main findings of this project.

2. Rail–road

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2.1. Road transport

Road transport is by far the most popular mode of transport. There are several reasons for this:

- *Flexibility*: One can reach almost any point by truck;
- *Compatibility*: A truck from one country can use the roads in any other country;
- *Speed*: Goods on medium or short distances normally cannot be transported faster by any other mean;
- *Cost*: Saving the fixed costs for maintaining a track and transhipment points allows cheap transport for short distances.

Of course, the speed and cost aspect is one that has to be continually re-evaluated as fuel gets more expensive and the amount of traffic is rising far more than the number of roads.

Figs. 3 and 4 only illustrate the situation for Germany, but this can be generalised for the whole of central Europe.

With the financial crisis, it is even harder to maintain the road network and often impossible to extend it.

2.2. Intermodal transport chain

What are the indications for good combination of rail and road? Let us have a look at Fig. 5.

One can observe that coal is most successful in using rail. Also, oil is successful but not as much as coal. What may the reasons for this be? Consider that:

- Coal and oil are heavy goods. Trains are able to transport huge amounts of heavy goods;
- Coal and oil are not particularly time sensitive. Firstly because they do not lose quality over time and secondly they are relatively cheap, binding not too much capital per kilogram;
- The coal transport network has few sources and few sinks, meaning, we have only a few places to mine coal and there are (nowadays) few places to consume it. On the contrary, oil has many recipients, e.g. all the people driving cars.

Looking at the other end of the scale we have:

- *Food*: Considering the "Best before" date, food has to be transported quickly. Furthermore, there are many places to produce, processed and consume food.
- *Products with high value/kg*: Flexibility and time are the most important factors.

In order to make rail more attractive, a few adjustments must be made. The time factor must be reduced as rail in its current state is slow; the main contributing factor to this is the relatively large amount of time that is used for waiting or shunting.

The second point is the cost factor. Fig. 6 illustrates the general cost structure of combined transport.

Table 2
Barriers to the production of co-modal transport services.

	Public decision markers	Terminal managers
Legal/Regulatory	• Complex legal framework • Hard to monitor a deregulated market • Absence of implementation of existing intermodality policy by national governments • Environmental rules curb the intermodality (e.g. standards on noise)	• Intermodality has not been part of planning processes of existing infrastructure • Different regulation in different countries or cities • There are no homogeneous standards for information services and safety aspects • The planning times in the political process are too long
Institutional	• Lack of a coordinating authority • Lack of cooperation between operators • Lack of institutional cooperation between the central and the local level • Several actors with different responsibility	• Lack of cooperation among transport modes • The market is very irregular: there are a lot of players, with different agreements • Different authorities and directors lead to diffuse responsibilities • There are often different own interests of politicians and transport operators
Contractual	• Absence of common standards in contracts • Absence of incentives for intermodality (transport operators)	• Lack of temporal coordination among transport operators • The economic aims of transport operators and terminal managers are different
Informational	• Lack of a coordinating authority to define information standards • It is necessary to create an integrated information system	• Absence of common standards in contracts • Absence of incentives for intermodality (transport operators)
Physical	• Absence of cooperation • No right to change or extend the interchange	• Absence of common standards in contracts • Absence of incentives for intermodality (transport operators)
Economic	• Complex economic framework • Other revenue should be charged to cross-subsidise other facilities	• Absence of common standards in contracts • Absence of incentives for intermodality (transport operators)
	Transport operators	User association
Legal/Regulatory	• Long-winded planning and licencing processes before investments in infrastructure can be made • Lack of simple technical standards • Too much regulation on the issue	• Intermodality is not part of the planning process • Lack of integration with soft modes such as bicycles • There are not enough intermodal offers or they are not noticed by customers, which leads to a low demand
Institutional	• Too many institutions that want to control and coordinate • Cultural, political and institutional barriers that causes a lack of planning activities • Absence of an entity/authority that coordinates the provision of operators	• Different companies/organisations are involved when transport nodes are concerned and there is lack of coordination among them • Lack of city or local participation in stations' activities • Transport operators are very competitive
Contractual	NA	NA
Informational	• Absence of common standards in contracts • Absence of incentives for intermodality (transport operators)	• Absence of common standards in contracts • Absence of incentives for intermodality (transport operators)
Physical	• Absence of common standards in contracts • Absence of incentives for intermodality (transport operators)	• Absence of common standards in contracts • Absence of incentives for intermodality (transport operators)
Economic	• Absence of common standards in contracts • Absence of incentives for intermodality (transport operators)	• Absence of common standards in contracts • Absence of incentives for intermodality (transport operators)

Source: HERMES Deliverable 3 (2011).

The costs of truck transport are almost linear in the distance, meaning that they are represented by a straight line. For combined transport, the service starts with a truck, there are costs for turnover (the line parallel to the y-axis). In the middle part, one observes the costs for rail transport followed by further turnover and transport by truck. It can be seen that truck transport has a higher derivative (i.e. the slope) than train transport, meaning that the costs per km are higher.

The intersection point of both curves indicates the distance where combined transport becomes cheaper than rail transport. There are three possible ways to move this intersection point further to the left on the graph:

1. Reduce the pre carriage;
2. Reduce the turnover cost;
3. Make train transport cheaper.

Point 1 is about infrastructure and reducing the distance to the nearest railway station that can handle the goods of the customer. Point 3 is more on the operational side, making organisations more efficient and optimising the transport routes.

Point 2 is especially interesting since transhipment is a delicate issue. The main advance in recent years is the standardisation of loading units, most prominently the introduction and the propagation of the ISO container. Transhipment is not only a matter of cost, but also of trust, and it has to be fast, easy and reliable.

There are different possibilities for transhipment. For large amounts of goods, a gantry crane can be used in most instances. It is fast and it also allows the storage of goods on relatively little space. There are disadvantages however, such as the high capital expenditure, and also, in connection with rail, the problem of the

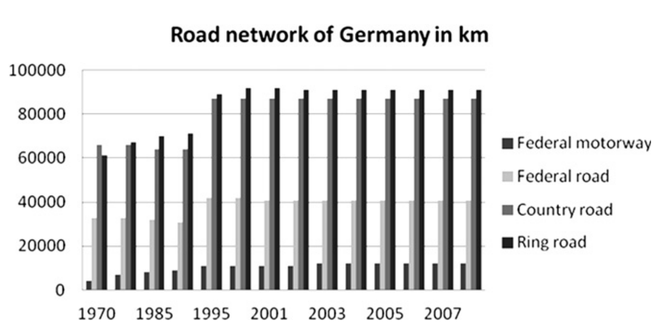

Fig. 3. Road network of Germany.

