Capacity for Rail

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

Standards

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Lead contractor for this deliverable:

- NEWOPERA

Project coordinator

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Executive Summary

The objective of this deliverable is to capitalize on the research made for the new vehicles in WP22 and for the terminals in WP23 and to suggest standards for 2030-2050.

After reviewing the proposed standards either in force on European Corridors or developed during past European projects, the deliverable recalls the main KPIs taken into account by the decision makers. These include; cost of the service, reliability, interoperability, the capacity to cope with traffic variations and the capacity to provide updated information on the cargo and train status and position and on its estimated arrival time at transfer points or final terminals.

Employing these decision criteria, the new wagon designs, new train length, new gauge, the gradients, the curves, the energy availability, new train operation and the new train management will be studied and their impact on the TSIs analyzed. A review of the main points of the infrastructure and rolling stock TSIs that might be impacted has been undertaken.

The introduction of these innovations will need to overcome strong barriers:

- Axle load will need a review of the capacity of the bridges to support such heavy trains with 25T load per axel and of the capacity of the tracks to accept such load and at what speed, thus introducing some speed limits and some reinforcement investments.
- The available knowledge of the infrastructure gauge may enhance the loading gauge with new modern pocket wagons. Although it is sometimes necessary to invest in removing some critical points in tunnels or under bridges to allow carrying P400 trailers or super high cube containers on modern wagons.
- Extending train length may affect the safety of certain critical points to be surveyed, inducing some small investments, including the control command system, which has to be adapted to the extra length. The variety of signaling system in Europe and the timing of ERTMS deployment means that specific solutions will have to be implemented and that parameters of ERTMS must cope with these future lengths of 750m to 1050m or even 1500m for coupled trains with distributed traction.
- For the existing gradients, the main impact relates to long trains for which central couplers or UIC reinforced couplers able to support 135T must be the target. Preserving adaptation of new wagons to central coupling in the future is essential and must be reintroduced in the Directives or TSIs.

The main drivers of change are related to the improvement of the KPIs; cost of the service, reliability, interoperability, the capacity to cope with traffic variations and the capacity to provide updated information on the cargo and train status and position and on its estimated arrival time at transfer points or final terminals. This means that improvements to train management, enhanced by a better maneuverability of freight trains obtained by EP braking system and by automated driving standardizing the driving behaviors and reducing the need of network capacity for each train and increasing the reliability as well as the competitiveness. An improved intermodal system, automation in SWL traffics specifically in marshalling yards (with automatic couplers) and in safety operations before departure will have a great impact. Introduction of Duo Locomotive to avoid changing traction for the final deliveries will boost efficiency. Flexibility offered by the End Of Train Device will be a significant step forward.

All the proposals described are to be adapted to the various types of trains, which have different needs and for each category, the most important improvements are described. They all have to be

incorporated into the new suggested global standards after a quick comparison with existing standards and various projects proposals. The main impacts on TSIs are limited and suggested timing of expected introduction has been suggested, justified by the impact of innovations proposed in C4R.

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1 Background

In this deliverable, the progress analyzed on the design of the wagons and on all connected devices enhancing the efficiency, the reliability, the sustainability and the competitiveness of the rail freight transport are taken into consideration to define the vision of the best up-to-date rail freight wagon and rail freight train. This long term vision which appears to be realistic as regards its introduction on the network and cost effective will serve to define the future proposed standards and consequently the amendments to be made to certain existing TSIs. It will serve also as a frame for a progressive introduction of these progresses in order to define a realistic roadmap. This roadmap will have to take into consideration the necessary return on investment for the actors investing in equipment or in software to be motivated.

2 Objectives

The overall objectives of WP24 are:

- To study and design new concepts for network-based services for fully integrated rail freight systems to meet the requirements of 2030/2050;
- To assess the performance of newly designed fully integrated rail freight systems using a modelling framework;
- To analyse the potential of newly designed, fully integrated rail freight systems and understand the expected market up take levels;
- To produce a catalogue on rail freight systems to contribute to the Commission's goals for 2030 and 2050; and
- To suggest standards for fully integrated rail freight systems.

In line with these objectives, two deliverables have been produced; D24.1 Catalogue Rail Freight Systems of the Future (Intermediate) and D24.2 Catalogue: Rail Freight Systems of the Future (Final), this deliverable will feed into the final report for WP24 D24.4 Final Technical Report.

The objective of this task is to suggest standards for fully integrated rail freight systems. The standards will focus on: wagons, locomotives, gauge, infrastructure design, train management. As a result of the innovations developed in WP22 and WP23, it may be that existing standards and technical standards for interoperability (TSIs) will require modification to meet the expectations of 2030/2050.

To achieve this, a review of existing standards will be undertaken, focussing on TSIs and the parameters within these which may require changes to accommodate C4R innovations and meet the expectations of 2030/2050.

Subsequently, analysis of the strongest barriers preventing change will be carried out, concentrating on; axle weight, gauges, length of sidings, safety installations in relation to the train length in the field of control and command, horizontal and vertical curves, gradients, energy availability, safety installations impacted by the profile of the vehicles.

Following this, the main drivers for change will be examined with emphasis on; competitiveness, reliability and interoperability. In line with this, it is logical to investigate existing proposals for change, this will include existing standards which may be moderated and will contribute to the development of new TSIs for 2030 and 2050.

The main innovations from WP22 novel rail freight vehicles and WP23 co modal transhipment and interchange/logistics will be described, with a focus on the expected impacts on TSIs of these innovations. Following this, standards will be proposed for; wagons, locomotives, gauge, trains, infrastructure design, train management and infrastructure management and the impact on the TSIs of the proposed standards will be assessed.

3 Review of the main existing technical standards of interoperability (TSIs)

3.1 Overview of Infrastructure TSIs

Infrastructure standards define the infrastructure structural subsystems such as the track width, maximum permitted speed, gauge structure, gradients and minimum curve radius (horizontal and vertical) track gauges, catenary type, energy supply, cant deficiency, equivalent conicity, rail inclination, ballast, minimum wheel diameter for switches and crossings and many other characteristics not considered within theCapacity4Rail project.

The energy structural subsystem involves maximum current intensity, which is possible at standstill per pantograph, the maximum power available per train, the nominal wire heights contact as well as pantograph compatibility.

The fixed installations of the control command and signalling structural subsystem, involves the type of ground system and the corresponding equipment, which are necessary on board the train.

Below is an overview of the infrastructure TSIs that may be impacted by the innovations in SP2 Freight.

Infrastructure TSI defines:

- (a) the infrastructure structural subsystem;
    - Track width
    - Load capability
    - Maximum permitted speed
    - Gauges
    - Gradients and minimum curve radius (horizontal/vertical)
    - Track gauges, cant deficiency, equivalent conicity, rail inclination, existence of ballast
    - For switches and crossings: minimal wheel diameter
    - And many other characteristics not considered within CAPACITY4RAIL
- (b) the energy structural subsystem;
    - Maximum current at standstill per pantograph and maximum train current
    - Nominal contact wire height
    - Type of catenary
- (c) the fixed installations of the control-command and signalling structural subsystem
    - Maximum/minimum permitted distance between two consecutive axels
    - Maximum permitted length of the vehicle nose
    - Minimum braking performance
    - Length of sidings

3.2 Overview of Rolling Stock TSIs

Other elements, related to the rolling stock involves among others the maximum and minimum authorized distance between two consecutive axles, the maximum length of the vehicle nose, the maximum distance between the bogies pins, the minimum braking performance and the standard sidings length guaranteed.

4 Analysis of the strongest barriers preventing change

Prior to proposing modifications or new standards and assessing the impact that this would have on TSIs, it is pertinent to investigate the strongest barriers currently preventing change to the vision for a longer, more maneuverable, connected and reliable freight train. The first stage in this process is to identify the barriers to change, acknowledged as; axle weight, gauges, length of sidings, safety installations in relation to the train length in the field of control and command, horizontal and vertical curves, gradients, energy availability, safety installations impacted by the profile of the vehicles.

These can be further divided into infrastructure barriers, for example; axle weight, track gauge, structure clearance profile are strong barriers to infrastructure change, because a modification in these aspects would imply extremely heavy investment in both infrastructure and rolling stock. Alternatively, a separate network may be created which can be operated by different rolling stock or very expensive multi-system rolling stock.

The length of sidings, the safety installations in relation with the train length are also important infrastructure considerations, together with the signaling and control command systems. For example the ERTMS development has identified that it is difficult to overcome both infrastructure and rolling stock barriers simultaneously. Horizontal and vertical curves gradients, energy availability and safety installations should also be considered, as they are impacted by the profile of the vehicles and of the trains.

4.1 Axle Load

A *high axle load* is favorable for freight traffic, as more weight can be loaded on each wagon, or there can be fewer axles per ton payload. It is also an advantage if the locomotive has a higher axle load, as the adhesion weight can be increased, which reduces the risk of slipping and allows for higher train weights. The maximum permitted axle load applied on most of the main lines in in Europe is 22.5 tons. This weight has been gradually raised; previously, it was 20 tons.

It is well known, that TEN-T guidance indicates a targeted increase to 22.5 tonnes, Europe wide by 2030. However, to achieve this a number of factors should be taken into consideration including; bridges, as many bridges will be required to be rebuilt should core network corridors transfer to 22.5 tonnes axle weight. Length of corridor should also be thought through, as an increase in axle load will only be beneficial if the whole route is upgraded as opposed to small sections in isolation.

One way to overcome these barriers would be to target shorter door to door routes from ports to heavy industries, which require mass transport of bulk or other raw materials. For these lines, if resources are available, given the nature of the traffic it may be possible to look at a progressive upgrade to 25 tonnes if no other urgent investments on the network are required.

