with expected revenues. This might be the critical element, given today's concern with financial performance.

CONCLUSIONS

More work must be done, but certain conclusions have already emerged. One is that there is little doubt that a light rail line can provide more economical service than an all-bus operation. A fleet of only 8 vehicles could carry the estimated passenger loads. In Rochester and most other places examined recently the rail concept has a clear advantage. It is not as certain that light rail can be self-sufficient, but the indications are favorable. It depends primarily on fare levels and revenue allocation.

No decision has been reached in Rochester. To some, the situation is encouraging, and light rail service is most attractive. Others see dangers and uncertainties. But the greatest concern is the amount of capital resources needed to implement it and where the resources will come from. Basically the issue is how society perceives the role and benefits of efficient mass transit. The evaluation will never be purely quantitative and explicit. Even using the worst set of assumptions, a light rail service in Rochester would draw 5000 riders away from automobiles and place them on public transit. This result will be interpreted differently by different people—as an additional burden on hard-pressed, subsidized public operations or as a welcome strengthening of an appropriate and efficient urban service.

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Cologne's Contribution to the Light Rail Concept

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West Germany has been one of the most active countries in the development and application of light rail transit. Cologne (Köln) is the largest West German city to rely upon LRT (Stadtbahn) instead of full rapid transit (U-Bahn) as the primary rail transit mode. The LRT system, operated by the Kölner-Verkehrs-Betriebe (KVB), has developed in a well-planned, gradual manner from a basic streetcar system to a high-performance LRT network. The system was built by adapting the right-of-way to the physical and operating environment. Therefore, most of the 30 km of fully separated right-of-way are located in the heavily congested city center. Most lines reenter the surface after leaving downtown, but retain some form of priority right-of-way.

To operate on the improved rights-of-way, the KVB developed and purchased the B-car, one of the highest performance cars in West Germany, but a car that is still flexible enough to operate on all surface sections, including conventional streetrunning. Other areas of investment, such as electrification, signals, and track, have kept pace with the overall system improvement. The result of these developments has been steadily improving performance and a ridership level that totaled 175.8 million passengers (LRT and bus) in 1980.

Many of the technical and operating elements can be seen in the new intercity light rail line that runs from Cologne to Bonn. The route was converted from a declining commuter railroad operation to LRT in 1977 after several technical and institutional problems had been overcome. Improved service and integration of the former rail system into the LRT networks in Cologne and Bonn led to dramatic ridership gains.

The city of Cologne (Köln), with a population of 1 million is the fourth largest city in the Federal Republic of Germany (West Germany). It is located along the Rhine River in the heart of the industrial and commercial center of West Germany.

Three larger German cities, West Berlin, Hamburg, and Munich, have transit systems that emphasize rapid transit; thus Cologne is the largest German city to rely upon transit LRT as the major rail mode for local travel. The combination of an extensive network and implementation of important technical and operating concepts makes Cologne a major contributor to the international development of light rail.

Public transportation in Cologne is carried out primarily by the Kölner-Verkehrs-Betriebe (KVB), a transit company owned by the city of Cologne. The backbone of the KVB network is the Stadtbahn, or light rail system.

The light rail system has experienced constant growth in terms of ridership, line length, and performance. This trend is the result of a well-planned effort to upgrade the rail transit system from a conventional streetcar to a high-quality light rail mode. The success of this effort in Cologne provides an excellent example of how a basic LRT system can undergo gradual, evolutionary changes to become a high-performance transit operation.

HISTORY

The streetcar system in Cologne was almost totally destroyed during World War II. The first priority after the war was to rebuild quickly a basic and inexpensive system. By 1954, the KVB was a stable system consisting of 144 km of streetcar lines and 148 km of bus lines.

Over the following decade, certain inadequacies became apparent. There was no north-south route through downtown and only one indirect route to the large commercial area around the train station. As the city became more motorized, automobiles were not only taking riders away from the transit system, but were also hindering the flow of streetcars in the city. There was a need for a transit service that offered higher speeds, more attractive service, and better downtown distribution. In 1962 the city began planning for the construction of downtown subway sections.

LIGHT RAIL CONCEPT

Although sections with complete right-of-way (R/W) separation (U-Bahn) were to be built, the system was not intended to be a full rapid-transit mode. The operating concept chosen from the General Transportation Plan of

1956 was that of an underground system, in which streetcars would operate in tunnels through congested areas.[1] This was viewed as a less costly alternative than rapid transit, but one that would still provide adequate capacity and level of service for a city the size of Cologne. A unified transportation plan for the city of Cologne was completed in 1972.

