The tram–train: state of the art

M Novales, A Orro* and **M R Bugarín**
La Coruña University, Spain

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Abstract: In response to the demand for improved mobility in metropolitan areas, the 1990s saw the development in Europe of a new transport system known as the tram–train. This system is based on the use of conventional railway lines with a low traffic density in order to extend urban tram or light rail services without the need to change vehicle, incorporating them into railway traffic. This allows for a wider range and scope of direct transport services and reduces waiting times and changes. The operation of light rail vehicles on conventional railway infrastructure involves finding solutions to a number of technical issues such as traction power supply system, rolling stock design, gauge, tyre and rail profile, structural strength, passenger access, signalling, etc. This paper describes these problems and the solutions arrived at by services currently in operation, or in advanced planning stages, worldwide.

Keywords: light rail transit, public transport, tram–train

1 INTRODUCTION

Conventional light rail vehicles are either integrated into or separated from urban traffic. They do not run at high speeds but do require excellent acceleration and deceleration performance and consequently an especially light design. In general, this kind of vehicles run on sight; however, at junctions, entries to single line sections, level crossings, etc., the movement of trams is usually controlled by a rudimentary signalling system. Similarly, on shared rights of way, trams usually have to obey traffic signals, albeit the traffic light aspect is usually repeated by a light system that shows stop/go aspects to the signal protecting level crossings.

Conventional railway vehicles, however, normally run on completely separate tracks and very rarely interface with other means of transport (with the exception of at level crossings). Train regulation, including routing and separation, is controlled by a signalling system. The points and signals are controlled from a traffic control centre and cannot normally be activated individually. This high level of control makes the system extremely safe relative to road transport and allows for relatively high maximum speeds [1]. Passenger services operated on a conventional railway tend to cover a relatively long distance with relatively few stops in comparison with a light rail system. As a consequence, average commercial speeds of conventional trains tend to be several times greater than those of light rail vehicles. For similar reasons, it is not necessary for conventional trains to possess such high acceleration and retardation rates as trams. Furthermore, since passengers tend to spend a proportionately longer time travelling on conventional trains than on trams, it is usual for greater levels of comfort and facilities to be provided on the former.

The combination of both systems has created a new concept, known as the tram–train, which consists of a light rail vehicle that has been specially adapted to run on both urban track (corresponding to an existing or newly created tram system) and on conventional railway tracks.

2 A BRIEF BACKGROUND

Interest in this new concept of rail transport first arose in Karlsruhe, Germany. In 1957 the city tram company extended its operations along a local narrow gauge railway, which was then converted to standard gauge. Direct services were then operated using conventional trams. Despite the fact that German rail and tram regulations are different, Karlsruhe found a way to solve the problem. Between 1979 and 1989 the line was gradually extended, sharing track with a German Federal Railways (DB) freight line [2].

A further step forward towards the concept of the tram–train was taken in 1992, when Karlsruhe commenced use of dual-voltage trams operating on DB lines

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* *Corresponding author: ETS Ingenieros de Caminos, Canales y Puertos, Campus de Elviña, s/n. E-15071.A Coruña, Spain.*

that were (and still are) also used by regional passenger trains. Since then, a number of projects have evolved along similar lines in other European cities [2].

3 ESSENTIAL FEATURES

As described above, the tram–train is a modified light rail vehicle. The following sections describe some of the technical features that have been adopted and compares them with conventional light rail vehicles:

3.1 Traction power supply system

This is a question of vital importance. Most existing light rail systems have traction power supplies in the range 600–750 V d.c., while conventional railways mostly use far higher traction voltages, i.e. 1500 or 3000 V d.c. and 15 000 or 25 000 V a.c. The former Southern Region of the UK network is an exception, using a 750 V d.c. third rail supply system.

If a railway line is not electrified, no technical problems usually arise in electrifying it for light rail operations. It is normally possible to meet the clearance requirements necessary in order to allow conventional rail vehicles to pass under the light rail wires without the need to raise existing structures. However, the line owner may refuse to give approval for light rail electrification, as this could create an 'entry barrier' for other potential train operators who may wish to use the line in the future [2].

In theory, it is also possible to install light rail electrification on a line that is already electrified with an overhead wire. This can be made by means of a third rail. Nevertheless, such a design would have to be studied closely in order to be able to supply light rail vehicles with a narrower car body, while respecting the loading gauge of conventional rail vehicles that normally have a wider car body.

In order to run on railway or metro lines that have been electrified to a higher voltage, it is necessary to adapt the existing vehicle traction devices to dual voltage. The design of this equipment is complex, as it must be adapted to fit into the existing available space. The use of diesel light rail may be suitable in some cases, especially on longer routes with a relatively high degree of separation and low traffic density. Similar vehicles could be used in town and city centres using a hybrid traction or energy-storage system, until other devices (such as fuel cells) become available, thereby eliminating the need for an exterior vehicle supply using wires or a third rail [2].

3.2 Track gauge

The different systems (tram or light rail and conventional railway or metro) must have the same track gauge in order to be compatible. Should this not be the case, then several possible solutions available include a third rail or a four-rail track. The solution will depend on the particular circumstances in each case, and will require careful study.

3.3 Structure gauge

In principle, light rail car bodies are narrower than those of heavy rail vehicles (conventional rail and metro). However, it must be pointed out that the Railway Safety Principles and Guidance Part 2, Section B, *Guidance on Stations*, states that 'platforms should have a clearance of at least 50 mm to the swept envelope. The platform level should be determined taken into account all rolling stock using the platform' [3].

Problems may also arise with the gauge in the lower parts because of the current trend for low-floor light rail vehicles.

3.4 Rail type/tyre profile

The wheel–rail interface is the basic element for the movement of rail vehicles. Generally, the set of specific wheel dimensions between conventional and light rail vehicles varies (distance between the two flanges, tyre width and coning angle, etc.). This is because the groove on tram rails is relatively narrow and shallow to avoid creating hazards for street users (pedestrians, bicycles, motorbikes, etc.). The diameter of light rail wheels is smaller, normally ranging from 500–750 mm (new), and can be even smaller (375 mm) on some modern low-floor designs. On conventional railway tracks these vehicles can derail on turnouts or crossings, as the size of the crossing nose gaps and check rails do not guarantee that the axles will be guided safely, owing to the reduced thickness of the wheel flanges. As a result, it is necessary to check all these measurements to make sure that they are compatible with existing or planned railways in order to prevent the risk of vehicle derailment [1, 2].

