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Multimodal LRT vehicles - a development for the future?

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Abstract

In order to make full use of existing urban and/or regional transport networks, there is a need for light rail vehicles able to operate in heavy rail mode in surburban and regional areas as well as in tramway mode in urban areas. Such a vehicle is already available in Karlsruhe, Germany which operates in dual mode, drawing power from either a 750V DC or 15kV AC supply. Operation of such vehicles on both heavy rail and tram tracks, and so offering direct connection between the city centre and its hinterland, is known as the "Karlsruhe Model".

In order to meet the needs of European cities in general, light rail vehicles are needed which are sufficiently versatile to be able to share track with heavy rail as well as sharing road space with other vehicles and operate safely within pedestrian areas. They must also be able to operate from a variety of external power sources as well as on unelectrified track.

This paper will furnish a short description of the Karlsruhe model, giving an overview of the different solutions needed in Europe dealing especially with power supply questions and finally shows an example of a potential application in the city of Bristol, where an extensive network of unelectrified track already exists.

Keywords: Multimodal Urban Transport Hybrid Propulsion

1 Introduction

The development of urban transport is going to require a blurring of the distinction between road and railway, with a range of options spanning a spectrum between them. Routes will increasingly comprise segments which

could be either ***segregated track***, including *heavy rail routes, former heavy rail routes deregulated to light rail, light rail routes or light rail routes combined with busways* or ***street running track,*** including *all railbound modes (except heavy rail) and all kinds of buses.*

The demands on multimodal vehicle design and operation therefore can be quite different and include a lot of aspects :

Heavy rail vehicles run on segregated track only and must be designed to heavy rail specification regarding impact resistance and automatic train protection, and to conform to regulations pertaining to heavy rail.

Light rail vehicles can be heavy rail compatible and have to be able to operate both as street running conventional trams, or as (light) rail vehicles on railway or LRT-routes and can include rubber tyred light tram with special guidance systems.

Looking at the urban part of a network, the main distinction is whether there are or will be rails available in the streets or not. The choice of system or a combination of systems is strongly dependant on that:

- ***Streets with tracks*** can allow all modes except heavy rail
- ***Streets without tracks*** allow steerable or otherwise guided vehicles only

A network can comprise any combination of these categories of route. This is especially the case if the existing rail infrastructure in a region is to be integrated in one transport system, as has been done successfully in Karlsruhe, Germany. Table1 gives information of the variety of route types to be found in Karlsruhe.

Route types	Examples
New LRT-line through town centre running parallel to existing DB-line.	• Durmersheim • Stutensee
Use of previous DB-lines by LRVs with new tracks through town centre.	• Neureut • Eggenstein-Leopoldshafen • Linkenheim-Hochstetten
Use of non DB-lines and conversion to LRT.	• Albtalbahn • Bruchsal-Menzingen/Odenheim
3rd track parallel to existing DB-line	• Pfinztal
Track-sharing of DB-lines of LRVs with DB-trains and the building of junctions between the LRT and heavy rail regulated networks.	• Bretten • Pfinztal • Durmersheim-Rastatt • Ettlingen-Rastatt • Wörth
Use of existing DB-lines with the incorporation of more stops.	• Bruchsal • Bruchsal-Bretten
Use of existing DB-lines with loop through town centre.	• Wörth • Bruchsal • Rastatt • Baden-Baden

Table 1: Different route types in Karlsruhe network

2 The Karlsruhe Model

During 1984/85 the connection of the urban LRT-system of Karlsruhe with that of the German National Railway, the Deutsche Bundesbahn (DB) was investigated in a study sponsored by the German Ministery for Research. This triggered the development of the so-called Karlsruhe Model.

This model consists of three components:

- a vehicle that can use regional DB-heavy rail tracks as well as LRT-tracks in the city centre
- a constructional junction of DB-tracks with the existing Karlsruhe tramway-system
- the building of new stops on existing railway lines, without causing longer travel times, which is possible through the better acceleration capability of LRT-vehicles

The ultimate aim was to create direct connections without passengers having to change vehicles, because every interchange causes modal split losses by making the public transport system less attractive. Figure 1 shows the main principle of the Karlsruhe model in a schematic drawing.