In some countries, an upgrade of the axle load to 25 tonnes is in progress on selected sections of line with heavy transports, and many new lines are dimensioned for 25 tonnes axle load. In Sweden, approximately 40% of the mainlines for freight are permitted for 25 tonnes axle load, mainly used by trainload for specific customers. On the Iron Ore Line in Sweden, 30 tons axle load applies and currently 32.5 tonnes axle load is tested. In the UK 25 tonnes axle load also is common. In Germany from Hamburg port to Salzgitter heavy trains with wagons of 100t (4 axel 25t) travel 100km /h between Hamburg and Northern Germany.

In Sweden research is being undertaken into bridges and existing infrastructure to see which lines can operate 25t for some wagons and the impact that this has on the infrastructure. By doing this, it can be determined whether the track will be damaged more quickly by 25t axle load. It is anticipated that newer bridges, which are more optimised have less chance of bridge damage with a higher axle weight.

When making the decision whether to upgrade from 22.5 tonnes to 25 tonnes the priority of the infrastructure manager in each country will be different, for instance in France regenerating the quality and safety of the network is the first priority. Having 25 tonnes on the core network is not satisfactory as the industries requiring such an upgrade are not all on the core network. Moving forward, a large review of the network status as regards the axel weight is essential to take a reasonable decision.

According to certain studies 25 tonnes per axel wagons, respecting also 8tonnes/m (category E4), may be authorized if their speed is limited to 100km/h. Although actually the available maps of the corridors do not explicitly give the indication of lines of E4category and above. In fact some of the D4 lines are able to support 25tonnes per axel wagons but only on request after analysis of the required route and imposing certain constraints if necessary.

In new projects, rail tracks are designed to support such wagons. The main difficulty for upgrading existing tracks is to reinforce the bridges that have to support such trains.

An increased axle load from 22.5 tonnes to 25 tonnes might require substantial investments in the already existing infrastructure, i.e. mainly related to bridges, tunnels and tracks. A higher STAX correlates with maximum allowed speed of the trains. To what extent is not possible to determine on a general level. Specific studies need to be made by the IM on specific lanes.

In Sweden there are a number of different lane categories determining what loads and speeds are permitted on the infrastructure. The line category determines the carrying capacity/resistance of the track to allow a specific axle load and linear load. The capability of the track is to resist vertical forces from the rolling stock without limitations to the number of trains passing. The lane category is described with a combination of a letter and a number, e.g. D4. The letters indicating axle load and the number indicating linear load. (TRV, 2014). Additionally an extension of the abbreviation D4-60 means that axle load is 22.5 tonnes/linear load 8.0 tonnes and maximum speed for a cargo train is limited to 60 km/h on this lane category.

Trafikverket has investigated the possibilities and estimated cost to allow cargo train speed up to 100 km/h with axle load 25 tonnes/linear load 8.0 tonnes (E4-100) on the lane between Hallsberg and Malmö.

This lane was selected due to an already existing high market demand for faster, heavier and longer trains in combination with the fact that the infrastructure on this lane already has relatively good prerequisites for heavier trains. The conclusion of this investigation resulted in that 100 km/h is not a realistic alternative taking into consideration the costs related to allow this speed. However, only one major bottleneck to allow 80 km/h (E4-80) on the lane was identified. Preliminary cost estimations to remove this obstacle are 333 MSEK for a new double track and ballast improvements.

Furthermore, there are approximately 300 bridges located on this lane (SSB) that need to be approved for increased buoyancy to remove the administrative process for the train operator to apply for a special permission for a train to pass the bridges at 80 km/h with STAX 25. All bridges needs to be examined separately by the IM in order to determine if the higher speed is within the safety parameters. If the findings of such an examination is not within the safety parameters for a specific bridge, additional cost for upgrading the infrastructure will occur. To what extent is impossible to predict or estimate before a thorough investigation has been conducted.

At a European perspective, there are at least 250,000 railway bridges in Europe and nearly 75% of them are older than 50 years, with about 35 % being older than 100 years.

Most infrastructure managers have a bridge management system, BMS, with various levels of explicit details. Some examples are: Latvia (Lat Brutus), The Netherlands (DISK), Spain (SGP), Japan (JBMS), Ireland (Eirspan), Germany (GBMS), Finland (FBMS), Denmark (DANBRO), Switzerland (KUBA), and Sweden (BaTMan), see Mirzaei et al. (2012). The bridges are in most countries well documented and maintained in a professional way. This means that the challenge for bridge managers is how regular operation and maintenance shall be used as input when upgrading in an optimal way, (D11.4, 2014 p.88), Casas (2015).

As a conclusion -from the perspective of an Infrastructure Manager- there are a number of different aspects to consider when it comes to speeds, weights, train length and gauge that interacts. Changes in one of these variables definitely affect the others to some extent. Thus, the variables should not be dealt with separately, but rather as “a package” on a specific lane in order to step by step identify the possibilities and costs to improve the railway network and meet market demands and the predicted increases in cargo volumes.

Railway tracks inevitably cross-regions of less appropriate subgrade materials, as well as high stiffness structures (e.g. bridges, tunnels etc.). Hence, the occurrence of variations in vertical stiffness is frequent. Track stiffness is a mechanical parameter deserving special focus, both from a theoretical and practical point of view. In contrast to infrastructures like bridges, which in some sense are known structures in terms of materials and can be subjected to visual inspection, the substructure of the track is often unknown and only limited visual inspection is possible. (C4R, D11.4 p.36)

In the course of time, permanent ways have been adapted to increased requirements. Ballast track today allows speeds of more than 250km/h and can carry axle loads in excess of 25 tons. The substructure and earth structure, however, has not progressed in the same way. Due to future demands for faster and heavier transports, the railway subgrade can thus experience problems, such as reduced stability, increase of settlements, and possibility of extensive vibrations. These issues have an adverse effect on the safety, reliability and economy of the railway operations. Therefore, it is necessary also to upgrade the subgrade in such a way, as it will withstand the new loading conditions. (C4R, D11.4 p34)

4.2 GAUGE

Gauge and track clearance have been identified in SP2 as a network improvement to increase capacity. It has been argued, that of the barriers explored in chapter 4, gauge modification would require the least investment and lead to the largest benefits. It is one of the less complicated barriers to address and is a short term measure which could increase traffic levels.

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.

The loading gauge in Europe varies very much; see examples of measures in Figure 1. There are different standards for wagon load and inter modal wagons. One standard is G1/UIC 505-1 also known as the Berne Gauge with a static width of 3.150 m and height of 4.280 m. In U.K. the loading gauge is smaller than in the European continent. On the contrary, in Sweden, a very generous loading profile

(C) is already being introduced in most of the network, which is 3.600x4.830 (width x height) and allows a loading area of 3.600x3600 m under the catenary. 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 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 1.

For trailer transportation, it is very important to have a high but not so wide loading gauge. In the continent of Europe, truck height of 4.00 metre is common and a loading gauge of P/C 400 is enough. That means that it is possible to transport a 4.00 m high trailer on a low floor pocket wagon. In Scandinavia, 4.50 m high trucks are allowed and 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.

The TSI standard for building new lines for freight stipulates a loading gauge of 3.150x4.650 and P/C 432 and a maximum train length of 740-1050 m. As an example, the attainable volume loading capacity in the German-Scandinavian corridor with the volume loading capacity can almost be doubled if the TSI maximum standard could be applied on all links and be three times higher if also the Öresund and Fehmarnbelt standard with loading profile C was applied in the corridor.

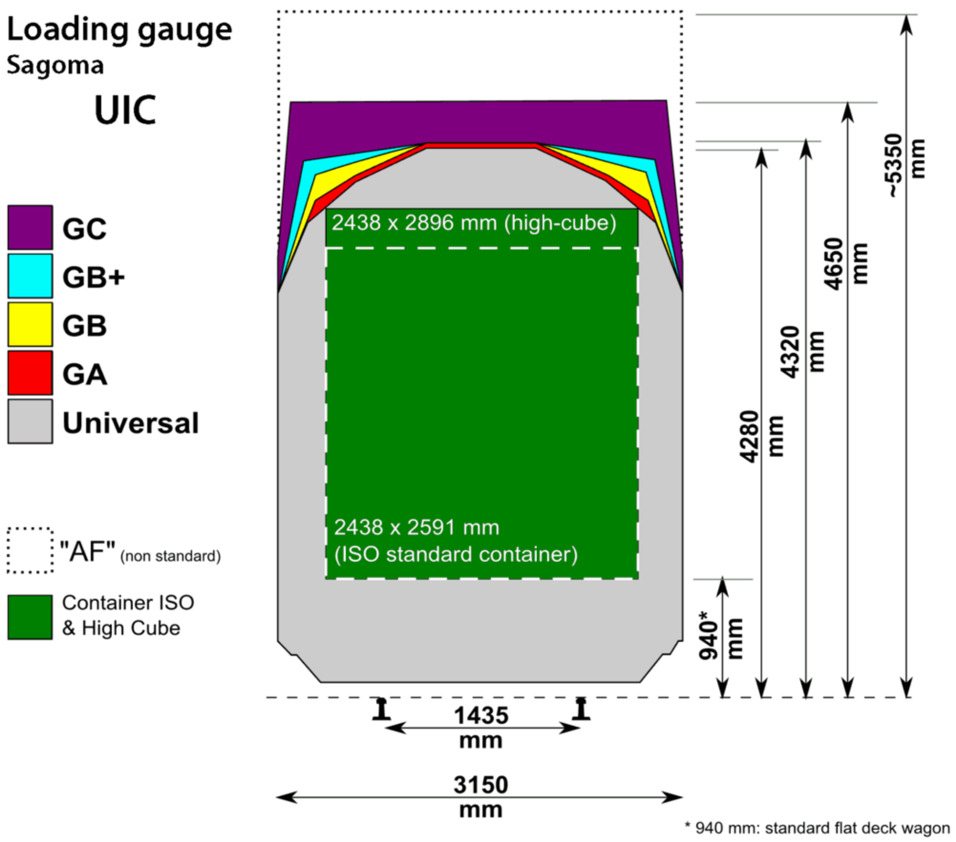

FIGURE 1: EXAMPLES OF LOADING GAUGES FOR WAGONS. SOURCE: CHEMINVENTO 2012.