It is thus necessary to develop a wheel profile that is capable of running on different types of rail, with varying inclination, at the same time minimizing noise levels and wear and tear. Rail type and inclination–vehicle tyre should be considered as a system, in order to determine the optimum equivalent conicity by studying the potential problems of both systems (track and vehicle) so as to prevent wear and tear at specific points and alterations in vehicle performance [2].

3.5 Structural strength

Active safety can be defined as the set of measures that can be taken in order to prevent an accident from happening (i.e. the degree of collision prevention), while passive safety is oriented towards minimizing the damage that occurs in the event of an accident (i.e. the protection afforded to those involved in a collision).

Light rail vehicles normally offer a greater degree of active safety than conventional railway vehicles, which is related to their greater acceleration and deceleration performance, yet normally fail to meet railway vehicle requirements in terms of crashworthiness, as included in the UIC (International Railway Association) leaflets 617-5, 625-7 and 631 (passive safety). According to these UIC standards, the carbody must be able to withstand a minimum 1500 kN compressive proof load. Typical compressive proof loads for light rail vehicles are 200 kN for French trams and 600 kN for the German tram–train [**1**].

British Rail Research carried out a study into the possibility of building light rail vehicles that met railway crashworthiness standards. They concluded that this was not feasible with available technology. Key factors to be taken into account are that the driver is required to have a clear view of the street traffic around him, and there are variations in floor height and vehicle size [**2**].

Since at present it is not technically feasible to make light rail vehicles as crashworthy as conventional rail vehicles, while maintaining their relatively low mass, the interoperation of the two vehicle types requires the adoption of a risk reduction strategy in such a way that the risks of a collision occurring between the two is reduced to 'as low as reasonably practicable' (ALARP).

3.6 Safety and communication systems

The incorporation of light vehicles onto shared track should not reduce the level of safety of the system. In order to assure complete train separation, a series of measures may be implemented affecting the vehicle, the infrastructure and operations. Wherever possible, the vehicles using shared tracks will be equipped with compatible operation mechanisms (such as ATP—automatic train protection) and the infrastructure must also ensure that the vehicles are noticeable and capable of interpreting the signals in each type of running system [**1**].

The light axle loads of light rail vehicles may cause poor electrical wheel–rail contact, so that mainline signalling systems do not work. This fact must be taken into account and where it occurs, the problem must be solved, e.g. by providing an electronic device to inject a high-frequency current into the rails [**4**].

3.7 Passenger access

It may be necessary to adapt existing platforms on a shared track in order to guarantee safety on both types of vehicles and improve accessibility. The narrow carbody of light rail vehicles may be compensated for by means of retractable steps. The demand for gap-free and level access requires more complex technical solutions, especially if floor (or platform) heights and vehicle widths vary [**1**]. Light rail vehicles might be fitted with sliding floor plates to close the gap between the vehicle and the platform. Light rail vehicles are often fitted with sliding plates of this type to improve access for those with impaired mobility [**5**].

3.8 Vehicle functional compatibility

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

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

4 CASE STUDIES

The following are examples of operations that are currently either operating or under construction.

4.1 Karlsruhe (Germany)

The metropolitan area of Karlsruhe has a population of some 550 000 inhabitants. The most important feature in understanding the tram–train is the fact that the city's main railway station is located on the outskirts of the city, some 2 km south of the centre. As a result, passengers travelling from other parts of the region to the city by train had to change at the station to either the tram or bus network. This had a negative impact on regional rail transport, as it lowered rail users' perception of the quality of the service. In order to boost regional mobility, the decision was taken to eliminate the need to change to another means of transport by offering direct services to or from Karlsruhe on trams that ran on existing conventional rail infrastructure.

The first railway that was used to operate trams was the Karlsruhe–Bretten–Gölhausen line, with a total length of 30.2 km; this was opened on 27 September 1992. The success of the system led to its extension to other lines around Karlsruhe (see Fig. 1) [6].

The functional requirements necessary for operation of this shared track system were as follows [7]:

1. The vehicles to be used had to be capable of running on light rail lines within the city area and on conventional DB railway tracks in the regional area. Both the compatibility of the rolling stock and the safety had to be assured.
2. Two different sets of regulations had to be met, that were: the German regulations over the building and operation of trams (*Verordnung über den Bau and Betrieb der Strassenbahnen—Strassenbahn-Bau-und-Betriebsordnung, BOStrab*); and the German railway-building and operating regulations (*Eisenbahn-Bau-und-Betriebsordnung, EBO*).
3. The different networks involved must be connected.
4. The new network had to include the construction of further stops along the existing conventional railway lines, which could be used without increasing journey time thanks to the improved acceleration of the light rail vehicles.

A description of the technical solutions offered to some of the problems of compatibility that arose, already discussed in Section 3, is given below.

