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The tram-train: Spanish application

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Abstract

The tram-train is a new urban transport system that was originated in Germany in the 1990's, and which is undergoing a great development at the moment, with studies for its establishment in several European cities.

The tram-train concept consists of the operation of light rail vehicles that can run either by existing or new tramway tracks, or by existing railway tracks, so that the services of urban public transport can be extended towards the region over those tracks, with much lower costs than if a completely new line were built.

The authors are developing a research project about the establishment of such a system in Madrid, which would involve the construction of a new light rail system in a suburban zone of the city, which could connect with Metro lines or with suburban lines of Renfe (National Railways Company). In this way, better communications would be achieved from this area towards the city centre.

During the development of this project we have studied the European systems that are in service at the present time, as well as those that are in construction, in project, or in preliminary study phase. So, we have determined which are the critic issues of compatibilization, and from these issues we have studied the particular characteristics of the Spanish case.

The aim of this paper is to carry out a brief summary of tram-train systems in operation nowadays, after which we explain the main advantages of this system, to pass later on to a deeper description of the Spanish case, with a discussion about the best solutions to each problem that has arisen in the development of this kind of system.

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1 Introduction

The tram-train concept was born in Germany, in the city of Karlsruhe, in 1992, year in which several lines of the railway network were connected to the tramway network of the city (Griffin [1]). A new light rail vehicle was made to run through this new extended network, with some adaptations to be compatible with the infrastructure of the two systems, each one with different characteristics.

The main difference between light rail and conventional rail systems is that in the first ones the vehicle runs "on sight", and are either integrated or separated from urban traffic, while in the second ones the vehicle running is controlled by a signalling system, and the tracks are generally completely separated, and very rarely interface with other transport systems (with the exception of level crossings) (UITP [2]).

2 Existing systems nowadays

A brief summary about the main systems of tram-train that are in service or in construction nowadays, is presented bellow:

2.1 Karlsruhe (Germany)

As it has been discussed above, the first tram-train system was established in Karlsruhe in 1992. Several measures had to be taken for it: the development of a vehicle compatible with the two kind of networks; the compliance of regulations over the building and operation of trams (BOStrab) and railways (EBO); the physical connection between both networks; and the construction of further stops along the existing conventional railway lines, which could be used without increasing journey times thanks to the improved acceleration and braking performances of light rail vehicles with regard to conventional railway vehicles (EAUE [3]).

The main technical problems that arose in Karlsruhe, and the answers to them, were as follows:

2.1.1 Electrification

The tracks of the national railways of Germany (DB) are electrified at 15 kV 16 2/3 Hz, while the urban tram lines are supplied at 750 V DC. The solution adopted was the use of a dual voltage vehicle, equipped with a transformer and a rectifier. All the additional equipment is fitted above the roof or under the floor, and does not therefore reduce the space available for passengers (Drechsler [4], Ludwig [5]).

The change from a voltage to another is made in a transition section, in which the vehicle automatically detects the new voltage and adapts accordingly, whilst the driver only have to put the controller in neutral position (Drechsler [4], Ludwig [5], Hérissé [6]).

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2.1.2 Structural strength

The Karlsruhe vehicle has a structural strength of 600 kN, instead of 1500 kN minimum required in the UIC leaflets for conventional railway vehicles (Griffin [1], UITP [2]).

2.1.3 Safety and communication systems

The Karlsruhe light rail vehicles are provided with two different safety systems: the Indusi system, DB signalling repetition system; and the IMU system, with automatic stopping, corresponding to the transport services of the city of Karlsruhe (AVG). The radio system is duplicated too (Ludwig [5], Hérissé [6]).

2.1.4 Tyre profile

It is necessary that the wheel profile of the light rail vehicle be compatible with the rail profile and geometry of the DB points and crossings, as well as with the rails and track material of the tram network. To get this, it was necessary to develop a special tyre profile, whose operation can be seen in figure 1 (Griffin [7]).

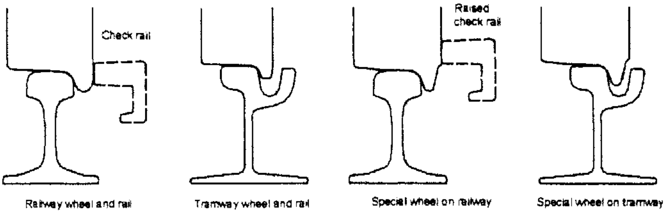

Figure 1: Use of raised check rails and special wheel profiles

2.1.5 Passenger access

Other problems are the co-existence of high platforms on conventional railway lines (height of 380, 550 and 760 mm over top of rail) and the low city platform (200 mm), as well as the fact that the body of light rail vehicles is narrower than that of conventional railways, that is why there is an excessive horizontal gap between the vehicle and the platform in railway stations. In order to solve these problems, the vehicle is fitted with retractable steps, which adapt the vehicle access height and gap according to the type of area it is in.