4.3 TRAIN LENGTH

The train lengths in Europe vary in different countries and lines. In a long term perspective train lengths has successively been increased. In Figure 2 there is an overview of normal maximum train lengths in Europe. The train lengths will affect the length of crossing stations on single track lines and overtaking stations on double track lines.

Train lengths of 740 – 1050 m has been recommended in Europe in TSI and for building of new lines and on the TEN-T network 740 m train lengths has been stipulated to be introduced until 2030 of EU for the TEN-T-network. 740-750 m are the standard which have been applied in many countries for building and upgrading railways in Europe and are also implemented in many countries as the maximum train length. However, this does not mean that it is possible to operate 740 m on all main lines, there are still much to do to get this standard in the many important RFC in Europe.

Then there are exceptions, some lines in France, Germany and Denmark allow 835-850 m long trains. Certain services from Le Havre to Marseille and Lille to Marseille are 835m long and are longer than most of the classical sidings and only some sidings every 250km have been lengthened. Between Hamburg (Maschen) in Germany and Copenhagen in Denmark 835 m long trains has been operated in many years. In Germany the sidings have been extended for 835-metre train lengths between Padborg and Hamburg and trains which are beyond normal dimensions on the Padborg to Maschen route find longer sidings every 40km. Sidings on single-track sections between Kolding and Padborg are already longer than 930 m. The line via Fehmarn Bält is planned for 1050 m long trains.

1050 m train length including locomotive has been planned for some lines in some countries as a long term target. This is an optimal train length because a modern 4-axle electric loco can haul 2 200-2 600 gross tonnes and an intermodal train weights approximately 2 tons/meter. That means that 1000 m wagon rake weight 1000x2= 2 000 tons with a marginal for variations and heavier freight. That is why a total train length of 1050 m are a good alternative for freight lines or corridors which can be introduced in the long term. 1050 m long trains have been tested in the Netherlands and Germany at the Betuwe line. An alternative is trains of 2x750 = 1 500 m which has been operated as an experiment in the Marathon project in France.

Longer trains require investments in the infrastructure, however they are less costly than to build than double or multiple tracks. Through better time-table and operational planning they can be implemented faster. Longer trains are easier to handle on double track because there are normally no crossings. Sometimes the freight trains must be overtaken by passenger trains and then there must be enough long passing stations. The density of lengthened sidings is related to the general traffic density and to the number of longer train running. But during night time, when freight trains dominate, it will be easier to find proper paths. Also the yards must be adapted to longer trains. On single track it is necessary to adopt most crossing stations to longer trains. This can be expensive, however cheaper than to build a double track.

Length of sidings is a barrier to the vision for a future freight service, as it is anticipated that the future freight service will be longer, up to 1500m. Research will be required to identify the minimum number of sidings which should be lengthened together with the maximum and minimum distance between sidings. Alongside this, analysis into the volume of current traffic and the impact longer services would have on this is required. As if only few longer trains are implemented it would be difficult to explain the economic benefits of longer services whereas if longer trains appear to be a positive solution to network capacity and increase the competition of rail freight then research will be required into the number of sidings which it is necessary to lengthen.

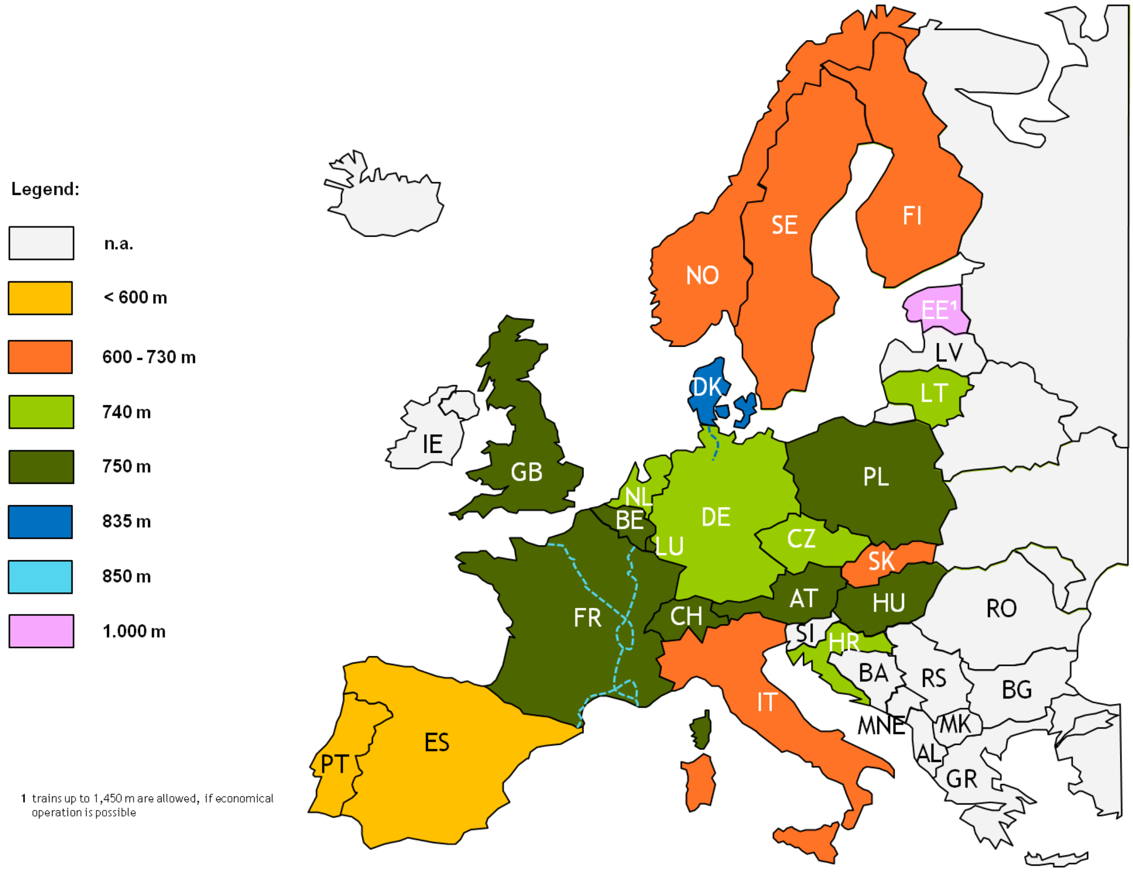

Figure 2Overview of standard maximum trains length per country (Source: CER). There are exceptions from this map i.e. 750 m train lengths on some lines in Germany

4.4 Safety installations in relation to train length & control command

The safety installations related to control command of the trains are the signalling system. The signalling system will be impacted by the train length in several circumstances according to the type of signalling system installed.

The first check to be performed is to detect what the new stopping distance of the longer train is, as most of the safety installations are based on a maximum stopping distance to determine the signals and the preannouncement signals positioning. It might be necessary to move some of them.

When a train is stopped by the signalling system it is necessary to check if, at the releasing of the brakes, the elasticity of the couplings will not create risks at critical points as the tail of the train may move. Of course this elasticity is extremely low with automated couplers or with draw bars but quite significant with classical UIC couplers.

The existing signalling and control command systems are very numerous but it is roughly possible to divide them in three main categories:

- The systems with fixed ground installations where the protection of the train is obtained by preserving a free length of track in front of the train with the ability to stop its movement before entering a length of track occupied by another train. In this category we will only consider indications given by traffic lights while the position of the train is only given by track circuits. Sub categories of this system are the axel counters system used for very low traffics and governing generally long segment of tracks. For higher traffics, traffic lights are manually commanded and for more intense traffics automated traffic lights are set up and control shorter segments of tracks.

- The second category involves a detection of the train by fixed balise, connected to the control centre which pilots the euro-computer installed onboard allowing the train to enter safely into the next block. This means a disappearance of the side traffic signals.
- The third category corresponding to ERTMS level 3 is based on a precise positioning of the train on the network, communicated by radio permanently to a control centre which, commands the eurocomputer installed on the locomotive to allow the train to progress if a safe stopping distance exists with the preceding train.

In each of these categories lengthening the train has different impacts:

- For the first category, no major difficulties are encountered as long as; the train length does not exceed the length of the protected zone, the parameters of the system allow a high number of axel for the axel counters and a high length of the train for some specific speed control subsystems, such as KVB which reacts if the driver does not respect the programmed slowdown in case of occupancy of the next protected zone. In any case, if the train must stop at a red traffic light or at an equivalent signal it is necessary to check if the extra length beyond the classical one does not occupy sensitive positions like a level crossing or like switches ensuring a track connection. It is also necessary to check the global elasticity of the train (according to the type of couplings) as the brakes release may induce a movement of the tail of the train linked to the buffers. This may mean some few tenths of meters.
- In the second category the most important parameter to check is the acceptability of the train stopping distance by the euro-computer as this signalling system may allow a little shorter distance between the moving trains linked to the permanent radio connection to the control centre.(This is referring to ERTMS level2)
- For the third category, equivalent to the so called moving block system (ERTMS level 3) the main feature is to check is the stopping distance of the train and the control of the sensitive network places (track connection, level crossings) not to be occupied by a long train.

