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16. Abstract

This report presents the results of a joint U.S./German technical assessment of the H-Bahn automated guideway transit (AGT) system under development in the Federal Republic of Germany. The system development is progressing with full-scale testing at the 1.4-km test facility in Erlangen. Siemens and DuWag, the system developers, have tested individual subsystems to gain an acceptable level of performance and maturity of the various system components prior to deployment in urban and special application situations. The present technology is the result of an evolutionary design process, and testing initated in Berlin and Dusseldorf in 1973.

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PREFACE

This report documents an investigation of the H-Bahn Automated Guideway Transit (AGT) system under development in the Federal Republic of Germany. The study was carried out by the Department of Transportation's (DOT) Transportation Systems Center (TSC) and the SNV Studiengesellschaft Nahverkhr mbH, under a bilateral agreement between the U.S. Department of Transportation and the German Federal Ministry of Research and Technology (MORT). The study was sponsored in Germany by MORT and in the United States by DOT's Urban Mass Transportation Administration's (UMTA) Office of Socio-Economic and Special Projects, Office of Technology Development and Deployment.

The study consisted of a review of technical reports and papers; on-site visits to the H-Bahn test facility in Erlangen, Germany; and interviews with technical and managerial personnel from the developers, Siemens Corporation and DüWAG. The developers cooperated fully throughout this study and have reviewed the material contained herein. This report is available in both German and English.

The authors wish to acknowledge the special efforts of Caron Tsapatsaris, Carol Newman and Richard Tucker of Raytheon Company who contributed to the editing and preparation of the English version of this report and Herman Zemlin who was instrumental in coordinating this cooperative effort.

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The authors wish to thank George Pastor, formerly of UMTA's Office of Technology Development and Deployment and Rainer Götz of the German Federal Ministry of Research and Technology for the special interest they have taken in this study.

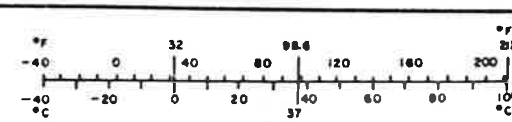
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1. EXECUTIVE SUMMARY

1.1 BACKGROUND AND INTRODUCTION

This report describes and provides the results of an assessment of the H-Bahn Automated Guideway Transit (AGT) system under development in the Federal Republic of Germany. The study was completed under a bilateral agreement between the U.S. Department of Transportation (DOT) and the German Federal Ministry of Research and Technology (MORT). It was conducted jointly by DOT's Transportation Systems Center (TSC) and the SNV Studiengesellschaft Nahverkehr mbH. The H-Bahn assessment was co-sponsored by MORT and the Urban Mass Transportation Administration (UMTA) and is one of several AGT system assessments, both domestic and foreign, being conducted by the Office of Socio-Economic and Special Projects of UMTA's Office of Technology Development and Deployment. The purpose of these assessments is to:

1) Gather and exchange information in Automated Guideway Technology to better understand the state of technological advancement and to obtain synergistic improvements for future development.

2) Review problems and solutions encountered during the design, development, implementation, and operation of AGT systems in order to improve the process based on experience.

3) Obtain information on engineering, economic considerations, operational performance, and public response which can be used in planning future AGT systems.

4) Provide urban planners with information which will enable them to determine the applicability of AGT systems to their specific transportation problems.

The H-Bahn system has undergone an extensive development program, resulting in the present test track configuration at the Siemens Research Center in Erlangen. The current H-Bahn technology is the result of an iterative design and test process which began in the early 1970s in Berlin, continued at a second test facility in Düsseldorf, and culminated in the construction of the 1.4 km loop system in Erlangen in 1976. Although not deployed in revenue service as yet, the H-Bahn system has been a candidate system for many feasibility studies in Germany and is currently planned for installation in Erlangen and at the University of Dortmund.

This report focuses on H-Bahn technology tested and observed by the assessment team at the Erlangen test facility. It includes a detailed description of the H-Bahn system, a technological assessment of the system maturity and design, and information about system, capital and operation costs.

1.2 SYSTEM DESCRIPTION

The H-Bahn is an automated transit system comprised of various sized vehicles, suspended from a narrow track beam. The system is designed to operate in a schedule mode, but demand operation can also be provided for off-peak hours. At a headway of sixty seconds, lane capacities ranging from 1,000 passengers/hr with the smallest vehicle to 15,000 passengers/hr and more with large articulated vehicles can be obtained.

The vehicles of the H-Bahn system consist of various sized cabins suspended from running gear units (bogies) which travel inside the track beam. A standard running gear unit has been designed to accommodate either propulsion made (dc drive or linear induction) and is used for various sized vehicles which are modularly assembled. Door spacing on the vehicles is the same for any sized vehicle or train formation which allows proper positioning with station doors. Wide sliding doors and a vehicle clamp device assures easy access for wheelchair patrons.

Each running gear is fitted with front and aft twin support wheels with hard rubber tires; four rubber tire guidewheels on each side provide lateral guidance. Active pneumatic springing between the running gear unit and the vehicle body provide a good level of ride comfort. Power equipment for the drive which is located in the running gear is separated from the auxilliary and control equipment which is under the end seats and is accessible in compartments at the ends of the vehicle body.