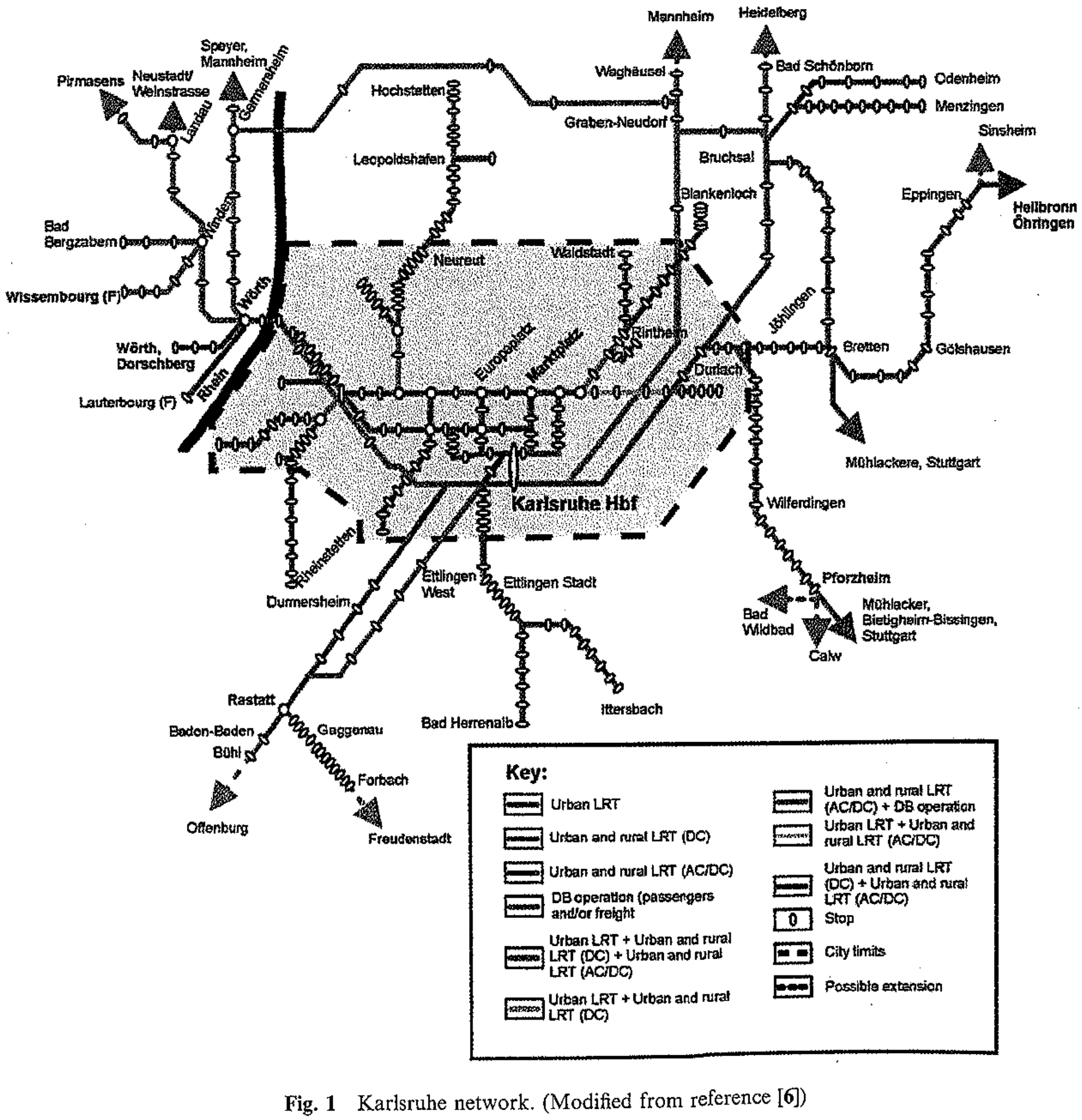

Fig. 1 Karlsruhe network. (Modified from reference [6])

4.1.1 *Electrification*

In Karlsruhe, the DB tracks are electrified at 15 kV $16\frac{2}{3}$ Hz a.c., while the urban tram lines are supplied at 750 V d.c. The engineers of ABB Henschel designed and built an electronic power system based on the chopper, using a highly compact format, enabling it to be fitted in the small space available on the light rail vehicles. The additional electrical equipment is installed in the central section of the vehicle. A transformer and a rectifier step down the 15 kV a.c. current to 750 V d.c. current and supply the d.c. equipment in the vehicle. This converts the tram into an alternating current vehicle with its own rectifying substation on board. All the equipment is fitted above the roof or under the floor, and does not therefore reduce the space available in the passenger cabin (see Fig. 2) [**8, 9**].

On the track, in the transition areas, the vehicle changes automatically from direct to alternating current and the driver only has to put the controller in neutral position. The vehicle automatically detects the new voltage and adapts accordingly. The driver can follow this operation by watching the line voltmeter and three control pictographs on his instruments. As the vehicle travels freely while it changes voltage in a neutral section, these sections are deliberately located away from restrictions such as signals, level crossings and stops [**8–10**].

4.1.2 *Structural strength*

The vehicle meets the construction and operational requirements for both trams and trains. Only the 600 kN compressive proof loading does not meet the requirements included in UIC leaflets 617-5, 625-7 and 631. The reason for this has previously been discussed in Section 3.

4.1.3 *Safety and communication systems*

The Karlsruhe railcars are the first urban vehicles to be equipped with two different safety systems: the INDUSI system (the DB signalling repetition system) and the IMU system, with automatic stopping, corresponding to the transport services of the city of Karlsruhe (AVG) and the Albtal transport company [**9, 10**]. In the driver's cab, next to the AVG radio, the DB transmission system is also installed. This latter system enables the drivers to announce their incorporation onto the line, as required by DB regulations, and also inform the station traffic controllers of the tram integrity, who therefore do not have to go onto the platform to check for the presence of the red tail lights [**9, 10**].

4.1.4 *Tyre profile*

Two problems arose related to the unguided length for wheelsets at DB standard points and crossings [**9**]:

1. This gap is longer than that arising in light rail crossings.
2. The check rail facing the nose crossings is placed at such a distance from the rail that it allows the wheel flange, thinner than that of conventional railway rolling stock, to strike this point and even to cause the wheel to jump in a direction opposite to that switching.

In Karlsruhe this problem was solved by using a special type of tyre shown in Fig. 3. The narrow flange meets standard requirements for street tramcars, but the

