Comparison of Light Rail Transit and Dual-Mode Bus System

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Before two transport systems, light rail rapid transit and dual-mode bus, are discussed one or two general remarks concerning the current situation of the public passenger transport sector in the Federal Republic of Germany are in order.

The public passenger transport sector has enjoyed a much smaller share of the considerable increase in public mobility that has been evident during the past few decades than has private transportation. Reductions in demand for public passenger transport in the less well-serviced areas have been balanced by substantial increases in passenger numbers, especially in large towns and conurbations that, with the aid of large investment programs, have expanded or modernized their public transport services and now enjoy the benefits of high-capacity transit systems. The high rate of increase in passenger numbers is a reflection of the attractive public passenger services offered. However, despite this, a considerable amount of effort must be put into improving the economic position of the transport companies in the future. Existing transport systems must be improved and new technologies developed and deployed.

For this reason, within the scope of a transit research program, the Federal Ministry for Research and Technology has been sponsoring the further development of rail rapid transit, light rail systems, and bus transit systems together with the development of automated-guideway transit, dual-mode bus, and command and control systems for public transport operations for more than 12 years.

STARTING POINT

Federal Republic of Germany

In the Federal Republic of Germany there are only four classical subway (U-Bahn) systems in operation, the origins of which go back to the beginning of this century. They are the U-Bahn systems in Berlin, Hamburg, Munich, and Nuernberg.

Most of the rail car companies in the Federal Republic of Germany today operate streetcar or light rail systems. There are altogether about 30 such companies. Of these, approximately 20 operate solely light rail systems or are in the process of changing from streetcar to light rail operation.

Development in the rail car sector in the Federal Republic is, therefore, clearly characterized by a move away from the older streetcar systems (systems that share road space with private transport and do not run on separated tracks) toward the more modern light rail systems (systems that not only share road space with private transport, like the streetcar, but can also be operated on separated tracks both below and above ground with level boarding platforms). Such systems can be developed into U-Bahn systems step by step (i.e., are compatible with superordinate systems).

In the foreseeable future, only extensions of existing streetcar and light rail systems will be realized in the Federal Republic. New systems are not planned. There are, however, a number of transport companies, which, because of the pattern of their transport demand, would require a mixture of bus and light rail operation. The problems that arise here are the relatively high costs and the resulting split transit system.

In this case the track-guided bus system offers a real alternative. At certain bottlenecks (e.g., in the city center where public transport operates more efficiently underground) the track-guided bus can be deployed. The existing bus system remains as an integrated system and need not be transformed into a "split" system with additional transfer requirements, as would be the case if an additional rail car system were introduced.

Worldwide

There are currently around 320 cities worldwide with rail car systems in the public passenger transport sector (5 percent U-Bahn systems, 11 percent combined U-Bahn and streetcar systems, and 84 percent streetcar and light rail systems).

In addition to the light rail activities in France, Japan, China, Australia, and the USSR, and the slightly more restrained activities in Great Britain and Belgium, the considerable level of activity in the United States and Canada must be mentioned here.

On the North American continent light rail is becoming more and more important: for example, the establishment of light rail systems in Edmonton, Calgary, and San Diego; the reconstruction and extension of existing systems, Pittsburgh, for instance; and the construction of systems in Portland, Sacramento, Buffalo, San Jose, and Vancouver. A whole series of further plans is under discussion.

There is one essential difference between the planning and realization of light rail systems in these cities and in the situation cited at the be-

ginning, for example in the Federal Republic of Germany or in the Soviet Union. In North American cities existing streetcar systems are not being modernized or expanded; rather, a second transport system parallel to fully developed bus systems is being introduced. This raises the following questions:

1. Step-by-step development of the bus system by way of a track-guided bus system leaving the options open for a rail car system at a later date, whereby the existing traffic problems can be solved quicker in the short term or
2. An immediate start with the step-by-step introduction of a light rail rapid transit system with a split service and a greater time requirement until reaching the desired level of service?

A brief discussion of the level of technical development and the possibilities for deployment of both systems may help answer these questions.