The H-Bahn system concept includes a slotted box track beam which houses the vehicle bogie and associated equipment. The beam is suspended from columns which are spaced at about 100-foot intervals at a normal height of 30 feet. Aside from the appealing appearance of a narrow carrier beam with slender columns and small efficient stations, the most noticeable advantage of this type of design is the protection provided from the environment by the closed track beam arrangement. The internal hardware, critical to safe and reliable automatic operation, is sheltered from environmental effects by the closed track beam configuration. The track beam is normally made using welded steel plates, stiffened by reinforcing frames spaced along the beam length. This permits the use of a constant cross section for straight as well as curved tracks, at the latter by reducing the spacing between reinforcing frames. The support columns are made of steel or concrete and can be of several configuration types, (depending on the number of track beams and available column foundation locations). The steel columns, although slightly more expensive than concrete from both initial and maintenance costs, are more attractive because of the ability to taper column heads and still provide the required strength. A significant cost-saving feature of the H-Bahn guideway system is the ability to prefabricate the track beam sections and columns. The fabricated guideway components can then be transported to the construction site where they are assembled and erected on concrete foundations. This time-saving feature reduces overall guideway cost as well as urban disruption and traffic congestion during construction.

The operation of the automatic command and control system consists of a central computer with several human operators to provide scheduling, dispatching, control of traffic density, and monitoring of wayside equipment operation. Failure of this supervisory system does not stop system operation, although long-duration central computer outages could impair its operation.

Each station houses a single computer that directly controls up to eight vehicles in its vicinity. The computer communicates with the vehicles via sixteen-bit digital messages. Maximum vehicle speed at any point along the guideway is defined by the fixed spacing of small permanent magnets, positioned within the track beam; the presence of the magnets is detected by Hall transducers located on the vehicles. The maximum speed can be modified downward by messages from the station computers; the vehicle interprets the detected time separation of the magnets in accordance with the message received from wayside. The station computers also control vehicle positioning in stations, door opening, dwell, and closing, and normal vehicle stopping and starting.

The safety system is totally independent of the supervisory and operational systems. It causes vehicles to stop if overspeed of fifteen percent or more occurs, if short headways develop, or if switch positioning is incorrect. The power to the affected section of guideway is cut off, and the vehicle is stopped by the spring loaded emergency brake which is held off as long as power is available.

1.3 DEVELOPMENT STATUS

The six vehicles at the test site in Erlangen include five small vehicles (seventeen passengers/vehicle) and one medium size (forty-one passengers/vehicle). Testing to date has focused on vehicle performance and endurance. A total of approximately 75,000 km has been accumulated on the vehicle fleet to date with most of the mileage being generated on the dc motor-driven vehicles. Endurance testing of the vehicles at the test site will continue until 100,000 km is collected on each of the six vehicles. Multiple-vehicle operation under station computer control was planned and accomplished in 1979, complete automatic operation including the central control supervisory level in 1980.

Although the H-Bahn system has not been operationally deployed in Germany as of this time, interest in the system by various communities is strong. Feasibility studies including the H-Bahn as a canditate system have been conducted for the cities of

Erlangen, and Berlin. Significant interest in the H-Bahn system is also being shown by the city of Nuremburg and by the University of Dortmund where an agreement has been signed to install an H-Bahn system linking the university's two campuses.

At the time of the visit in April 1979, one vehicle was being tested under station computer control. Software for the station computers had been completed and was being checked out at the test track; the near-term goal was to have these vehicles operating under station computer control by June, 1979. The safety system had been fully installed, but was not yet operating. Programming for the central computer had been defined, but not done. By mid-1980, Siemens expected the test track to be completely automated with all three levels of control operative. According to Siemens, approximately 90 percent of the required software for an urban deployment was completed at that time. (See Update pg)

In general, the CC&C subsystems appear to promise safe, reliable, automatic operation. They are not notably innovative and use many existing components that have already been proven. For example, the safety system logic--"URTL" logic as called by Siemens--has been under development for some time for use on the railroads. The sensors used in the guideways both for the safety system and for speed profile definition are off-the-shelf parts, and the station and central computers are standard Siemens products, although the software for them is peculiar to the H-Bahn. The digital communication, using sixteen-bit words for the vehicle messages, is accomplished by frequency shift keying (FSK), a common form of data transmission.

The three-level hierarchical control system is conceptually conventional. There is, of course, much new hardware, including switches, power pickups, electronic boxes, but these have been and are being tested extensively and modified as difficulties develop.

Since the change in system concept at the end of 1975 from a synchronous to an asynchronous system, testing of the vehicles had focused on revised designs for the linear induction motor, the on-board switching device, support wheel and power collector wear, structural capacity of the smallest vehicle and, in general, vehicle endurance. Important tests during 1979 involved the structural endurance of the bogie design, the linking mechanism for automatic training of vehicles, and the on-board vehicle control system for the linear induction motor. Endurance testing continued throughout 1980 on the six vehicles located at the test site.

The test track located within the Siemens complex in Erlangen includes 1.4 km of the guideway, three stations and a variety of column types in both steel and concrete. The track beam is constructed of welded steel plates reinforced by steel frame braces. The aesthetics of an elevated guideway is recognized as an important feature for public acceptance, and therefore, different finishes have been used and examined at the test track. In most sections, the track beam is painted white with a thin blue stripe along each side. In other sections, other color schemes have been tried including white, orange, and solid green. Aluminum or plastic plates designed to cover the steel bracing have been used in one section while another is constructed of CorTen steel.

Various column types, L-shaped, T-shaped, and gantry are in use at the track - some made of concrete, others of steel.

There are three stations located at the test facility. Each station represents a different application: 1) an at-grade station; 2) an elevated station; 3) an elevated station which is fixed to an existing building. The stations are constructed of steel and concrete with large glass windows wherever possible. Glass is also used on elevator doors, for narrow windows along the elevator shaft and stairwells in order to increase the perceived security of the H-Bahn patron in an unmanned station. Selection of station materials was based on their maintainability, durability, and resistance to vandalism. Fare collection and ticketing equipment is simple and easy to use and quite similar to that employed by transit authorities in Germany.