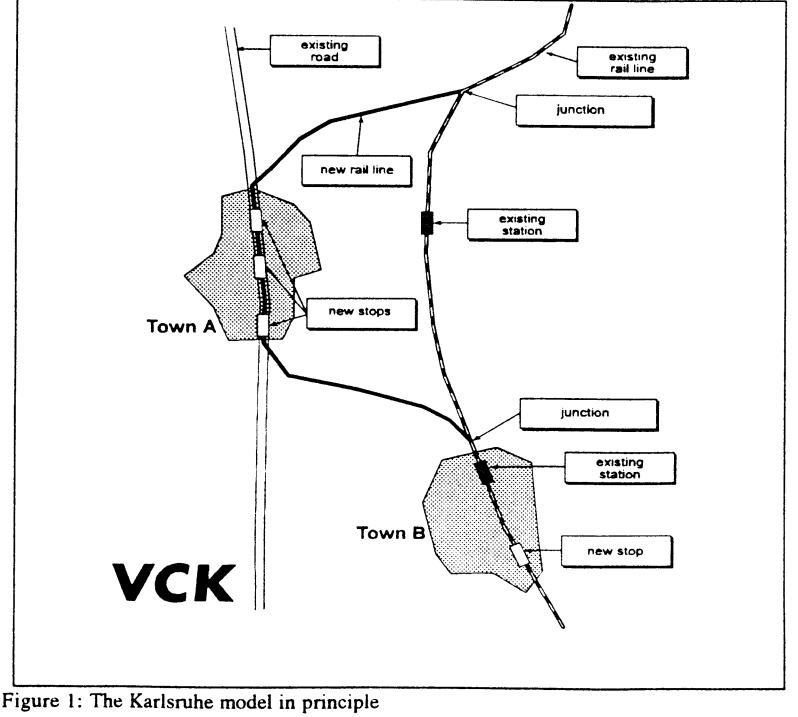


Figure 1: The Karlsruhe model in principle

The way from idea to practice was not very easy during the following years. This was especially the case when the eligibility of LRT-vehicles on DB lines, particularly concerning safety measures, had to be proved.

In the mean time all these problems have been solved:

- The LRT-line from Karlsruhe to Bretten opened in September 1992 was a huge success and experienced a 600% passenger increase [1]
- Since the introduction of the Karlsruhe Public Transport Services (KVV, Karlsruher Verkehrsverbund) in 1994, LRT-vehicles are operating in a preliminary phase on the DB lines of Karlsruhe-Bruchsal, Bruchsal-Bretten, Karlsruhe via Rastatt to Baden-Baden and from Karlsruhe to Wörth.

The Deutsche Bahn AG itself has bought 4 dual mode vehicles of the GT8/2S type and uses them together with those of the Karlsruhe public transport operators VBK and AVG. The Karlsruhe dual mode vehicle for 750V dc / 15kV ac is the first of its kind on the market. Further developments e.g. low floor vehicles are just following.

Vehicle length and width as well as the type of power supply are parameters to be chosen according to the specific conditions in the area.

Initial developments for a battery/direct current LRT-vehicle were given up in Karlsruhe due to incomplete battery technology.

Transferability to other situations does not mean that the Karlsruhe Model could and should be copied in a 1:1 scale. The basic idea of providing through connections needs to be adapted to the specific conditions of the region.

Use of the regional national railway infrastructure and the linking of regional and city transport is the primary feature of the Karlsruhe Model.

3 European situation

The European railway network shows a variety of overhead systems from 3000V dc in Ireland, Italy, Slovenia and Spain over 15kV 16,66Hz ac in Germany, Switzerland, Austria and Scandinavia to 25kV 50Hz ac in France, the UK, Denmark, Belgium, Luxemburg, Croatia and Portugal, and in some of these countries several systems are used.

Table 2 gives detailed information on supply systems and shows that, in contrary to the general understanding, over half of European network is not electrified.

Application of the Karlsruhe model in other European countries would not only need a dual mode vehicle for the use of electrified and unelectrified tracks but one which is suitable for urban transport as well.

