FOREIGN LIGHT RAIL VEHICLE DEVELOPMENT

Joachim von Rohr, Rheinische Bahngesellschaft AG,
Düsseldorf, Federal Republic of Germany

This paper begins with a brief description of how the light rail mode has been developed in several West European countries, especially in the Federal Republic of Germany. The basic features of the light rail vehicle and how the vehicle was derived from the streetcar and the subway or heavy rapid transit car are explained. Finally, the various attempts at standardization of light rail vehicles in West Germany after World War II are discussed. Several modern light rail vehicles are described, and it is explained why standardization could only be partially achieved.

This paper discusses the light rail mode in western Europe and especially West Germany. The light rail vehicles that are being used also are covered.

EVOLUTION OF THE LIGHT RAIL MODE

Outside the United States, the light rail mode has shown an interesting development in recent years, especially in some West European countries. The reasons for this are well known. Some cities are too small to justify a full-size heavy rapid transit (HRT) system, and, in both large and small cities, there is a desire to operate tunnel sections with existing streetcars as soon as they are completed. In the latter case, European countries avoid letting the large amount of money spent for the civil engineering works lie idle for a long time.

Before the first tunnel sections were actually built, many existing street running routes were transferred to private rights-of-way, and, in West Germany at least, considerable financial help was received from the federal and state governments. These sections were situated mostly in the suburbs and outside the central business district and formed the basis for the subway network in the downtown areas.

In the 1960s, some cities such as Stuttgart, Frankfurt, Cologne, Ludwigshafen, Essen, Federal Republic of Germany; Brussels, Belgium; and Vienna, Austria, started tunnel construction along their most heavily trafficked routes or on those where existing operating conditions made tunneling appear advantageous.

Of these systems, only the one in Frankfurt planned for and implemented the use of new cars considerably wider than their existing ones because the tunnel section was to be connected with 2 suburban routes on private rights-of-way with generous clearances and a new route partially in tunnel into a new satellite town (1). The other systems also built their tunnels and rights-of-way for wider cars with greater capacity but used and still use existing conventional streetcars on these routes with low platforms the edges of which extend toward the tracks. Of these cars, only the Cologne 8-axle, articulated, single-end cars that are 30 m long and 2.5 m wide are of adequate size for long-term light rail operation. The Stuttgart 4-axle, articulated cars have a rather small capacity even with multiple-unit (MU) operation, and the Belgian

Presidents' Conference Committee (PCC) cars used in Brussels and Antwerp, Belgium, are seriously handicapped by their narrow doors and car bodies. Ludwigshafen uses medium-capacity, conventional, 6-axle, articulated single-end cars that are 20 m long and 2.2 m wide, and Essen still has not yet opened its subways for local reasons (2, 3, 4).

Frankfurt decided to have its first genuine light rail route from the downtown area (railway station) to the new satellite town operated by new light rail vehicles (LRVs) of a 6-axle, articulated design, 23 m long and 2.65 m wide instead of the 2.3-m-wide, conventional, 4-, 6-, and 8-axle surface cars. The 2 connecting suburban routes could not be converted immediately to such wide car clearances because of limited financial resources and physical difficulties (freight interchange with the German Federal Railway) and are still partially operated with modified conventional cars with movable steps and a fiberglass structure along the right side of the body to bridge the gap between the platform and the narrow body of the car. As soon as both suburban lines are converted for operation of wide cars, the modified cars may be rebuilt to their original appearance or scrapped.

Further evolutionary developments have taken place almost exclusively in West Germany since 1968, and most of this paper therefore deals with cars of that country. Several types of cars have been designed that truly can be classified as LRVs. One reason for this boom in LRVs is that more West German cities (Bonn, Düsseldorf, Bielefeld, Hannover, and several cities in the Ruhr) had started subway construction about that time, but lack of money and limited construction capacity for civil and electrical engineering works as well as the impossibility of closing several major streets at 1 time for construction work had slowed down considerably the upgrading of existing streetcar routes and the construction of the new HRT lines.

DEFINITION OF THE LIGHT RAIL VEHICLE

The LRV is defined as a vehicle not as heavy as a conventional rapid transit or subway car and is usually associated with a less substantial right-of-way. Therefore, its construction is less expensive than that of HRT vehicles. The lower weight results because LRVs are less wide than HRT cars. They are less wide because they have to run on existing streetcar tracks with restricted clearances and because the car structures are designed for shorter trains and consequently lower stress levels. The generally lower passenger-carrying capacity can be compensated for in part by MU operation, which is optional with light rail transit (LRT) but mandatory with HRT.

The LRV evolved from the streetcar but has taken features from HRT cars particularly in the area of improved passenger-handling capability. The transition from LRV to HRT vehicle is fluid, and, therefore, it is difficult if not impossible to define precisely whether a certain car is a LRV or a modified HRT car. The presence of common pieces of equipment does not make such a definition easier. However, the LRV is preferred where the number of passengers to be carried in 1 direction does not exceed about 20,000/h. Because of its design, the LRV can run not only on segregated private rights-of-way but also on streets (as a streetcar) and on private rights-of-way with level crossings with other streets. It can run "on sight" without signaling, but the use of signal equipment, and even cab signaling, is desirable, especially in tunnels.