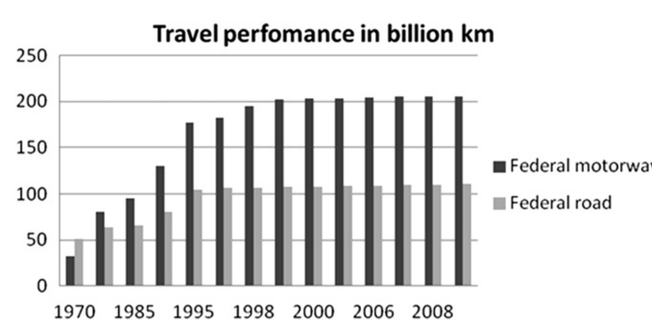

Fig. 4. Travel performance. Source: BAST Bundesanstalt für Straβenwesen.

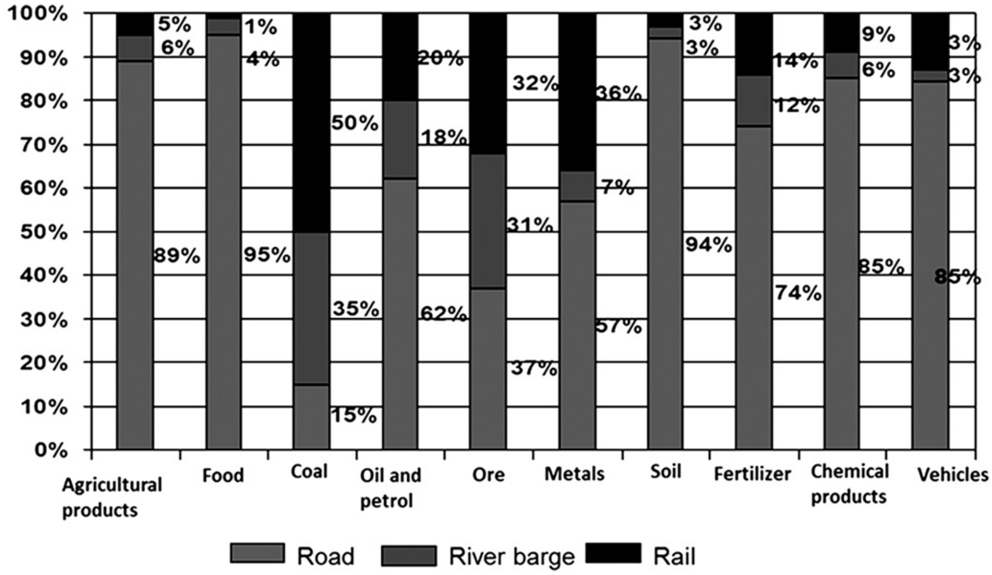

Fig. 5. Modal share of different goods.

contact wire which makes vertical transhipment techniques nearly impossible.

The alternatives are mobile instruments, which are relatively slow and also need driving lanes (in contrast to public opinion many ports are short of space). But as a cheap and flexible solution, they are indispensable for small ports and also can be used as additional instruments for the "rush hour" in bigger ones.

There are also different methods for multi-modal transport, such as semi-trailers and swap bodies. The main advantage of these methods is the possibility to change modes without further equipment. Few connections are equipped with means for whole trucks to "roll-on and roll-off" (roro). This allows particularly easy loading and unloading, but the quotient between the overall weight and the transported weight is too high for many situations.

2.3. Factors of success

The importance of the rail–road transport depends on several factors, having fast and reliable transhipment is one of them. But one should not forget that building railways and operating trains is a very political issue, since still many railway companies are state-owned and/or in some or the other way subsidised by a state. Reasons for this can be different, but an important and probably growing part of this, is the environmental issue.

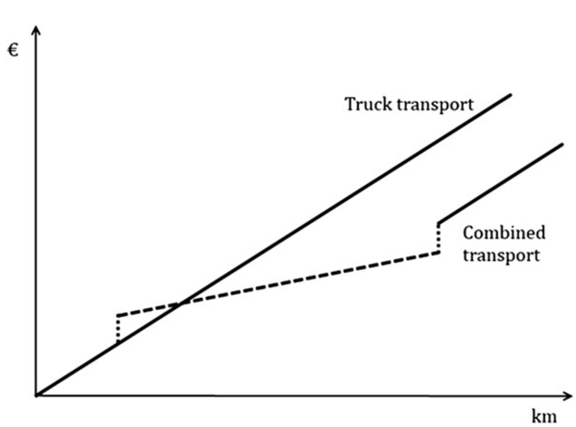

Fig. 6. Truck vs. combined transport.

Nevertheless, the problems with capacity and compatibility (Fig. 7) should not be forgotten. Efforts should be made to resolve these issues and improve rail, in order to give rail–road transport a chance to compete with other transport modes. Recent information about these topics can e.g. be found in (Clausen and Sender 2010) and (Clausen et al 2010).

3. Rail–sea

Giuseppe Pace, Ghent University and ISSM-CNR

3.1. Passengers and freight

Historically, the transport system has been segmented and has lacked integration. Each mode, particularly the carriers that operate them, has sought to exploit its own advantages in terms of cost, service, reliability and safety. It could be argued that this lack of integration has not been helped by public policy that has frequently barred companies from owning firms in other transport modes, or has placed a mode under a direct state monopoly. Another possible explanation of the uni-modality is the difficulty of transferring goods from one mode to another, thereby incurring additional terminal costs and delays.

Intermodal transportation represents a major effort to integrate separate transport systems. Passengers or freight transhipment from one mode of transport to another commonly takes place at a terminal specifically designed for such a purpose. All modes of transportation use terminals in one context or another.

Specification	Country
1,5 kV DC	South France, NL
3 kV DC	B, SLO, I, PL, parts of CZ, SK
15 kV, 16 2/3 Hz AC	Germany, Austria, Switzerland
25 kV, 50 Hz AC	North France, GB, H, DK, FIN, India, China, etc.

Fig. 7. Voltages and currents in European railway.