Country	Railway	Length of Lines Total km	Unelectrified km	%	Supply System
France	SNCF	32579	19007	58	25kV50Hz
Germany	DB	26334	14164	54	15kV16.66Hz
Germany	DR	13982	9839	70	15kV16.66Hz
UK	BR	16534	11566	70	25kV50Hz
Ireland	CIE	1944	1907	98	3000V
Netherlands	NS	2757	766	28	1500V
Belgium	SNCB	3410	1048	31	25kV50Hz
Luxemburg	CFL	275	13	5	25kV50Hz
Austria	ÖBB	5600	2327	42	15kV16.66Hz
Switzerland	BLS	245	0	0	15kV16.66Hz
Switzerland	CFF	2983	16	1	15kV16.66Hz
Italy	FS	15942	5912	37	3000V
Spain	RENFE	12601	5707	45	3000V
Danmark	DSB	2311	1986	86	25kV50Hz
Norway	NSB	4023	1601	40	15kV16.66Hz
Sweden	BV/SJ	9746	2560	26	15kV16.66Hz
Finland	VR	5885	4172	71	25kV50Hz
Slovenia	SZ	1201	702	58	3000V
Croatia	HZ	1907	1138	60	25kV50Hz
Portugal	CP	3062	2601	85	25kV50Hz

Table 2: Power Supply systems in Europe

As urban tramway or LRT-systems normally run under 750V dc overhead the mismatch of supply systems is problematic. LRT-vehicles for the city of Luxemburg would have to cope with the inner city supply system and with 3 different state railway supply systems [5, 6].

Propulsion and power supply therefore are the most important questions to be solved when considering multimodal LRT-vehicles of the future, bearing in mind that space for additional technical equipment is very limited and can only be found underfloor or possibly on the roof of such vehicles.

4 Internal supply systems

Today nearly hundred per cent of railbound vehicles on unelectrified routes are powered by Diesel-engines, and attempts in the past to use gas-turbines or accumulators for propulsion have been largely unsuccessful, because gas turbines alone are unable to cope with the fluctuating load which occurs in urban operation, and accumulators lack the required energy density and recharge rate.

The bus sector is presently also dominated by the Diesel engine. However in urban conditions the Diesel engine operates mainly on part load with poor efficiency and there is concern over poor performance, excessive noise, vibration and emissions and high maintenance costs.

In a hybrid system, the primary power rating is sized to cover the mean vehicle losses, rather than the peak demand. For urban conditions, this can be below

50% of the rating of a conventional engine. Where the transmission system is electric, as on the vehicle mentioned above, multimodal operation is facilitated by having a common DC link as shown in figure 2.

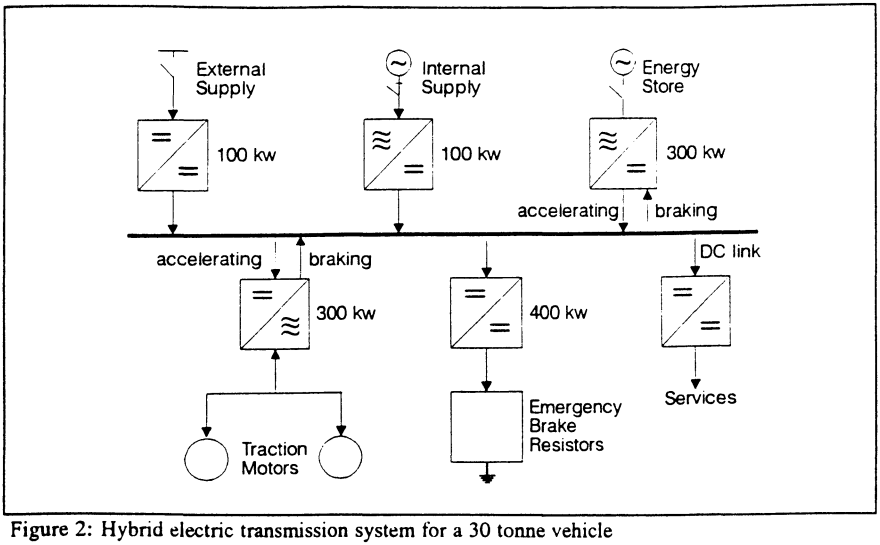


Figure 2: Hybrid electric transmission system for a 30 tonne vehicle

The requirement for primary power can therefore be set at a continuous uniform level corresponding to the mean vehicle losses. If the supply is external then the peak demand on this supply can be significantly reduced, so allowing increased route capacity, as in the case of the Basel trolleybus system [2]. If the supply is internal then it can be met by a relatively small power source designed for constant power output at maximum efficiency. Power sources to be considered are:

Diesel electric

This could be a conventional diesel engine running under optimum operating conditions (speed and load) for minimum emission, driving an alternator rectifier system, possibly modified or redesigned to run on clean fuels, such as natural gas.