The other safety installations involve essentially the hot box detection from the ground where it is necessary to check that the system can absorb a much higher number of measurements to be transmitted to the control centre.

4.5 Horizontal & Vertical Curves

The tracks are characterized by the horizontal radius of the curves and in very specific places by the vertical curves (at the top of the hump of marshalling yards). The future freight train should not be impacted more than a classical freight train by the vertical curves and in certain marshalling yards it is necessary to check if the type of couplings (Jacob bogies) allows the longer wagons to pass over the hump.

For the radius of the horizontal curves the detailed study of the new wagons may impose a speed limit for very tight curves in yards. On main lines and out of these specific points no more restrictions should affect the future freight train than the classical 750m train.

4.6 GRADIENTS

Concerning gradients, the main problem is to check the capacity of the couplings to accommodate the traction forces in the most critical situations. For the future freight train, if it is equipped with all improvements stated in the proposal no difficulty should appear, as the automatic couplers are 135T resistant (compared to the 85T resistance of the classical UIC couplers), the synchronous braking and releasing would avoid the main risks of derailment. The major problem may appear with longer trains not yet equipped with reinforced couplers or automatic couplers but only with EOT devices. In that case restarting a train on a steep gradient will imply issuing strict operational procedures to be applied, in order not to break the couplings. For coupled trains with distributed traction these types of procedures have been tested successfully.

4.7 ENERGY AVAILABILITY

The electric energy supply to railway is a patchwork in Europe, see Figure 3.

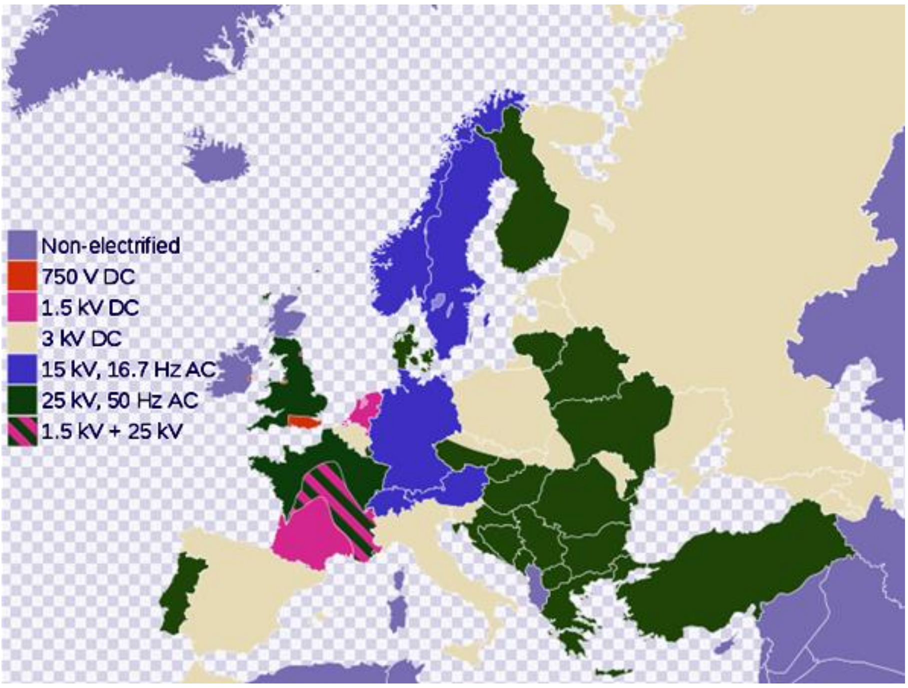

FIGURE 3MAIN ELECTRIC SYSTEMS APPLIED ON RAILWAYS IN EUROPE

The energy supply system of the railway consists of two “sub-systems”, the main system that via converters, traction transformers and catenaries supplies electricity to the trains and an auxiliary system supplying electricity to switchgears, signals, switches and level crossings.

Without going into too detailed description of the Swedish rail energy supply system a brief introduction in order to visualize the complexity of the systems follows; the electricity is supplied to the Infrastructure manager (IM) as 132 kV, 3-phase high voltage with a frequency at 50 Hz. The trains runs on 15 kV, 1-phase with a frequency at 16 2/3 Hz and needs to be converted.

In France the energy supply comes from the main energy transport network at high voltage (from 63KV to 400KV) and has then to be converted to 25KV AC current 1 phase or to 1500V DC current. This implies a serious control of the power utilized to ensure the stability of the Network.

This patchwork of energy across Europe induces higher costs to build multi-current locomotives but changing the energy supply is a huge investment. 25000V AC 1Phase is the main type of supply across Europe and trying progressively to harmonize that standard should be a long term objective.

As regards the future freight train, it is only long and heavy trains that have to be driven by two or three locomotives. These will require a specific study to fix the constraints in terms of frequency for this type of trains or the possibility to run such trains at certain time of the day because of the overall energy supply limit.

4.8 Safety installations impacted by vehicle profile

The new freight train proposed shall respect the infrastructure gauges for the high and the lower limits. The dynamic behaviour will not be different from the dynamic behaviour of a classical freight train. So the profile of the new freight train will not impact safety installation because of its profile.

However, the new freight system enhancing the efficiency of rail freight transport involves the use of ROAD-RAIL engines to haul the wagons from the main line sidings to the final terminal or private sidings. The evolution of this type of engine must be studied cautiously keeping in mind that a groove may appear on the tyre, which might then touch some specific installations at critical points (switches). Simple solutions to that problem are being studied, such as an alarm linked to the depth of the groove or a modification of the position of the safety device along the track. These engines are progressing their homologation in Germany.

Terberg-ZAGRO-Truck RR222-6x4

Figure 4 Combined road-rail tractor.

5 Analysis of the drivers of change

When innovations are elaborated the main questions are to see if they fit in the general trends of the market requirements and if they will be rapidly endorsed or adopted by the present decision makers because they answer market requirements. At this stage, it is important to underline the key factors which have a positive impact on decision makers in favour of rail freight transport. The general framework in which innovations take place is ring fenced by the TSIs applicable to the railway sector. Some of the innovations proposed in the Capacity4Rail project will breach the fences and seek amendment of the TSIs which will be introduced after a review of the TSIs.

The major key performance indicator (KPI): improvements related to competitiveness, reliability and interoperability will be the drivers of change. The essential parameters that will impact each of these factors are described below.

5.1 Review of existing technical standards of interoperability

Inside the framework defined by the TSIs, various standards are defined for the corridors and also suggested by certain projects. Our proposal for another standard will result from the analysis of the drivers of change; competitiveness, reliability and interoperability.

Infrastructure standards define the infrastructure structural subsystems such as; track width, maximum permitted speed, gradients , minimum curve radius, horizontal and vertical, cant deficiency, equivalent conicity, existence of ballast, minimum wheel diameter for switches and crossings and many other characteristics not related to Capacity4Rail.The energy structural subsystem may include maximum acceptable current at standstill in the pantograph and maximum drain, current nominal contact and wire heights.

The fixed installations of the control command and signalling structural subsystem may include; maximum and minimum permitted distance between two consecutive axles, minimum permitted length of the vehicle nose, minimum braking performance and siding length.

5.2 Competition from the road sector

The rail sector is facing challenges from the road sector from a number of different aspects: road sector's inherent advantages include; flexibility, one-to-one connection with customers, lower driver wages, huge progress in the fuel economy and thus less emission (CO_2 and GHG).

The road freight sector enjoys added advantages such as the operators can offer door-to-door, customised one-to-one and flexible services. The capital investment in a trucking company is much lower (than rail) and an operator can easily enter or exit the market without major financial setbacks, in case of an inability to run services in the competitive environment. In contrast, the rail sector operates in a restrictive environment with regards to market entry/ exit and capital investment.

Also, the trucking sector is totally deregulated which allows smaller truck companies to compete both with rail and with ordinary trucking companies. A low-truck company which can pay a salary of €300 per month for a driver compared with €3000 per month for a full cost company in Western Europe (Nelldal, Ricci, & Islam, 2017). With all these advantages they can offer a price which is much cheaper (35% lower) than the typical rail sector price.

In addition, there are ongoing plans to permit longer and heavier trucks in Europe. In Germany the truck length will be extended from 18.75 m to 25.25 m whereas in Scandinavia these services are already in operation. This will lower the cost for transport by truck by 26 % and also lower the market price for transport. Alongside this, in Sweden there are proposals to increase the gross weight for trucks from 60 to 74 tonnes, which will lower the cost for transport by truck by another 19 %. Together with plans to further increase the truck length from 25.25 to 34 m so that it will be possible to handle two trailers by one truck, lowering the cost per trailer by 42 %. In the long term it is expected that this can be implemented in other European countries(Nelldal, Ricci, & Islam, 2017).

Truck Platooning, successfully experimented in the Netherlands, comprises of a number of trucks equipped with state-of-the-art driving support systems (smart driving with ICT) – one closely following the other. This forms a platoon with the trucks driven by smart technology, and mutually communicating. Truck platooning is innovative and full of promise with huge potential (in terms of safety, reduction of congestion, cost-saver and efficiency) for the transport sector. Once it is in commercial operation, the rail freight sector will face further tougher competition from the road sector.