Terminals are places where the movement of freight (and also passengers) pauses or stops for a modal interchange or a value-adding activity, or both. Although the term "terminal" implies an end, a final destination, they are typically intermediate locations in the global flows of passengers and freight. Terminals are the nodes in a shipper/carrier system and perform various functions to facilitate the movement of freight (and also passengers).

The varying nature, composition and timing of transfer activities give rise to significant differentiations in terminal types and functions. A basic distinction is between passengers and freight.

3.2. Port terminals

Port terminals are the most substantial intermodal facilities in terms of traffic, space consumption and capital requirements, but they should not be identified with the port itself, which can have several terminals of the same or different nature (types of terminals are container, ro–ro, passengers, rail, etc.). In many parts around the world, ports are the points of convergence from which inland transport systems, particularly rail, were laid. Some terminals are bounded by sea access and located in the port area (maritime terminals) whereas others are located in the hinterland (inland terminal), provided that there is an inbound/outbound transport link. The other essential component is the rail terminal, located at the start of the inland intermodal chain and linked with port terminals.

The most important typologies of port terminals are the container terminal, the intermediate hub terminal, and the barge terminal for the inland navigation.

Container terminals provide an interface between the maritime and inland systems of circulation. Containerised transportation has substantially changed port dynamics to favour the emergence of specialised container ports. Container terminal facilities have to provide capital intensive cranes and ample storage space to stack containers dockside. Containerisation has become a fundamental function of global port operations and has changed the structure and configuration of port terminals that tend to occupy more space.

The growth of long distance maritime container shipping favours the emergence of a new function for several container terminals that is transhipment (ship-to-ship). Transhipment dedicated terminals are intermediate hub terminals, with some even having an offshore location. Their purpose is mainly to tranship containers from one shipping network to another and they essentially have little, if any, hinterland connections. Intermediate hubs can connect long distance and short distance (feeder) maritime services, connect different long distance services and connect services calling different ports along a similar maritime range. Smaller ports, particularly those that are well connected to inland transport systems, are feeders through the use of short sea shipping.

Finally, containerisation of inland river systems has led to the development of an array of barge terminals linked with major deep sea terminals with scheduled barge services. At maritime container terminals, barges can either use regular docking areas or have their own terminal facilities if congestion is an issue.

3.3. Rail terminals

A rail terminal can be connected to a port terminal through three different typologies. The first is the on-dock rail terminal, where containers move directly from the dock (or the storage areas) to a railcar using the terminal's own equipment. Their design tends to lean towards handling containers only on flatcars (COFC).

The second type is the near-dock terminal, where containers (or other freights) clear the terminal's gate (delays) using the local road system (congestion) and clear the gate of the near-dock rail terminal (delays). It tends to have more space available and can play a significant role in the sea–rail interface, especially if combined with trans-loading activities.

Finally, the third type is the satellite terminal, which together with the load centre and the trans-modal terminal can be qualified as a form of inland port. This last type can typically handle both COFC and trailers on flatcars (TOFC) and can be linked to maritime terminals through rail shuttle or truck drayage (more common) services.

Rail freight terminals perform intermodal and shunting functions. The first is the process of loading and unloading freight from railcars, and depending on the nature of what is been carried, it requires various specific equipment. For cars, roll-on and roll-off ramps are required. For grain, grain elevators are commonly used to store, mix and load grain into railcars. Containerisation has greatly expanded the intermodal productivity of rail terminals since it permits quick loading and unloading sequences, but this is at the expense of more trackside space available. Shunting is the function of assembling, sorting and breaking up of freight trains. Since trains can be composed of up to about 100 railcars, often of various natures, origin and destination, shunting can be a complex task to perform especially when it is done frequently.

3.4. The "hinterland" concept

One of the most enduring concepts in transport geography, especially in ports, is the hinterland, a land space over which a transport terminal, such as a port, sells its services and interacts with its clients. It accounts for the regional market share that a terminal has relative to a set of other terminals servicing a region, and regroups all the customers directly bounded to the terminal and the land areas from which it draws and distributes traffic. The ocean-ward mirror of hinterland concept is the foreland, which refers to the ports and overseas markets linked by shipping services from the port. It is above all a maritime space with which a port performs commercial relationships, namely its overseas customers. With the emergence of feeder services and hub ports, the concept of the foreland has been expanded as a port can service a hinterland through a maritime link.

The term main or fundamental hinterland refers to the market area for which a terminal is the closest. It is assumed that this zone's traffic will normally pass through the terminal, because of proximity and the lack of competitive alternatives. The competitive hinterland (or competitive margin) is used to describe the market areas over which the terminal has to compete with others for business. Container mobility has facilitated market penetration, so that many ports compete over the same market areas for business therefore, hinterlands may be overlapping. Many hinterlands have become discontinuous, a process facilitated by the development of corridors and inland terminals.

3.5. Port regionalisation

Linked to the hinterland, there are the functions of centrality and intermediary performed by terminals. For centrality it is taken into consideration the function of the terminal as a point of origin and destination of traffic. Thus, centrality has a link to the generation and attraction of movements, which are related to the nature and the level of economic activities within the vicinity of the concerned terminal. The function of centrality also involves a significant amount of intermodal activities. The intermediary focuses on the terminal as an intermediate point in the flows of passengers or freight. This term is applied to the frequent occurrence of places gaining an advantage because they are between other places.

Spatial relationships between terminals are a vital element in competition, particularly for ports and rail terminals. Different geographical scales, from the global to the local, can be integrated in a multi-modal transport system, and to increase the accessibility of regions and cities to the international market. A new development of the traditional local function of the ports is their regionalisation and evolution in industrial complexes. A port throughput is linked to a variety of local and regional industrial terminals. Through improving hinterland transportation, ports can go beyond their own facilities to help accommodate additional traffic and the complexity of freight distribution. Port regionalisation indicates a higher level of integration between maritime and inland transport systems, particularly through using rail and barge transportation, which are less prone to congestion than road transportation. It is characterised by strong functional interdependency and even joint development of a specific load centre and logistics platforms in the hinterland.

Once terminals are surrounded by various economic activities, many of them freight related, they have to cope with challenges in terms of local and regional accessibility. Road congestion increases and terminal access becomes more and more problematic. To cope with that, two interdependent strategies can be implemented:

- *Modal shift*: Closer integration with an alternative transport mode to share the shipments entering or exiting the terminal through another mode, which commonly involves rail or barge shuttles;
- *Freight diversion*: Satellite terminals enable the interception of freight shipments which instead of entering a congested metropolitan area, are bound to terminals for easier access.

