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**Applying Innovations and Cutting-edge Technology
in Railways and Contribution to Economic Growth.**

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Applying Innovations and Cutting-edge Technology in Railways and Contribution to Economic Growth

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Abstract

The High-Speed railways should be scheduled as the core of a combined transports-network providing efficient interfaces with the different transport means (rail-road/road-rail/high-speed rail-peripheral rail/ship/aviation) presenting minimal costs. The enterprises which exploit/operate railway lines are of capital-intense, consequently the application of innovative cutting-edge technologies is of decisive importance in order to succeed minimal costs (in operation and annual maintenance), rendering these enterprises competitive in the free market of the transportation sector.

Keywords: Slab Track, Signaling, Traffic Management, High-Speed Railways.

1. Introduction

The second half of the 20th century, after World War II, was characterized by intense decline in the railway's share of the transport market. In absolute values (kilometer tons and kilometer passengers) railway volume increased slightly, yet the percentage participation of the railway in the total transportation volume decreased, given the fact that the increase of the total transport volume was much faster. The railway which, in the beginning of the 20th century was the pioneer means of transportation that fully responded to the needs and conditions of the time was left behind by the developments and placed in a disadvantageous position in relation to the other transportation means, especially compared to its competitors in land transports (Giannakos 2000, p. 49).

The increase of freight and passenger transport, though, which appeared in the European Community was not the same for all types of transport. As shown in Fig. 1, road transports now represent 44% of freight transport, against 41% of sea transport for short distances, 8% of railway and 4% of inland water transport.

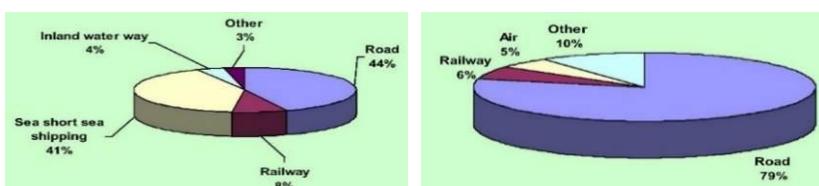


Fig. 1: (left) Freight Traffic, (right) Passenger Traffic in the modes of Traffic (EU-White Paper 2001).

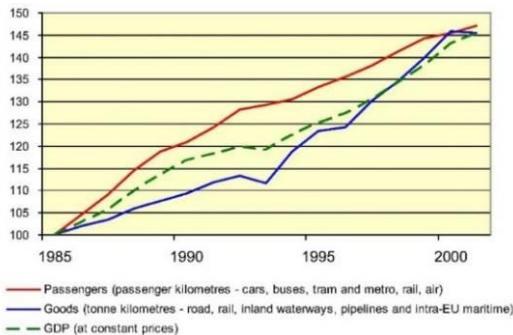


Fig. 2: Evolution of traffic vs GDP in EU (Γιαννακός 2000).

The domination of road transports is yet more evident in the sector of passenger transport, where they hold a percentage of 79% of the market, while air transports at a percentage of 5% are soon expected to exceed the railways, which represent 6%.

Railway freight transport (8%) tends to be marginalized, as the average speed of an international train reaches 18 kilometers/hour in Europe. As a model example, we should take into consideration the United States of America, where 40% of freight transports is conducted via the railways.

It is imperative that balance is achieved among the means of transport, in the center of the strategy for sustainable development. This target was introduced by the Amsterdam Treaty and confirmed by decision of the European Council in Gothenburg.

In the 21st century the frame of rail transport will be defined by the major structural changes that must and will take place in five sectors:

1. The creation of consistent Trans-European Networks, which will cover Europe entirely and ensure interoperability.
2. The promotion of the railway as the core of a combined-transport network in Europe.
3. The reorganizing-restructuring of railway services, with the separation between Infrastructure – Operation at the centre of activities.
4. The reform of the railway enterprises' finances.
5. The creation of high-speed railway axes

2. The High-Speed Railway-Corridors as the Core of the Future Network of Combined Transports

Road-railway and railway-through-waterways Combined transports are often considered a panacea. Combined Transports can combine the capabilities of diverse methods of transport in an ideal way, assigning the appropriate role to each means; railway and barges for long-distance transports, road transport for local distribution. The different ways of transportation are linked with standard units for combined transports (containers, swap bodies, trailers) and specific transshipment techniques.