Gas turbine

The hybrid configuration reopens the possibility of use of the gas turbine, which has the advantage of compactness, maintenance free operation and the ability to run on a wide range of fuels, including clean biofuels and natural gas. High speed alternators are becoming available which obviate the need for a reduction gear.

Batteries

In the hybrid configuration, batteries would give extended range and increased life because of the reduced power demand and cycling frequency. The zinc air battery may well provide such primary power, having the advantage of effective rapid 'refuelling' rather than the slower process of electrical recharging.

Fuel cell

The fuel cell could provide the possibility in the medium term of using hydrogen as a fuel in a system which is entirely clean and silent. In the longer term, the development of reformers will allow the use of liquid fuels such as methanol.

5 Hybrid systems design

Hybrid systems require buffer energy storage to level the load on the primary power source. Currently, many hybrid designs involve batteries as the storage element. However, they are not suited to this application owing to their poor storage efficiency and cycle life, which is important here, since each start-stop sequence counts as one cycle. However, the supercapacitor, with its relatively high storage efficiency and cycle life, could eventually considerably enhance the performance of hybrid systems by virtue of its high power density [4].

Of the various energy storage devices available, flywheels offer the best performance, having a high power density on charge and discharge, high cycle life and acceptable short term storage efficiency. The disadvantage of low energy density and limited storage time do not weigh heavily in this application, since the energy storage is not expected to provide for long range operation.

The energy storage device should be designed to provide power for propulsion from one stop to the next and should therefore be capable of storing kinetic energy corresponding to the maximum speed, for full performance. In urban conditions, stopping distances are short and maximum speeds, thus energy storage requirements are relatively low, so that energy density is not so critical.

Flywheels have proved satisfactory in this application and the magnetodynamic storage system (MDS) has been successfully demonstrated on a bus in service in Munich [3]. This bus has all the features of a trolleybus and a fleet of trolleybuses incorporating the MDS is in operation in Basel. The purpose is therefore to reduce the demand on the supply and therefore to reduce headway, to allow limited operation of the vehicle off line (about 2km) and to allow full regenerative braking.

Since the Karlsruhe model has left the experimental stage and has proven very successful, there is now increasing interest from network operators in a dual or multi mode vehicle, able to operate on electrified and/or unelectrified routes [5, 6].

Hybrid propulsion systems offer the opportunity to operate passenger transport services over unelectrified routes to the standard of performance expected from an electrified system, without the considerable costs of electrification. Electric transmission permits multimodal operation over electrified and unelectrified routes. This opens up the possibility, for instance, of extending urban rail networks into the unelectrified hinterland. The hybrid propulsion system is predicted to be the most energy efficient because of the assured brake energy recovery and the energy consumption of a hybrid rail vehicle is predicted to be in the order of 220kJ per passenger km [4]. Because of the reduced size and optimised operating conditions of the primary power source, future emissions regulations should be met without difficulty. The opportunities for environmental improvement over existing diesel powered systems, opened up by this measure, are therefore considerable.

6 Street Design and Urban Transport

Many railway routes and stations are isolated or at the edge of built-up areas. To use them means a long journey before starting a ride. The private car however - in almost every case- stands outside the front-door. Therefore public transport has to come near to its customers, which means that stations need to be closer to their home and destination. To achieve this public transport lines have to run through city centres. Tramways in cities throughout the world have provided access to the centres for decades. It was the growing car traffic in the fifties and sixties which lead to the displacement of tramways in many of our cities.

For architects, the tracks and the overhead power supply still today present a problem when designing urban areas - and buses are often adopted because of their 'flexibility' and low infrastructure cost. Both older examples like Karlsruhe, where all tramway and LRT-lines go through the main pedestrian zone "Kaiserstraße", or some quite recently implemented LRT-schemes like Nantes, Grenoble or Strasbourg show that the integration of LRT-schemes is not only possible but very beneficial even in close urban environments [7].