3.6. Cluster port and inland rail terminal

Concerning port regionalisation and congestion, it is possible to implement a concept of port as a "cluster", directly linking through a dedicated rail corridor on-dock rail facilities to a nearby inland rail terminal where containers can be sorted by destination. It involves two modes of operation for the on-dock rail terminal, such as the block swap and the 'No Sort' Shuttle Trains. The first is a full-length train assembled at the on-dock facility, and consisting of blocks of 10 container cars each sorted for specific inland destinations. The second is an unsorted full-length train assembled at the on-dock rail terminal. In such a setting, the inland rail terminal becomes an important component of the system and its role becomes focused on trans-modal (rail to rail) operations. The "synergy" creates a new type of maritime/land interface and a regionalised port.

In order to better think about modal shift or freight diversion, it is necessary to analyse the four main functions of the intermodal transport chain; composition, connection, interchange and decomposition. Composition is the assembly and consolidation of freight at a terminal that offers an intermodal interface between a local/regional distribution system and a national/international distribution system; referred to as the "first mile". The connection function involves a consolidated modal flow, such as a freight train or a container ship (or even fleets of trucks), between at least two terminals, which takes place over national or international freight distribution systems. The interchange function is the major intermodal function taking place at terminals whose purpose is to provide an efficient continuity within a transport chain. Those terminals are dominantly within the realm of national or international freight distribution systems, with ports (transhipment hubs) being the most notable example. Finally, decomposition is the fragmentation and transfer of a load of freight to the local/regional freight distribution system once it has reached a terminal close to its destination. It is referred as the "last mile" and often represents one of the most difficult segments of distribution.

3.7. Case study: the TIGER project

TIGER (Transit via Innovative Gateway concepts solving European – Intermodal Rail needs) is an FP7 funded project for the development of rail transport in competitive and co-modal freight and logistics chains. With the objective to alleviate European port and road congestion, TIGER suggested to increase rail freight's market share and improve rail network productivity and developed four demonstrators to find the right balance between geographical location, existing infrastructure, local context, hinterland penetration and sustainability. The first demonstrator, the Genoa Fast Corridor (Fig. 8), is based on the concept of freight diversion in a satellite terminal (Rivalta Terminal Europa), where containers arriving both at Terminal S. Giorgio and Genoa Voltri are transferred by shuttle trains, adopting random loading from ships to speed up operations and using a secondary rail link from the port and returning via the mainline, creating a "loop". New ICT and management systems have been introduced, as well as investments in port infrastructure and signalling. Rivalta is linked to two main TEN-T corridors and offers custom facilities for the Genoa Port.

The second demonstrator is the Mariplat "Y" (Fig. 9), that aims to concentrate container traffic from two main Italian ports, Gioia Tauro and Taranto, and consolidate them in longer and heavier trains operated between Bari and Bologna Interporto freight village, using the Adriatic Rail Line. In Bologna containers enter in the main European freight corridors, avoiding the very congested Tyrrhenian Line passing through the city of Naples, Rome and Florence.

The third demonstrator, the iPORT (Innovative Port & Hinterland Operations) (Fig. 10) is based on the "web" concept and aims to optimise the container flows from the ports of Hamburg and Bremerhaven to the hinterland. In selecting an inland terminal location, it evaluated two different approaches, "close-to-the-port" and "close-to-the-market", in terms of hinterland coverage and efficiency. The first approach demonstrated a reduction of waiting time of 92% and a relevant road decongestion, promoted strong IT support and cooperative business models between different actors, as well as in general supporting the development of a cluster model. The second developed a good number of best practices, such as frequent shuttle trains from/to German seaports, and IT tools like Blue Opti, a train monitoring system with customer interfaces. Results showed

Fig. 8. The Genoa fast corridor "LOOP" system. Source: Tiger Newsletter 1/2010.

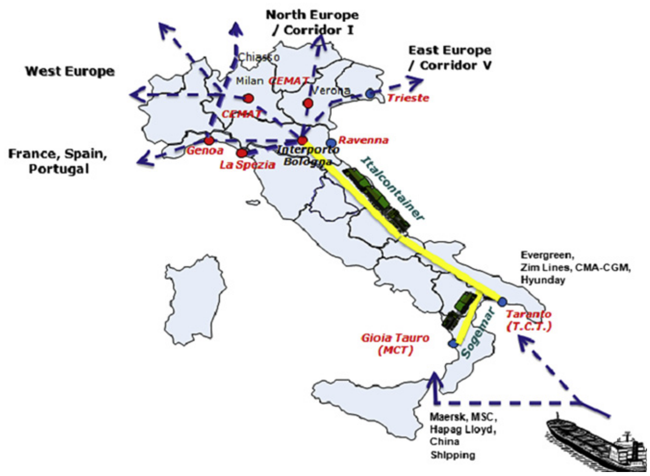

Fig. 9. The MARIPLAT "Y" concept. Source: Tiger Newsletter 1/2010.

improved train punctuality (85–90%), an increased rail usage and the same level of capacity with less trains (−15 to 20%).

The last demonstrator, the Mega-Hub (Fig. 11), is based on a "spider" concept and aims at making a relevant step forwards in inland distribution by shuttle trains from/to mega hubs in Hannover and Munich. Both terminals are designed to combine maritime as well as overland traffic in order to achieve larger scale economies, by improving shuttle frequencies and connecting additional terminals in the production network.