If an H-Bahn system was to be built for an urban application, the guideway and station features would not change greatly from those employed at the test facility.

1.4 FINDINGS AND CONCLUSIONS

1.4.1 System Development and Testing

- In contrast to extending the state-of-the-art in automated system through innovative concepts and new hardware, the H-Bahn approach has been one of utilizing existing technology with emphasis on simplicity, flexibility, and extensive testing.
- The developers have relied heavily on an extensive test program in order to evolve and mature their system design. With such a high level of dependence on conventional technology, the emphasis has been and is anticipated to continue to be focused on the integration of hardware into applications representative of revenue operation.

1.4.2 Systems and Subsystems

- Overall safety of the H-Bahn system has been addressed by the system developers through a fail-safe approach to design and through general safety practices and features. Detailed analyses, such as failure mode and effects or fault-tree analyses, have not yet been accomplished to date. At the present time an analysis of the fault types and their effects based on stringent Federal Railroad requirements is being carried out for safety-related components.
- The concepts proposed for passenger rescue appear adequate, but some effort will be required for a specific site to develop an emergency action plan which classifies emergencies and outlines the approach measures which must be taken to remedy a particular situation. Field testing of the rescue concepts for their practicality in revenue systems should be demonstrated.

- Although several good reliability practices and features have been incorporated into the design, a detailed analysis allocating and specifying reliability requirements and goals for each subsystem has not been conducted. The approach of utilizing test track experience to evaluate system reliability will be sufficient if the 600,000 km goal of the testing is achieved.
- Maintainability features of the H-Bahn system are good, especially with respect to the vehicle. Pallets are utilized for the auxiliary and control equipment. The enclosed track beam extends into the maintenance facility, where all bogie equipment can be easily serviced or replaced. The equipment located within the beam is not as easily accessible, but infrequent repairs or maintenance is required for beam hardware.
- The primary cost-saving feature of the H-Bahn system is the guideway design. Its narrow cross section can be prefabricated, requiring fewer materials than other AGT systems, and only a narrow right-of-way resulting in lower land costs. Operating costs for the track beam are less than those for other concepts, since no snow/ice removal measures are necessary, and life-cycle costs for beam hardware are reduced because of added protection provided from adverse weather conditions.

1.4.2.1 Vehicle

- Because of the conventional technology and hardware used in the system's design, the H-Bahn vehicle has an inherent level of maturity. The H-Bahn vehicle development program has focused on the interfacing and integration of technology and on new designs and hardware. Extensive testing has especially been conducted on new design parts.

- Physical separation of the vehicle bogie from the passenger cabin is an excellent design feature in that it separates the potential fire-source areas from the passengers. Use of non-flammable materials in the vehicle design also minimizes the possibility of fire.
- The attention given to vehicle maintainability by the developer is significant, particularly in relation to hardware accessibility.
- A significant level of redundancy is incorporated into the vehicle design, enhancing system availability.
- The availability of several vehicle configurations with varying capacities provides flexibility in adapting the H-Bahn system to the travel demands of any local community.
- The option of using linear induction motors for the H-Bahn vehicle offers significant advantages over the dc drive motor relative to grade, noise, wear, and all-weather operations.
- The reversible nature of the vehicle offers added flexibility in designing the guideway at the network ends and also provides increased system capability to react to a disabled vehicle.

1.4.2.2 Guideway

- The H-Bahn guideway is constructed of proven materials using conventional construction methods and extensive testing at Düsseldorf and Erlangen has produced a mature H-Bahn guideway design.
- The guideway system displayed at Erlangen is similar to the one which would be proposed for operational deployment with a few changes: 1) The mounting bracket for fastening the track beam to the column head would be modified to allow easier, quicker beam erection. 2) The running rails will be eliminated making the bottom web of the beam the new running surface.

- Using a steel box beam with steel ribs allows for the construction of a beam with a strong and stiff cross section; the stiffness can be varied by changing the spacing of the ribs. This feature can result in substantial cost savings over the solid-steel plate beam construction.
- The stations and guideways are aesthetically pleasing and therefore should be easily accepted by the public. The narrow track beams and tapered columns could be easily integrated into an urban environment without detracting from the surroundings.
- The track beam configuration provides maximum protection from the environment (rain, snow, wind, etc.). The protection afforded by the closed track beam has a positive effect on performance parameters such as dependability, availability, and traction for propulsion and braking. This should improve system reliability as well as reduce life-cycle costs of system components mounted within the beam and operating costs of system in adverse weather.
- Condensation along the top chord of the track beam combining with brush fibers and tire filings often formed a slippery surface on the test track during operations in Erlangen. As a result, Siemens has changed the tire and brush materials to ones which have reduced wear and shed and are developing a device which will be used to keep the running surfaces clear of contaminents.
- A significant cost-saving feature of H-Bahn is that guideway components can be prefabricated and transported to a site for erection. If transportation is not a major expense, significant cost savings can result. Prefabrication also reduces site and traffic disruption during construction and can provide the tight tolerances necessary for beam positioning and alignment.

- Guideway maintenance is minimized by the closed track beam arrangement and the fact that switch ramps are the only moveable parts. When maintenance is required, access must be gained through small manholes on the beam top or from the beam end at the maintenance shop; however, this might prove difficult for certain infrequent repairs. Siemens has developed a vehicle which can be driven through the inside of the track beam and anticipates completion of an automatic monitoring device design which can be circulated through the beam to detect potential problems.