SYSTEM OBJECTIVES

The system was planned to operate as a Stadtbahn, or high-performance LRT. Routes could thus operate over the following types of right-of-way:

- Type A—fully separated (U-Bahn);
- Type B—partially separated, with longitudinal, physical separation from other traffic, but with grade crossings for vehicles and pedestrians, including regular street intersections; and
- Type C—surface streets with mixed traffic and no separation.

Any one route could encompass operations on one or all types of right-of-way, although no route is yet strictly a U-Bahn line.

This mode of operation has several advantages. A fully separated subway system provides safe, high-speed, reliable service; however, its high investment costs limit the number of lines that can be built and force a heavy reliance upon a trunk feeder system. In Cologne, the rapid-transit sections are but one component of the light rail system, and the system's lower overall investment cost enables a greater number of lines to be operated. For example, from the busy downtown Dom/Hauptbahnhof station, a passenger may travel to five destinations in one direction and to four destinations in the other.

RIGHT-OF-WAY

Rapid-transit sections are concentrated in the inner city or other areas where demand is high and potential hindrance from automobile traffic is greatest. As of January 1982, 30 km, or 21 percent, of the rail network consisted of U-Bahn sections. The inner city of Cologne, like many other German cities, is characterized by narrow and winding streets that are too small for any streetcar priority. Plans call for most remaining surface lines in the downtown area to be replaced by subway sections by the end of the 1990s.

Other high-priority locations for construction of tunnels are the heavily used but narrow arterial roads, such as the Kalker Hauptstrasse, Venloer Strasse, and Neusser Strasse. In the two latter sections, tunnels are to be built where heavy traffic conditions on the surface warrant a grade-separated alignment. The U-Bahn has also been used for new sections or extensions where right-of-way is easily available and new residential development produces high ridership demand. A prime example of this joint development is at Chorweiler, a "new city" built in the mid-1970s on the outskirts of Cologne. A new light rail line (KVB), a regional rail line (German Federal Railway), and an automobile expressway were built to coincide with the opening of Chorweiler.

The U-Bahn can be divided into subway tunnels, elevated viaducts, at-grade rights-of-way, and open-cut rights-of-way. Tunnels are all double-tracked and constructed by the cut-and-cover method. They are built in rectangular cross sections and without center supports unless required when passing under large structures. After tests with ballastless and tieless slab track proved successful, a reduction in tunnel height of 15 cm to 4.70 m was achieved.

The design speed of the subways is 80 km/h (50 km/h in parts of the inner city); however, allowable speeds are limited to 70 km/h due to signal, vehicle, and safety considerations. Other important design features are the following:

- Maximum gradient, 4 percent;
- Minimum radius, 120 m; and
- Maximum superelevation, 16.5 cm.

The elevated viaduct is located over part of the Gürtel highway that forms a semicircle around the outskirts of the city. Unlike most other U-Bahn lines, this route provides completely new service, as surface lines did not previously operate in this part of the city. Construction of viaducts is significantly less expensive than subways; however, for aesthetic reasons, viaducts are limited to the outskirts of the city.

All U-Bahn lines are equipped with automatic block signals and automatic train-stop and speed-control devices. Automatic train operation was not judged to be necessary, since manual control is required when the vehicles reach the surface. Most of the heavily loaded downtown stations have a signal at midplatform that enables two trains to board simultaneously. The maximum capacity of the system is 60 trains per hour; currently, 44 trains (both one- and two-car trains) per hour per direction operate over the most heavily used section between Appelhofplatz and Neumarkt. This is significant because of an at-grade crossing at Appalhofplatz.

Outside of the center city, extensive efforts are made to provide as much separation as possible using a right-of-way Type B, as both rail transit and automobile traffic flow better when the modes are separated. As a result of this policy, about 80 percent of all route kilometers have various forms of priority rights-of-way (types A and B) for rail vehicles.

The types of priority right-of-way include private right-of-way with at-grade crossings (both protected and unprotected) and physically separated right-of-way along highways. The physical separation is provided by low concrete curbs, raised concrete barriers, and shrubbery. In addition, ballasted roadbed and wooden ties prevent automobiles from conflicting with rail vehicles.