The tracks and the overhead system are the two most visible features of railbound urban transport. The tracks are necessary, if one is to combine regional railway networks with the city centres. The overhead wires however, which often are the main problem because of visual intrusion, might not be necessary if low emission propulsion technologies allow vehicles to run through city centres independantly from external power supply.

7 Bristol as an example

Taking Bristol as an example, Figure 3 shows part of an existing heavy rail network. As is the case in many cities, a change of mode between rail and bus is needed to complete the journey to the centre, which in this case is at a distance of some 1000m from the main station.

A future network could be developed in phases as shown in Figure 3:

1. The heavy rail route from Stapleton Road to Severn Beach could be deregulated to light rail, allowing more stops to be included and eventually to allow street running as required.

2. The route between Temple Meads main station and Clifton Down via the centre, currently served by buses, could be upgraded to light rail.

3. Light rail vehicles could operate between Severn Beach and Temple Meads via the centre (street running), while heavy rail compatible vehicles could operate on the existing rail route via Stapleton Road.

4. The entire network could be served by LRT-vehicles which are both heavy rail compatible and street running.

By including the whole existing heavy rail infrastructure, the network could be considerably expanded.

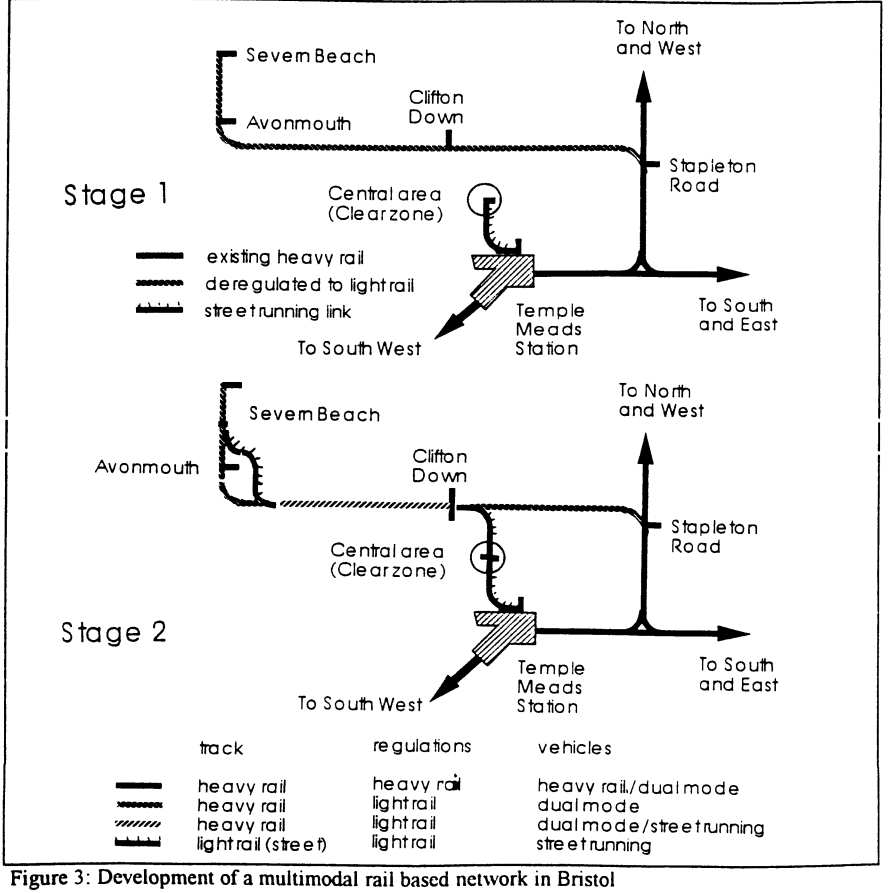


Figure 3: Development of a multimodal rail based network in Bristol

8 Summary

The development started in Karlsruhe will lead more and more to a view of public transport, which combines the capabilities of the different transport modes to form an overall integrated system. Regional and urban transport are seen as one and the distinction between railway and tramway looses importance.

Feasibility studies in many European countries [5, 6] in recent years have shown that new opportunities are created by new vehicle technologies.

The rail vehicle of the future will be multimodal, providing the opportunity for significant environmental improvement and increased social cohesion and economic development by the combination of regional and urban transport networks.

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