2.2 Saarbrücken (Germany)

The first stretch of line with shared tracks in Saarbrücken was opened in 1997.

The technology used in the case of Saarbrücken is basically the same as that used for Karlsruhe, but with two main differences: on the one hand, the fact that trams had not been in use in Saarbrücken since 1965, reason why lines of new construction would be used, thereby avoiding the need to take the characteristics of existing trams into prior consideration; on the other hand, the use of a low floor vehicle. The low floor does not imply any problem regarding to the DB structural gauge, because the lower part of the vehicle is 75 mm over the track.

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2.2.1 Electrification

The question of electrification was solved in the same way as in the case of Karlsruhe, except that the length of the neutral section is 80 m, instead of 170 m in Karlsruhe.

2.2.2 Structural strength

Regarding to the structural strength of vehicles, it was adopted the same reasoning as in Karlsruhe.

2.2.3 Safety and communication systems

The tram-train runs mainly on run on sight, without signalling, which only exists on single track stretch, that is still operated as a conventional railway line, fitted with classical DB signalling (main and advanced signals), and with train detection by means of axle counter devices (ScanRail [8], Kremppe [9]).

2.2.4 Tyre profile

As the Saarbrücken light rail is a completely new system, it has been possible to select a tyre of the type traditionally used on the German railways, thereby avoiding problems of compatibility with DB infrastructure. So, the system was fitted with a wide grooved rail, which allows railway wheels to run over it (Kremppe [9], Kendel [10], Veinnant [11]).

2.2.5 Passenger access

In urban zone the platform heights are of 350 or 200 mm (in case that the stop is shared with the bus). On the railway sections, the platforms are at a height of 380 mm, but there is a horizontal gap of 275 mm, because the light rail vehicle is narrower than conventional rails. This gap is covered by a retractable step of 197 mm, thereby reducing the gap to around 78 mm (ScanRail [8], Kremppe [9]).

2.3 Kassel (Alemania)

The main particularity of the tram-train of Kassel is the way to solve the passenger access from railway platforms, that consists of diverting the tram line from the track axis, nearing it to the platform, in that way that it produces a four rail section (Catling [12]).

2.4 Sunderland (England)

In Sunderland they are going to extend the existing metro system, making a conection with Newcastle, using the railway lines of the Railtrack between Pelaw and Newcastle, and serving this section with metro vehicles (ScanRail [8]).

The metro gauge is 1435 mm, while the Railtrack gauge is 1432 mm. It is expected that this minimum difference will not cause any problem in operation, although a speed limitation will exist in the connection zone (ScanRail [8]).

The electric supply will be done by 1500 V DC catenary system.

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The conventional railway is to be fitted with TPWS (Train Protection and Warning System), and the Indusi inductive loop protection system will be installed for the metro cars. It will have an integrated radio infrastructure in order to enable staff at Railtrack's IECC (Integrated Electronic Control Centre) to talk to all vehicles on the line, both metro and conventional trains (ScanRail [8]).

3 Main advantages of the tram-train concept

The tram-train system has several advantages, some of them are discussed below:

3.1 Financial advantages

- Existing traditional railway infrastructure can be used, thereby reducing the amount of investment necessary in new infrastructure.
- The need to build long sections of new track necessary for new lines is avoided, thereby offering considerable cost savings compared with completely new light rail systems.
- Increases in passenger numbers provide extra income, thereby reducing subsidies on annual operational costs. The increase in passenger numbers is the result on the one hand of additional stations, improved links with the urban system and more direct links with residential and business areas. On the other hand, this increase is also due to the improved quality and image of the light rail system, encouraging private car users to change to this mode of transport without any sensation of "quality loss".
- Vehicle composition may be adjusted during periods of low traffic density (evenings, Saturdays and Sundays), thereby reducing total running costs.
- Operation costs for this kind of vehicles are lower in comparison with conventional rolling stock.