Obviously, the railway can only benefit from the development of combined transports and, on the whole, it must play the leading role in their development. This is particularly important, given the fact that railway-infrastructure development programs depend on the exact forecasts of the freight volume expected to be transported through the new transport connections. This holds for railway lines as well as terminal stations, coaches and locomotives.

In the future, it is also expected that an important role will be played by the combined transport of railway and airplane, and thus the appropriate infrastructures will have to be developed for the accommodation of this mode of transport.

The quality of the offer made by a transportation system can be summarized in four elements:

- The speed (customers' view, suggested journey time)
- The frequency of services
- The line's capacity
- The price

By this rationale, it can be immediately concluded that the optimum use of high-speed railways (operational speed $V_{\text{operational}} > 200 \text{ km/h}$) is the connection of major cities that are several hundred kilometers far, if possible, with no intermediate stop. Within the competition of high-speed railways, on one hand, and the airplane and car, on the other, high-speed railway – in various European cities – constituted the means of attracting new customers, mainly from airline companies (high speed trains can compete effectively with air transport over average distances, as they tend to be cheaper, more comfortable but also overall faster. Travel time to the airport, check in and check out times must also be considered in the total amount of time for air transport. As airports tend to be located at the periphery of cities a significant amount of time must be spent to access them. Train stations tend to be located in central areas (easily accessible).

A European high-speed network cannot be viewed only in the frame of the European Union but it must also foresee the integration of all the countries of the Continent, taking into consideration the procedure for its homogenization and integration, which results from the recent political developments. This PanEuropean network will constitute a strong, consistent and structural element of borderless Europe and a fundamental factor for the economic and social cohesion of Europe. The future high-speed network in Europe (see maps in the following pages) will connect the major urban centers, in prices that will antagonize airfares for distances up to 1500 km, and, in the case of night travel for longer distances as well. The new generations of high-speed trains will allow speeds of 350-km/h, while lines for such speeds are already under construction (Madrid – Barcelona). Figs 3, 4 depict the success of the services offered by high-speed trains.

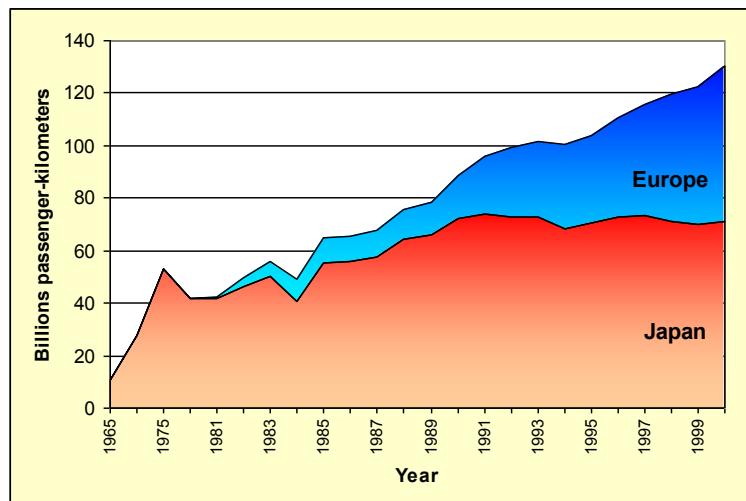


Fig. 3: Development of High-Speed Rail Traffic in Japan and Europe (Γιαννακός 2012, 2000)