- Guideway materials govern the amount of maintenance required for beams and columns. Where concrete is used, maintenance is minimized; but where steel or painted concrete is used, periodic repainting will be needed (repainting will be needed at approximately 10-15 year intervals). Use of Cor-Ten has been curtailed because the self-rusting feature does not slow down after an initial rust coating is formed, but continues to rust at nearly the same rate.

- Design specifications used for guideways are similar to those used for U.S. construction and in some cases, such as for impact resistance, are more stringent resulting in an improved product.

- Switch design has evolved from refinement of earlier designs, and extensive testing helps to increase confidence in switch reliability and safety. The use of a back-up system comprised of nearly all mechanical components contributes to safe switch operation.

1.4.2.3 Command and Control

- The command and control subsystem (hierarchical) is an adaptation of conventional technology. This should ensure that with adequate testing, the system will be relatively mature when first deployed. Data transmission is conventional and due to innovative applications of existing technology, data transmission in normal operation is minimized.

- The safety system is independent of the other two levels of control, thereby improving its reliability. The associated electronics have been under development for several years and have been certified "fail safe" by the German Federal Railways.

- Little reliability analysis has been done on the H-Bahn subsystems and components, with the exception of the URTL safety electronics. The developer prefers to perform extensive tests, failure analysis, and redesign of parts when necessary. This is an effective approach when conscientiously followed, and particularly for as complex an assembly of equipment as the command and control subsystem.

- The command and control system incorporates jerk limitation and limits on normal acceleration and deceleration, ensuring a smooth ride for the passengers.

- Automatic reporting of on-line failures to central control will enhance passenger safety and reduce the time needed to restore the system to normal operation.

- Safety of passengers will be enhanced by the anticipated:
  - passenger-central voice communications
  - failure and fire sensors in the vehicles
  - mimic boards and CRTs in central control giving the operator continuous awareness of the vehicle condition.

1.4.2.4 Dynamic Simulation

- The simulation tests that have been performed thus far have demonstrated that H-Bahn is an efficient system and indicate that it is also effective.

1.4.2.5 Power Supply

- The power supply system of H-Bahn, as provided for specific applications, is designed to be redundant in its most important parts. This helps protect against breakdown and ensures a high level of availability for urban transit systems. The emergency power generator must be designed so that even the last section of line can be cleared in a space of time which passengers will tolerate.
- The power rail/current collector system is currently undergoing long-term testing at the H-Bahn test facility, and is being developed further. The protected arrangement of the power rails inside the guideway supports ensures that the traction current will be available even in extreme weather conditions. Even during the harsh winter of 1978/1979, there were no operating problems at the test facility caused by failures in the power supply.

1.4.2.6 Maintenance and Repair

- In order to achieve long maintenance and repair intervals, low-maintenance, high-reliability components are being developed within the framework of long-term testing. Requirements for high reliability of all components and, hence, for low-maintenance costs have been met by extensive use of conventional technology in H-Bahn.

1.4.2.7 Fare Collection

- Equipment for fare collection and passenger handling, at the stations, is in every application determined by the local specific installation and the operator's requirements. In its basic operating form (line operation according to a fixed schedule), fare collection in Germany will largely correspond to the current practice used on public transit systems in the Federal Republic of Germany. For applications outside Germany, the particular type of equipment generally found at stations in that location may be used.

2. SCOPE OF REPORT

The H-Bahn system, at the time of the assessment visit in March and April 1979, existed at the 1.4 km long test track at the Siemens Research Center in Erlangen, Germany. Feasibility studies on the system have been conducted for Berlin and Erlangen. In the summer of 1979, the Government of the State of North Rhine, Westfalia and the German Federal Ministry of Research and Technology (MORT) approved the construction of the H-Bahn facility at Dortmund. It had also been proposed for deployment in the city of Erlangen; but at the time of the visit, the proposal had been rejected by the city's government after initial discourse. In a later vote an H-Bahn system was approved for Erlangen.

The report begins with a review of the H-Bahn's background (Section 3); this is followed by a comprehensive technical description of the test system and of possible applications in Erlangen, Dortmund, and elsewhere (Section 4), and includes descriptions of how a deployed system would differ from the test system.

The actual assessment of H-Bahn makes up Section 5, highlighting its development status, system performance and areas where further development is needed, as well as assessing how an H-Bahn system would fit into the urban environment. Technological factors, and safety and human factors are evaluated.

Costs are reviewed in Section 6. Section 7 covers various aspects of the certification of AGT systems in general and of H-Bahn in particular.

Finally, Section 8 is devoted to a summary of the findings and recommendations derived from the whole assessment effort.

3. INTRODUCTION

3.1 REASON FOR STUDY

In the fall of 1978, plans were made for a joint German-U.S. study of the H-Bahn AGT system under development in the Federal Republic of Germany. It was initiated under an agreement between the German Federal Ministry of Research and Technology (MORT) and the United States Department of Transportation's Transportation Systems Center (TSC). The agreement calls for cooperation in the assessment of AGT technologies in order to guide further research, development, demonstration, and deployment decisions relative to AGT.

The development of H-Bahn is sponsored and partly funded by MORT. It is conducted by the German firms of Siemens in Erlangen and Düwag-Waggonfabrik Üerdingen AG, (hereafter referred to as Düwag) of Düsseldorf through a joint venture agreement.

The H-Bahn investigation is one of several AGT system assessments, both domestic and foreign, being conducted by UMTA's Office of Socio-Economic and Special Projects. The H-Bahn report and the Cabintaxi/Cabinlift report are two examples of international joint projects completed by TSC and SNV.