GENERAL DESCRIPTION OF THE WEST GERMAN LIGHT RAIL VEHICLE

Features that the LRV has taken from the streetcar are numerous. Overhead current collection is required because of operation on unprotected rights-of-way and third-rail clearance problems on sharp curves. A third rail also is impractical when cars have fixed or retractable steps for street loading because the third rail would not clear these steps. Pantographs are used exclusively in European tunnel operation because of their advantages over the trolley pole. That they cannot become dewired (which can be dangerous, especially in tunnels) and that they can take much higher currents from the contact wire are the advantages of pantographs. Also there is no need to change poles when cars are reversed at crossovers, which would be most impractical in tunnels. In fact, the trolley pole was almost completely phased out in most European countries by the time the light rail mode was introduced. Various types of pantographs are used including standard diamonds, semipantographs of the Faiveley type, and a design with 2 lower arms in 1 plane only.

Because of the necessity of loading from the street surface or from safety islands, LRV floor height is kept to the minimum compatible with the power rating of the motors, the gear ratio, and the wheel diameter. (All 3 parameters are interrelated.) Floor heights vary between 880 and 1000 mm; motor power ratings vary from 120 to 235 kW (monomotor trucks); and wheel diameters vary from 660 to 740 mm.

In almost all cases, the floor height is divided into 3 steps; the lowest usually is between 370 and 400 mm above the rail head (with new wheels). The remaining height between the lower step and the floor is divided equally by 1 intermediate step. This arrangement, however, is not particularly well suited for elderly or handicapped passengers. A fourth step, however, intrudes too much on floor surface at the doors, which is especially bad for double-end cars with doors on both sides of the car. A solution to this problem is to make the lowest step retractable and to divide the floor height into 4 almost equal parts (5). This arrangement will be used for the first time in the M-type standard car designed for several Ruhr area systems. The sliding retractable step should not be confused with the movable steps used alternately for low- and high-platform operation andthat close the opening in the car floor so that it is flush with the car side leaving only the usual gap between the floor and the platform. Both movable and retractable steps can be used simultaneously, as on the Rhein-Ruhr and Rhein-Sieg Stadtbahn B car, which already is in operation in Bonn and Cologne.

Folding doors are used on most cars for 2 reasons, which are simplicity and suitability for electric operation. Although many LRVs are all-electric cars, even those that have compressed air equipment do not necessarily use it for the doors. Some cars, however, use swing-slide or plug doors that do not occupy space inside the car when opened but are more sensitive to collisions. For such doors, compressed air is more suitable. When closed, these doors are flush with the car sides. When opening, the doors first swing out perpendicular to the side panel of the car and slide parallel to the panel at a distance of about 100 mm until the doorway is fully opened. Because these doors can open under pressure from the inside of the car (by passengers leaning against or pushing on the doors), mechanical locks must provided. This leads to a more complicated design than that for folding doors.

Light rail vehicles often may have to use existing streetcar lines with restricted clearances and where short radius curves are common. Short radius curves can be defined as being below 150 m in normal operation and 70 m for shops and yards. Minimum radius for cars running on tracks designed for streetcar operation is between 15 and 25 m. Overhead current collection is mandatory in these cases because the under-floor equipment of the cars, including steps, would not clear a third rail. The foregoing requires the cars to be articulated to permit shorter truck-center distances and thus reduce overhang in curves. With adequate clearances on tangent tracks, cars wider than nonarticulated cars of practical length may be used. Another reason is for using articulated cars to permit passengers to travel through the whole car regardless of curves and to provide a large 1-operater car that the driver can oversee (6). Articulated cars were built in the United States as early as 1915; they were introduced in Europe, especially in Italy, before and during World War II and were developed significantly and mass produced after 1956 in several European countries, especially in West Germany.

With articulated cars, usually only the 2-end trucks are motored, either with 1 motor per truck (monomotor truck) or 2 as on many Dutch articulated cars. Monomotor trucks make maximum use of adhesion; with their coupled axles, the effects of weight transfer are automatically compensated for. This is most useful when not all trucks are motored. This is the case for trucks under articulations that usually cannot be motored because of the reduced space available, especially if monomotor trucks are used. (With 6-axle cars, the resulting 3 motors would also create problems with series-parallel and dynamic braking control.) When 2-motor trucks are provided, special truck designs may permit motoring axles under articulations. Some 6-axle HRT cars have been built that use 6 × 200 V motors; Brussels 6-axle PCC streetcars use 6 × 300 V motors and 2 complete sets of controls. Any nonmotored axle or truck, of course, reduces performance, especially on 8-axle cars where up to 40 percent of the total weight may rest on these. Accordingly, European cars use all types of drives, depending on the wishes of the operators and the topography of the systems. For example, Freiburg, Germany, has recently acquired 8-axle articulated cars on which all axles are powered. In West Germany, principally monomotor drives are used, however, and they are being used more and more in other countries.