LIGHT RAIL RAPID TRANSIT

Level of Technical Development of Light Rail

The technically highly developed, safe, reliable vehicles of the streetcar, light rail, and U-Bahn systems in the Federal Republic of Germany, which have proven themselves countless times in many years of development, unfortunately suffer from an excessive variety of types and components. The reasons for this are as follows:

- The existing infrastructure differs to some degree from system to system so that vehicle width and length have to allow for existing track design (curves) and tunnel cross sections. The newer light rail operators have ignored the opportunity to agree on a standard vehicle profile.
- Even if infrastructure characteristics permitted standard vehicle design, individual transport operators would often settle for their own vehicle development because they believe that solutions tried and tested in the past are the most reliable.
- Differing vehicle sizes and the different emphases placed on vehicle development by various operators--reinforced by diverse operational strategies in the individual companies--lead to alternative basic concepts in the design and construction of bogies and coaches and a multiplicity of choice in the vehicle equipment sector. In contrast to buses, this wide variety of choice leads to relatively high costs as far as vehicle purchase, maintenance, and purchase of spare parts are concerned.

A comparison of purchase price and vehicle weight for rail cars and buses (Figure 1) shows that vehicle weight and purchase price per seat for light rail vehicles are, in both cases, twice as high as for the standard articulated bus. The comparison also shows, however, that the cost per unit weight for both light rail and buses is approximately the same at DM 30 to DM 40 per kilogram. This indicates, whatever reservations the reader may have, not that the manufacturing costs for the light rail vehicles are too high but that the vehicles are too heavy. Aside from the high purchase price, the considerable vehicle weight also means an increase in the cost of energy required for day-to-day operations. What has happened is that the energy savings achieved by using modern high-performance electronics have been almost totally offset by the increased demands placed on vehicle technology and equipment and the resulting increase in weight.

Against this background the Federal Minister for

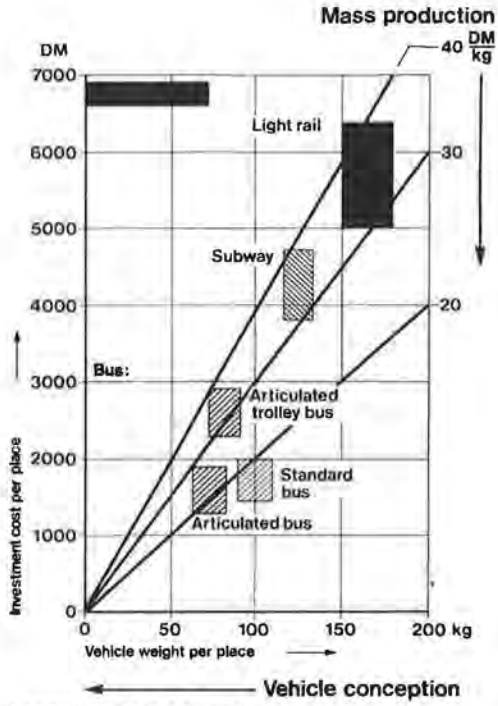


FIGURE 1 Vehicle costs.

Research and Technology is sponsoring the research and development project "Technologiepaket Stadtbahn 2000" (Light Rail Technology 2000). The aim of the project is to design and realize an economical modular system for the construction of light rail vehicles and vehicle equipment taking into account the interconnections of such facets as lightweight construction technology, standardization, operational life of vehicles, comfort, maintenance expenditure, and vehicle purchase price.

The research and development work covers all component groups of light rail vehicle construction and can be roughly subdivided into the following groupings:

- Undercarriage,
- Car body, and
- Electronics.

The latest developmental status of standard light rail vehicle technology will not be addressed in detail. However, some of the key research aims of the project "Light Rail 2000" will be presented.

Possible Improvements to the Undercarriage

Both the weight and running characteristics of the undercarriage could do with improvement. As far as reduction in weight is concerned, the following points could be considered:

- Improving the load factor. Bogie design is currently based on theoretically determined load factors bolstered by safety factors that are much too high. Actual forces acting on the undercarriage can be determined by realistic operational measurements.
- Using smaller wheels. Apart from the advantage in weight, smaller wheels also permit lower floor levels (approximately 15 percent weight reduction on a motored bogie).
- Using individual axles. Extremely high weight

savings can be achieved by using individual axles instead of bogies (weight reduction on a motored bogie with normal wheels about 30 percent, with smaller wheels about 45 percent). The guided electrical bus (O-Bahn)--(three-section, automatically track-guided trolleybus), designed in the Federal Republic of Germany, requires only four axles for a vehicle length of 24 m. Light rail vehicles, on the other hand, approximately 5 m shorter in length require six axles and weigh 4 tons more (Figure 2).