The purposes of these assessments are to:

a) Gather and exchange information on Automated Guideway Technology, to better understand the state of technological advancement, and to obtain synergistic improvements for future development.

b) Review problems and solutions encountered during the design, development, implementation, and operation of AGT systems in order to improve the process based on experience.

c) Obtain information on engineering, economic and operational performance, and public response, which can be used in planning future AGT systems.

d) Provide urban planners with information which will enable them to determine the applicability of AGT systems to their specific transportation problems.

This particular assessment has also provided the opportunity for international cooperation and technical exchange.

3.2 SYSTEM BACKGROUND

The rapid increase in the number of individual vehicles during the 1960s and 1970s has posed a problem for small and medium sized communities. While the U-Bahn offers a proven transit alternative for a large city dependent on automobiles, it does not suffice as a viable mode of transportation for less populated cities. Consequently, industrial research, supported by public assistance, has worked for several years to close this gap. Siemens in Erlangen and Waggonfabrik Üerdingen AG have tried, in the development of H-Bahn, to demonstrate a modern public transit system for communities which have not found the U-Bahn to be an economically feasible alternative to automobiles.

The development of this elevated transit system by Siemens and Düwag has the following objectives:

a) Increase attractiveness for user by high traffic frequency and short travel time.

b) Decrease high personnel cost by driverless automatic operation of the vehicles

c) Decrease capital investment requirement and construction time for a track-bound short-distance traffic system by means of prefabricated guideways which can be rapidly installed

d) Adaptation of system performance by means of various vehicle sizes and train formations without change in the guideway, to be able to transport over 10,000 persons in each direction per hour, while satisfying the safety requirements of railroad operation and public transit.

H-Bahn development began in 1972 with problem analyses of traffic, technology, and with simulations, and component development in Erlangen. The results led to construction of a test track for linear motors in Berlin in 1973, and for switch development in Düsseldorf in 1974. In 1979, the system development had advanced to the test phase for a complete system on a 1.4 km loop of test track at Siemens in Erlangen. This report details the H-Bahn version now being tested and also elaborates on the concept of the final system.

At the time of this assessment of the H-Bahn system at the Erlangen test track, all safety sensors were installed, the command and control system was operative along one section of the guideway, computer software was validated, and central control software was being designed. In early 1980, the automatic operation of three vehicles was demonstrated to the Minister of MORT.

3.3 GOVERNMENT REQUIREMENTS

The Federal government of West Germany through the Federal Ministry of Research and Technology (MORT) subsidizes the kinds of development that Siemens has done. Government policies require that these funds can be used for research and development, if the projects under consideration fulfill the following criteria:

1. The companies' headquarters as well as the development and research capabilities and facilities must be located within the Federal Republic of Germany, including West Berlin.

2. The project and research associated with it must support and improve the capability of the German economy and German science.

3. The necessary qualifications and capabilities for carrying out research and development of the type required must be available.

4. The company must be viable and must demonstrate that it can provide an auditing system suited to account for the spending of public funds.

5. The firms involved must be prepared to work together on this project with scientific and technical institutions and their equipment.

Participating industrial firms are required to share with the government the total cost of the project. For governmental participation, funds are available (especially in resulting research and development) in accordance with the following criteria:

1. Important technological projects demanding a large amount of resources together with a high risk of technical scientific success which are not within the capabilities of a single developmental firm.

2. Further development and technical utilization of important new knowledge and experience resulting from work carried out in public owned scientific resources, such as technical schools, research centers and other research facilities.

3. Research and development in which German industry is engaged in competition with foreign countries having similar programs funded by their governments.

MORT is supported in planning transport systems, in evaluating proposals, and in checking the progress of on-going or completed projects by: 1) the Industrieanlagen-Betriebsgesellschaft GmbH (IABG) in Ottobrunn near Munich, which acts as project monitor, 2) panels of consultants, 3) periodic status seminars and other presentations, and 4) research and development results.

In the case of H-Bahn, the failure records of vehicles and equipment at the test track are being truned over to Industrieanlagen-Betriebs-Gesellschaft (IABG) for analysis.

For H-Bahn development, there are several German laws, regulations, guidelines and requirements to consider which have to be met as for other forms of public transport, i.e.:

Many of the parts used in H-Bahn are covered by specifications, which are based on the German Industry Standards (DIN).

VÖV - Association for Public Transport Operation, which is equivalent to APTA in the United States publishes many transportation guidelines - for example, type recommendations for rail vehicles, some of which have been used for H-Bahn design.

The result of safety-investigations in Germany was that AGT-systems should be fail-safe, and H-Bahn developers strive to ensure a fail-safe system. TÜV (translated as Technical Supervision Society) has studied and approved the H-Bahn safety system, which was originally developed for the railroads, but will be seen in its first operational use in H-Bahn.

3.4 PROJECT ORGANIZATION

The H-bahn system has been developed by Siemens and Düwag. It has been run by a project group set up under the Traction Department of Siemens in Erlangen. The relationships are approximately as shown in the following figure.

The project office began at Erlangen with 2 people in 1973 and currently employs 50 people. All Siemens work except work related to safety subsystems is done at Siemens in Erlangen.

As mentioned, the program has been largely funded by MORT. Through March 1979, 45 million Deutsch Marks (approximately $25M) have been spent, divided up (approximately) as follows:

MORT: 80 percent of the cost of the test track and facilities;

50 percent of the cost of system and component development;

Siemens and Düwag: the balance of the costs.

Düwag-Waggonfabrik Ürdingen AG was a partner in the development from the outset. They designed and built:

- drive units
- cabins
- some of the beams
- switch parts of the track
- parts of the maintenance facility.