There are still a few remaining sections of conventional streetrunning; however, these are generally in locations with light traffic volumes. Two surface routes with heavy traffic conditions (Venloer Strasse and Kalker Hauptstrasse) are planned for eventual conversion to U-Bahn.

Suburban lines that do not run along highways have allowable speeds of up to 70 km/hr. These lines are not signalized except before crossing gates, where two signals are located to indicate whether the gates have been activated and lowered.

SUBWAY-SURFACE RAMPS

An important part of Cologne's transit policy is the attempt to bring a completed U-Bahn section (generally 3 to 10 km long) into operation as soon as possible. This will bring a quick return on the high investment for building subway tunnels and avoid having finished sections lie unused for years while the remaining U-Bahn network is completed.

When a section is completed, a temporary ramp is constructed to connect it to the existing surface network. Meanwhile, work continues on extending the subway. When the next tunnel section is completed, the temporary ramp is closed, and trains operate only in the U-Bahn for that section. This method brings sections of U-Bahn immediately into service and reduces public criticism of subway construction for the years of inconvenience before any benefits are realized.

VEHICLES

An important characteristic of the KVB rail network in the 1970s and 1980s is the mixed operation of conventional streetcar-type (primarily 8-axle) and 6-axle light rail vehicles. A summary of the KVB rail fleet is shown in Table 1.

The 4-axle vehicles are used only as supplements during the peak period. They are 15 m long and have a top speed of 60 km/h. Each car has two trucks, only one of which is powered by a single motor (monomotor). The 4-axle cars are operated in two-car trains and will probably be retired when new vehicles arrive. Many 4-axle cars have been converted into work cars.

Since the older streetcar-type vehicles have steps arranged only for low-level boarding, all U-Bahn stations had to be built with these platforms. All new vehicles purchased since 1972 must have the capability for the present low-level boarding and for the high-level boarding that will prevail after all U-Bahn stations are operating only with the new light rail vehicles. New vehicles must also have the flexibility to operate on rights-of-way ranging from high-speed U-Bahn and interurban (right-of-way type A) to conventional streetrunning (right-of-way type C).

In response to these needs, the KVB, in conjunction with Duewag, designed the concept for the Stadtbahnwagen B (type B Light Rail Car). The success of this design is demonstrated by its acceptance as the standard light rail vehicle of the state of Nordrhein-Westfalen, which has one of the world's largest concentrations of light rail networks. B-cars are currently operating in Mülheim/Essen, Bonn, and Düsseldorf and will soon be running in Duisburg and Dortmund.

Table 2 compares the major features of the two main types of vehicles in the KVB fleet. The increased width and longer truck center distance and wheel base prevent B-car operation on certain surface lines. However, with only 59 cars currently in service, this is not a major problem, and the restricted lines are gradually being reworked to allow B-car operation. In 1981, the KVB placed an order for 60 additional B-cars, which should be delivered by 1983. The B-cars are being phased in gradually to prepare for their operation and because the older, 8-axle cars are still in good structural and mechanical condition.

As indicated by Table 2, the B-car represents a major upgrading of design standards. Two large 235 kW motors (longitudinally mounted monomotors), one on each end truck, enable the car to accelerate at a rate of 1.2 m/s^2 to a top speed of 100 km/h, making it the fastest transit vehicle in Germany. Control is through resistors mounted under the car, and acceleration and deceleration are electronically regulated to provide smooth starting and braking rates.

Retractable steps allow boarding from high- or low-level platforms. Even after U-Bahn station platforms are raised to a height of 900 mm, many surface stations will retain low-level platforms, and the system will still require a dual-purpose vehicle.

Table 1. KVB rail fleet.

Type	Number	Builder	Year Built
4-axle	39	Westwaggon	1956
8-axle	65	Duewag	1964-66
8-axle	39	Duewag	1968
8-axle	21	Duewag	1969-70
8-axle	18	Duewag	1971
8-axle	56	Duewag	1963-65
6-axle (Stadtbahnwagen)	2	Duewag	1973-74 (prototypes)
6-axle (Stadtbahnwagen)	57	Duewag	1976-77

Table 2. Comparison of vehicles in KVB fleet.