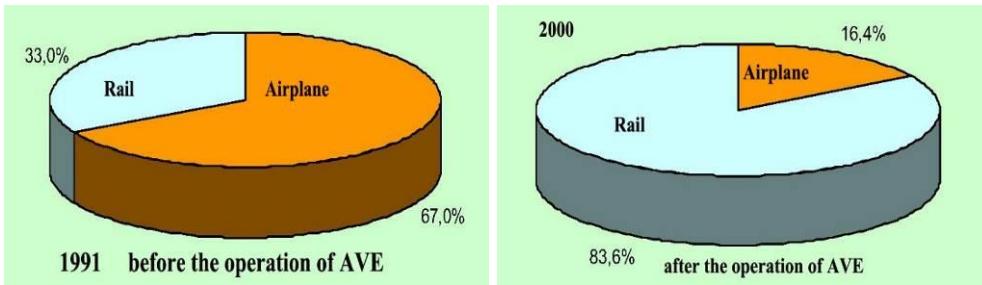


Fig. 4: Passenger Market-share of Rail and Airplane before and after the operation of the AVE High-Speed Line between Madrid-Sevilla, Spain (Γιαννακός 2012, 2000)

Interoperability in rail transport should be assured, e.g. from Munich to Thessaloniki, at great speed and without delays, because of changes of traction units or rolling stock in general in different countries, in journey-time that will meet the needs of Europe's citizens in this century. Delays due to technical reasons (e.g. signaling incompatibility) as well as administrative ones (e.g. police controls at the borders) should not be minimized but eliminated. Only in this way will the railway become competitive in relation to the other transportation means, for the above-mentioned distances. The Trans-European Networks (TEN) that will be created with these characteristics will cover Europe entirely, they will need to be consistent, and operate, if possible, as an integrated network. These TENs must concern certain high-speed "railway corridors" that will link the major cities/capitals of Europe and constitute the core of the railway network.

The high-speed network must be combined with measures that will assure interoperability with no journey delays for passengers and freight.

In the future, the circulation of freight high-speed trains should also be considered. The high-speed lines that will be constructed will have to be designed for mixed operation (passenger/freight), in order to be economically viable. The railway network of the EU [of 25] has a total length of 197.000 km. The target in the guidelines for the Trans-European Networks – Transport (TEN-T) defines a network to be composed of 1/3 high speed lines (app. by 16% new high-speed lines and 21% by lines upgraded for high speeds) and 2/3 conventional lines (operational speeds $V_{operational} \leq 200$ km/h).

Progress has already been made in the construction of high-speed lines. The total length of these lines increased from 6.800 km in 1996 to 10.000 in 2001. Moreover, the increase of the transportation volume between 1991 and 2001 was great, as it tripled from 21.6 million passenger kilometers to 65.4 million passenger kilometers. Between 1998 and 2001 there was an increase of 35% (from 48,5 to 65,4 million passenger kilometers).

Improvements on the conventional network of TEN particularly concern the following:

- electrification
- alignment improvement and construction of double-track lines
- improvement of the loading gauge, so that combined transports will be favored
- improvement of the weight per axis (especially in the Scandinavian countries, so that the use of longer and heavier freight trains will become possible)
- signaling and traffic control systems

3. Operation/Exploitation of Peripheral Secondary Lines

As for the peripheral lines of today's networks, there is often a tendency to pause their operation, if they are considered non-viable and the (Member)-State is not willing to pay "*Public Service Obligations*" (PSO).

In many cases it has been demonstrated that, a change of their operation mode (e.g. via local bodies) may render them viable. Additionally, pausing their operation may result in reduction of the transportation volume, also on the main axes, which the clients cease to use when the operation of the peripheral lines has been paused. Therefore, every effort must be made in order to retain peripheral secondary lines, by making them more attractive and taking into consideration their contribution to the transportation volume of a railway network. In parallel the Innovations and Cutting-edge Technology can contribute to a drastic cost-cutting towards the economic viability of these lines which feed the main high-speed railway axes.