Siemens at Erlangen and Braunschweig designed and built the command and control system, including the entire safety subsystem.

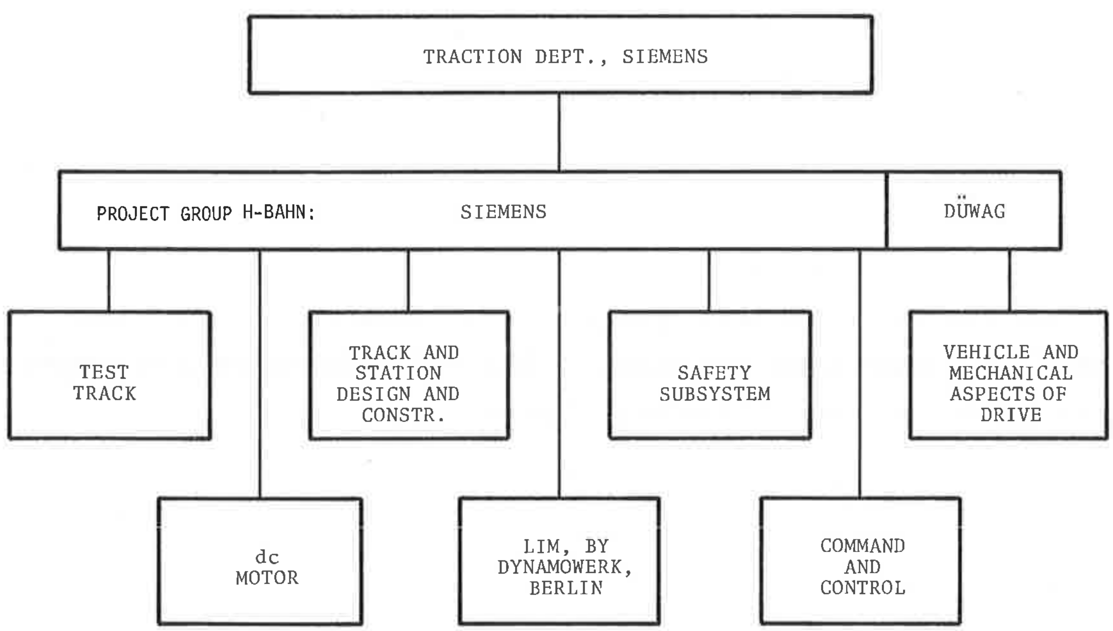


FIGURE 3-1. H-BAHN PROJECT ORGANIZATION

4. TECHNICAL DESCRIPTION

4.1 GENERAL SYSTEM OVERVIEW

The H-Bahn system, as now proposed and as being tested at the Siemens AG test track in Erlangen, West Germany, has several potential advantages over most other AGT systems for use in crowded central business districts, especially in older cities:

a. Its entire operation is elevated utilizing a narrow guideway which requires a smaller right-of-way.

b. Its running rails, power rails, signaling system, and switches are enclosed and totally protected from the weather. The system is designed to be impervious to snow, ice, and rain.

c. It is designed to be flexible, having a series of vehicles of the same basic design and technology, so that each site-specific application can be realized with the same hardware, assembled modularly in various ways.

The technical description in this section provides a summary of system characteristics in tabular form and describes each of the major elements of the H-Bahn system. In addition, operational support equipment and procedures are reviewed along with a discussion of dynamic simulation, theoretical performance and the proposed applications to date of the H-Bahn system.

4.1.1 <u>System Technology</u>

The H-Bahn system, as it now exists, is a system that can be either partly or fully automated, or it can evolve from a manually operated system (with an operator in each vehicle) into a fully automated driverless system. There is a choice of propulsion systems, either rotary dc motors for grades up to 7.5 percent, or linear induction motors (LIMs) for sites having grades up to 15 percent. A variety of vehicle forms is planned: single vehicles varying in capacity from 17 to 149 passengers, trains of two or more vehicles, and articulated vehicles. The automated systems are entirely computer controlled; even in the manual version, the safety level, plane, or subsystem is operating to provide independent limits and checks on speed, headway, and switch setting.

The initial concept design of the H-Bahn visualized a personal rapid transit (PRT) system with small vehicles, off-line stations, and non-stop, origin-to-destination travel for each vehicle. Studies made in 1973-1975, however, convinced the developers that such a pure system would not meet the needs of most candidate cities. Accordingly, a line operation concept was adopted as the prime operational mode, which provides stops at each station. Transfers may become necessary, but the decrease in attractiveness to passengers, if any, is compensated for by system simplification and substantial savings in capital costs. The on-line stations, each designed to handle maximum passenger flow, are equipped with fare collection machines and information and dispatch facilities for use by the passengers; each station also has its own station computer and data transmission terminal. It is expected that every station will be automatic, requiring no attendants, at least none on a full-time basis. The passengers waiting on station platforms are protected by doors which enclose the vehicle side of the platform that are synchronized to open with the doors of stopped vehicles.

In general, there appears to be little radically new technology in the H-Bahn system. Safety is effected by a modern version of the block system, and the safety system is fail-safe. Data transmission is accomplished by frequency shift keying (FSK) via guideway antennas and antennas on the vehicles. The most radical departure from past practice is the use of suspended vehicles, with a choice of dc rotary or linear induction motors. The newly designed enclosed guidebeam offers protection to running surfaces, power rails, signal rails and safety equipment and should make the system more winterproof than most other AGT systems.

The following sections of this report describe the technical aspects of the H-Bahn system.