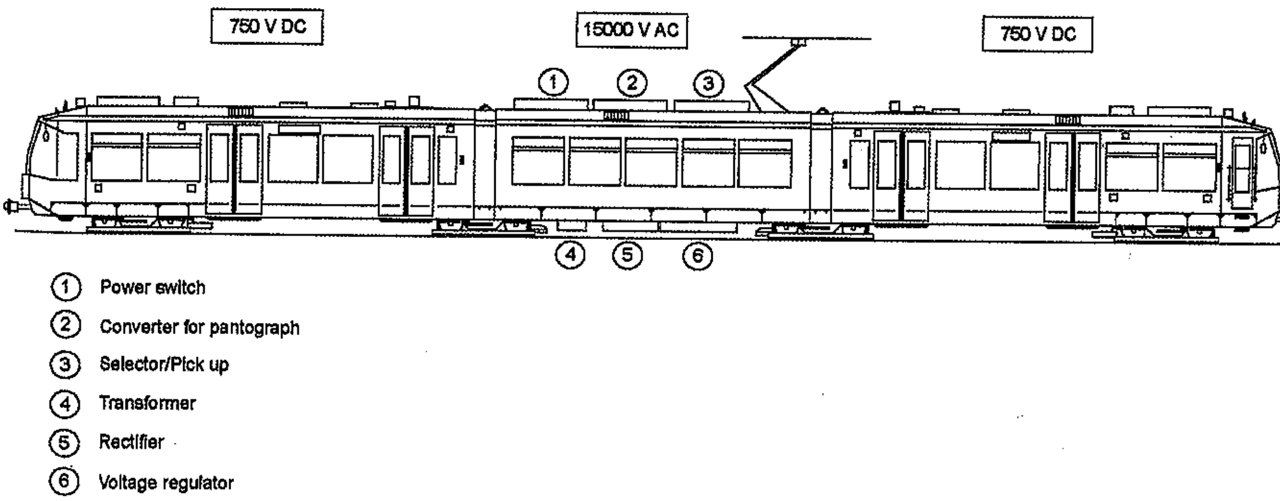

Fig. 2 Power units on a Karlsruhe vehicle

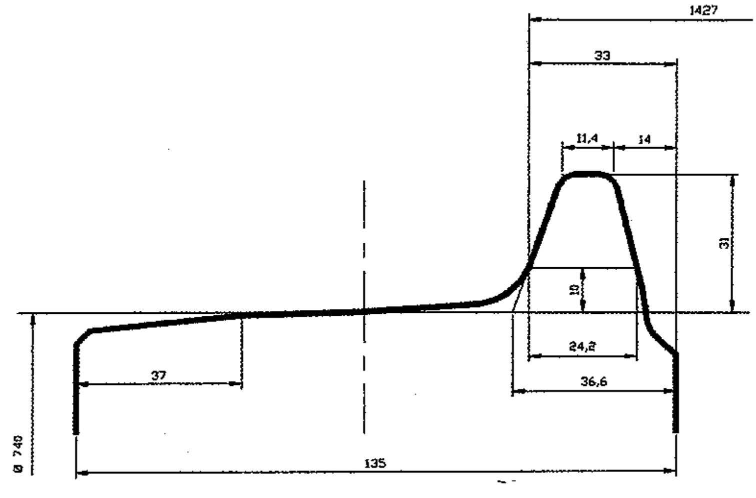

Fig. 3 Karlsruhe tyre profile

interior part of the wheel, which is wider over the level of the street surface, comes into contact with the check rail (which has to be raised) and whose gap is designed in accordance with heavy railway wheels (see Fig. 4) [5].

4.1.5 *Platform heights*

In order to solve the problem of the coexistence of high platforms on conventional railway lines (380, 550 and 760 mm) and the low city platform (200 mm), the vehicle is fitted with retractable steps that adapt the vehicle access height according to the type of area it is in.

4.1.6 *Results*

The results obtained after the opening of the first shared traffic line in Karlsruhe were highly satisfactory. Since its opening, there has been a 479 per cent rise in passenger numbers (from 553 660 to 2 554 976 users), 40 per cent of whom were former private car users. The number of passengers using the service at weekends has also increased [7]. Public transport within the city of Karlsruhe accounts for 17 per cent of all transport. This rises to 50 per cent in the case of transport between the city and the rest of the region, and on some highly successful routes this figure reaches as much as 67 per cent [6].

4.2 Saarbrücken (Germany)

The city of Saarbrücken, with 196 000 inhabitants and 101 000 jobs, is the capital and economic centre of the area known as Land de Saar, with a total population of more than a million people [11]. The first stretch of line with shared tracks, from Ludwigstrasse to Sarreguemines, was opened on 24 October 1997. Figure 5 shows a plan of the light rail line.

The technology used in Saarbrücken is basically the same as that used for Karlsruhe, but with two main

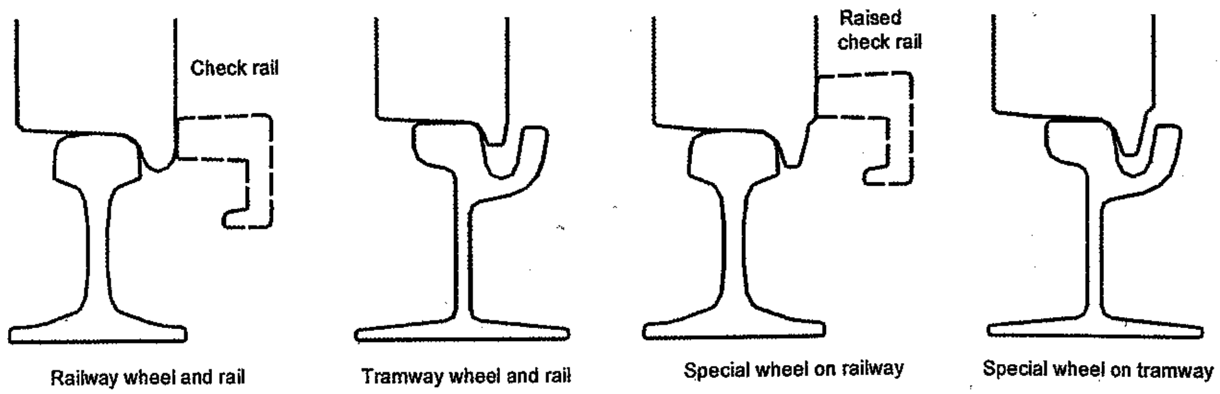

Fig. 4 Use of raised check rails and special wheel profiles. (Modified from reference [5])