Resilient wheels are used on most European LRVs mostly to reduce the noise resulting from wheel squealing in short radius curves and general rolling noise. Noise levels inside modern cars should not exceed 75 dBA, but 70 dBA can be achieved on good tracks with good wheel and track maintenance (grinding). Wear of tires, particularly on the flanges, also is reduced with resilient wheels.

Contrary to HRT practice, where doors are opened and closed by the driver or conductor regardless of whether passengers board or leave the cars, LRVs usually are provided with a door-control system that permits passengers to open the doors inside and outside the cars by pressing buttons after the local door control has been activated by the driver. Electrical interlocking ensures that this is possible only when the car is stopped. Doors close about 4 s after a passenger has left a step treadle or ceased to interrupt a light beam across the door opening. The light beam is sent out by a lamp and reflected by a mirror into a photoelectric cell. This kind of door control usually is combined with a system that permits the passenger to signal the driver to stop the car at the next stop by pressing the same buttons as are used for the doors. (In surface operation, not all stops are compulsory.) The reason for this scheme is to avoid opening all doors of a car or train when only a few passengers board or alight; this reduces wear on the door mechanisms and prevents the escape of heat from the cars during the cold season.

Government regulations usually require any cars operated "on sight" to be fitted with a brake system that is independent of the adhesion between wheels and rails. This brake system is provided by magnetic track brakes that are operated by the driver in emergencies. They also are included in the emergency brake system that can be operated by the passengers.

For safety reasons, cars also have to be provided with sanders placed before the first axle of each motored truck. Double-end cars thus require sanders at both axles of the trucks. The sanders are tubes with gates through which sand can fall on the rails in front of the wheels to increase adhesion and reduce braking distances in emergencies. They also can be used during acceleration to prevent wheels from spinning.

Because of the many junctions found within surface networks, a considerable number of track switches have to be set for each route. It would be uneconomic and inconvenient to operate these switches manually by switch tenders or by the drivers with the usual switch iron (the driver can do so if necessary). Therefore, the track switches are provided with electric drives (motor or solenoid) that can be actuated by the driver by either the conventional power-and-coast method or by inductive control coupled to wayside equipment. The inductive control also can be used for preemption of traffic lights. At junctions, such preemption can be made depending on the position of the track switches so that the proceed signal is given only for that direction for which the switch is set. Preemption of traffic lights can, however, also be achieved when no inductive equipment is available. Overhead contacts touched by the pantograph shoe are used in this case. Where buses use the paved-in rights-of-way of LRVs, they also can preempt traffic signals when inductive equipment is used. This equipment also can be used for the automatic setting of all track switches for a route by means of coded signals transmitted to wayside equipment as well as for setting destination indicators in stations and for transmitting the position of each car to a central control room.

In Europe, all passengers are required to carry tickets or fare receipts that indicate that their fares have been paid. These are inspected at random by roving inspectors who are empowered to levy spot fines against those without prepaid tickets, receipts, or other proof of fare payment. (In West Germany, the fine is currently 8 dollars.) Thus, European streetcar and light rail systems do not require passengers to file by a fare box to deposit their fares as is the custom in the United States. On many European transit systems, especially those in Germany, passengers are permitted to board and leave cars by whatever door they choose. However, when they have no fare receipt or ticket and must purchase one, they must board at the front door close to the driver. Light rail vehicles thus have at least a single door close to the driver's cab. In some cases this door is only on the right (near) side of the car to give more space for the driver's cab. Sometimes it is also on the left. If there are center island platforms (with left-side loading) and if these stations are provided with ticket-selling machines so that the driver does not have to sell any tickets, it is possible to omit the left-side door.

There are features that the LRV has taken from the HRT car. The LRV must be able to reverse in tunnels or on surface crossovers because underground loops are costly and difficult to build. In addition, piece-by-piece construction of LRT lines in tunnels or on the surface, temporary cutting of surface routes due to tunnel construction, and space difficulties in constructing surface turning loops make a double-end car design with doors on both sides advantageous. With a few exceptions, streetcars generally were single ended and thus required turning loops or Ys (track triangles) for reversing the direction of travel. Another reason for doors on both sides is center island platforms, which sometimes are used in subway and even surface stations (7).

Some car designs incorporate movable steps to permit loading from either high-level platforms or from the street surface as is done with streetcars. Such steps, however, are very expensive to manufacture and maintain. They are also extremely sensitive to collisions. If the headway on the LRT lines is not too short, the gain in loading time with movable steps is not important, and fixed steps for loading from low platforms would be preferred. In this case, special precautions must be taken for the day when HRT cars will be introduced. The platform height must be increased to the floor level of HRT within a short time. This is done first for half of the station length (with reduced LRT train length for that time). After the vehicle change, the other half of the platform has to be raised (with reduced HRT train length until the work is finished). This will be done in Brussels and may be done in Düsseldorf. The various step and platform heights show that this problem is complex and highly dependent on local conditions.

Light rail vehicles generally are built for higher maximum speeds and higher acceleration and deceleration values than streetcars are. Maximum speeds of 80 to 100 km/h are usual. Accelerations on level track for empty cars are around 1.2 m/s^2; decelerations are about 1.5 m/s^2. Emergency brake decelerations (with sand and use of track brakes) are about 3.5 to 4 m/s^2. However, there are limits to the normal values because of nonmotored trucks and for the comfort of passengers.