4. Rail–air

Dr. Vasco Reis, Instituto Superior Técnico, Technical University of Lisbon

4.1. Air transport

The European Air Transport System is a vital element to European mobility and a significant contributor to European wealth. Tourism and business travel have led to a strong development in airport capacities at a worldwide level, supporting millions of jobs in both developed and developing countries. Additionally, the air transport sector has arguably been a major catalyst of globalisation and one of the main pillars of today's economies and

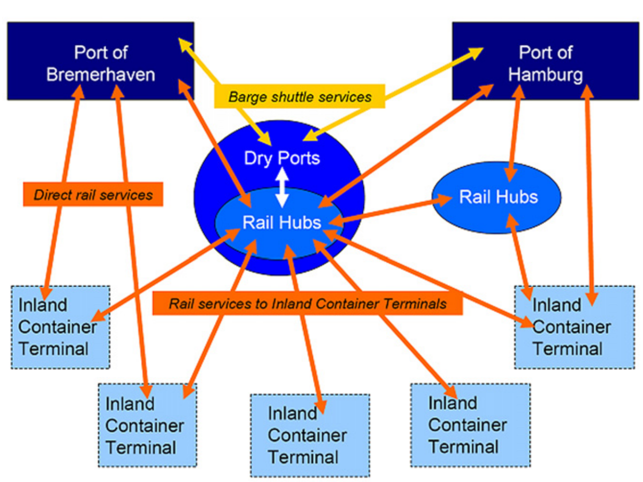

Fig. 10. The "iPORT web" concept. Source: Tiger Newsletter 1/2010.

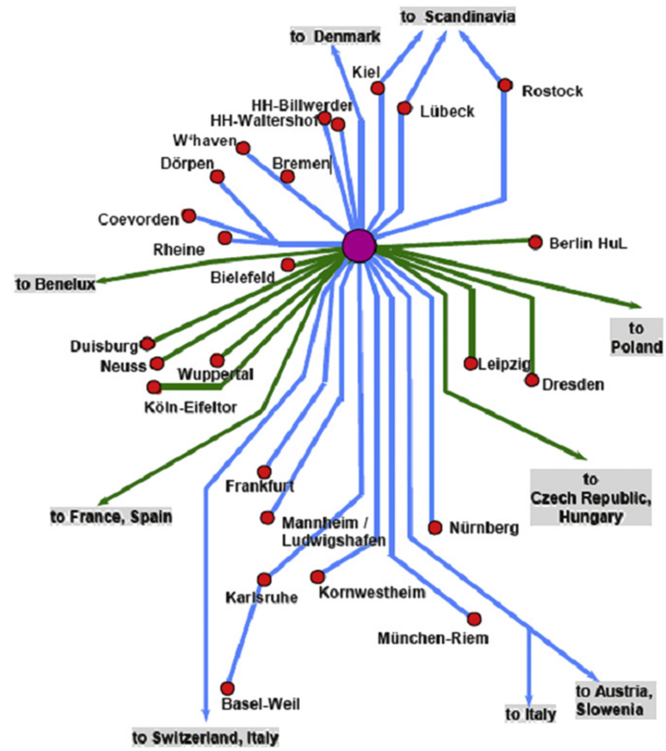

Fig. 11. The "MEGA-HUB SPIDER" concept. Source: Tiger Newsletter 1/2010.

societies. The world economy is now increasingly dependent on air travel, and a growing share of freight in terms of value is conveyed by air. Not surprisingly, air traffic has enjoyed continuous growth ever since the advent of civil aviation, both in terms of passengers and freight carried (Fig. 10). Looking back, since 1945 world passenger traffic grew at an average annual rate of 12%; from 1960 a 9% annual growth is reported, with freight growing at a rate of 11% per annum and mail at 7%. As the industry grew and matured, a decrease in growth rates is observed; nevertheless a growth of 5% per annum was registered in the period 1985–1995. The first historical decline occurred in 1991 due to the Gulf War, followed by a slow recovery in the following years, as a result of the economic recession. In any case, air traffic is expected to continue in the future, leading to a doubling in traffic every 12 years (TRKC, 2010).

The air transport industry is going through a paradigm shift, due to the disintegration of the concept of modal superiority of the sector (Macário, 2011a). Typically regarded as independent nodes of the transport network airports benefit from a monopolistic market positioning, which allows them to keep their attractiveness even if they don't have a connection to the overall transport network. However, this reality is changing significantly and nowadays the interaction between transport modes is more intensive than what it was in the past, which has led to the concept of transport integration, co-modality and intermodality (Eurocontrol, 2005). Airports are no longer exceptions, being now important multi-modal interchanges and central nodes in the network.

The shift in the instituted paradigm, within air transport, was accompanied by intense modifications concerning how governments regarded the transport industry. In the past, governments have considered the air transport as a national strategic asset, due to its importance regarding public interest and of its role as a promoter of regional development. This sector's protectionism, also with the aim of ensuring national pride and international affirmation, was generally based in the airport industry being used as a shielding vehicle of the national airline company, which has led to several operational and financial inefficiencies (usually with the airport sector protecting and subsidising the less financially attractive, but internationally recognised, national airline business) (Pena, 2011). The recognition of the airport sector's potential came later, attached with the liberalisation and deregulation of the airline market, as of the 1980s, and what caused a revolution in the industry and led to:

- *Private involvement in the airport sector*: The liberalisation of airports started in the 1980s, with the privatisation of the British Airport Authority, and was followed by partial divestitures and by the launch of public–private partnerships (Graham, 2008). Nonetheless, most airports in Europe remain nowadays under public control. However, over the past twenty years there has been an increasing use of private capital in airport financing as the current use of private capital;
- *Marketisation of public airports*: Airports kept under public control but shifting towards market-oriented management perspectives and politically autonomous.

Fig. 12 summarises the key trends and factors that emerged as a consequence of the worldwide liberalisation and deregulation of the air transport sector and economic markets in the 1980s and that led some airports to evolve towards the concept of an "airport city" or others similar.

Airports today are dynamic centres of economic activity, incorporating several commercial and entertainment services inside passenger terminals, with developed land side areas comprising shopping centres, hotels and accommodation, office complexes, conference and exhibition centres or leisure facilities. They are also vital logistics and distribution centres, as well as major centres of employment and sites for business contacts.

Moreover they have become the most influential transport infrastructures in the transformation of the metropolitan area, taking on many features of metropolitan central business districts and establishing themselves as new regional development poles. They exercise strong influence in the rearrangement of land side traffic networks and in the reorganisation of the metropolitan area's territory. In the European Union, examples of these airports include Frankfurt Main (Germany), Schiphol (the Netherlands), Arlanda (Sweden), or Milan Mapensa (Italy).

Peneda (2010) has identified the critical factors for the development of such an airport, being connectivity, economic potential of the hinterland, commercial attitude of the airport operator and a sustainable development context.