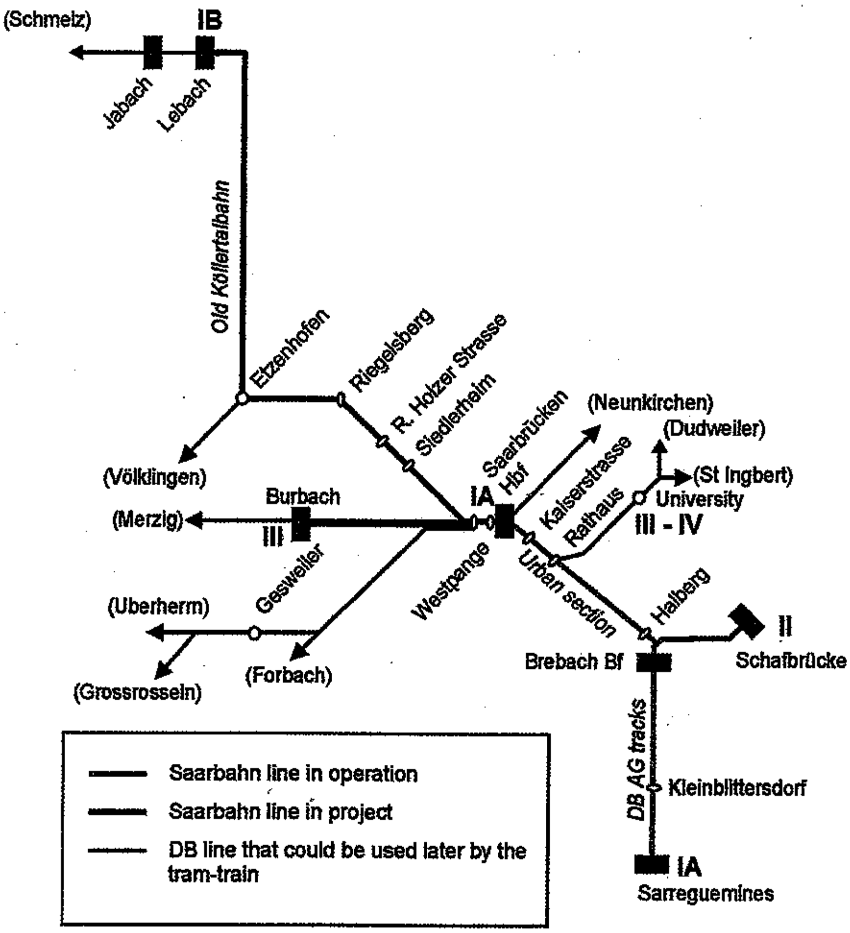

Fig. 5 Saarbrücken network. (Modified from reference [**12**])

differences: first, the use of a low-floor vehicle and, second, the fact that trams had not been in use in Saarbrücken since 1965, thereby avoiding the need to take the characteristics of existing trams into prior consideration. As with the case of Karlsruhe, the solutions provided for some of the most important issues are described below.

4.2.1 *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, where the change in voltage takes place, is 80 m rather than the 170 m in Karlsruhe.

4.2.2 *Signalling and operational aids*

Except for the Köllertalbahn and the section between Brebach and Sarregumines, the tram–train runs mainly on line of sight, without signalling, in accordance with the BOStrab regulations. Signalling only exists on single track stretches [**6, 12**]. The Köllertalbahn continues to be used as a conventional railway line, fitted with classical DB signalling (main and advanced signals, *haupt und vors signal*). Occupied track detection is carried out by means of axle counter devices [**12**]. The DB tracks use inductive train safety devices and automatic colour light blocks, thereby assuring safety [**6**].

4.2.3 *Tyre characteristics*

As the Saarbahn (the Saarbrücken light rail) is a completely new system and therefore does not need to be connected to the existing urban tracks, 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 [**12–14**]. In order to avoid having to fit its vehicles with wheels that wear out quickly due to their thin flange, Saarbrücken chose a type of rail for the urban area that could take a railway wheel. Either the standard S 49 flat bottomed rail foot or the Ph37a rail will be used, depending on the solution adopted for track construction [**12**].

4.2.4 *Platform heights*

Within the city area, the station platforms are 350 mm above the track. The platform edge is 1.40 m from the track axis, leaving a 75 mm horizontal gap between the door and the platform (vehicle width is 2.65 m). At the stops that also incorporate a bus stop, this height drops to 200 mm [**6, 12**].

On the railway sections, the platforms are at a height of 380 mm (in line with EBO regulations) and the platform edge is approximately 1.60 m from the track axis, leaving a horizontal gap of 275 mm. This gap is covered by a retractable step with a total extension of 197 mm, thereby reducing the gap to around 78 mm [**12**].

4.2.5 *Low floor*

The lower section of the tram–train kinematic envelope is 75 mm over the track, which allows the vehicle to pass over the DB track devices.

4.2.6 *Results*

The introduction of the Saarbahn has led to an increase in use of the line. The Saarbahn is used by 25 000 passengers a day from Monday to Friday in both directions. Initial forecasts calculated 11 000 passengers in each direction. The Saarbahn has meant a considerable increase in the number of passengers in the area between Kleinlittersdorf and Sarraguemines. A comparison of current figures and those obtained during surveys carried out in 1996, when DB_AG (German Railways) operated a passenger service between the stations of Saarbrücken and Sarreguemines, shows a 400 per cent increase [**14**].

4.3 Kassel (Germany)

In May 1995, tramline 5 was extended as far as Baunatal in the south-east, using a private goods line running from Kassel to Naumburg. The number of passengers rose from 2800 to 5800 a day. The difference in width between tramcars and the traditional railcar bodies meant that a special solution was required at the stops. This consisted of diverting the tram line from the track axis, thereby creating a four-rail section (see Fig. 6) and enabling both systems to use the same 20 cm high platform [**15, 16**]. This solution has several problems in relation to maintenance, due to the eccentric live load imposed upon the sleepers and ballast, the hazards of mechanized tamping of a track with four rails, and the operation of points and crossings in sections in which the track with four-rail starts or finishes. All these issues must be studied in depth when a solution of this kind is considered.

To the east of the city, tramlines 4 and 8 were extended as far as Kaufungen Papierfabrik in 1999. Since its opening, the number of passengers on this short section has risen by 16 per cent. Work is currently being carried out on the Lossetalbahn from Kaufungen Papierfabrik to Helsa. The 14 km long line will make use of the old Waldkappeler Van railway line, which was used exclusively for freight trains. Part of the line will be converted to double rail and catenary will be installed [**16**].

These extensions are part of a more ambitious tram–train plan for Kassel called the Regiotram. It includes an interchange at Kassel Hauptbahnof (the main railway station), and a new tram line in the city centre. This provides a direct link from the city centre to the cities and towns around Kassel. An initial line could link Kassel with Hofgeismar and Warburg (30 km north-east of Kassel). Vehicles similar to those used in Saarbrücken would run along the line [**16**]. Current plans for the Regiotram network include eight lines (see Fig. 7), and construction of several of these lines is planned for 2001 and 2002.

4.4 Sunderland (UK)

The aim is to create a link between Sunderland and Newcastle, using metro vehicles on Railtrack infrastructure between Pelaw and Sunderland (see Fig. 8) [**6**]. The existing metro system has a total of 59 km. The shared section between Pelaw and Sunderland would add a further 14 km, and another 4.5 km would be built between Sunderland and South Hylton. This would increase the number of stations on the network by twelve, eight of which would be new, and the remaining four existing stations would be upgraded in order to meet metro standards and requirements [**6**].

4.4.1 *Signalling and operational aid*

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 to enable staff at Railtrack's IECC (Integrated Electronic Control Centre) to talk to all vehicles on the line, both metro and conventional trains [**6**].

4.4.2 *Catenary*

The 1500 V d.c. catenary system will be installed at a height of 5.08 m, with no level crossings in the line. As no conventional electric rolling stock will be running on this route, there will be no problems of compatibility [**6**].