Multiple-unit control is used extensively with modern LRVs especially to increase the number of cars per hour on those sections that are used by more than 1 route. Acceleration and deceleration are controlled semiautomatically, which is similar to that for PCC and HRT cars. Anti-wheel-slip and anti-wheel-spin control as well as maximum deceleration for emergency brake applications also are provided.

Restricted visibility for the drivers in subways does not permit operation "on sight"; therefore, block signals are provided in such sections. Automatic train control (ATC) and automatic train stop (ATS) equipment thus is necessary. These provide an emergency brake application if a stop signal is passed. Wayside equipment consists of electromagnets placed between or alongside the rails to act on the car equipment when required. Under special conditions, a stop signal may be passed at low speed. This equipment may be combined with that used for actuating electric track switches and preempting traffic lights. The deadman control, used more and more on LRVs, is combined with the ATC.

Overhead line voltage is often increased from the usual 600 Vdc to 750 Vdc for 2 reasons: (a) to increase the power output of the traction motors without increasing their size and (b) to reduce voltage drops and power losses in the overhead contact wire system.

Compressed air equipment sometimes is used on LRVs although most streetcars built in Europe after 1945 have been all-electric cars. The amount of such equipment can be quite different. Some cars have as complete an air system as an HRT car does, and others use air merely to operate accessories such as sanders and mirrors. The decision to use compressed air for LRVs is rather arbitrary, but, because of space problems and the increased friction brake performance requirements on larger, faster cars, compressed air sometimes is indispensable. Its availability also permits the use of air springs for secondary (body) suspension.

Streetcars, especially single-end cars, rarely have fully enclosed cabs because there is no need to lock up the control equipment. In double-end cars and for MU operation, rear-end driving positions must be locked to prevent access by passengers and to prevent damage to the equipment. An opening in the door is provided to permit sale of tickets. It is closed by a vertical sliding glass pane. A ticket-issuing machine combined with coin changer and fare box can be fitted in the opening. Tickets or fare receipts also can be issued from a block instead of a machine. In both cases such tickets need not be specially canceled. For multiride tickets, which are common in Germany and are generally sold by machines on the platforms, tobacconists, and the like, several cancelers are provided in each car usually near the doors. In experiments, some cars have been provided with ticket-selling machines to be operated by the passenger, but such machines are still not working satisfactorily.

WEST GERMAN LIGHT RAIL VEHICLES AND STANDARDIZATION

It is not possible to present here a detailed description of the 6 or 7 LRV cars built in West Germany after 1968. Table 1 gives the most important dimensions and technical data of these cars as do Figures 1 through 10. It is interesting to look at standardization, which was so admirably achieved 40 years ago with the PCC car.

The first attempts for standardization were made before, during, and shortly after World War II, but it covered only conventional 2-axle streetcars. About 1956, when modern designs of double truck and articulated cars became available, most West German systems so desperately needed to replace their worn-out cars, which in some cases were built before World War I, that they ordered large numbers of cars without bothering about standardization. Also development of trucks, motors, gears, and electric equipment was still far from a state that would permit standardization. The individual systems, however, generally adhered to 1 design after it had been proved successful. Therefore, cars within 1 system were almost all alike. A certain standardization resulted because 1 manufacturer supplied about 70 percent of the cars at that time and others built their cars totally or partially under license to this 1 manufacturer. This policy continued until about 1970 when most systems had more or less renewed their fleets and the market had shrunk to such a degree that only 5 manufacturers stayed in the business. The major manufacturer covered about 90 percent of the market, and 3 others were building cars under license to that one. Further orders could only be expected from large- and medium-size systems especially because the planned upgrading of their streetcar routes to HRT routes (within the Stadtbahn Rhein-Ruhr and Rhein-Sieg schemes) had slowed down considerably.

In 1966, the Rail Vehicle Committee of the West German Association of Public Transit Properties (VÖV) began to develop recommendations for the standardization of LRVs and HRT cars. At that time, no vehicles existed in West Germany that could be classified as genuine LRVs. When the recommendations of the committee were finally published in 1969, they covered only a single-ended, 6-axle, articulated LRV and 2 types of HRT cars. By this time, however, the first true LRV already had been built for Frankfurt (Figure 1) and had been in operation for more than a year (1, 8). Two other systems, in Cologne and Stuttgart, had opened tunnel sections with conven-

Table 1. Dimensions and technical data for West German light rail vehicles.