Item	B-Car	8-Axle
Number	59	199
Years built	1976-77	1963-77
Builder	Duewag	Duewag
Length (m)	28.0[a]	29.70
Width (m)	2.65	2.50
Height (m)	3.36	3.22
Truck center dist. (m)	10/10	7.10/8.65/7.10
Wheel base (m)	2.10	1.80
Floor height (m)	1.00	0.89
Minimum radius (m)	25.0	15.0
Tare weight (t)	39.0	29.0
Weight/m^2	0.55	0.39
Maximum train length (# cars)	4	1
Driver's cabin (#)	2	1
Seats	72	82
Capacity (0.25^2/standee)	183	208
Acceleration rate (m/s^2)	1.2	1.0
Maximum speed (km/h)	100	70
Motors (kW)	2 x 235	2 x 175
Power/weight (kW/T)	12.05	12.07
Passenger boarding	High/low	Low
Body construction	LAHT steel	LAHT steel
Door channels (#)	10 (each side)	10 (one side)
Door type	Sliding plug	Folding

[a]Length over couplers; body length is 26.9 m.

TRACK

The KVB has been a leader in the development and application of concrete slab track, which does not use ties or ballast. This type of track is favored for several reasons: it allows tunnel height to be reduced up to 20 cm; it reduces weight on bridges and viaducts; it has lower track maintenance costs (ballasted track must be reworked every 3 to 4 years to maintain proper rail level); and it decreases noise levels to a range of 19 to 25 dB.

The track fasteners use rubber pads to perform the energy- and vibration-absorbing function of the ballast. The KVB recently developed the Type 1403/c fastener, or the "Cologne Egg," named for its oval shape. In this type of fastener, the rail rests on a baseplate permanently attached to a rubber collar through vulcanization. Both the baseplate and outer sleeve narrow toward the base. Directly under the baseplate is an air space that allows the plate to sink 5 mm without developing any compressive stresses in the collar, which then can resist shearing stresses. Because lateral forces are about twice those developed along the axis of the rail,[2,3] maximum absorption of shearing forces is accomplished by placing the elliptical mountings at right angles to the rail.

Use of Type 1403/c also increases the permanency of the track. Fatigue tests with 2.1 million loadings revealed the maximum elastic gauge widening to be 7 mm (it is estimated that this would be only 3 mm under normal loading conditions), and the permanent gauge widening after 2.1 million loads was only 1 mm. Even a gauge widening of 7 mm is well within the allowable safety tolerances, given the wheel dimensions.

To avoid the difficulty and expense of boring the bolts into the concrete floor, the KVB has developed a new track-laying method in which the concrete is poured around the bolts and allowed to harden. First, the track and its mountings are held in place with temporary ties under the rail while necessary adjustments in rail height and gauge are made. Wooden borders are constructed under the temporary ties to form a frame for the poured concrete. The concrete is then poured into the frames from a self-propelled vehicle on a temporary side track. The concrete fills in around the bolts and soon hardens. The temporary ties are removed, and the track is made ready for service.

The KVB now has over 22 km of slab tracks. Compared with ballasted track, slab track produces a savings in maintenance cost of DM 30 000/year. This results in an annual savings of DM 650 000 (approximately $300 000/year) in systemwide maintenance costs.[4]

The type of rail normally used in the U-Bahn is the S 41 (41 kg/m). Girder rail is used on much of the surface track. A major problem in rail maintenance is the excessive wear and high noise levels on curves. The KVB has developed two methods for solving these problems.

The first method is a setup that automatically lubricates the flanges of a passing train before it reaches the outside rail of a sharp curve (reducing the friction on the flanges of every passing train). The oil is sent through small holes drilled into the rail head from a pump activated by a train-actuated magnetic loop. The excess lubricating oil drains into a trough beside the rail, where it is filtered and sent for reuse in the pump. This method ensures that every vehicle receives proper lubrication and avoids maintenance costs involved in operating a special work train for subway track lubrication. The recycling of lubricating oil increases the time between refills and further reduces costs.

The other method involves culling out part of the rail head and rebuilding it through welding. The rebuilt rail is then grounded and put into service. Although this method costs four times more than rail in an as purchased condition, it has increased rail life on curves by as much as 12 times and its average maintenance costs are only a third of the normal costs.

The KVB places great emphasis upon standards for high-quality track. This has resulted in long-term benefits of low noise levels and lower track maintenance costs and underscores the willingness of the KVB to adopt and even take the lead in developing new technology.