The following changes might be made to improve running characteristics:

- Undercarriages with individual axles and idler wheels. Without doubt this represents a target that would be hard to achieve because it challenges some of the long-accepted rules of track guidance. Realizing this design would result in considerable reductions in weight, a lowering of the level of wear and tear, and a dampening of noise levels.
- Integrated engine power section. The integration of engine-transmission casings and bogie frames into one load-bearing unit would enable reductions in structural weight to be made.
- Use of lightweight metals. The use of lightweight metals for certain bogie components and also for the entire bogie frame is currently being practically tested. Weight savings of up to 500 kg have been achieved.

Possible Improvements to the Electronics

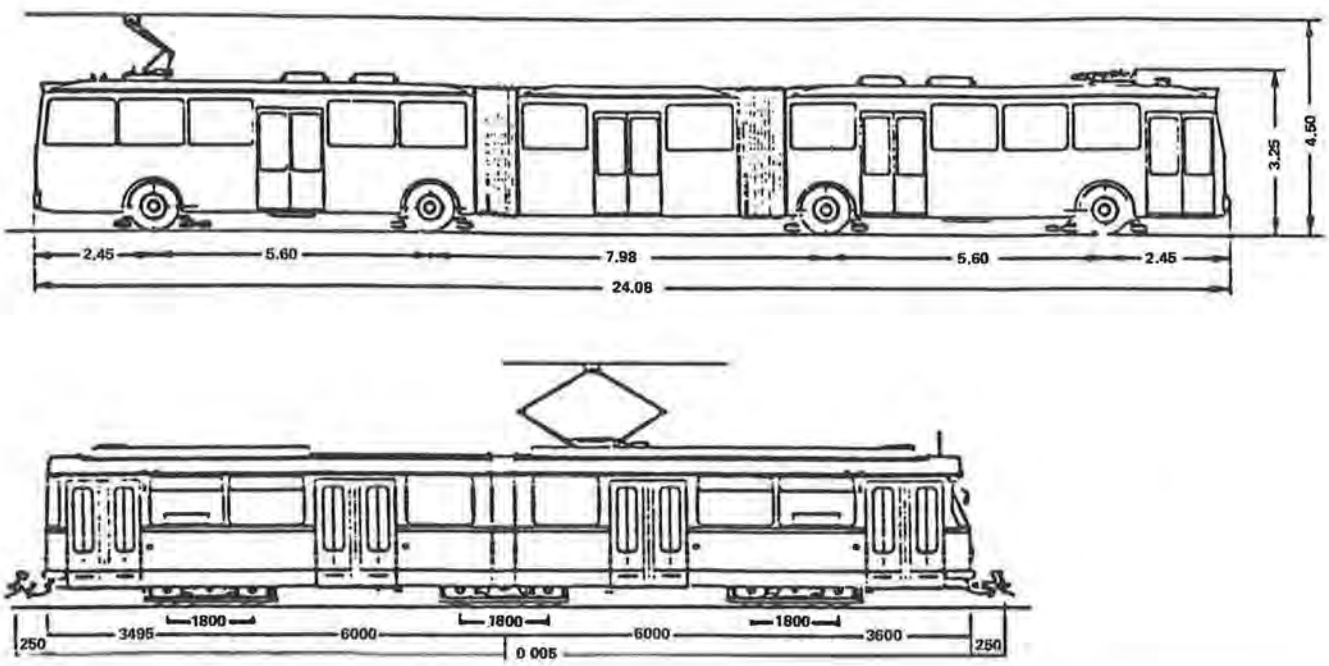
Innovations in vehicle equipment have been introduced in light rail vehicles in the past, the significance of which only became clear after a long period of operational deployment.

"Improvements" were sometimes introduced that caused problems to occur among associated equipment. This was true to such an extent that today a question arises about the extent to which individual improvements can be considered improvements to the whole system. With this in mind, investigations are being carried out, for example, in the following areas:

- Integrated vehicle on-board control systems;
- New systems of data transmission;
- Standardized on-board electronics in a modular form;
- New systems for determining failures and reporting malfunctions; and
- Standardized heating, ventilation, and air conditioning systems.

Possible Improvements to the Car Body

It is intended to develop a modular construction system for vehicles in which standardized vehicle sidewall sections will ensure uniform boarding, pas-



	Length (m)	Weight (tons)		Weight per Meter (ton/m)	
		Total	Undercarriage[a]	Total	Undercarriage[a]
Track-guided bus (O-Bahn)	24	20 (100%)	4 (20%)	0.83	0.17
Light rail	19	24 (100%)	7.5 (31%)	1.26	0.39

[a]Without propulsion system.

FIGURE 2 Comparison of O-Bahn and light rail rapid transit.

senger, and driver sections for varying vehicle widths.