4.1.2 System Operation and Type of Service

The presently planned service to be offered by H-Bahn is scheduled for all but low-density traffic periods. According to this mode of operation, most stations are usually on-line; an example of two station types at the Siemens test track in Erlangen is shown in Figures 4-1 and 4-2.

Full demand-responsive operation requires many small vehicles. The direction of the H-Bahn developer has been toward larger vehicles with the intent to confine demand-responsive operation to late-hour periods with low-density traffic, if desired by the system operator. This reduces the probability that many large vehicles would have to operate with little or no load during low-intensity periods.

In the demand mode now planned, the few passengers requesting rides could summon a vehicle by pressing a button in the station. If no vehicles were flowing at that time, a vehicle would leave the next storage facility.

The passengers would enter the vehicle of the requested line and if all were going to the same destination, they would be transported there non-stop. Before arriving at their destination, they have to press a button, just as on a bus which stops at the next stop when signalled. If a passenger wanted to get off at an earlier station, he has to press the button earlier.

During scheduled operation, of course, all vehicles stop at all stations; vehicles may be added or subtracted to the operating fleet by the central computer, whether in response to inputs from

FIGURE 4-1. AT-GRADE STATION AT ERLANGEN TEST TRACK

FIGURE 4-2. ELEVATED ON-LINE STATION AT TEST TRACK

the operators or automatically by vehicle overload signals, which are provided to signal the system's need for more vehicles.

4.1.3 Applicability of the System

The H-Bahn system is planned for the following applications:

1. Complete urban rapid transit service in medium-size towns.
2. Feeder system for rapid transit systems and commuter railroads in large towns and metropolitan areas, particulrly for connecting satellite towns to existing track-bound transport systems.
3. Special transport applications, such as connecting major airports to existing rapid transit systems, handling of passenger and freight traffic at such airports, and connecting disjointed campuses or facilities in a way similar to the Morgantown People Mover.

In order to solve these kinds of traffic problems, it is necessary to form networks and to provide the possibility of branching tracks even with simple route layouts.

At least five studies of the installation of an H-Bahn system in an urban environment have been made: one for Erlangen, which illustrates the first application itemized above; one for Berlin, which illustrates the second; and two studies illustrating the third application - one for the exhibition grounds at Hanover, and one for the campus of the University of Dortmund. At the time of the assessment, a simulation program for the Karlsruhe feasibility study was being worked on by SNV and has subsequently been completed. The program represents a good tool for operational optimization analysis. A simulation of a network operation was also considered for Hamburg-Farmsen, as an example of a feeder to the mass transit system of a large city.

In the case of Erlangen, the studies showed that with a minimum interval of 80 seconds between trains, and double and single vehicles with a 56-person capacity, the system could handle the expected peak load of 3300 passengers per hour (820 persons in peak 10 min).

The Berlin study visualized a system devoted to feeder service from satellite cities or suburbs to surface and underground rapid transit lines and concluded that H-Bahn was capable of this operation.

The H-Bahn system compares well with other modes of transit. The following is a comparison of automobile, bus and H-Bahn comfort levels.

	H-Bahn	Auto	Bus
Travel comfort (in "flow index numbers" - small numbers are better)	18	38	51
Interior Noise - dBA at 50 km/h	68	65	79
Exterior Noise - dBA at 50 km/h, measured at 7.5 m from the vehicle	62-66	72	71-78

One of the most difficult hurdles to overcome in an old city is accommodating any AGT system with existing city structures. Problems of aesthetics, city disruption during construction, and interferences with existing structures make its application difficult. Developers believe that the installation of dense networks with elevated guideways on every street is improbable. Such networks cannot be justified either by cost or public demand. A good coverage by a few lines must, therefore, be the goal.

In summary,

- The H-Bahn can be an efficient mode of travel, as has been shown in the applications studies;
- The H-Bahn characteristics on ride comfort and noise are generally better than busses and autos;
- Economically, H-Bahn should be justifiable because of its reduced operational manpower compared with that required for manned modes. This reduction was shown in the Erlangen study to be even more important in the future, because of wage inflation.

- The integration of the structures of any system into the city environment is a difficult problem. By concentrating the lines into a few accessible corridors, it appears capable of solution.

4.1.4 Test Facilities and Status of the System

System development, which was done by a project group at Siemens AG in cooperation with the Düwag carbuilders, and which was funded by MORT in 1973. Component development, simulation of automatic control, and a series of small-scale tests were performed. In August 1976, construction began on a 1.4 km test track (Figure 4-3) at the research center of Siemens in Erlangen.