Type of Car	Number of Cars	Year Built	Track Gauge	Axles		Weight When Empty (Mg)		Car Length Over Coupler Faces (m)	Car Width (m)	Truck Center Distances (m)	Truck Wheelbase (m)	Floor Height Above Rail (mm)	Number of Steps		
				Total	Motored	Total	Adhesion						Fixed	Movable	Retractable
Frankfurt U2	65	1968 to 1975	Standard	6	4	26.7	20	24.0	2.65	2 × 7.72	1.8	970	1	–	–
P8	100	1972 to 1977	Standard	8	4	34.5	22	28.7	2.35	2 × 6.5 + 7.1	1.8	960	1	1	–
Hannover 6000	100	1974 to 1976	Standard	8	4	38.8	23.4	28.3	2.4	3 × 6.4	1.8	940	1	1	–
Düsseldorf 3000	69	1973 to 1975	Standard	8	4	34	20.5	26.2	2.4	2 × 6.2 + 6.5	1.8	880	2	–	–
Bonn and Cologne B	110	1973 to 1977	Standard	6	4	38	26.5	26.9	2.65	2 × 10.0	2.1	1000	1	1	1
Ruhr and Bielefeld M6	22	1975 to 1977	Meter	6	4	27.8	21.5	20.4	2.3	2 × 6.2	1.8	880	2	–	1
M8	31	1975 to 1977	Meter	8	4	34.5	21.5	26.6	2.3	3 × 6.2	1.8	880	2	–	1
Bremen 500	22	1973	Standard	4	4	21	21	17.4	2.3	8.35	1.8	850	2	–	–

Type of Car	Step Height Above Rail (mm)	Wheel Diameter (mm)	Minimum Curve Radius (m)	Number of Seats	Seat Arrangement	Standing Capacity[a]	Motors		Type of Control	Compressed Air Equipment	Doors		Maximum Speed (km/h)[b]	Car Builders
							Number	Power Rating (kW)			Type	Operation		
Frankfurt U2	680 + 290	710	25	64	2 + 2	100	2	150	Motor-driven camshaft	No	Folding	Electric	80	DÜWAG, Siemens, AEG
P8	400 + 295 + 265	670	18	62	2 + 1	110	2	120	Motor-driven camshaft	No	Folding	Electric	70	DÜWAG, Siemens, AEG
Hannover 6000	390 + 295 + 260	730	17.5	46	2 + 1	105	2	217	Thyristor chopper	Yes	Folding	Electric	80	DÜWAG, Siemens, Kiepe, AEG
Düsseldorf 3000	360 + 260 + 260	670	18	51	2 + 1	90	2	150	Electromagnetic contactor	No	Folding	Electric	80	DÜWAG, Siemens, Kiepe
Bonn and Cologne B	400 + 300 + 300	740	25	72	2 + 2	110	2	235	Motor-driven camshaft	Yes	Plug	Pneumatic	100	DÜWAG, Siemens, Kiepe
Ruhr and Bielefeld M6	280 + 200 + 200 + 200	680	14.5	36	2 + 1	65	2	150	Electromagnetic contactor	Yes	Folding	Electric	80	DÜWAG, Siemens, BBC
M8	280 + 200 + 200 + 200	680	14.5	54	2 + 1	85	2	150	Electromagnetic contactor	Yes	Folding	Electric	80	DÜWAG, Siemens, BBC
Bremen 500	335 + 255 + 250	680	16	44	2 + 1	56	2	120	Hand-operated camshaft	Yes	Plug	Pneumatic	70	Wegmann, Kiepe, AEG

[a] 4 passengers/mile^2. [b] Empty, level truck.

Figure 1. Frankfurt U 2 car, general view.

Figure 2. Frankfurt U 2 car, principal dimensions.

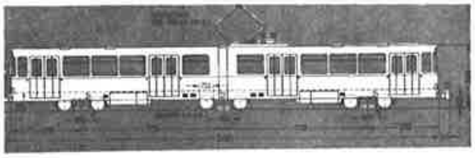


Figure 3. Frankfurt P 8 car, general view.

Figure 4. Frankfurt P 8 car, principal dimensions.

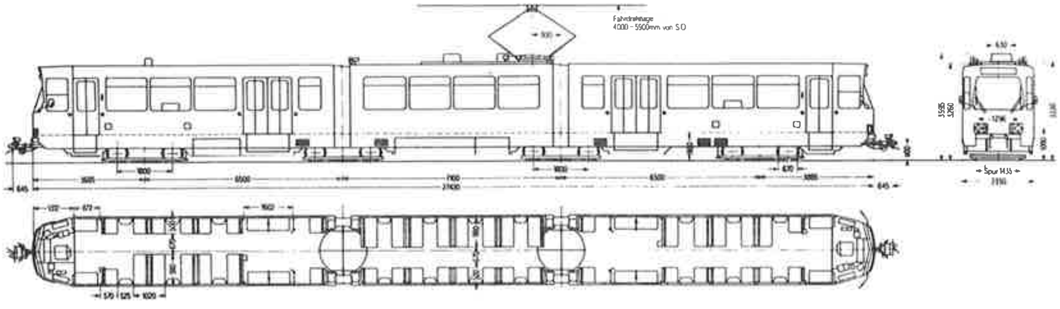


Figure 5. Hannover 6000 car, general view.

Figure 6. Hannover 6000 car, principal dimensions.