4. Innovation and Cutting-edge Technology of Civil Engineer Works

4.1. Slab (Ballastless) Track

The selection of railway superstructure's Technological Level leads to the adoption of structures and materials and plays an important role in the acting stresses on the substructure, and as a result, on the maintainability of the geometry of the railway track and the annual maintenance costs. The relation between the stress of the track provoked by the vertical -static and dynamic-loads and the deterioration in the quality of the track's geometry can be given by the AASHTO² equation (Giannakos 2011, Eisenmann & Mattner 1984, Esveld 2001, p.94):

Deterioration in the quality of the track's geometry =

$$= (\text{Increase in stress on the ballast bed})^m \quad (1)$$

where $m=3$ or 4 .

If, for example, the stress on the substructure increases by 10%, the quality of the track deteriorates by 30% to 50% and, therefore, a corresponding increased level of maintenance and consequent increased annual maintenance cost is required.

After many years of international experience in High-Speed lines (in Japan, Germany, France, et al.), substantial ballast wear was observed. Ballast can be literally crushed and compressed due to dynamic loads, breaking, etc., thus resulting in loss of elasticity, insufficient drainage of rainwater, etc. Under these circumstances, maintaining the line's geometry requires (of utmost interest in high speed lines) most frequent and expensive maintenance interventions, while the structural components of the superstructure (sleepers, rails, fastenings, etc.) incur unacceptable wear and subsequently need to be replaced long before their expected life-cycle. Costly interventions are also required on the infrastructure. The ballast must be entirely replaced at intervals of traffic, much more frequently than that used for lower speeds, even if it is comprised of granitic or basaltic rocks (Giannakos 2016a).

The slab track system (or ballastless track) is an innovation which constitutes the advanced cutting-edge technology in the sector of Civil Engineering in Railways, and it is recommended for use in the infrastructure of high-traffic, high-speed lines; it offers increased passenger comfort, has a longer life cycle and it requires minimal maintenance over time (compared to the ballasted track) provided that fastening of high elasticity are used (Leykauf et al., 2006). *The initial construction cost of the slab track is approximately 30% to 40% higher than the cost of the ballasted track, according to Deutsche Bahn data (DB-AG). However, this difference in cost is depreciated*

² American Association of State Highway and Transportation Officials.

drastically over time, given the fact that, comparatively, the cost of maintenance is almost non-existent. Moreover, the use of slab track in newly constructed tunnels may also allow the narrowing of its cross-section, resulting in the reduction of the project's total cost (Giannakos 2016a). Measurements of the quality index of the railway track presented by the German State Railways depict the drastic decrease of the demand for maintenance in Slab Track sections compared to the adjacent ballasted track's sections (Fig.5 upper, lower), consequently these indexes are in practice indexes of the drastic reduction of the annual operational and maintenance cost.

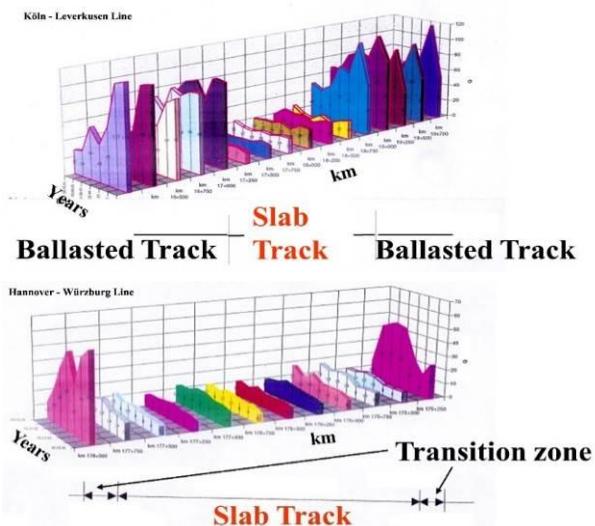


Fig. 5: Quality Index of Slab Track vs Ballasted Track in the Line Köln-Leverkusen (upper illustration) and (lower illustration) in the Line Hannover-Würzburg Germany (Γιαννακός 2012, 2000)