Apart from the above aspects, the leadership in the trucking sector is more proactive and forward looking than that of rail sector. For example, European trucking came forward with the Public Private Partnership (PPP) approach (European Green Vehicles Initiative) to tackle the negative emission issues and progress towards safer mobility through the programme. Following the initiative, the rail sector came with the PPP approach and established SHIFT2RAIL JU.

As trucks are one of the major sources of emissions such as CO2 and GHG, public awareness regarding their harmful effects are growing and Western governments are putting pressure on trucking companies. Under these circumstances, the road sector has improved its performance significantly, for example in fuel economy (DIRECTORATE GENERAL FOR INTERNAL POLICIES, 2016) see Figure 5, in both US and Europe.

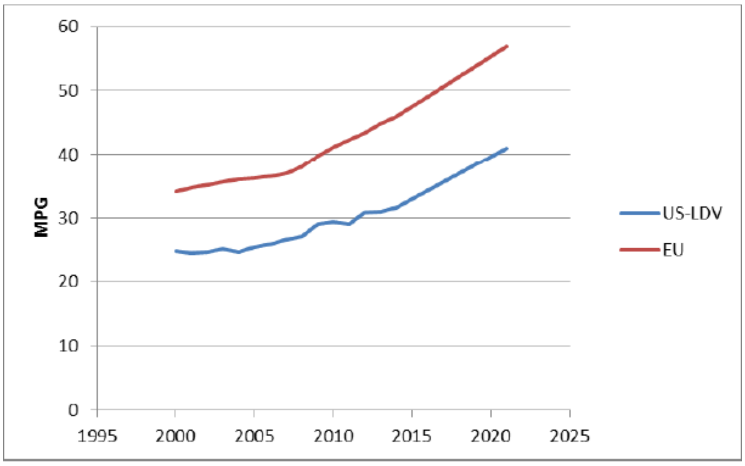

FIGURE 5 COMPARISON OF PROGRESS IN FUEL ECONOMY STANDARDS FOR LIGHT-DUTY VEHICLES (LDVS) ON THE CLEAN AIR FOR EUROPE (CAFE) PROGRAMME TEST CYCLE IN THE U.S. AND EU (DIRECTORATE GENERAL FOR INTERNAL POLICIES, 2016)

5.3 Competitiveness of rail freight sector

There are at least three critical questions for the rail sector:

- To offer the quality that is needed to attract customers to fulfil targets

- To offer its customers a price that is competitive with road
- To offer the capacity to meet the demand for modal shift

5.4 Reliability

Improved global reliability will be obtained through an increased availability of the equipment, due to predictive maintenance enabled by sensors on the wagons and locomotives with an on-train and train to ground connectivity. Also by enhanced and more resilient paths, by higher freight priority versus passengers and by the reliability of all terminal operations.

5.5 To get a competitive price

The increase of the global train length, axle weight, usable length and payload will boost the competitiveness of rail freight sector, as the optimal use of the clearance profile will enable to rail freight to enter into new markets in particular the P400 craneable and non-craneable semi trailer market. An increase in train maneuverability, combined with better braking and quicker releasing of the brakes will enhance competitiveness. Together with, the versatility of loading platforms for a better utilization coefficient of the assets and the increase rolling stock availability resulting from a predictive maintenance. A shorter time spent in transfer points facilitated by better accessibility and smoother operations due to advanced and coordinated information on train location will also increase rail's ability to compete with other modes. Movements and wagon/container compositions, and the automation of train preparation for departure will enhance the competitiveness as well as automation in the cargo handling and transfer operations to and from the storage areas.

5.6 More efficient inter modal systems

From today's conventional system to innovative intermodal systems

Conventional large end-point terminals are relatively expensive, as regards both investment and operation costs. On the other hand, they can handle all types of loading units (LUs) and have a high handling capacity. However, because they use gantry cranes or reach stackers with top lift, they cannot be electrified and trains must be shunted by diesel locomotives. Furthermore, several tracks are for parking wagons waiting to be loaded and unloaded. The consequence is that they cover a relatively large area, where reach stackers and other lifts for high axle loads operate. Large intermodal terminals are therefore cost- and space-intensive and the cost per LU handled, is relatively high even with large freight volumes. Therefore, new terminal and traffic concepts are very interesting.

Easy access to terminals

There are different methods to make terminal access easier with electric hauled trains. One is to let the train roll through the terminal with pantograph in down position, like in Germany. Another is to have an electrified section to the border of the terminal so the loco can push the train to loading position, like in Sweden. However, in the latter case the loco must change place first. A third method is to use duo-locomotives which both have electric and diesel propulsion. They are available on the market now but yet not so common.

Linear trains

A liner traffic terminal is located on a track siding, where the train can drive straight in and out onto the line again. The electrified track does not require switching the train in which 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, which obviates the need to park wagons. The terminals can be more compact and with the right handling technology do not need dimensioning for high axle loads. They require less space and will be more cost-effective than conventional terminals.

Horizontal transfer

To use a linear terminal in an efficient way, a horizontal transfer system can operate under the catenary, see Figure 6

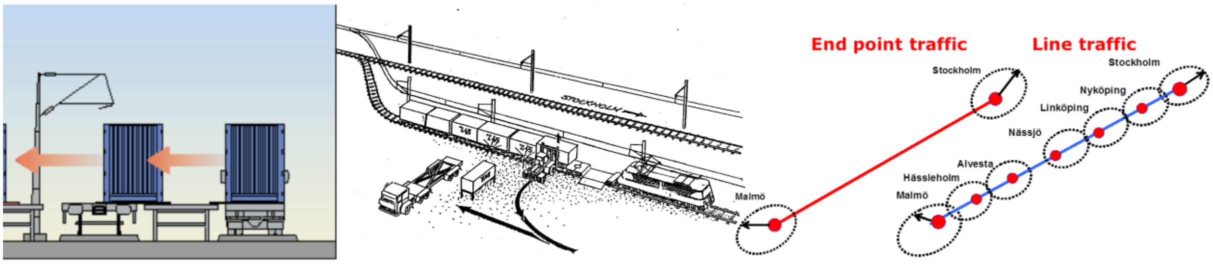

FIGURE 6 SYSTEM CHANGE FOR INTER MODAL: HORIZONTAL TRANSFER EQUIPMENT TO HANDLE CONTAINERS UNDER THE CONTACT WIRE. THE TERMINAL CAN BE ON A SIDING AND THE TRAIN CAN MAKE SHORT INTERMEDIATE STOPS AT MANY STATIONS. THE MARKET WILL BE WIDER AND THE FEEDER DISTANCES SHORTER

A system in operation in Switzerland is the ContainerMover system: the device is on the truck, which makes transhipment possible at every terminal or siding. Another system is the CarCon Train (CCT), which consists of a wagon that travels parallel with the track, equipped with arms for transferring freight horizontally. There are many other systems designed or planned, but many are complicated and do not anticipate lower costs than today´s system.

With a linertrain and a system for horizontal transfer, the following is achievable in the logistics system:

- Containers and swap-bodies can be reloaded under a live catenary;
- The terminal can be located on a siding where the train will make a short stop for transhipment;
- No requirement for a diesel shunting engine to handle the train at the terminal;
- No need to park wagons and the terminal can be very compact;
- Possibility to have more small terminals along the line to widen the market and shorten the feeder transport;
- The train and the truck can be independent of each other.

This means lower logistics costs for both customers and society.

Fully automated terminals

There are already fully automated terminals in service in various ports and for inland terminals in Germany. So far, these systems are rather complex, expensive, and used on very large terminals. What rail requires are automated terminals for smaller demand, profitable on shorter distances and more relations.

The cost of handling units with a reach stacker at conventional end-point terminals is approximately 30 €/unit. With liner traffic and automatic horizontal transfer system like AMCCT the cost is estimated to be around 10 €/unit.

An example of measurable achievements estimated for a future system for automatic horizontal terminal handling in combination with liner trains are as follows:

- Cost for terminal handling of a unit will be reduced by approximately 60%;

- Break-even point for intermodal will be reduced from 500 km to 300 km;
- Energy consumption will be reduced by 93%;
- CO2 emissions in kg per unit will be reduced by 99% with electric propulsion;
- Terminals will be cheaper and smaller so it will be possible to have more terminals which will reduce the distance for feeder transport and widen the market further

Roll-on/roll off terminals for trailer handling

Most trailers today are not suitable to lift onto a railway wagon. The trailer market is in practice, very limited even at conventional intermodal terminals that have lifting equipment. It is therefore a great advantage if trailers can roll on and off the wagons: solutions where trailers do not need lift, which can thus widen the market considerably. One example is the Modalohr system in France, which has the possibility to handle trailers without lifting; however, it needs a rather complicated wagon and special ramps at the terminal. This point is being handled and improvements are in preparation. It is also interesting to note that for liner intermodal solution described above much smaller terminals to unload and reload are cheap to install and need only a few minutes to operate.

5.7 Automatization

Today´s system has many disadvantages compared with road and has lost market share in many countries. Structural problems include closing of industrial sidings and feeder service and at the same time a more concentrated system with fewer destinations and market coverage. One reason is the terminal handling, which for SWL is crucial to handle trains to, from and between marshalling yards. Therefore, the next section deals mostly with the internal production system, techniques and traffic systems for SWL.

Liner trains instead of node systems

Instead of a conventional hub and spoke system, a system of linertrains is an option, where the trains run on a main route and wagons pick up and drop is managed at the stations along the way. In many cases, feeder trains are not necessary and the wagons no longer need shunting at a marshalling yard and hauling by feeder trains. The liner train system is also combinable with a hub system, so that the trains can exchange wagons at suitable places and marshalling yards can handle more relations. The liner train is easier to implement with duo-locomotives and if automatic couplers will be introduced.