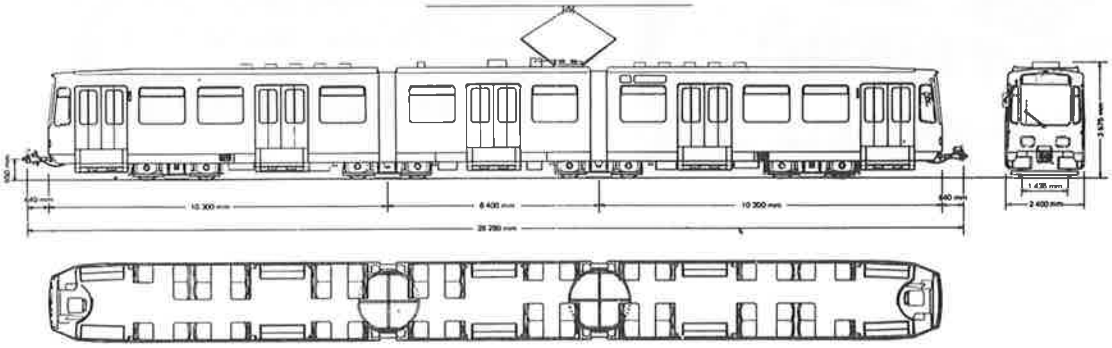


Figure 7. Düsseldorf 3000 two-car train, general view.

Figure 8. Düsseldorf 3000 car, principal dimensions.

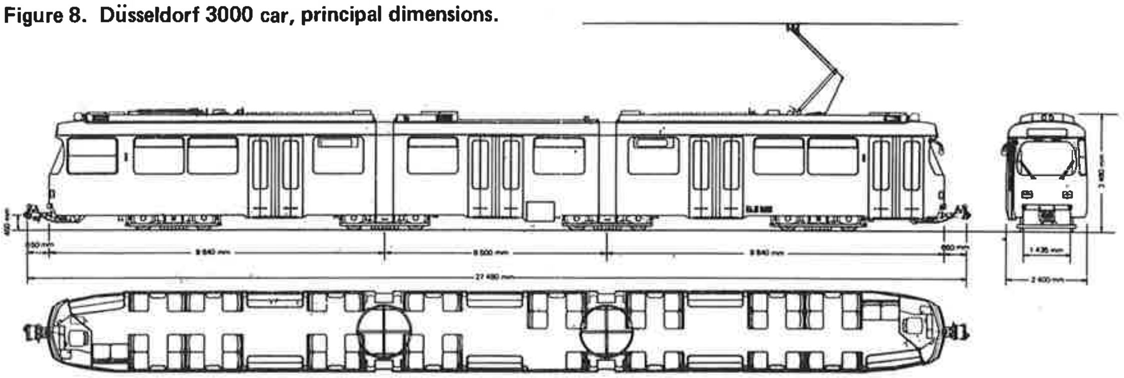
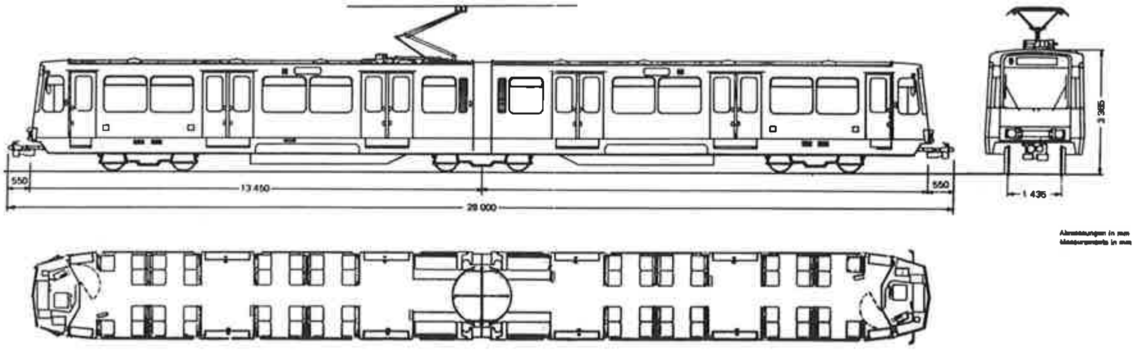


Figure 9. Bonn and Cologne B-car, general view.

Figure 10. Bonn and Cologne B-car, principal dimensions.



tional streetcars modified slightly by the addition of inductive equipment for ATC and operating track switches. Other West German transit systems, such as those in Düsseldorf, Dortmund, Duisburg, and Frankfurt, had plans to replace their remaining 2-axle cars in 1971 or 1972. In some cases, these replacement cars were intended to be used as LRVs in tunnels. When the operators checked the recommendations, they soon found out that they could not easily use the VÖV 6-axle car for 3 reasons.

1. The required car width of 2.4 m could be used only in Düsseldorf without major track relocations. The other systems could use only cars with a maximum width of 2.3 m.
2. The car had to be double ended.
3. The 6-axle car was considered too small for single-car operation. All the systems mentioned wanted an 8-axle car.