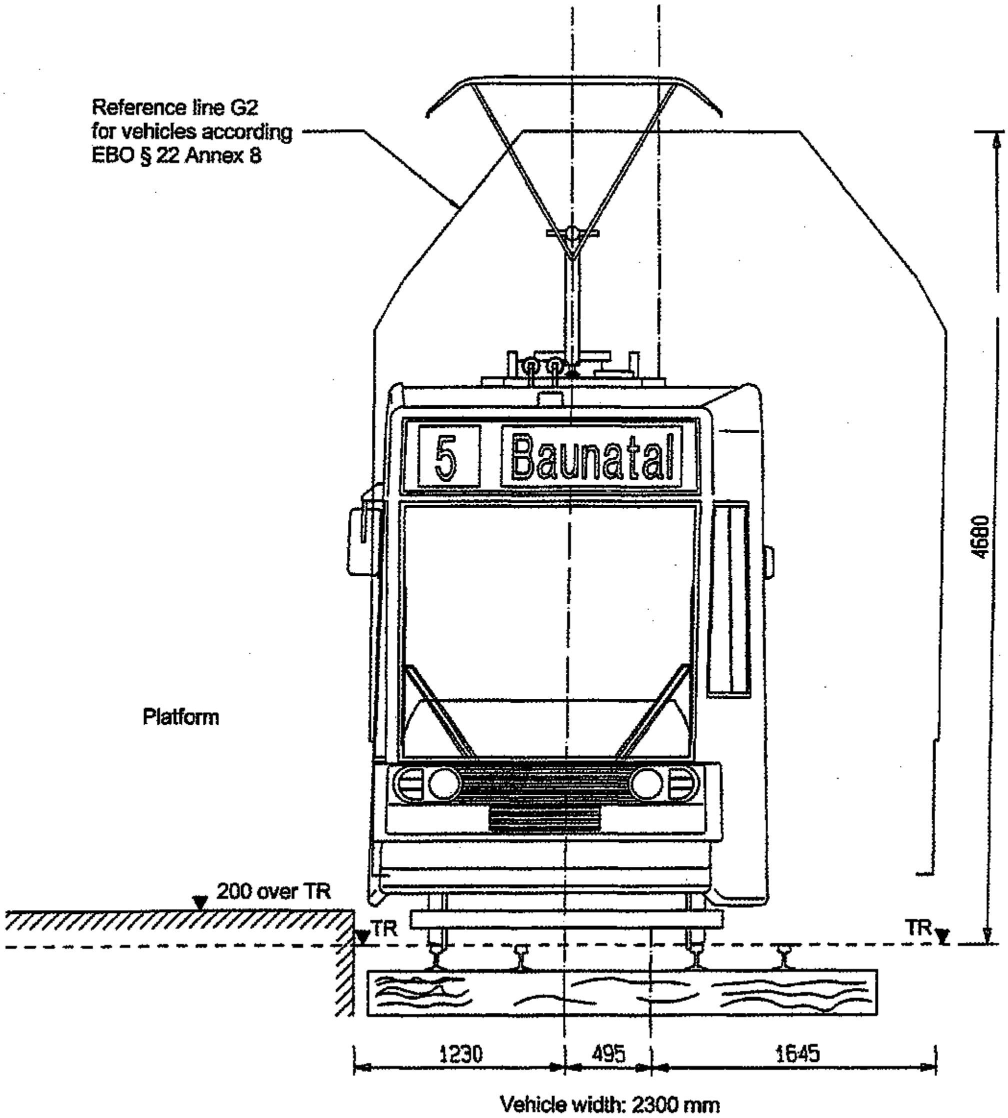

Fig. 6 Four-rail station [17]

4.4.3 Rail features

The slight difference in rail width between traditional railway lines (1432 mm) and the standard width (1435 mm) is not expected to cause any operational difficulties. The widths are sufficiently similar as to guarantee that there will be no restrictions during normal operations, although they will exist at the two sections where the metro joins the rail network [6].

5 IMPLEMENTATION STUDIES IN OTHER CITIES

Table 1 details the characteristics that best define some of the projects currently under study for the incorporation of a tram–train system into the transport network. It also includes the characteristics of the systems currently in operation, described in earlier sections.

As far as Spain is concerned, plans exist to introduce a system of this type in Valencia, between the metro and tram. In the case of Bilbao, studies were made looking into the possibility of a future tram system running on certain lines belonging to the Ferrocarriles Vascos (Basque Railways), although for the moment this option has been ruled out. Lastly, several options are currently under consideration for the city of Madrid.

6 ADVANTAGES OF THE TRAM–TRAIN CONCEPT

Traditional rail services are unable to provide a convenient door to door service. Travelling by public