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 be automatic. There are also new network strategies, which mix full trainloads and 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 coupling and decoupling.

Automatic couplers

The ultimate solution is to introduce automatic couplers. The process will demand minimum number 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 widen the market for wagonloads through more efficient operations on sidings and stations. An advanced idea which does not exist in reality yet is to have self-propelled wagons which can operate themselves shorter distances on sidings or on marshalling yards.

Automatic train operation (ATO) is technically possible already and is used on metro-systems in many towns. Experiments with automatic freight trains have been done in different countries.

Autonomous trucks are under development and have also been tested. This can reduce the cost for truck transportation by approximately 30-40% if the driver can be totally replaced by IT-systems assuming that the legal aspects can be solved. Maybe the driver must be there at the origin and destination for the last mile and for loading and unloading freight.

The cost reduction for automatic train operation is not as big as for trucks, because a freight train can handle the same freight as 30-40 trucks. Typical cost for the engineer of a freight train is 5-10 % of the total operating cost. It is to be noted that ATO could increase the available capacity of the network because of the standardisation of the driving behaviour which are very different between various drivers implying larger safety interval between paths. The potential for automation in the rail system is mostly bigger in marshalling yards and shunting. In the combination of duo-locomotives, automatic couplers and liner trains the engineer can operate many functions, which today are handled by other, staff categories and by that reduce the total cost for the customer.

5.8 INTEROPERABILITY

Freight transport demand is often trans-European and thus crossing member states borders must be seamless in all aspects. The standards must be common for a real freight development. ERTMS for the control command system is a fundamental concept if it is affordable by the various types of traffic. For a quick market uptake of the standards that are proposed, a realistic implementation roadmap will ensure success. For that purpose, analysis of the impact on infrastructure TSIs is essential to assess the importance of the modifications requested.

The optimal extension of standards application, the avoidance of any progress introducing compulsory extra transfer operation, hampering an efficient door-to-door service, the removal of gaps of interoperability on long-distance trips by the lightest possible investments are key factors of progress interoperability.

5.9 Deregulation and market orientation

One important driving force is the market orientation of railway companies and forwarders pushed by the deregulation of rail stipulated by EU. In Capacity4Rail mainly technical and operational measures to improve the freight rail system have been analyzed, but there is still big potential for market adoption.

It is still much easier to order a truck transport than to order a rail transport, especially for smaller customers and consignments. To order a truck transport, the customers only have to call a truck company and there are many competing companies to choose, some of them low-price. Sometimes also the truck companies call the customers to ask for transports. To order a rail transport, the customer in most cases needs to have a logistic manager who can negotiate with a few railway companies to get the proper time table and price. The time for planning new transport systems with rail as a base is long and dependent of the time-table planning scheme which can takes years.

Here the rail transport companies have to overcome an available IT-system for filling existing and new trains with consignments from origin to destination and fulfill all customer needs.

6 Review of existing proposals for change

Corridors standards requirements on the core network defined by the TNT guidelines as 740 meters train length, 22.5 axle load, 100 km/h line speed, electrification and ERTMS .

The Ferrmed standard includes: bypass for large cities, UIC track gauge of 1435 mm, electrification, loading gauge C, axel load of 22.5 tons up to 25 ton, train length up to 1500 m with a weight of 3,600T up to 5000 tons, adequate length of sidings and terminal tracks, a maximum gradient between 1.2% up to 1.5% on short distances and the control of command system ERTMS level 2 .

Characteristics of the future Freight Train: a first step towards standards by segments

– **Train Load and wagon load for bulk: mature market in need of competitiveness**

- **Shuttle train**: dedicated fleet, blocks of several wagons linked by drawbars. Blocks connected by automatic couplers ensuring energy and air continuity, as many blocks as possible up to the traction possibility of the locomotive and the couplings resistance. EP brake equipment installed for better asset availability, sensors for cargo and train component status connected to a smart box and transmission to the locomotive by train bus. Speed between 80km/h to 100km/h. Automated brake test by train driver and cameras on the ground at departure for departure checks. Positioning devices are compulsory. For deliveries directly to a private siding, a dual mode locomotive will be implemented.

- **Non Shuttle trains** with wagons from various origins. A wireless train network for all equipped wagons, an end of train device (radio, low frequency wave and first depression in brake pipe control) to lengthen the train safely. Speed 80km/h to 100km/h according to wagon and coupling resistance and also to power the locomotive. Positioning device is compulsory.

- **Inter-hubs Trains resulting from international trains coupled together**

These trains are long trains up to 1500m with a head locomotive and a middle remote controlled locomotive, each behaving like a classical block train of 750m. The global gross weight may reach 4500T. The speed is 100km/h. Two wireless train networks are insta**lled converging on** each locomotive respectively for a transmission to ground. Each wagon is equipped with intelligent sensors and a smart box for cargo and components status. Each sub-train may involve blocks of several wagons linked by drawbars

- **Interhubs trains or inter marshalling yards involved in wagonload transport system**

These trains are composed of blocks of 2 or more wagons with the same destination, with drawbars linking them and automatic couplers linking the blocks between them. EP brake overlay system is installed, energy is provided by the cable running along the train carrying a bus of information. Wireless sensors are connected to the wagon network, with its smart box consolidating information sent by the bus to the locomotive. The speed is 100-120 km/h. Automated brake test and departure controls by ground are organized. Trains with flexible length in order to empty the marshalling yards after each marshalling sequence.

- **Wagon load feeder trains for last mile services** Linear trains where long haul and last mile is integrated in a origin-destination-system. This is possible by Duo-locomotives which can operate both on electric main lines with electric traction and at sidings and yards with diesel traction. The liner train system is also compatible with a hub system, so that the trains can exchange wagons at suitable places and marshalling yards can handle more relations. The liner train is easier to implement with duo-locomotives and if automatic couplers will be introduced. They run 100-120 km/h on long haul main-line service and in lower speed where there are customers to change wagons.
- Trains directly serving a private siding or a terminal after being reshuffled at the last marshalling yard after the long distance run. Their main characteristic is to be equipped with a light dual mode locomotive or road rail engine to avoid any change of traction equipment if the last mile is partly non-electrified. They run generally at 60km/h serving the sidings (if status of infrastructure allows). They deliver all the wagons at the siding and return with the collected wagons from the siding. These trains are lighter and composed of 10 wagons on average.
- Trains serving several sidings on a round trip delivering and collecting wagons. A road rail engine shared between the sidings operators will serve all sidings performing delivery and collection simultaneously from the departure tracks of the marshalling yard, until returning with the collected wagons. In these trains, the blocks of wagons are linked by Automatic couplers equipped with remote control from the driver for an efficient delivery operation. These trains will be driven either by dual mode shunting locomotives or by railroad engines. The speed will be around 60km/h, generally on single-track lines. The number of wagons is between 10 to 15 and the number of deliveries is three maximum to be able to perform a round trip.

– **Combined transport Trains**

- **Trains for maritime containers:** the average weight of maritime containers being 12T per TEU including the container deadweight, these container trains will not be very heavy per metre but as long as possible, in order to transfer the large flows of containers arriving in ports by giant container vessels to in-land. Shuttle trains will link ports to dry ports where containers will be marshalled, to be reloaded on long distance trains towards hubs for separation between two main destinations, or transported directly to combined terminal for final delivery. The future trains for shuttle or long distance services will be coupled trains composed of blocks of 5 wagons 12 axels for 40’ containers or blocks of 5 wagons 12 axels for 45’ containers. This will enable trains to convey 2 X 55 (40’) containers or 2 X 50 (45’). The speed of these trains should be 100km/h or 120 km/h according to the braking equipment. These trains will be equipped with the necessary connectivity device for predictive maintenance, adequate positioning and cargo status information to be transferred to interested stakeholders.
- **Trains for inland swap bodies**. The main difference from maritime container trains, is that the average gross weight of these ILU (intermodal loading units)

is slightly heavier at 24T and the maximum weight may be around 33T. The train will incorporate blocks of 5 flat platforms and reach a length of 1000m with EP brakes or an EOT device at 100-120 km/h. The solution of coupled trains of 750m each will be applied for long runs after coupling at hubs and decoupling before final delivery run. These trains will weigh between 1560T up to 2150T, which is compatible with one Locomotive of 4.2MW power (BB27000 in France). The connectivity equipment will be installed for cargo and wagon status as well as track and trace with all information transferred to interested stakeholders.

- **Liner trains for containers and swap bodies**. Liner trains will stop at intermediate terminals located on an electrified track siding, where the train can drive straight in and out onto the line again. The stop does not require switching the train. The terminal has a fully automated transfer system and can operate under the catenary. The train will be loaded and unloaded during a stop of 15-30 minutes, which removes the need to park wagons. The train unload and load LUs and is independent of the truck, which can catch the loading units with the same transferring system. The trains are fast 120-160 km/h but not so long and heavy to operate quickly on the main-lines and the intermediate stops at the terminals. More terminals will make feeder transports to the customers shorter and widen the markets for inter modal to shorter distances and relations.
- **The transport of craneable semi-trailers** is comparable to the preceding category, with a slight difference in the average weight of the ILU which will be around 27T with a maximum weight of 37T (taking into account the generalized 44T allowed to road haulage). The trains will be composed of blocks of 4 pocket platforms. The trains will have a length of 1000m weighing 3000T hauled by two locomotives of 4.2MW each at the head of the train with automatic couplers between the 14 blocks, equipped with EP braking system transporting 56 craneable semitrailers with a maximum payload of 2072T. If the average load of the semitrailer is only 27T the train weight behind the locomotive will be reduced to 2440 T which could be hauled by only one locomotive BB27000 in France or if necessary by a of 5.6MW (BB37000 for France, Belgium and Italy). The speed for these trains will be 100km/h as 22.5T per axel are necessary.
- **The transport of non craneable semitrailers** needs Horizontal transfer and specifically low floor wagons. The reference for the future train is the Modalohr system or the Cargo Beamer. This segment has the largest potential of development and the quickest ramp up. The system is today viable at 850m long trains and the target of 900M should be reached by 2030. These trains will composed of 3 blocks of 9 double platforms linked between them by drawbars while the blocks are linked between them by UIC couplers of 135T. An end of train device will be installed to insure safety at 100km/h and full connectivity along the train will be set up through a wireless network. The weight of that train with semitrailers weighing 38T each will be 3150T driven by two 4200MW locomotives at the head of the train. The train will transport 54 semi-trailers for a payload of 2052T maximum. For an average 27T per semitrailer, the weight behind the locomotive will be 2660T compatible with a BB37000 locomotive in France. EP braking system will be installed on such

trains. The speed for these trains will be 100km/h as 22.5T per axel are necessary.