4.2. Dynamics of competition and cooperation

Air- and land-based connectivity is a necessary condition for the success of airports and the development of an airport city and other similar concepts. Although not all airports have embraced the concept of airport city, they all have been affected by the liberalisation and deregulation phenomena and consequently, have changed their business model. The following picture depicts the evolution of airport business models over the last few decades. Over time, airports have reduced their dependency on the aviation business and progressively increased the amount of non-aviation activity (such as: retailing, conference centres, amusement parks, business centres, etc.), in particular in the land side of the airport (from over 95% in the 1970s down to 30% currently). Thus, current airport business models are based on the generation of traffic, showing that the profitability of airports does not necessarily depend on the number of air passengers, but rather the number of people that use the airport for any reason (for example, as a transfer between land-based modes of transport).

Nowadays, an airport's economic development depends to a large extent on the capacity to induce air- and land-based traffic to feed their non-aviation business. Consequently, in the current context fundamental conditions for the success of airports include (air- and land-based) connectivity, integration with the modal transport networks or the existence of co-modal services.

On the other hand, the transport industry has been drawing significant attention to the research of how to improve the sustainability of the sector and to the promotion of cleaner transport modes and more optimised systems, through better network integration. Being as the railways are the most sustainable transport links, there has been a clear tendency at the political level, to encourage investments in this field (EC, 2011). The European Commission's White Paper on Transport 2011 gives an evident look at this reality. The definition of the Trans-European Transport Networks (TEN-T), now in the 2011 White Paper on Transport converted into the concept of the European Core Network, has aimed to promote the very same transport co-modality and

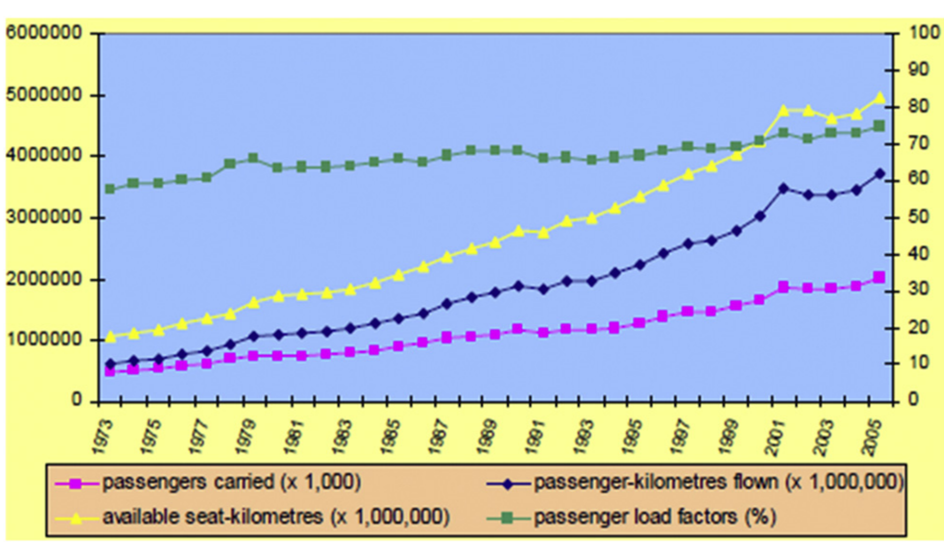

Fig. 12. World air transport scheduled services (domestic + international) – passengers. Source: IATA.

intermodality, where it is clear the design of an integrated pan-European transport network, with road, rail, maritime and air transport sectors being approached altogether with a clear harmony between all. Therefore, the development of efficient railway infrastructures and its integration with central transport nodes, as airports, is a prominent topic in planning more efficient and sustainable transport networks. Nevertheless, the relationship between rail and airports is mixed, going from competitors to partners. Fig. 13 sketches for air transport (green line), rail transport (conventional – red line, and Higher speed Rail (HSR) – purple line) and road transport (car – blue line) the transport times in function of length. As we can see up to 100 km road transport is the fastest mode, simply because it offers a door-to-door transport service with no need for passengers to go to a terminal (train station or airport). From 100 km up to 300 km, HSR is the fastest mode of transport and from this distance onwards air transport becomes the fastest mode of transport. Despite being the fastest mode, only for routes above 300 km air transport is more convenient than HSR. The problem is that passengers spend a considerable time at the airport (during check in, security lanes, boarding etc.), which leads to an increase of the time of transport and, consequently, requires time on air to be recovered.

The advent of High-Speed Rail (HSR) brought major change to the dynamics of competition and cooperation with air transport. Until that moment, air transport ruled was undoubtedly the preferred mode of transport for longer distances; however the situation completely changed with the construction of the first HSR routes. Table 3 presents the reduction on the transport time on well-known rail routes with the introduction of HSR. The reductions can go up to 65%.

Such reductions in time changed the transport paradigm and many passengers shifted from air to rail transport. Table 4 presents the evolution of the market share on two corridors, before and after the introduction of the HSR. In both cases, air transport has been reduced to a residual fraction of the initial values. Also the Eurostar train has gained significant market share, nowadays accounting for around 80% of the traffic between London and Paris and Brussels.

Despite the inevitable competition between the two modes of transport, significant synergies can be obtained from the integration of these two modes of transport. Currently, the so-called traditional air transport companies (Lufthansa, Air France, or British Airways) get most of their revenues from the long distance routes (intercontinental routes) since the medium distance routes (regional and continental) are largely dominated by low cost companies. In this situation, the medium distance routes are eminently loss makers. The need to maintain these routes only is to feed the long distance routes and herein lays the major opportunity for cooperation with rail transport. The rail network is far denser than that of the airport network, meaning that rail transport is more accessible than air transport. Therefore, if the feeding traffic could be replaced by rail transport, the air transport companies could end the medium distance routes and focus their resources on the long distance ones. In parallel, the rail transport companies would benefit from an increase of traffic from and to the airports, and could create a win–win situation for both parties. Unfortunately, this has seldom been tested or put into practice.

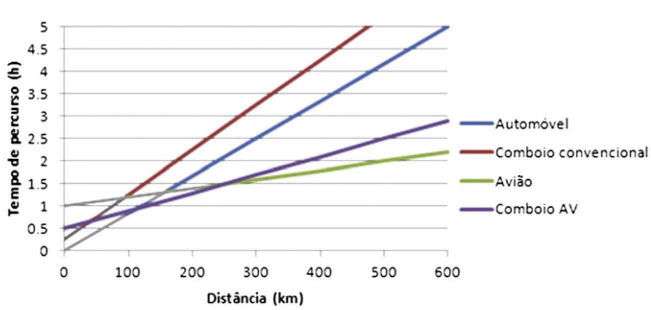

Fig. 13. Comparing time of transport with distance for air and rail transport. Source: Barreira (2012).