The problem of item 3 could be solved easily by adding a center section, but the car width would have to be reduced to 2.3 m. Frankfurt, which needed cars most urgently, had decided to go ahead with its own development, which resulted in the P 8 car, which was 2.3 m wide and incorporated much of the equipment parts previously used in the U 2 car (9, 10). For subway operation on routes that also ran on surface street tracks, about 30 of the cars were built with movable steps. Düsseldorf had begun to develop its 3000-class cars, which at present come closest to the VÖV recommendations both in dimensions and interior and electrical equipment. In 1972, Düsseldorf itself tried to get Duisburg, Dortmund, and Essen fixed on 1 common design based on its 3000-class cars, but, apart from the car width problem, it was impossible for various other reasons to reach an agreement among the 4 systems. The 3000-class cars were already under construction, and it would have been difficult to modify the design at that time to meet the requirements of the other systems (11, 12, 13, 14).

Meanwhile, Cologne and Bonn had started to develop a 6-axle, articulated car suitable for their subway and LRT lines with financial support from the Nordrhein-Westfalen state government because Cologne had started tunnel construction long before the Stadtbahn Rhein-Ruhr scheme was set up in 1969 and could not use the A-car. This A-car consisted of 2 semipermanently coupled, 100-km/h, 4-axle cars that were 2.65 m wide. It was designed for the Rhein-Ruhr scheme including the proposed local subway routes of the Ruhr area cities from Duisburg to Dortmund and for Düsseldorf. Their efforts resulted in the 100-km/h Stadtbahn B-car, 110 units of which are in service or under construction for Cologne, Bonn, and the Essen-Mülheim standard gauge Stadtbahn route (15, 16, 17, 18, 19). This car also will be used on the Cologne-Bonner Eisenbahn system when it is merged into the Stadtbahn Rhein-Sieg scheme (20). It also is intended to be used in Düsseldorf on the intercity routes to Krefeld and Duisburg in about 1982. The B-car thus can be regarded as a standardized car although it is likely that the cars in Düsseldorf will be different in some details because of the technical evolution that probably will have occurred by then. For example, chopper control may be used instead of motor-driven camshaft controllers. The B-car is likely to be included in the VÖV recommendations.

Hannover got two 6-axle prototype cars from 2 manufacturers in 1972. The cars are 2.5 m wide. After they had tested them thoroughly, Hannover ordered 100 cars of the more successful design but with 8 axles. Width was reduced to 2.4 m to permit unlimited use on the entire system, but the VÖV recommendations were respected only partially. These are the first cars with chopper control equipment (18). (The chopper is regenerative.)

The last move in standardization was made in 1973 and 1974 when the 3 central Ruhr area systems of Mülheim, Essen, and Bochum-Gelsenkirchen decided to place a joint order for about 50 cars. The small system of Bielefeld, which is halfway between Hannover and the Ruhr area, later ordered some cars of the same design. Because of the rather small track center distances, the cars could only be 2.3 m wide (the 4 systems had previously used cars 2.2 m wide). All 4 systems use meter gauge; therefore, the cars are called M-cars. Unlike the 8-axle designs for Frankfurt, Düsseldorf, and Hannover, the center section of the 8-axle M-car is neutral; that is, this section has no electric equipment parts necessary for the operation of the car. The M-car therefore can be built as a 6-axle or an 8-axle car. Bochum-Gelsenkirchen ordered only 6-axle cars; the other systems ordered 8-axle cars. The VÖV recommendations were respected as much as possible, but low first and operating costs were emphasized.

The foregoing clearly shows that complete standardization has not and cannot yet be achieved because local conditions are too different and because fixation of a car design for a long time would seriously hamper technical progress and development. The VÖV Rail Vehicle Committee therefore will limit its future work to standardization of equipment parts and groups for such cars and will give recommendations only for basic dimensions.

ACKNOWLEDGMENTS

In compiling this paper, I was assisted by the following transportation systems and manufacturers: Stadtwerke Bonn, Verkehrsbetriebe, Bonn; Bremer Strassenbahn AG, Bremen; Rheinische Bahngesellschaft AG, Düsseldorf; Essener Verkehrs-AG, Essen; Stadtwerke Frankfurt am Main, Verkehrsbetriebe, Frankfurt; Hannoversche Verkehrsbetriebe AG, Hannover; Waggonfabrik Uerdingen AG, Werk Düsseldorf, Düsseldorf; and Waggonfabrik Wegmann and Co., Kassel. Their help is fully appreciated.