– For all type of trains
  - The total connectivity and tracking and tracing will be installed onboard
  - The EP braking system will reduce the stopping distance by 30% to 50%.
  - The End Of Train (EOT) device reduces significantly the Longitudinal compression forces as shown on the diagrams of Figure 7
  - This allows an extension of the existing trains safely from 850m to 1000m in terms of risk due to compression forces.
  - An interesting feature shows that the maneuverability of the train is improved with an EOT device as the speed reduction is obtained quicker.
  - These elements confirms that 1000m long trains will arrive soon with EOT as a first step as the low frequency waves carrying information through the bake pipe will offer a possibility to enhance the SIL level of the EOT control by the driver.
  - The EP brake system will follow, bringing flexibility in train length even with UIC couplers as long as an energy cable is installed all along the train.

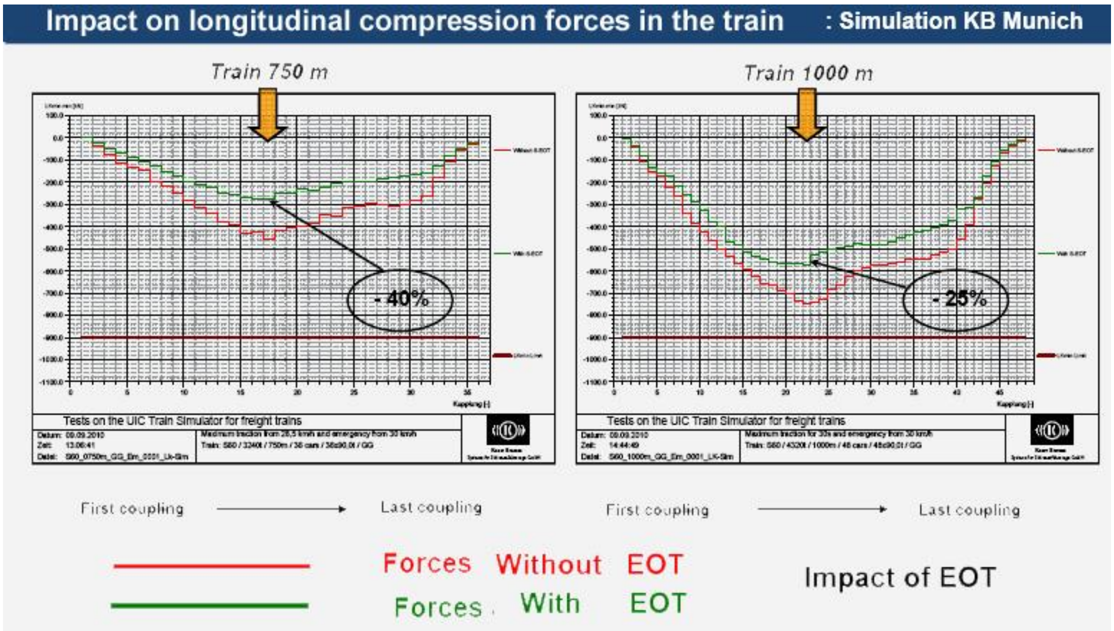

FIGURE 7 BRAKING PERFORMANCE WITH AND WITHOUT END OF TRAIN DEVICE (EOT): LONGITUDINAL COMPRESSION FORCES IN THE TRAIN. SOURCE: SIMULATION BY KB MUNICH.

FIGURE 8 DUO-LOCOMOTIVES WITH BOTH ELECTRIC AND DIESEL TRACTION

Duo-locomotives with both electric and diesel traction makes it possible to go direct into non electrified tracks as sidings, container terminals and marshalling yards without change of engine. The picture shows a TRAXX last-mile locomotive which has capacity to move long haul with full electric power and on shorter distances to shunt a full train in lower speed with its diesel engine.

7 Analysis of input from C4R SP2- Freight

Elaboration of new standards and potential impacts on TSIs

The proposed innovations for the future freight train induce standards modifications and after analysing the strongest barriers restricting change, defining the main drivers of change and describing various existing standards, the impact of the innovations resulting from the Capacity4Rail work packages 22 'Novel Rail Freight Vehicles' and 23 'Co-modal transhipment and interchange/logistics' must be described. Finally, these impacts will lead to amend certain points of the TSIs:

WP22 has developed some improvements:	
IMPROVEMENT	IMPACT ON TSI
To the usable length with blocks of several wagons linked by Jacob bogies without reducing usual available payloads necessary for traffic.	No impact on infrastructure but on rolling stock and on market uptake impact to be checked
To the versatility of the wagons with inside blocks of 3 classical 40' bogie wagon an extension of the middle platform allowing 30% of 45' containers or swap-bodies without extending the train length.	-No impact on infrastructure but on rolling stock and on market uptake to be checked -Market response to be verified
To the installation of an electric line to feed electronic overlay valves for quicker braking and releasing, resulting in better maneuverability of the train and thus a better reliability and an increased competitiveness.	-For a standard train of 750m a better path should be obtained. Modifications should be carried out to the path planning methodology and systems. -If train lengthening is introduced, infrastructure standards will have to be adapted
To connect blocks of 2 wagons linked by drawbars with central automatic couplers. Enabling train lengthening beyond 750m which is possible on large networks and main lines. This enhances competitiveness but requires a careful study on the number of sidings to be lengthened and on the possibility to reach the consignees premises.	-Impact on rolling stock is important and costly, a market study for coupled wagons is required -The standards of infrastructure have to be adapted to allow longer trains on the network
To the length of the trains with End of Train devices	The TSI of infrastructure must be added and a new category of trains with EOT introduced
The creation of an on-train communication network based on very low energy consumption	• No TSIs modifications • Implementation needs work on rolling stock with installation of a smart box per

provided by long life batteries while train to ground communication is endorsed by the locomotive offering updated information to all stakeholders.	wagon with battery and sensors of various types as well as equipment equipped with internet of things • Reception equipment to be fitted on locomotive with adequate transfer of information to interested stakeholders
• **WP23 has brought some improvements**	
To the automation of transfer operations	• No impact on any TSI
On the connection with train management for advanced preparation of terminal operations	• No impact on TSIs only procedures to be adapted
On the simulation tools for terminals to optimize operation planning	• No impact on TSIs

As the future wagon vision has been defined, the impact on Rolling Stock TSIs should be analyzed, the table below offers a reminder of the essential elements of the Rolling Stock TSI.

Basic parameters and their correspondence to the essential requirements

Point	Basic parameter
4.2.2.1.1	End coupling
4.2.2.1.2	Inner coupling
4.2.2.2	Strength of unit
4.2.2.3	Integrity of the unit
4.2.3.1	Gauging
4.2.3.2	Compatibility with load carrying capacity of lines
4.2.3.3	Compatibility with train detection systems

Point	Basic parameter
4.2.3.6.4	Characteristics of axles
4.2.3.6.5	Axle box/bearings
4.2.3.6.6	Variable gauge wheelsets
4.2.3.6.7	Running gear for manual change of wheelsets
4.2.4.2	Brake — Safety requirements
4.2.4.3.1	Brake — General functional requirements
4.2.4.3.2.1	Brake performance — In-service brake
4.2.4.3.2.2	Brake performance — Parking brake
4.2.4.3.3	Brake — Thermal capacity

Basic parameters and their correspondence to the essential requirements

Point	Basic parameter
4.2.3.4	Axle bearing condition monitoring
4.2.3.5.1	Safety against derailment running on twisted track
4.2.3.5.2	Running dynamic behaviour
4.2.3.6.1	Structural design of bogie frame
4.2.3.6.2	Characteristics of wheelsets
4.2.3.6.3	Characteristics of wheels

Point	Basic parameter
4.2.4.3.4	Brake — Wheel slide protection (WSP)
4.2.4.3.5	Friction elements for wheel tread brakes
4.2.5	Environmental conditions
4.2.6.1	Fire safety
4.2.6.1.2.1	Fire safety Barriers
4.2.6.1.2.2	Fire safety Materials
4.2.6.1.2.3	Fire safety Cables
4.2.6.1.2.4	Fire safety — Flammable liquids
4.2.6.2	Protection against electric hazard
4.2.6.3	Attachment device for rear-end signal

All the new wagon designs will have to fulfill the requirements of the TSI, which already provides rules for group of wagons which is the type proposed. Most of the essential elements are applicable.

A part where a modification should be introduced, is a derogation to the rectangle of Berne when coupling in extended platform wagon (to be able to accept 45’ containers on classical 40’ wagons) to a classical 40’ wagon. This should be in the coupling procedure to preserve the safety of the staff operating the couplings. This is to be introduced in operational TSI.