Table 3
Change in the rail transport times owing to the introduction of HSR.

Route	Before (min)	After (min)	Reduction (%)
Tokyo–Osaka	420	145	65
Paris–Lyon	227	115	49
Madrid–Seville	390	140	64
London–Paris	380–420	135	64–68

Source: Gourvish (2010).

In 2003, Deutsche Bahn, Lufthansa and Fraport Airport implemented the AIRail service. Through this service, a passenger could buy an integrated air and rail ticket. This service has been a major success and for example, on the route Frankfurt–Cologne the number of rail passengers increased by around 100.000 passengers, from 2003 to 2005. Lufthansa has meanwhile discontinued this route. There are also examples of cooperation with HSR. In France, Air France has established an agreement with TGV to sell integrated tickets on the route Lille and Paris – Airport Charles de Gaulle.

5. Energy use for sustainable rail

Roberto Palacin, Newcastle University.

5.1. Introduction to energy use and sustainable rail

Transport modes are energy-intensive systems requiring significant amounts of energy not only to run but also to be set up and built. This energy can be in the form of electricity, combustion engines or any other possible combination. Without energy there is no transport. This section aims to explore the general energy usage requirements of railway systems as well as their implications within a framework of sustainability.

What is sustainability? Before venturing into the assessment of the energy profile, the needs and requirements of rail and the sustainability framework must be clearly understood. Sustainability is a word and concept that is being used and perhaps abused in modern society with different meaning and emphasis for different people.

A commonly accepted definition of sustainability was given by World Commission on Environment and Development (known as the Brundtland Commission) for the United Nations. Sustainability was been defined as the ability to meet the needs of the present without compromising the ability of future generations to meet their own needs (Brundtland, 1987, p. 54). Most recently the world-renown Newcastle Institute for Research on Sustainably (NIReS) gave a simple but powerful definition of sustainability as “enough, for all, forever” (Newcastle University, 2011) which can be interpreted as sufficiency, with the understanding of the limited

Table 4
Evolution of market share on designated corridors.

	Paris-Lyon		Madrid-Seville	
	Before 1981	After 1984	Before 1991	After 1994
Air Transport	31	7	40	13
Rail Transport	40	72	16	51
Road Transport	29	21	44	36

Source: Gourvish (2010).

availability of resources and maintaining at the same time a balance between current and future generations.

Energy performance is a key aspect critical to achieve a sustainable railway, but there is not clear consensus about what sustainable rail is. Some believe that sustainable rail should be a railway system capable of adapting to the changing needs of the end users (passengers or freight customers) in terms of level of service, network capacity, flexibility and impact in the surroundings. The optimisation of energy and resources is a critical element on the way to achieving this goal.

Historically, railways have been regarded as a green and sustainable transport mode. However, this reputation has been questioned in recent times as the true energy performance of modern rolling stock is under scrutiny. As a result there is now a significant incentive for the rail industry and public institutions to establish an enhanced culture of sustainability, befitting the demands of a 21st century transport mode. Whichever the approach, a whole systems perspective is essential to effectively tackle the issue of sustainability.

Rail is already one of the cleanest and safest modes of transport, but it cannot afford to rest on its reputation. The automotive industry has demonstrated that better technology can reduce emissions while maintaining vehicle performance. The rail industry has also seen performance improvements. Newer designs of diesel engines are more efficient than their predecessors and modern semiconductor-controlled trains have lower losses than the resistor-controlled trains they replaced. However this benefit has been used to increase performance and not to reduce energy consumption. Higher speeds, better acceleration, better disabled access, more stringent safety provisions and wider use of air conditioning have all contributed to a growth in energy consumption per seat (Palacin & Kemp, 2005).

5.2. Types of rail propulsion systems

Even if a systems approach is essential, it is clear that one of the main energy users in the railways is the rolling stock. Railway vehicles can have autonomous or non-autonomous propulsion systems.

5.2.1. Autonomous propulsion systems

Electrified rolling stock is considered to be autonomous as the power source (electricity) is expected to be readily available on demand. The infrastructure to deliver this energy includes pantograph-mounted rolling stock over catenaries or the use of third rail (e.g. where space is limited and full catenary infrastructure cannot be erected).

Issues such as environmental impact (e.g. GHG emissions) are then allocated to the energy mix of a particular region/country. For instance, the energy mix in the UK is over 80% coal and natural gas (responsible for GHG emissions) while in France only around 3% of electricity is generated by GHG emitting fuels (EU, 2012).

5.2.2. Non-autonomous propulsion systems

In current railway systems these tend to be diesel-powered rolling stock. Alternatives are starting to emerge in the shape of hybrid-powered rolling trains using on-board energy storage systems (ESS) such as batteries and/or double-layer capacitors.

In this case, environmental impact issues are at the point of source and regulation has been introduced to reduce these. Fig. 14 gives an overview of the evolution of emission levels for rail in the European Union.

5.3. Railways in context: statistics

Before considering what are the areas and options that can yield better results in terms of optimising energy consumption it is important to understand the impact of railways in the wider context of emissions and energy usage.

Transport is responsible for approximately a quarter of the EU's global CO_2 emissions. Of this quarter, less than 2% is attributed to railways (Fig. 15).