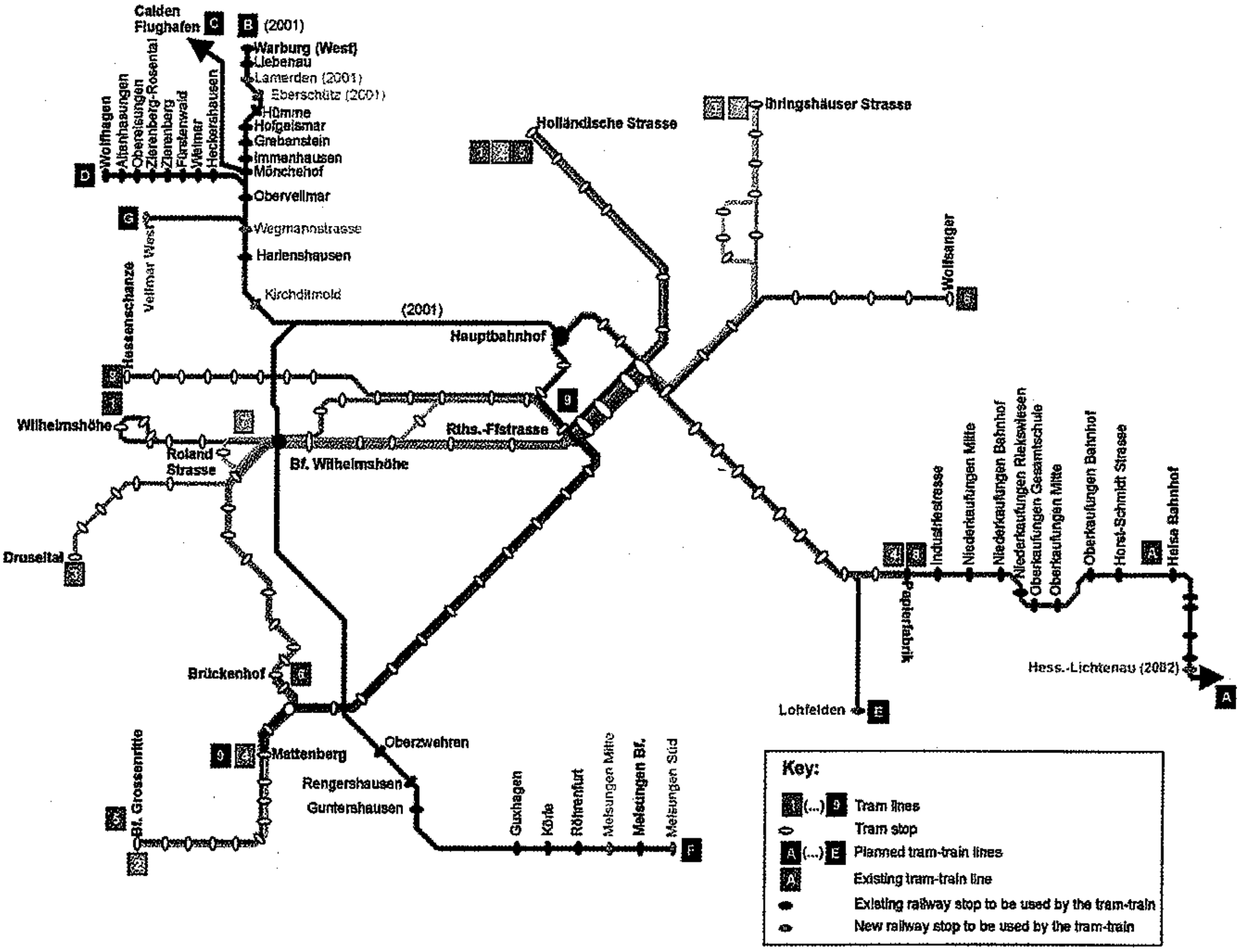

Fig. 7 Tram and Regiotram network in Kassel. (Modified from reference [18])

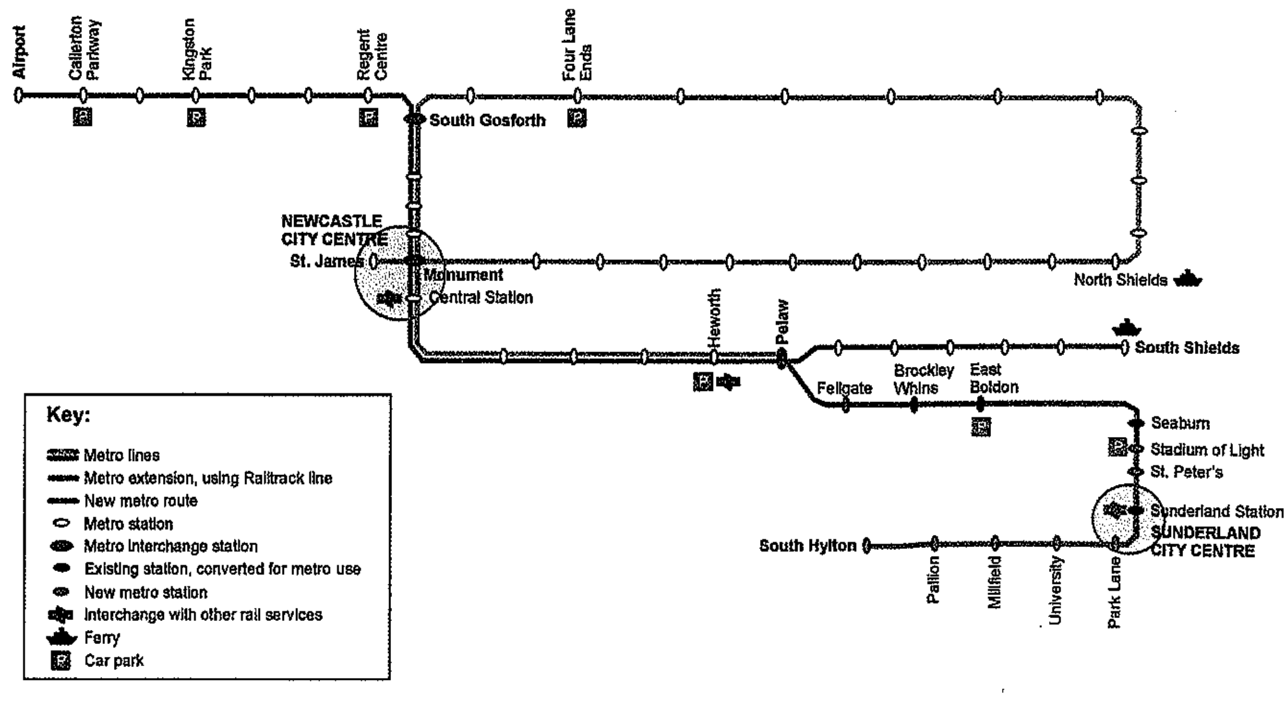

Fig. 8 Sunderland Metro network. (Modified from reference [6])

Table 1 Main data of some tram–train systems (in operation or planned)