The Ballastless or Slab Track, which is a rigid structure, (Fig. 6) includes the rail, the fastening with its pad or two pads, the concrete slab or Continuously Reinforced Concrete Pavement (CRCP), which seats on a series of successive bearing layers with a gradually decreasing modulus of elasticity: the Cement Treated Base (CTB), underlain by the Frost Protection Layer (FPL) and the foundation or prepared subgrade. The three layers under the concrete slab (i.e. CTB, FPL and foundation), constitute the substructure of the Slab Track. The Slab Track is typically used in High Speed lines ($V > 200$ km/h) of mixed passenger and freight traffic with maximum axle load of less than 17 (modern high-speed trainsets) to 20 t (ICE-1 of Germany).

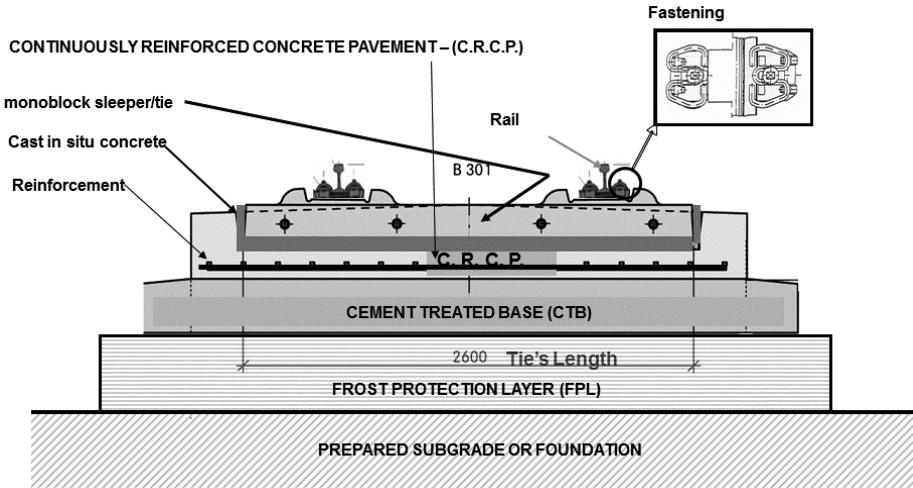


Fig. 6: Greek network: cross section of classic Ballastless Track, Rheda-type, with monoblock B70 sleepers, as in Tempi tunnel in Greece (Giannakos 2016a)

Under reserve of a minimum of stiffness the standardization transpositions of wheel loads in loads over supporting structures can then be considered for a calculation type according to EU's prEN 1991-2 applied to supporting structures. Some tests with measurement of wheel loads (type according to the code UIC 518) can be considered on ballastless tracks to justify by measurements the dynamic overloads to keep in rules of calculation (UIC 2002). The design philosophy and the behavior of the rigid bearing concrete layers (CRCP, CTB) of the slab track is the same as these of rigid pavements, supported on an elastic base. Advantages of slab track in comparison to pavements are (Giannakos et al., 2014):

- (a) Slab track has determined (small) width, hence, longitudinal joints in the slab are not required, and
- (b) the acting loads are applied in determined constant positions (rails), away from the edges (the extremities of the slab) of the bearing structure; that is in this case they are acting on favorable places.

For the design of the slab track, after the choice of its formation (structure) the acting loads must be determined as well as the level of its resistance. The acting loads (cf. also Giannakos 2016b) on the slab track are derived from:

- The static and dynamic loads from the railway vehicles whose magnitude is estimated as in the sleepers on ballast (it is a probabilistic approach depended on the probability of occurrence, since the acting loads are random).
- The temperature fluctuation –mainly– in the CRCP

The CRCP of the slab track is designed -as in pavements too, with a concrete slab- (Giannakos 2016a):

- (a) as a layer of appropriate thickness with contraction joints to concentrate the cracks:
 - (i) without dowels
 - (ii) with dowels
- (b) as continuous reinforced concrete slab (with free cracking) and percentage of steel reinforcement $\rho_s = 0.8 \div 1.0 \%$ in the middle of the concrete layer.