3.2 Advantages for passengers

- Public transport users save time, as the tram-train can reach speeds double those of buses. Door to door travelling time is comparable with that of the private car, as running times between stations are reduced thanks to the braking and acceleration values of light rail vehicles in comparison with traditional trains. Stopping times at stations are also shorter, thanks to improved passenger access due to the number of side access doors. Finally, waiting times between different modes of transport are reduced.
- Direct access from the region to the main business and shopping centres, without the need to change to another mode of transport, as occurred before the introduction of these services.
- Punctuality rates are extremely high, as this means of transport is not affected by road traffic incidents.
- Greater comfort, due to an increased number of larger seats in each car and their improved dynamic features, which make for a smoother journey.

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- The system is easy to use, as its introduction is usually accompanied by improved passenger information systems, with electronic information devices at stops, normally operated from the control centre, specifying the arrival time of the next vehicle, as well as the stops along the route and waiting times.
- Integrated pricing, due to the fact that an operating company is normally set up to take charge of planning and co-ordinating the timetables and prices of both urban and regional public transport in order to make it user-friendly.
- An increase in the number of stops on the routes previously covered exclusively by trains entails that stations are now closer to potential users, which makes the system more accessible.
- Greater frequency of light rail services compared with traditional rail services, thereby reducing waiting times at stops.

3.3 Non-user benefits

- Reduced congestion on motorways and local roads
- Reduction in the need for investment in road building and maintenance.
- Lower environmental impact
- Savings on parking costs.
- Savings on costs arising from accidents.

4 Spanish application

The possible solutions for each one of the technical problems that arise when a light rail vehicle is going to run over rail tracks or metro tracks in the Spanish area are shown below:

4.1 Electrification

If we want to do compatible a light rail system, usually under 750 V DC, with the Metrosur system in Madrid, with 1500 V DC power supply, or with the suburban railways of Renfe, with 3000 V DC power supply, we have the following options:

- Use of a dual voltage vehicle, either 750-1500 V DC, for the case of Metrosur, or 750-3000 V DC, for the case of suburban railways.
  The case of 750-1500 V DC has already been developed technically, and it does not have too many problems, because the ratio between the voltages is 2, and the change from one to another can be obtained by connecting the electric motors in series or in parallel. The case of 750-3000 V DC would be technically more complicated.
- Use of a light rail system that runs under 1500 V DC through the streets, in that way that the connection with Metrosur will be direct. In the case of the connection with suburban railways, it would be necessary to use a dual voltage vehicle of 1500-3000 V DC, but this is easy to do because the voltage ratio is 2.

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This solution seems to be the more technically acceptable, although it is not usual to establish systems under 1500 V DC in urban environment, sharing the way with road traffic. Nevertheless, there is examples of cities with this kind of operation, as the city of Kyoto, in Japan, in which the conventional heavy rails share the way with the road traffic in a stretch of 600 m, under 1500 V DC. Other examples are the lines Aigle-Sépley-Diableretes and Aigle-Leysin, of the company Public Transports of the Chablais, in Switzerland, that run under 1500 V DC through the cities without protection.

- Use of a diesel-electric vehicle, that runs in the Metrosur network under 1500 V DC, but that use the diesel group through the city. The same approach can be applied for suburban railways of Renfe, but in this case it would be with 3000 V DC in its network.
  This solution has the problem that the passengers are used to the idea of the light rail as a very high environment quality, so that it would not seem acceptable to them that in the urban zone, which is the most affected by the atmospheric pollution, the vehicle runs under diesel traction.
- Use of a vehicle with accumulators, batteries, or other similar devices.
  Generally, these solutions imply a very important weight penalty, and they are not profitable unless the stretches to share are very short.
- Use of a vehicle that runs with fuel cells traction.
  This solution is too premature, because the fuel cells have not still been used in rail vehicles. Nevertheless, with the great development that this technique is undergoing, it seems very probable that this is a feasible option in the future.

Among the solutions that have been presented, it is recommended like the optimum nowadays the second one, that is, running through the streets under 1500 V DC, with a direct link to the Metrosur line, and with change of electric motors connection in series or in parallel, to link with Renfe.

4.2 Track gauge

The problem is due to the fact that light rail systems use to have a track gauge of 1435 mm, while Metrosur system has 1445 mm, and suburban railways of Renfe have 1668 mm.

For the case of Metrosur, it is recommended that the light rail system is built with the Metrosur gauge, that is, in 1445 mm, which is not a problem for manufacturers of vehicles or for the street infrastructure.

For the case of Renfe, there are several solutions:

- Construction of the light rail system in 1668 mm gauge, establishing the lines through the cities with this gauge.
  This solution has the problem that the negotiability of sharp curves can be reduced, but a vehicle of the Saarbrücken type, adapted to this gauge, would be able to negotiate curves of radius 25 m, and less value can be obtained varying the bogie and box pitch.
- Light rail system in 1435 mm gauge, and adaptation of Renfe lines that are to be used by means of three-rail tracks.