REFERENCES

1. J. Fester. U-Strassenbahnen oder U-Bahnen? Nahverkehrspraxis, Dortmund, Germany, No. 7, 1964, pp. 282-286.
2. G. Groche. Die Stuttgarter U-Bahnkonzeption. Nahverkehrspraxis, Dortmund, Germany, No. 11, 1969, pp. 539-542.
3. W. Semmler. Der I. Bauabschnitt der U-Strassenbahn in Ludwigshafen. Nahverkehrspraxis, Dortmund, Germany, No. 8, 1969, pp. 390-393.
4. E. Thiemer. Warum U-Strassenbahn in Essen? Nahverkehrspraxis, Dortmund, Germany, No. 7, 1964, pp. 287-296.
5. H. Ahlbrecht. Stand und Entwicklung der Fahrzeuge moderner Stadt- und Strassenbahnen. Technische Mitteilungen des Hauses der Technik, Essen, Germany, No. 3, 1975, pp. 87-99.
6. H. Goltz. Die Zukunft der U-Bahn. Verkehr und Technik, Bielefeld, Germany, No. 2, 1975, pp. 41-43.
7. H. Ahlbrecht. Kommt der Zweirichtungswagen wieder? In Zur Frage des zweckmässigsten Fahrzeuges für die Weiterentwicklung der Strassenbahn zur Stadtbahn, Der Stadtverkehr, Bielefeld, Germany, Nos. 11-12, 1972, pp. 352-357.
8. W. Hofmann. Elektrische Ausrüstung für die Stadtbahnwagen U 2 der Stadtwerke Frankfurt am Main. Nahverkehrspraxis, Dortmund, Germany, No. 9, 1969, pp. 457-467.
9. H. Oesterling. Neue Doppelgelenk-Triebwagen für Zweirichtungs-verkehr, Bauart P 8, Stadtwerke Frankfurt am Main. Der Stadtverkehr, Bielefeld, Germany, No. 3, 1972, pp. 84-86.
10. E. Houzer, G. Scholtis, and G. Wolff. Elektrische Steuerung mit Simatic für Gleichstrom-Nahverkehrs-Triebwagen. Elektrische Bahnen, Munich, Germany, No. 10, 1969, pp. 220-233.
11. H. Scheucken. Neue Stadtbahn-Fahrzeuge in Düsseldorf. Verkehr und Technik, Bielefeld, Germany, No. 9, 1974, pp. 321-331.
12. Verkehr und Technik. Bielefeld, Germany, No. 10, 1974, pp. 374-386.
13. W. Hofmann. Elektrische Steuerung in integrierter Bauweise für Gleichstrom-Nahverkehrs-Triebwagen. Nahverkehrspraxis, Dortmund, Germany, No. 11, 1972, pp. 464-470.
14. Nahverkehrspraxis. Dortmund, Germany, No. 12, 1972, pp. 504-512.

15. H. Scheucken. Neue Stadtbahn- und U-Bahn-Fahrzeuge. Nahverkehrspraxis, Dortmund, Germany, No. 11, 1971, pp. 451-461.
16. Nahverkehrspraxis. Dortmund, Germany, No. 12, 1971, pp. 500-507.
17. Der neue Stadtbahn-Wagen B. Nahverkehrspraxis, Dortmund, Germany, No. 6, 1973, p. 234.
18. W. Stock. Der Stadtbahn-Betrieb in Bonn. Der Stadtverkehr, Bielefeld, Germany, No. 4, 1975, pp. 133-137.
19. Stadtbahn Rhein/Sieg in Bonn, Eröffnung am 22.3.1975. Der Stadtverkehr, Bielefeld, Germany, Nos. 11-12, 1974, 24 pp.
20. H. Braitsch. Köln-Bonn LRT Route Will Be Completed in 3 Years. Railway Gazette International, London, No. 5, 1975, pp. 175-178.
21. W. Stock. 100 Stadtbahn-Wagen für Hannover. Der Stadtverkehr, Bielefeld, Germany, No. 4, 1975.
22. H. Ahlbrecht. Stadtbahn-Wagen M, ein Vorbericht. Der Stadtverkehr, Bielefeld, Germany, No. 3, 1975, pp. 98-100.
23. D. Neubronner. Der Stadtbahn-Wagen Bremen. Der Stadtverkehr, Bielefeld, Germany, Nos. 5-6, 1973, pp. 144-148.
24. K.-H. Schade and G. Scholtis. Elektrische Ausrüstung für moderne Stadtbahnwagen. Der Stadtverkehr, Bielefeld, Germany, No. 1, 1974, pp. 22-26.
25. F. Wallochny and E. Hegner. Lüftungs- und Klima-Anlagen für Nahverkehrsfahrzeuge. Nahverkehrspraxis, Dortmund, Germany, No. 4, 1974, pp. 138-142.
26. Designing a Car for the Tramway/Metro Transition. Railway Gazette International, London, No. 5, 1975, pp. 178-181.
27. T. Parkinson. All Aboard the LRT Band Wagon. Railway Gazette International, London, No. 5, 1975, pp. 181-184.
28. US and Canada Develop Standard Trams. Railway Gazette International, London, No. 5, 1975, pp. 182-183.
29. H. Reinfeld. Zur Frage des Strassenbahn-Antriebs mit gekuppelten Achsen. Nahverkehrspraxis, Dortmund, Germany, No. 1, 1967, p. 6.
30. H. Reinfeld. Haftreibungsbeiwert gekuppelter Strassenbahn-Triebachsen. Nahverkehrspraxis, Dortmund, Germany, No. 2, 1967, pp. 36-38.
31. H. Scheucken. Konstruktive Tendenzen im Fahrzeugbau schienengebundener Nahverkehrsmittel. Schriftenreihe Verkehr und Technik, No. 41, Bielefeld, Germany.
32. Typenempfehlung für Schienenfahrzeuge des Öffentlichen Personen-Nahverkehrs. Verband Öffentlicher Verkehrsbetriebe, Cologne, Germany, No. 6.030.1, Oct, 10, 1969.