The existing method of calculation, for the dimensioning of a slab track cross-section (concrete, reinforcement et.), is cited in: (Giannakos et al., 2014; Giannakos & Tsoukantas, 2008).

4.2. Advantages of the Slab Track Innovation

The main advantages of the slab track method are:

- the passenger comfort provided
- the long life-cycle, and
- minimized maintenance over time, in relation to the ballasted track, which renders it the most appropriate method for the construction of High-Speed Lines of mixed circulation.

It should be stressed that the slab track on new tunnels allows the reduction of the tunnel's cross section, thus resulting in the reduction of the project's total cost.

The disadvantages of the slab track, always in comparison to the ballasted track are:

- Initially higher construction cost, which is depreciated in time, though, considering the almost zero maintenance cost. Yet, if we take into consideration the experience from the German network, the total cost of the slab-track applications tends to become lower (today it is between 20%-40% more expensive than the cost of the ballasted track, which amounts to 6% of the project's total cost).
- The noise increase by about 3db by running of the trains on a slab track.

In cases, though, that this noise increase has a substantial environmental impact, measures can be taken for noise reduction, e.g. covering of the slab at railway stations, or addition of sound barriers along the lines, where trains pass through residential areas. Today, coordinated, international research is being carried out on the issue of noise reduction on slab tracks and it is expected that soon this issue, too, will be sufficiently dealt with, for the years to come.

For the selection of the type of track to be constructed various factors are considered, such as:

- life cycle cost (initial investment, service life, maintenance cost)
- construction time
- availability and durability

In the past, the selection of the construction mode was based on the initial investment cost, while today the life cycle cost should be taken into consideration. This will result in the selection of slab track systems. This selection has additional economic advantages in the cases of tunnels.

Construction of a new line is expensive (10 - 25 Mio €/km) and in general can only be justified if the available capacity on the existing line has been exhausted and/or journey times are far from satisfactory. Competition from the road and air modes should also be taken into account.

Where for quantitative and qualitative reasons a new line is not required, ways are often sought to bring about improvements at a low cost.

The permissible speed and as a result the journey time of a train is contingent on:

- the vehicle design type
- the type and length of train
- the braking conditions
- the line conditions
- the operating conditions.

When it comes to line conditions, the curves and gradients are of decisive importance. A good track alignment should allow shorter journey times to be achieved and, with energy consumption and braking efficiency in mind, should keep breaks in speed to the strict minimum.

In curves, the speed is determined in particular by:

- running conditions
- lateral forces exerted on the track
- stability of goods
- comfort thresholds for passengers

The centrifugal force in the curves can be partially or wholly compensated by track cant. We can achieve increase in speed and reduction of time on conventional lines by using tilting trains. The profile of the track in principle does not -or hardly- require any special conditions to be satisfied other than the basic conditions to be fulfilled for conventional trains operation.

4.3. Efficient track maintenance

Efficient track maintenance requires inspection of the track and execution of measurements (recording). Most railway networks (infrastructure managers) today use recording cars to measure track geometry and ultrasonic inspection systems. The recordings and inspections dictate whether there is a necessity or not for track renewal, for reasons of safety and speed increase.

Speed increase and loads are imposing ever-tighter restrictions on the permissible tolerances in track geometry. The measurements have to be highly accurate. So, it is very important to formulate the specifications for the track structure in a way, by which the relative parameters can readily be measured and verified. This applies not only to the construction tolerances but also to the maintenance standards.

The use of new technologies, new inspection methods (e.g. automatic video inspections), and the use of informatics and decision support systems, could increase the efficiency of track maintenance and reduce maintenance costs.