OPERATIONS

The KVB operates 14 light rail and 31 bus routes daily. In 1980, KVB carried 175.8 million passengers, an increase of 1.7 percent over the previous year. A summary of 1979 KVB ridership is given below:

Category	Average Weekday	Average Saturday	Average Sunday
Total rides	886 127	440 047	258 842
Percent rail	73.0	73.1	76.2
Percent bus	27.0	26.9	23.8
Passenger/km (million)	3.505	1.681	1.063
Percent rail	76.5	76.5	79.5
Percent bus	23.5	23.5	20.5
Percent of weekday ridership	100.0	49.7	29.2
Peak hour	7:00-8:00	11:00-12:00	14:00-15:00 or 2:00-3:00
Percent rides during peak	13.1	10.5	10.7

Headways during the peak period generally range from 4 to 10 minutes; however, in the U-Bahn, several routes use the same stretch, effectively reducing headways. Most rail routes begin at 4:30 a.m. and operate until 1:15 a.m. During the peak hours, an average of 214 vehicles are required to meet demand.[5] All routes, with the exception of line 16 (the intercity line to Bonn), operate throughout the day with one-car trains.

All vehicles, buses and rail cars, are designed for one-man operation; conductors have not been used since 1967. Station loading and unloading are performed by the driver; no additional station or platform personnel are required. This one-man operation is made possible by the relatively short length of the trains (compared to rapid transit), mirrors on the side of the car, and safety devices that prevent doors from closing on a passenger. Door control devices include pressure plates, sensitive edges, and photo-sensitive cells (on B-cars and some 8-axle vehicles).

Operations control is handled primarily by four supervisors who patrol designated areas in mobile vehicles. These field supervisors act in conjunction with a supervisor in the central control tower and provide an important communication link for responding to delays and other conditions. With the many lines and junctions in the KVB rail network, there are many possibilities for diversions around a blocked section of track to avoid the loss of too much running time.

Reducing deadhead and unproductive time is an important scheduling goal. Because there are four rail and two bus depots in different parts of the city, an individual route can be supplied with vehicles from more than one depot. This reduces deadhead time from the end station to the depot. A computer optimization program obtained from Hamburg Consult is currently used to schedule bus routes and will be tested shortly for the light rail system. The objective of the program is to reduce unproductive time (layovers, running time to terminals, etc.) and minimize the number of drivers required.

Buses serve largely as feeders to the light rail network and operate mainly on the outskirts of Cologne. The KVB maintains a fleet of standard buses, but has recently purchased articulated buses to serve the rapidly growing population in outlying areas.

FARE COLLECTION

A self-service fare collection system is used that allows boarding and alighting from all doors, reduces labor requirements, and speeds service. To reduce the number of transactions, passengers are discouraged from buying single-ride tickets by a 50-percent price differential over the cost of multi-ride tickets. Only the more expensive, single-ride tickets are available from drivers, which further discourages the purchase of tickets on board the vehicle.

The following table shows a breakdown of the types of fares used during a typical weekday:

Type Fare	Number	Percent
Single-ride (adults and child)	62 303	9.5
Multiride	225 735	34.6
Weekly (adults)	106 890	16.3
Monthly (adults)	22 270	3.4
Senior citizens (monthly)	57 126	8.7
Handicapped pass	11 615	1.8
Student (weekly, monthly, yearly)	156 985	24.0
Other	10 948	1.7
Total	653 872	100.0

The effort to discourage purchase of single-fare tickets has been a success: they are used by less than 10 percent of all passengers, and only a fraction are purchased on board vehicles. A large number of school children use the system, which has enabled the city of Cologne to avoid the expense of purchasing and maintaining a separate fleet of school buses.

The only fare collection duty of the driver is to sell single-ride tickets, which, because of the pricing policies described earlier, account for only a small percentage of total ticket sales. Single-ride tickets are not available from drivers at stations on U-Bahn and other light rail sections (mainly the high speed suburban lines) because of the high speeds on these lines and the heavy passenger volume. At these locations, all tickets must be purchased in advance and are available from manned ticket booths at some subway stations or automatic ticket vending machines at all subway and designated light rail stations. Since most light rail stations are not enclosed, the machines must be sufficiently weatherproof to withstand the elements. Multi-ride tickets are available at numerous small stores and shops.