5.4. Traction energy management

5.4.1. Driver advisory systems (DAS)

The optimisation of energy usage is an objective that transcends the railways and transport to any industrial sector and indeed any society in the twenty first century. Railway systems are already introducing

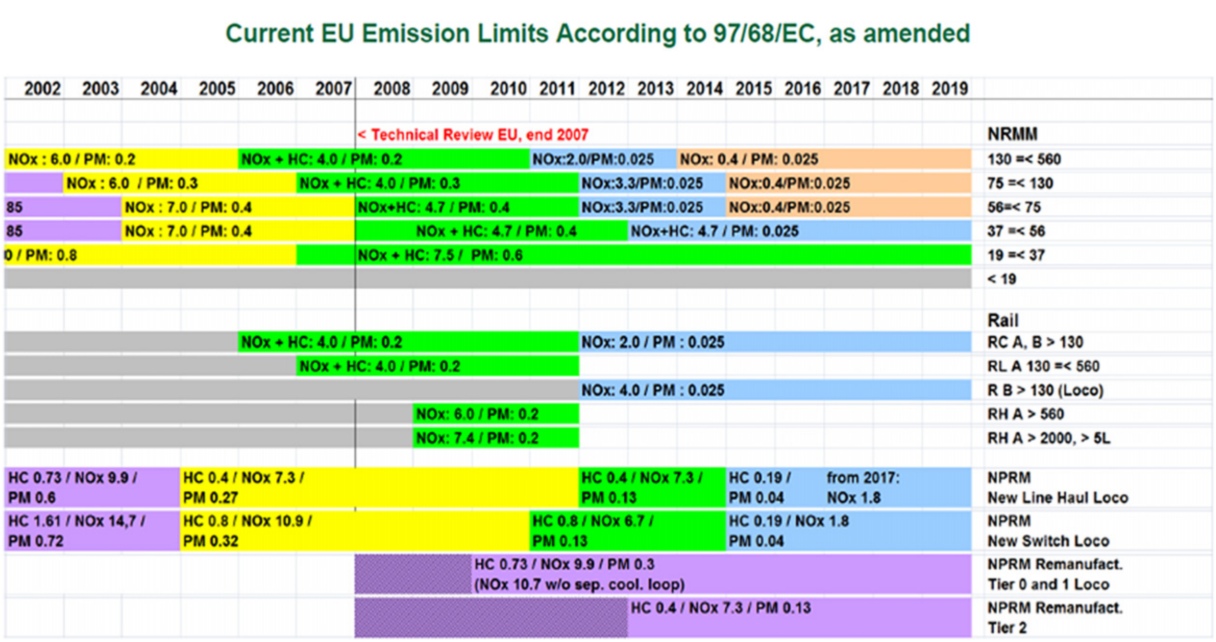

Fig. 14. EU emissions levels for railways according to directive 97/68/EC. Source: EUROMOT.

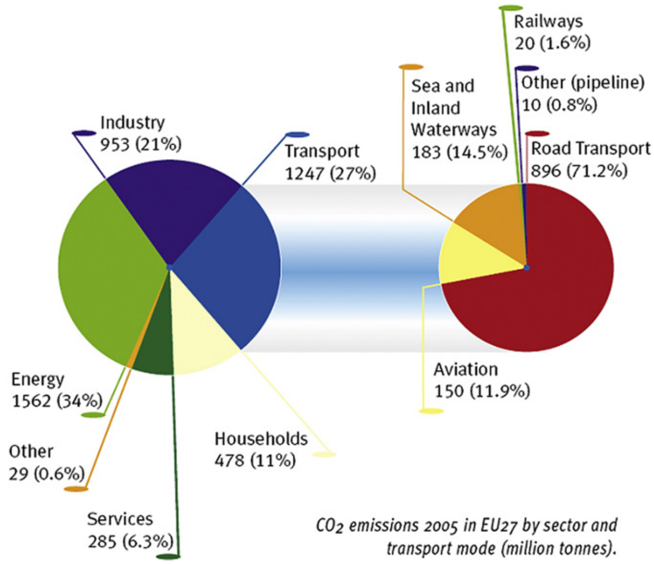

Fig. 15. CO_2 emissions in the European Union by sector and transport mode. Source: EC (2007) and UIC Energy/CO_2 database.

solutions to reduce the carbon footprint and the energy usage of subsystems such as signalling where modern signal heads have the size and weight of a television set in comparison with the larger and heavier versions of the past. They also use LED technology with less costly installation and maintenance requirements (How, 2012).

Driver Advisory Systems have the potential to significantly reducing the traction energy consumption of vehicles. For instance, these systems can provide accurate information to the driver in terms of optimum speed profile allowing for the introduction of so-called eco-driving approaches to the railway. They can also pave the way to sophisticated timetabling and support for intelligent traffic management systems.

5.4.2. Traffic management systems (TMS)

Traffic management systems are essential to the operation of a railway. However, they are more than just running these operations to a timetable (How, 2012). TMS can also facilitate a number of tasks such as the ones listed below which have direct effect in the amount of energy used:

- Optimise traffic movements;
- Inform timetable improvements;
- Predict and resolve traffic perturbations over wide areas;
- Help reduce wear and tear on infrastructure and rolling stock.

5.5. Innovative solutions: Energy Storage Systems (ESS)

Energy Storage Systems (ESS) have the potential to optimise the energy usage of railways by either reducing the amount of energy required to run them or reduce the energy losses (thermal) in the form of regenerating the energy dissipated during braking (within the same vehicle or sharing it with other vehicles in the systems via the catenary). This is particularly true for on-board ESS.

There are a variety of ESS systems available each one of them with their advantages and disadvantages. Specifically, railway systems are investigating the use of the following types of ESS:

- Battery technology;
- Double-layer capacitors;
- Flywheels;
- Hydrostatic accumulators.

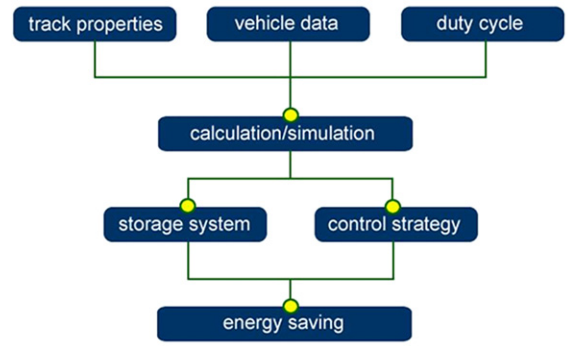

Fig. 16. Choice of on-board storage system methodology. Source: ModUrban project-EC's FP6 contract No. 516380.

Multiple factors influence the choice of ESS for a specific application. The methodology shown in Fig. 16 summarises a suitable preliminary approach.

Hybridisation of power drives has a strong potential to significantly reduce the energy consumed by railways as well as minimise their impact on the environment. Urban and suburban operations can maximise this potential due to the particularly favourable operational conditions and duty cycles. For instance, they have multiple short and frequent stops requiring sharp acceleration and braking phases. Their track properties can also benefit hybridisation e.g. metro systems have pronounced incline topography between stations favouring coasting approaches.

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