City	Population	Rail gauge (mm)	Light rail gauge (mm)	Electric supply (rail)	Electric supply (light rail)	Electric supply (tram–train)	Rail lines to be used	Kind of rail traffic	Rail operator	Light rail/tram operator	Light rail/tram operator	Tram-train operator	Minimum radius	Urban platform height (mm)	Rail platform height (mm)
Nantes	547 000	1435	1435	1435	None*	750 V d.c.	750 V/25 kV	Haluchere–Suce sur Erdre	Freight	SNCF	SEMITAN	—	25 m	250	380–550
Strasbourg	430 000	1435	1435	—	25 kV and not electrified	—	750 V/25 kV†	Espianade–Molsheim–Obemal–Barr Molsheim–Gresswiller	Passengers and freight	SNCF	CTS	SIBS	23 m	280	350–385
Geneva	400 000	1435	1000	1435‡	25 kV SNCF 15 kV CFF	—	750 V/25 kV /15 kV	Coppet–Comavin–Airport (CFF) Evian–Thonan–Annemasse–Eaux Vives (SNCF)	—	SNCF and CFF	TPG	—	26 m	—	—
Klel	240 000	1435	1000 — removed	1435	15 kV and not electrified	—	750 V/15 kV 50 Hz or 750 V/diesel	Klel–Neumünster (NOB and DB) Klel–Plön (DB) Klel–Eckernförde (DB) Klel–Readsburg (NOB)	Passengers and freight	NOB and DB	Tram system removed in 1985	—	30 m	—	380–760
Bremen	540 000	1435	1435	1435	15 kV a.c.	—	750 V/15 kV 50 Hz	Bremen–Delmenhorst-Nordenham Bremen–Rottenburg/Wömme	—	DR-Regio	—	—	30 m	100	380–760
Aarhus	282 137	1435	No	—	Not electrified	—	Electric–diesel	Odder Line Grenaa Line	—	HHJ in Odder y Danish National Railway Agency in Grenaa	—	—	25 m	—	280–500 Grenaa 500–800 Odder
Göteborg	600 000	—	1435	—	15 kV 16 2/3 Hz	750 V d.c.	—	Alingsas–Göteborg Floda–Göteborg	—	SJ	GS	—	20 m	170–250	580–730
Tallinn	411 594	1520	1067	1520	3300 V d.c.	600 V (750 V new line)	750/3300 V	—	Passengers and freight	Eleldriraudtee AS Edelaraudtee AS	TTA	—	25 m	—	1100
Aachen	500 000	1435	New planned 1435 mm	—	3300 V d.c.	750 or 1500 V d.c.	—	Aachen–Heerien	—	—	—	—	—	—	—
Brussels	964 000	—	—	—	3300 V d.c.	700 V d.c.	700/3300 V	—	—	SNCB/NMBS	STIB/MIVB	—	20 m	150 surface 275 tunnel	250–760
Anvers	590 000	1435	1000	1435§	3300 V d.c.	700 V d.c.	—	—	—	SNCB/NMBS	DE LIJN	—	25 m	300	—
Kalowice	400 000	1435 and 1524	—	—	3000 V d.c.	—	—	—	—	—	—	—	—	—	—
Patra	200 000	1000	No	1000	Not electrified	—	Electric–diesel	Psathopyrghoe–Patras–Achaia	—	OSE	—	—	—	—	—
Valenciennes	332 000	—	No — study for building	—	—	750 V d.c.	—	Mons–Qulevrain–Valenciennes Mons–Borinage-St. Ghislain-Qulevrain–Valenclennes Mone–Cuesmes–Quevy–Autnoye–Maubeuge	Passengers and freight	SNCF and SNCB	—	—	20 m	—	—
Nottingham	300 000	—	1435	1435	Not electrified	—	—	Line to Hucknall	Freight now re-opened to passengers	British Rail	Greater Nottingham Rapid Transit	Greater Nottingham Rapid Transit	—	—	—
Liverpool	450 000	1435	No — proposed	1435	750 V d.c. and 25 kV a.c.	—	750 V	—	—	—	—	—	—	—	—
Systems with tram–train in operation or in construction															
Karlsruhe	550 000	1435	1435	1435	15 kV 16 2/3 Hz	750 V d.c.	750 V/15 kV 16 2/3 Hz	Kalrsruhe–Bretten Karlsruhe–Wörth Karlsruhe–Pforzheim-Bietigheim–Bissingen Karlsruhe–Raslatt–Baden–Baden Bretten–Eppingen–Heilbronn Bruchsal–Menzingen/Odenhelm	Passengers and freight	DB-Regio	AVG VBK	KVV	—	0–200	380–560
Saarbrücken	500 000	1435	No	1435	15 kV 16 2/3 Hz	750 V d.c.	750 V/15 kV 16 2/3 Hz	Brebach–Sarreguemines Old Köllertalbahn	—	DB-Regio SNCF	—	Stadtbahn Saar GmbH	30 m	200–350	380
Kassel	200 000	1435	1435	1435	—	600 V d.c.	—	Kassel–Baunatal Kasael–Helsa	Freight	RBK	KVG	—	30 m	200	200
Sunderland	200 000	1432	1435	1432 and 1435	Not electrified	1500 V d.c.	1500 V	Pelaw–Sunderland	Passengers and freight	Northern Spirit	Nexus	Nexus	—	—	—

*Must be electrified.
†Must have three voltages if it is extended to Kehl.
‡Third rail in urban area or changing gauge device.
§Three or four rails in urban area.

transport often requires using a combination of buses and trains, changes, long waiting times, uncertainty, and fairly long distances that must be covered on foot [2]. Moreover, it is often the case that older rail networks do not serve the routes on which current transport demands are concentrated [2].

When a person is going to travel, he or she must expend both time and money, and the overall package of disutilities is combined into the composite index of generalized cost (GC). It is generally accepted that passengers act so as to minimize disutility of travelling, where disutility is measured by generalized cost, as a direct function of fare, waiting time, access time and running (in vehicle) time [19]. Thus, by removing some of the disutility of time for changes and reducing access time, the tram–train decreases the passenger GC; this is one of the main advantages of this concept.

Urban interoperability could be achieved by using the same vehicle on existing rail and tram infrastructure, and incorporating new sections of light rail in order to create an integrated network. This would provide a system that would be able to compete effectively with private transport, requiring less investment and with a lower impact on the environment than a light rail system with completely new lines [2]. This type of service offers a number of advantages:

6.1 Financial advantages

1. Existing traditional railway infrastructure can be used, thereby reducing the amount of investment necessary in new infrastructure.
2. 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.
3. 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 'loss'.
4. Vehicle composition may be adjusted during periods of low traffic density (evenings, Saturdays and Sundays), thereby reducing total running costs.
5. Operation costs for this kind of vehicles are lower in comparison with traditional rolling stock.

6.2 Advantages for passengers

1. 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.
2. Direct access from the region to the main business and shopping centres can be provided, without the need to change to another mode of transport, as occurred before the introduction of these services.
3. Punctuality rates are improved appreciably because the length of tracks with shared rights of way is smaller.
4. Greater comfort, due to an increased number of larger seats in each car and their improved dynamic features, which make for a smoother journey.
5. 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.
6. Integrated pricing, due to the fact that an operating company is normally set up to take charge of planning and coordinating the timetables and prices of both urban and regional public transport in order to make it user-friendly.
7. An increase in the number of stops on the routes previously covered exclusively by trains means that stations are now closer to potential users, which makes the system more accessible.
8. Light rail services are more frequent than traditional rail services, thereby reducing waiting times at stops.

6.3 Non-user benefits

1. There is reduced congestion on motorways and local roads.
2. There is a reduction in the need for investment in road building and maintenance.
3. Environmental impact is lower.
4. There are savings on parking costs.
5. There are savings on costs arising from accidents.

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