To use the system, a passenger must insert the ticket into a cancellation machine, which marks a code on the ticket, giving time, date, and location. Cancellation machines are carried on all vehicles and are also located at U-Bahn station concourses to speed flow in boarding vehicles. Weekly or monthly tickets need not be cancelled.

Key to the effectiveness of a self-service fare collection system are the roving fare controllers. These controllers travel around the system in groups of three or four and check the tickets of all passengers in the vehicle. Passengers without a valid ticket must pay a surcharge of DM 40 ($20).

Inspections are particularly vigorous at times when passengers are more likely to try to avoid paying fares, such as during off-peak hours or at night. (An irregular or intermittent rider is more likely to try to avoid payment.) On average, 5 percent of passengers receive a fare inspection, and 1.6 percent of these are without valid tickets.

INTERCITY LIGHT RAIL LINE BETWEEN COLOGNE AND BONN

A major success story of recent years is the light rail line (the Reinufer Route 16) to Bonn, the capital of West Germany. This line, 44 km long and with 48 stations, starts in the northern outskirts of Cologne, runs through the downtown and the fringes of downtown to the southern suburbs, along the Rhein to Bonn, and finally through Bonn to the suburb of Bad Godesberg.

This project was completed in 3 years at a cost of DM 60 million. It was made possible by using and upgrading the light rail systems in both Cologne and Bonn and the heavy rail network of the Cologne-Bonn Railway (KBE, a private railway) between the two cities. Before light rail service was introduced, the KBE operated its own heavy rail passenger service between Cologne and Bonn alongside its freight trains. However, this line, which operated along the Rhine River for its entire length, had only one station in downtown Cologne and it was not centrally located. A similar situation existed in Bonn. Integration of KBE heavy rail services into the light rail networks of the KVB in Cologne and SWB in Bonn has provided superior downtown distribution and easier connections with the rest of the system.

To integrate these three separate systems, each with its own characteristics, and to make the conversion from conventional heavy rail to light rail, a number of problems had to be overcome:

1. Vehicles — The KBE railroad passenger cars, with a truck center distance of 12 m, were too large for the clearances of Cologne's subway tunnels, designed for a maximum truck center distance of 10 m. The streetcars in Cologne and Bonn had a maximum speed of 70 km/h—too slow for railway operation—and they could not be coupled to form trains.

The development in Cologne and Bonn of the Stadtbahnwagen B-car provided a vehicle compatible to all networks. With a truck center distance of 10m, it can run in Cologne's subways, and its top speed of 100 km/h makes it suitable for high-speed running on the KBE. Many of the high-performance features of this vehicle were designed for operation on the Cologne/Bonn line. Bonn also has purchased the B-car, so one vehicle type can provide all service. Except for their color, the cars in Cologne and Bonn are identical.

2. Electrification — The KBE, which operates at 1200 DC, was the first German rail mainline to be electrified. The KVB was later electrified to operate at 800 DC, and the Bonn network to operate at 600 DC. The KBE vehicles could operate at the lower KVB voltage, but acceleration and speed were unacceptably low over long sections.

The solution was to adopt a uniform current of 750 DC. This involved an increase in Bonn from 600 to 750 DC, a decrease on the KBE from 1200 to 750 DC, and a nominal drop in Cologne from 800 to 750 DC. The large decrease on the KBE has had little adverse effect; freight traffic on the Rheinufer is handled exclusively by diesel locomotives, and the old (1200 DC) passenger vehicles can be used on this line.

3. Track — In Europe, rail wheels on freight cars are wider than those of light rail vehicles or streetcars; that is, the back-to-back distance between the wheels is greater for light rail vehicles than for railroad cars, since light rail vehicles must be able to operate on girder rail in street sections. Also, the flanges on light rail vehicles are not as deep as those on railway cars.

Despite these profile differences, light rail vehicles normally have no problem operating over straight or curved railway sections. Problems do occur, however, over frogs at switches where one wheel passes over a gap. The smaller profile of the light rail wheel allows enough lateral movement in these switches (designed for railway vehicles) for derailments to occur.

The solution was to install movable frogs on all switches used by both light rail and freight vehicles. This eliminated the gap of conventional switches and provided a safer operation. Movable frogs also eliminated most lateral acceleration and resulted in a much more comfortable ride over switches. The KVB had previous experience in joint passenger-freight operation through its operation of the Köln-Frechen-Benzelrather Eisenbahn (KFBE).