A second point where new points should be introduced in the future is the gauging subject. For that subject for which a new article should be written, introducing the notion of full respect, in any operational circumstances of the acceptable dynamic structure gauge. This implies from the RUs a capacity of calculating the envelop of the real loaded wagons in all possible circumstances all along the route to be used and to check the full respect of the dynamic structure gauge defined by the IMs.

8 Proposed standards for wagons, locomotives, gauge, infrastructure design, train management, infrastructure management

The objective of WP22 of Capacity4Rail was to propose new vehicle designs able to improve the main KPIs of rail freight transport: competitiveness, reliability, capacity of transport, network capacity and sustainability. These improvements were to be checked on the basis of their ability to be introduced on the network as regards general train management, of their market uptake and of a realistic deployment roadmap.

The safety of the proposed innovative wagons or of innovative devices to be fitted to the wagons had to be checked. Their running safety was tested by simulation by KTH university of Technology and certain recommendations were issued for movements in very tight curves in shunting areas.

A cost benefit analysis has been performed for the various proposals comparing the cost increase for such wagons to the capacity increase, assuming that today existing wagons were operating profitably. However a check made among wagon keepers showed that as long as existing amortized wagon fleet was available and that no new legal requirements were preventing their utilization the investment decision would be postponed.

The main innovations that would be welcomed, are those needing minor investments without mobilizing wagons outside their regular overhaul periods, generating immediate operational gains in competitiveness, in market attractiveness, in reliability and in network capacity.

The main innovations fulfilling these criteria are: the lengthening of the trains with the EOT, the flexibility of carrying 30% of 45’ containers on trains optimized for 40’ containers, the connectivity devices linking sensors incorporated to certain components to the locomotive via a smart box enabling to provide customers with track and trace of their shipments with a control of crucial elements like temperature and security for example. The connectivity devices which allows the compulsory brake test before each departure to be performed directly by the train driver, will appear rapidly. The possible increase of axel load from 22,5T up to 25T for wagons carrying heavy stuff should be recommended for new buildings.

Important investments like automatic couplers do not have a valid business case currently, until logistics by a couple of wagons can demonstrate its viability.

However if a certain fleet of wagons are dedicated to shuttle trains, for a long period investments on EP braking systems could be envisaged. This is for a number of reasons; the asset utilization will be improved as more efficient paths will be attributed due to the capacity of such trains to adapt their speed without long delays, as the risk of deterioration of wheel tread due to new composite brake shoes, necessary for noise reduction, is reduced .

The standard wagon of 2030 is interesting to define, as it should provide guidelines for the new building, avoiding designs incompatible with a probable evolution.

Multibody wagons will certainly appear if the rail freight transport increases, as expected in the white papers of the EU. This implies that central connections by draw-bars must remain possible as well as the installation of central couplers. **The structure of the new wagons must preserve that possibility and it must be compulsory in the TSIs. This is a strong recommendation as this obligation has been recently waived.**

The standard wagon in the short term will be connected to the central base via smart boxes on wagons, enabling to create a train network or in case of isolated wagons on a shunting area to connect directly by GSM with the central base. The train network enables the locomotive to transfer information coming from the train network to the central base, thus saving energy of the smart boxes placed on the wagons. The use of LPWAN on the wagon and a mesh system on the train enable to have long life batteries lasting 8 years for the smart box.

The use of the EOT will spread rapidly, as soon as new communication solutions via the brake pipe will increase the safety of the system. This may become a standard if this process is successful.

The future of rail freight implies gains of competitiveness and reliability as well as the best use of the network capacity.

The improved knowledge of the network characteristics in real time may allow RUs and wagon keepers to optimize the use of the network and enter some major potential markets like semi trailer transportation by horizontal transfer implying no investments by the road haulier. The existing solutions will benefit immediately from this up-to-date knowledge and new buildings will be required on which the innovations proposed in WP22 like multi-body wagons could be applied. The potential of development in that respect is important.

At the same time, if automated transfer of ILU develops in dry ports, shuttle trains may link them to automated hubs and terminals and competitive new wagons may be dedicated to such traffic, as long as predictive maintenance based on connected devices is developed on such fleets.

For wagon load traffic, as explained here above, competitiveness requires a very high level of punctuality, automated marshalling implying automatic couplers (by couple of wagons), road-rail engines to perform the last mile runs (homologation is progressing in Germany). This will only be possible with guaranteed paths obtainable for trains equipped with EP Braking.

The table below suggests a possible timing for the deployment of these innovations.

POSSIBLE TIMING FOR MARKET UPTAKE

Type of traffic→ Innovations ↓	Block trains: bulk	Wagon load	Combined-transport	Car carriers
connectivity	X	X	X	X
EP Braking	X wheel protect	X	X	
Multi-Body	X		X	X
EOT		X For inter-hub trains	X	
25T	X Heavy Stuff			
Automatic couplers		X		
Extension over buffers			X	

Short term · medium term · long term

Standards proposed in the various fields

TOPIC	TARGETS	MOTIVATION	IMPACT
Wagons	Multi-body wagons Connected wagons equipped with sensors Structure designed for development of central couplers. EP brakes equipment Automatic couplers	Better use of train length, monitor of wagon and cargo status, track and trace of the shipments	No change in TSIs but for EP Brakes and central automatic couplers Increased competitiveness, reliability, safety and information for customers
Locomotives	Multi-current, track friendly CoCo , hybrid locomotive Connected to base servers	Interoperability, best use of the power, possibility to serve non electrified sidings Track and trace Remote technical support	Increased interoperability; seamless door to door service; increased punctuality, reliability and competitiveness Transfer of train information to base servers
Gauge	Accurate and updated information on real infrastructure existing gauge and gauge C for new routes	Optimize the use of existing clearance profiles for semitrailer transport with efficient wagons, harmonize gauge on corridors to northern and eastern Europe	Enter the non craneable semitrailer transport segment and the oversized containers and swap bodies. Infrastructure TSI to be reviewed.
Trains	Trains up to 1000M with one locomotive. Coupled trains with distributed traction up to 1500M.	Network capacity saving, increased competitiveness	Increased competitiveness. Infrastructure design to be reviewed on authorized routes for efficient and safe traffic management.
Infrastructure design	Gauge C for new routes, adaptation of terminals, sidings and critical points to trains of 1000m with one locomotive and 1500m with distributed traction	Ensure safe and efficient train management	Increased competitiveness, open new market segments
Train management	ERTMS low cost for freight trains	Interoperability affordability	Seamless cross border transport.
Infrastructure management	Maintenance works by tracks (for double track lines), coordination of works to preserve continuity of itineraries, diverted routes with 6 month notice, new structure to reduce maintenance periods and costs.	Preserve traffics	Competitiveness, reliability

9 Review of the impact on the technical standards for interoperability

The impact on the TSIs

The global impact on the TSIs will result from the final vision of the future freight train.

The train length extension will become unavoidable in the near future because of the scarcity of money for new investments and the difficulty to execute these investments because of the restrictions on the traffic. This implies that solutions enabling an increase in capacity with the smallest and the least traffic constraints will become major drivers.

For that reason, all connectivity developments inducing optimal capacity and asset utilization will become priorities. Solutions such as Marathon trains or trains with end of train device (EOT) or better use of existing train length requiring only extension of sidings to keep a smooth train management, in line with the increase of number of such trains will be second priority. Improvement of transfer points with increased automation will have a high priority to enhance competitiveness, as well as horizontal collaboration between actors to ensure the best use of train transport capacity.

Increased train performance with safe maneuverability will have high priority as for infrastructure managers this immediately enhances network capacity use.

Alongside these developments , higher axle load where possible on door to door routes will be interesting if investments do not hamper capacity during the works.

Solutions to enhance structure clearance profile are extremely urgent and should be carried out at critical points with as short as possible interruptions of traffics.

10 Conclusions

In summary

The future freight train vision: longer, more maneuverable, connected, more reliable, will impact TSIs on certain points:

- Authorizing longer trains on certain routes with the adequate number of longer sidings and adaptations to the control command system, as long as their performance on acceleration, braking are the same as today or even better. (No issue with ERTMS level 3)
- Reinforcement of energy availability will be most urgent and TSIs should be adapted accordingly
- Definition of real structure gauge with adequate and updated information is urgent
- Introduce the EOT device equipped trains in the TSIs
- The speed of the train will still be in-between 100km/h and 120km/h
- The 25T axel load will be authorized on certain door to door runs
- Many modifications will happen simultaneously in the commercialization with web platforms to exchange data on transport offers and demand, in order to find those that can be matching under trustees to control and optimize the use of the train capacity both in length, volume and weight.
- Rolling motorways will develop largely with long trains or coupled trains as long as it enables to match the road competitive prices.
- For high speed traffic demand for less than wagon load transport, some trains running at 160km/h or more up to 200km/h will be equipped with ABS to avoid damaging infrastructure. This potential development, will be dependent on the toll policy of the IMs.
- For wagon load traffic, automatic couplers for groups of wagons (for one destination) will enable total automation of marshalling. Final delivery to private sidings or terminals will be done by Rail road engines. All wagons will be connected which will enable full automation of marshalling, efficient train loading and optimized organization of distribution and data sharing.
- All this progress will only be possible if the reliability of transport matches the road transport level above 90%.
- Final progress will be achieved with automated train for final delivery on single tracks, before wider automation of freight trains on certain tracks which will be properly equipped. For these new trains, a fundamental adaptation of TSIs will be unavoidable as soon as responsibility problems resolved.

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