One possible vehicle format for an improved LRT car could consist of a double articulated vehicle with six individual axle undercarriages and a total length of 30.85 m with a standardized section of 1.65 m for boarding, passenger, and driver sections. Such a vehicle would have a total of 185 passenger places, an empty weight of around 30.0 tons, and a maximum axle load of 10.0 tons (Figure 3). Compared to a vehicle of similar width today, this would mean

- An increase in vehicle length of around +20 percent,
- An increase in the number of places by about +30 percent,
- A reduction in empty weight of around -30 percent, and
- A maximum axle load of +25 percent.

So much for LRT-vehicle technology. As mentioned earlier, conventional light rail vehicles also display a high degree of technological development. This must, however, be further developed to achieve a more economical system.

Possibilities for Deploying Light Rail Systems

At this point it should be pointed out that light rail systems must be viewed as integrated systems in which, aside from the vehicle, the other components (guideway, stations, propulsion power, and command and control technology) must be attractively and economically harmonized.

Even supposing that this precondition is met, the advantages of a newly established light rail system can only prove their full economic worth when the system is serving a certain level of demand, which means peak demand at around 18,000 passengers per hour and direction.

As a rule these conditions are met on urban or regional corridors of large-scale conurbations. It must be ensured that the light rail system

- Can run largely on its own exclusive right-of-way without disruption caused by other traffic throughout the whole length of the corridor and
- Can be operated in a train mode with even more attractive service frequency to ensure a higher degree of driver productivity.

Ideally, all stations should be equipped with raised platforms to avoid the necessity of furnishing the vehicles with carriage steps and the attendant increase in passenger transfer time.

The proportion of underground track should not be too high, for reasons of both cost and attractiveness. Underground stations generally result in greater distances between stops and therefore increase passenger walking distances to and from stations.

If the prerequisite of a sufficiently large passenger demand is met, light rail rapid transit systems offer an almost ideal solution to public passenger transport requirements from the point of view of

- Low exhaust levels attributable to the electrical power source,
- A high degree of reliability due to the robust nature of the vehicles and equipment, and
- An attractive service on account of trip speed and the punctuality of the system.

A new light rail system can be constructed and installed section by section, whereby the construction of a section should be carried through as rapidly and with as few steps as possible in order to take full advantage of the benefits offered by the system.

DUAL-MODE BUS SYSTEM

Since the middle of the 1970s special efforts have been made in the Federal Republic of Germany to develop integrated bus transit systems. The target here has been to integrate the individual system components with each other to a high degree. The system components consist of

- Guideway,
- Stations,
- Vehicles, and
- Command and control aspects.

Within the scope of dual-mode bus development special attention has been paid to the track guidance, propulsion, and busway components.

Automatic track-guided bus technology has been developed under the sponsorship of the Federal Ministry of Research and Technology by two German vehicle manufacturers, Daimler-Benz and Maschinenfabrik Augsburg-Nürnberg (MAN). Development has been carried out along two different lines, mechanical track guidance and electronic track guidance, with the idea of an integrated system in the foreground (e.g., O-Bahn).

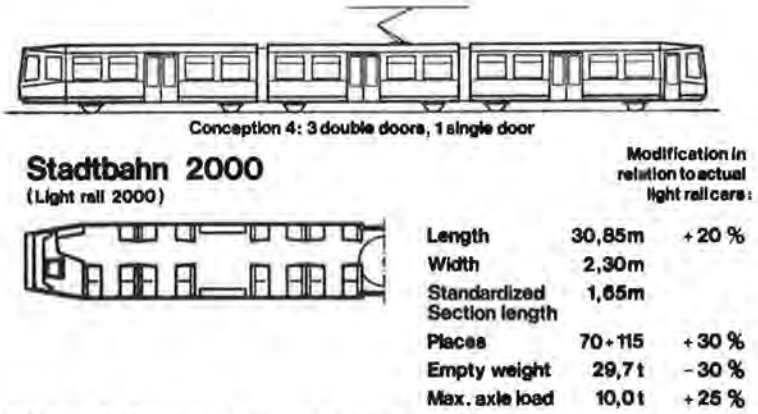


FIGURE 3 New vehicle conception (commas should be understood as decimal points).