5. Innovation and Cutting-edge Technologies in Operation, Signaling and Traffic Control/Management Systems

At the past, each of the railway networks in Europe had adopted a national approach. This is particularly evident in the train signaling and control sector. The various systems used were not at all compatible with each other. The continuous growth of circulation throughout Europe and the unification inside the European Union altered this way of thinking considerably, towards the improvement of their interoperability, at the levels of system and standardization. This was the cause for the adoption of the **European Rail Traffic Management System (ERTMS)**. ERTMS was established in 1995 by initiative of the European Commission and today is the official system in EU. The core of the ERTMS is its management control system **European Train Control System (ETCS)** which combined to the telecommunication's system GSM-R (that is GSM for Railways, the new radio system for voice and data) constitute the ERTMS.

The ERTMS/ETCS targets at:

- the achievement of the interoperability among the various European networks
- the enhancement of the performance through high speeds and shorter headways.
- the reduction of the investments on the network's infrastructure, by eliminating the need for side-track signaling and deregulation of equipment

- the stimulation of the competition within the European market, using common European standards, and
- *the drastic reduction of the personnel costs in combination with a spectacular increase of the safety level.*

ERTMS in practice is also a system which -in its integration- leads to competitive railway companies in the free market of the transportation system. Its integration (Level 3) constitutes a fully tele-commanded (automated) railway system, as it is depicted in Fig. 7.

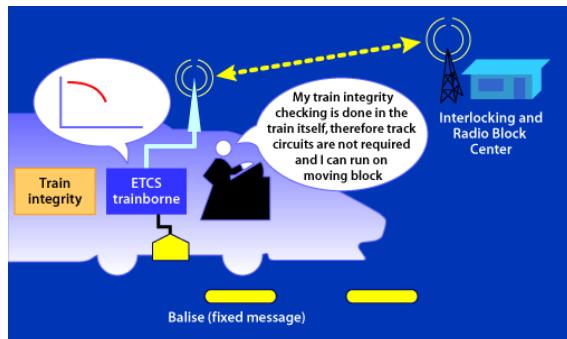


Fig. 7: ERTMS/ETCS Level-3; a fully automated railway operation (Γιαννακός 2012, 2000)

It is noted that in the Metro of Paris, Line 14 along the Seine is completely remotely driven and there are no drivers in the trains.

Existing command-control systems adapted for medium traffic density lines or the future ERTMS/ETCS system dedicated to high speed and/or high-density traffic railway lines remain too expensive to allow their use on railway lines with low and very low traffic density. As a consequence, many Low-Density Traffic Lines (LDTL) in the EU, in Eastern Europe, in the USA, and in developing countries all over the world are still equipped with over-aged safety equipment with high maintenance costs, keeping the capacity of these lines to a very low threshold.

In this context, there is a need for the development of an innovative and cost-effective system for Low Density Traffic Lines based on new available technologies. Thus, offering the same level of safety as in high-density lines and enhancing the efficiency of these lines in very small every-day cost, rail transport becomes more attractive. *These systems could also be applied in the line Lianokladi-Bralo (in Fthiotis) in order to support its operation as touristic line with reduced operational -mainly- but also maintenance costs.*

6. Conclusions

The exploitation/operation of the railway lines form enterprises of capital intense, consequently the application of innovative cutting-edge technologies is of decisive importance in order to succeed minimal costs (in operation and maintenance), rendering these enterprises competitive in the free market of the transportation sector. The High-Speed railway infrastructure should be scheduled as the core of combined transports providing efficient interfaces with the different transport means (rail-road/road-rail/high-speed rail-peripheral rail/ship /aviation) with a scheduling for minimal costs also. This leads to the use of the Slab Track.

The operational costs are reduced drastically with the Level-3 of ERTMS for the High-Speed Lines and the adoption of cost-effective system(s) for Low-Density Traffic Lines, like e.g. the Lianokladi-Bralo Line in Fthiotis.

The railway infrastructure should be efficient, of high performance, reliable, available, maintainable and safe (RAMS) to an acceptable price, allowing also the highest level of interoperability plus simplicity and safety. This infrastructure is attractive to PPP financing, given that it has a low Life Cycle Cost (LCC).

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