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This system has the characteristic problems of a three rails track: the complexity of points and crossings, with lower reliability, and greater seriousness of derailments; greater impact of the failure of rolling stock, due to the use of vehicles of different gauges and the decentred position of the couplers; duplication of space in the workshops; complexity of the signalling system; dissymmetry of loads and decentred position of the contact wire.

- Light rail system in 1435 mm gauge, and adaptation of Renfe lines that are to be used by means of four rails tracks.
  This solution avoids some problems of the three rails track, like the impact of the failure of rolling stock, the dissymmetry of loads and the decentred position of the contact wire, but adds greater complexity to all of the others. Moreover, due to the short distance between rails, the feet of the two rails of each stretch of rails do not fit completely, reason why they must be cut, and this results in a weakening of rails, and in the need of establishing a special system of fastening, which increase the price of the solution.
- Vehicles with variable gauge.
  This solution does not exist nowadays in the tram market, and this has some inconvenients like: technical difficulties for its development; great complexity and loss of reliability; and considerable increase of expenses of vehicle production and maintenance.

Among the solutions that have been presented, it is recommended the use of vehicles of 1445 mm gauge for the connection with Metrosur, and the use of vehicles of 1668 mm gauge for the connection with Renfe.

4.3 Structure gauge

In principle, there might not be problems with structural gauge, because light rail car bodies are narrower than those of heavy rail vehicles (conventional rail and metro). Nevertheless, the structural gauge of the lower parts of the vehicle must be checked, because in the case of use a low floor vehicle, may cause some problem.

4.4 Rail type / tyre profile

The problem of the tyre profile consists of the difference between wheels of rail and tram vehicles, with narrower tyres and flanges in the case of tram. This fact can cause problems of guidance when running over turnouts or crossings, as the size of the crossing nose gaps and check rails do not guarantee that the axles will be guided safely, due to the reduced thickness of the flange wheel (Griffin [1], UITP [2]).

This problem can be solved in two opposed ways:

- Use of a modified tyre, of Karlsruhe type, adapted to the running over tram sections with narrow groove, and to the running over railway lines. This solution implies the raising of the check rails in railway deviations.

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- Use of a typical railway tyre, like in the case of Saarbrücken. This solution can only be adopted in the case that the light rail network is of new construction.

Therefore, the recommended solution is the Karlsruhe type, in the case that the light rail system is going to use existing tram lines, and the Saarbrücken type, in the case that the light rail network is of new construction.

4.5 Structural Strength

The problem in this case is due to the impossibility of building light rail vehicles which met railway crashworthiness standards (structural strength of 1500 kN according to UIC leaflets). This impossibility is due to the requirement that the driver have a clear view of the street traffic around him, and to the variations in floor height and vehicle size regarding to a conventional railway vehicle (Griffin [1]).

The solution recommended to this problem is the European one, that consist of accepting that light rail vehicles that are going to share tracks have a intermediate structural strength (of 600 kN), improving their performances in active safety (protection against accidents by means of signalling systems and acceleration and braking characteristics).

4.6 Safety and communication systems

The solution to this problem consist of the duplication of systems, that is, the vehicle must be fitted with compatible systems in both operation areas, and must be noticeable by the two kind of equipments. It must be checked the existence of operation problems (as interferences) between both systems.

4.7 Passenger access

In this case the problem is double: on the one hand, it is the smaller width of light rail vehicles relating to conventional railways; on the other hand, it is the differences between platform heights in urban and rail zones.
The possible solutions to each of these problems are:

- Smaller width of light rail vehicles: this can be solved by means of retractable steps, like in Karlsruhe and Saarbrücken, or by means of a deviation of the tramway track axle in the stations, like in the Kassel case.
- Different platform heights: this can be solved by means of retractable steps, double-height platforms, double-height doors, modification of the track height, etc.

4.8 Vehicle functional compatibility

Finally, for each individual case it will be necessary to study several specific aspects of the light rail vehicle which must be adapted to enable it to run on shared track. Some of these aspects are listed below:

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- Pantograph: this must allow current collection both in an urban context (normally through trolley wire) and in the conventional railway context (through a catenary system).
- Coupling: In the event of a breakdown, the vehicle must be adapted for coupling with a conventional rail vehicle.
- Vehicle signalling: Vehicle lights must be compatible with those required by the railway authority owning the shared track.

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