In the mechanical track guidance design, guide rollers are fitted on either side of the bus forward of the front wheels and run along a guide rail 18 cm high. The guide rollers are directly connected to the steering linkage of the bus. The conventional steering of the bus remains unchanged. The driver can switch from manual steering to automatic track guidance at any time without any mechanical switching having to be carried out on the bus. In the electronic track guidance system, the vehicle automatically follows a cable that has been laid in the roadway. Redundant electronic and hydraulic equipment is fitted to the bus for this purpose.

For propulsion, track guidance can be complemented by a dual propulsion system (Duo-bus). In this case, an electric motor is installed in addition to the diesel engine and is powered by an overhead wire like a trolleybus. Buses with every conceivable type of propulsion system can be fitted with track guidance (diesel buses, trolleybuses, battery buses, duo-buses, and so forth). This also applies to every possible size of bus (40-ft, articulated, high-capacity buses). Figure 4 shows a high-capacity bus on an elevated track.

FIGURE 4 High-capacity bus on elevated track.

Track-guided buses can drive on normal roads like conventional buses. When necessary or desired they can use their own separated busways that can be constructed on the surface, in tunnels, or on elevated tracks. Special prefabricated roadway sections have been developed for this purpose so that the construction of busways can be rapidly and economically achieved (Figure 5).

The reasons for the development of automatic track-guided buses and some of their specific advantages are presented next. The first advantage is that the width of the roadway has been reduced from 3.50 to 2.80 m. This results in considerable cost savings in the construction of the roadway infrastructure, especially on elevated tracks and in tunnels. The platforms at stations can be raised to the level of the first vehicle step, which facilitates boarding and deboarding. The reduced amount of wear and tear on the sidewalls of the tires when entering the bus bays is a further economic advantage. The construction of the busways using prefabricated concrete elements makes for a high degree of travel comfort. Favorable working conditions are created for the driver by the automatic track guidance. Track-guided buses using their own busways, which,

FIGURE 5 Prefabricated roadway sections.

under certain circumstances, can be easily constructed in the urban environment, also provide the conditions for a high degree of passenger capacity, attributable in large part to the smooth operation.

The possibility of expanding the bus system step-by-step is particularly appealing. Depending on the operational, transportational, and financial conditions obtaining at any particular time, improvements can be achieved in stages, and, at each step of the process, a functional transit system is available to all concerned.

Deployment of Track-Guided Bus System

After initial tests and trial operation on the manufacturer's testing grounds and deployment at exhibitions in 1978 and 1979, line-haul operation of mechanically track-guided buses started in the city of Essen in 1980. In Essen a dual-mode bus demonstration project is being established in three phases. The first phase consisted of testing the mechanical track guidance on a 1.2-km track section along Fulerumer Strasse. In the second phase, a track-guided duo-bus has been operating in a mixed operation with streetcars along Wittenberg Strasse since May 1983 (Figure 6). After expansion of the track-guided bus system on the surface in the course of this year, a third phase is planned for 1986 in which the track-guided duo-bus will share existing streetcar tunnels in downtown Essen.

In the city of Fürth, electronically track-guided buses have been in passenger operation since May

FIGURE 6 Mixed operation of duo-bus and streetcars.

FIGURE 7 Articulated bus.

1984. After a test period it is intended to equip various sections of the whole city of Fürth network with electronic track guidance so that the transportation problems of Fürth will be substantially alleviated. In Adelaide, Australia, a track-guided bus system is being set up to provide passenger operation along 12 km of track starting in 1986. In October 1984 in the English city of Birmingham a first section of track for guided buses was put into operation. In this case double-deck buses are being track guided and the track guidance represents one component of a number of improvements that are being introduced along the whole line. In a variety of Italian cities electronically track-guided buses are being brought into operation this year.

A further important component of the dual-mode bus system is the duo-bus, which has been undergoing testing in Esslingen since the mid 1970s and in Essen since 1983. Additional vehicles are currently being constructed for both cities. In France, too, duo-buses have been an important aspect of passenger operations for several years. The transportation system in the city of Nancy should be noted.

Planning studies for dual-mode bus systems are being carried out for a number of German cities, and in a large number of European and overseas cities consideration is being given to the deployment of this new technology.

Possible Deployment of Dual-Mode Bus Systems

From the points already mentioned, it can be seen that there is a broad potential spectrum for the deployment of track guidance and dual propulsion for buses. The high degree of flexibility ensured by a combination of different technologies enables the guided bus system to meet the specific requirements in the area in which it is deployed. This applies both to improvements in today's urban bus transit in specific places as well as to the further development of bus transit into an integrated bus system.