4. Stations — Original plans called for high-level platforms at all stations. However, several factors hindered these plans, including the continued use of a large number of streetcar-type vehicles in Cologne and joint operation with freight vehicles, whose profile does not permit running by high-level platforms.

The solution was to build all stations in Cologne and those on the KBE (where freight trains still operate) at an intermediate height of 350 mm. In Bonn, all stations have high-level platforms, including a nonsubway section where the line runs in the middle of a highway. The flexible Stadtbahnwagen B-car can operate from platforms of either height.

5. Organizational Difficulties — The operation of the Cologne/Bonn line involved facilities of two public transit companies (the KVB and Stadtwerke Bonn-SWB) and one private railway (KBE). This provided the impetus for development of the coordinating agency Stadtbahngesellschaft Rhein-Sieg (SRS). SRS provides the framework for unified fares, schedules, planning, and operations. The coordination task has become relatively simpler since the KVB purchased KBE's freight and passenger operation on August 2, 1980.

After these problems were solved, the line was completed and has become a successful showcase for light rail. The entire line is separated from traffic by a variety of means—subways in central Cologne and Bonn and separate rights-of-way in the middle of highways with conventional street crossings. All grade crossings on the KBE railway section have automatic protection at crossing gates. The section from the end station of Mülheim in northern Cologne to Barbarossaplatz on the southern fringe of downtown now has a fully separated right-of-way.

Normally two-car trains are run, except late at night when one car is sufficient. Signal systems in the Cologne and Bonn LRT systems are similar; the KBE has German standard railway signals. Drivers are trained on all signal systems. Trains operate through from Cologne to Bonn and vise versa; drivers, however, change in Wesseling near the halfway point. Through operation by drivers is not yet possible because of different pay rates for workers in the two systems.

The average (1979) daily ridership patterns on line 16 are as follows:

Day	Ridership
Weekdays	47 475
Saturdays	22 118
Sundays	13 761

The success of the new light rail line is illustrated by the following figures showing passenger growth since completion.[5]

Section	Area	1965	1977	1979	1977-79 Percent Growth
Marienburg-Rodenkirchen	Cologne	16 200	12 880	18 100	+41
N. Wesseling-Wesseling	KBE	8 500	5 700	8 200	+44
Buschdorf-Tannenbusch	Bonn	8 100	4 500	8 100	+80

Before the implementation of light rail, these sections were served only by the heavy rail services of the KBE, and between 1965 and 1977, ridership continued to decline despite population gains in the area. Ridership gains since the implementation of light rail have been dramatic and are expected to continue.

The success of the Rheinufer light rail conversion has led to similar plans for the other KBE line between Cologne and Bonn—The Vorgebirgs, or "foothills," line. This route travels between the two cities on a more circuitous, westerly path. Vehicles are still the conventional rail type and, therefore, do not use the subways in Cologne or Bonn, but terminate at stations located in fringe downtown areas. Conversion is slated for the mid-1980s, and work (including the purchase of new B-cars) is already in progress.

FUTURE SYSTEM GROWTH

The KVB continues to expand and upgrade its facilities in all parts of the city. Subway construction was recently completed in Vingst and is currently underway in Deutz (open-cut) and Friesenplatz, near downtown.

The pace of future expansion and construction will depend largely on the financing available. Germany has enthusiastically supported transit and currently dedicates one-half of the federal gasoline tax for public transportation capital projects. The federal government provides 60 percent of the funding for the Cologne light rail capital projects; the state of Nordrhein-Westfalen provides 30 percent, and the City of Cologne, 10 percent. The city is also responsible for covering 100 percent of the operating deficit. Because of recent funding difficulties in the public sector, particularly the city, plans to build a subway under the ring highway around the CBD had to be postponed. The LRT, therefore, will continue to operate on the surface with priority right-of-way in the median.

Funding difficulties may slow the pace of future expansion, but the system is still expected to improve in terms of performance, ridership, and modern facilities. It has been built gradually, so it does not experience major disruptions if certain components of the transportation plan are altered; it is less sensitive to funding shortages than a more expensive rapid transit system. Most of the basic elements of a high performance LRT network are in place and the KVB will continue to make incremental improvements to the system. As the rate of new automobile ownership slows and energy costs increase, the LRT will continue as a major factor in transportation and in the urban structure of Cologne.

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