Because of the possibilities provided by track-guidance technology for constructing separated busways and the high capacity levels that can be achieved using articulated and high-capacity buses (up to 250 passenger places), it is possible to achieve more economically viable and attractive solutions for urban transit, especially in corridors where there is a particularly high volume of traffic (Figure 7). The great advantage of the dual-mode bus system, the possibility of step-by-step expansion of the system depending on the financial means available, means that right from the beginning an attractive system can be offered to both operator and passenger. Construction of a track-guided bus system on its own separated busway also leaves open the option of changing to a rail transit system at a later date if demand calls for it.

SUMMARY

At the beginning the question was asked:

- Step-by-step development of the bus system by way of a track-guided bus system leaving the options open for a rail car system at a later date or
- The immediate start with the step-by-step introduction of a light rail rapid transit system using buses as a feeder?

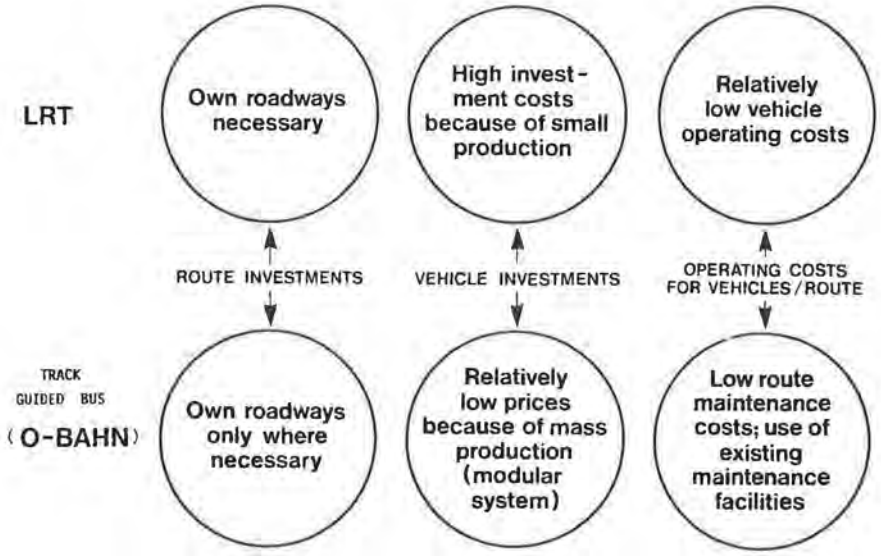


FIGURE 8 Comparison of investment and operating costs.

The introduction of light rail systems in the Federal Republic of Germany cannot be compared with conditions on the North American continent. Where there are existing streetcar systems, as there are in Germany, the only possibility is a step-by-step change to a light rail system. Where pure bus systems already exist, as is the case in North American cities, both possibilities, LRT or guided bus, can be considered. Which possibility is chosen must be decided on a case-by-case basis.

Of decisive importance is the total traffic volume on the route under consideration. Given the capacity of bus and light rail rapid transit systems, there are three conditions that may be used as guides in decision making:

- Condition A: Total traffic volume at peak up to 9,000 passengers per hour and direction. Clear decision in favor of buses and track-guided buses.
- Condition B: Total traffic volume at peak of between 9,000 and 18,000 passengers per hour and direction. Both systems are possible. This is a transitional zone between guided bus and light rail systems. Guided buses should be preferred because of their cost advantages: (a) low investment costs, (b) short time required for construction, (c) ability to use completed sections of the system at once, (d) ability to integrate a guided bus system into an existing bus operation, and (e) low cost of operation.
- Condition C: Total traffic volume at peak more than 18,000 passengers per hour and direction. Decision in favor of light rail rapid transit will be made because larger units can be formed.

If the total traffic volume is going to increase slowly, the existing bus system in Condition B should be developed into a dual-mode bus system leaving open the option for later development to a light rail system.

In the case of a rapid increase in total traffic volume, each case must be carefully examined to determine whether an immediate change of a route to a fully fledged light rail system might not be more economical.

With regard to the investment costs a bus system is more profitable than a light rail rapid transit system (Figure 8): route investments are only necessary on route sections where separate roadways are considered to be requisite and prices for vehicles are relatively low because of mass production in a modular system.

The decisions depend on a whole range of different criteria. It should, however, be pointed out that a high level of transport performance can be achieved with guided buses.

As a result of the extreme flexibility of the dual-mode bus system (freedom of choice for duo-bus, track-guided bus, or dual-mode bus), this system is an excellent, highly advanced transitional system for urban transit today. The possibility of a later change to light rail can always be kept in mind.