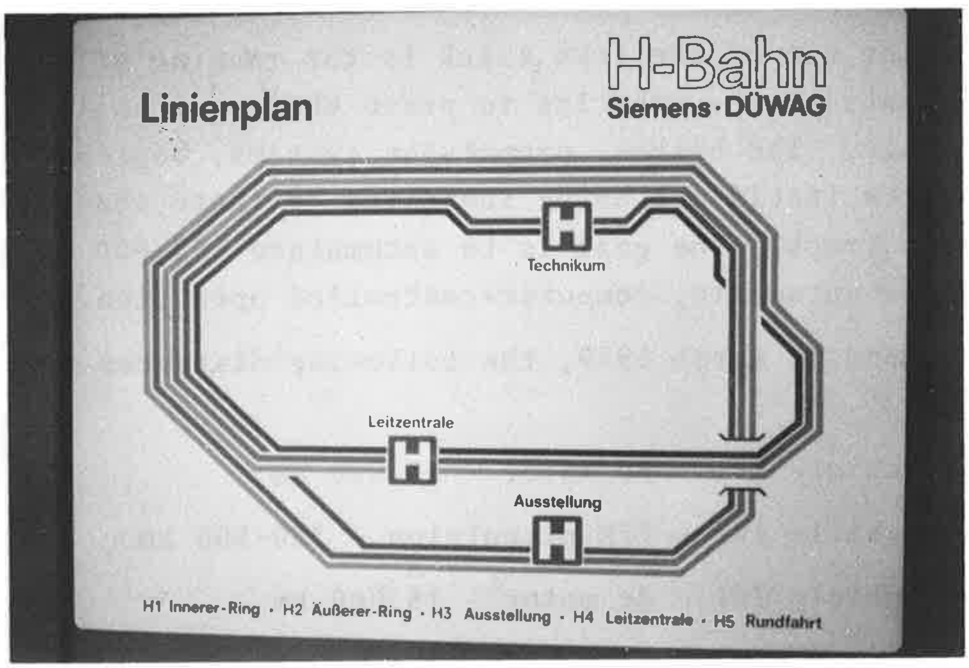


FIGURE 4-3. TEST TRACK LAYOUT AT ERLANGEN

The guideway at the test track can handle about 10,000 passengers per hour in each direction. The first prototype vehicle for use on this track had room for eight seated passengers and nine standees and uses a rotary dc motor for propulsion. Five additional vehicles have been built and are currently being tested. Of the five vehicles, four are small vehicles powered by a linear induction motor while the fifth vehicle is a 41-passenger vehicle powered by a dc motor. Automatic operation tests began in March 1979. Three stations, two elevated and one at-grade, are provided at the test track; one of the elevated stations is an integral part of the maintenance center. The following aspects of passenger and vehicle handling are installed and are being tested: anti-sway clamps to hold the vehicles solidly during loading and unloading; automatic stopping of vehicles; automatic positioning of vehicles opposite the station doors; biparting doors both on the vehicles and in the stations; destination signage; fare collection equipment; electronic equipment - station computers, data transmission equipment, and safety equipment; and elevators to bring passengers to the elevated stations.

One major use of the test track is the running of long-term endurance tests on the vehicles to prove their suitability for public transit. The brakes, propulsion systems, bogies, cabins, and the system itself are being subjected to these tests on the Erlangen track. The goal is to accumulate 100,000 km on each vehicle under automatic, computer-controlled operation.

By the end of March 1979, the following distances had been accumulated:

Small vehicle 101 - dc motor - 45,000 km

Small vehicle 102 - LIM propulsion - 300-500 km

Large vehicle 201 - dc motor - 15,000 km

4.1.5 H-Bahn System Characteristics

OVERALL SYSTEM:

Type of traffic service	Line operation
Operational mode	Usually scheduled; demand operation during off-peak hours
Stops	Make all stops (at scheduled operation)
Stations	On-line (single or double channels)

OVERALL SYSTEM (Continued)

Max. train length	3-5 vehicles
Headways	1-2 minutes (Due to station capacity)
Nominal day	19 hours (as desired by operator)
Operational monitoring	Central control
Transport of luggage?	Yes
Transport of freight?	Yes
Transfers needed?	Probably, but number dependent on network layout and destination of passengers
Test track	1.4 km, at Siemens Center in Erlangen
Capacity of system Passengers per hour	about 4,500 per hour per direction*

VEHICLES: (Smallest)**

Style	Overhead suspension
Suspension	Vehicles hang from guideway - oscillation dampers - vehicles tilt to compensate for centrifugal force on curves
Length	3.4m
Width	2.3 m
Height	2.3 m
Coupling length	3.7 m
Empty weight	3220 kg
Payload objective	1400 kg max
Operational weight	4620 kg max

*Assumes Veh. 3/3, 4-car train, 50-second headway.
**Note: See Section 4.4 for information on other options.

VEHICLES: (Smallest) (Continued)

Seated passengers	8
Standing passengers	9
Space per standee	0.25 m^2 max
Doors	2
Doors per side	1
Door width	1.7 m
Door height	2 m
Door operation (prototype)	ac motor 380V, 50Hz
Intercom to central	Yes
Audio announcement capability	Yes
Heating and cooling	Electrical, with blowers. No air cooling at present, but possible if desired.
Construction	Smallest vehicle, plastic sandwich; (larger vehicles, aluminum light weight)

RUNNING GEAR (bogies):

Number	1 on small vehicle, top mounted (see Section 4.4 for others)
Running wheels	4 per bogie, bearing on running surface inside beam
Tire material	Bandaged rubber tires
Guide wheels	8 per bogie, bearing on side of beam
Switching wheels	8 per bogie
Switching mechanism	Toggle, set on vehicle by control, and backed up by safety ramps in the beam

PROPULSION AND BRAKING:

	Type of Propulsion	
	dc Rotary	LIM
Maximum speed	60 km/h	60 km/h*
Control	Voltage	Voltage

Motor Type	dc Rotary		LIM
	Prototype Vehicle	Production Vehicle	
Number of motors	2	2	1
Power input	17 kw each	27 kw each	44 kw**
Armature voltage	130 Vdc	440 Vdc	380 Vac 3 phase, 50 Hz
Distribution power	380 Vac 3 phase, 50 Hz	660 V 3 phase, 50 Hz	380 V 3 phase, 50 Hz
Dynamic braking	Regenera-tive	Regenera-tive	Electrical, reverse current: or dc
Mechanical braking***	Spring loaded, held off by power		

(Note: The prototype dc motor powers the rotary motor vehicles at the test track in Erlangen.)

PERFORMANCE:	DC Motor	LIM
Maximum speed	60 km/h	60 km/h
Operational speed	50 km/h	50 km/h
Acceleration (m/s^2) (Max)	1.4	1.4
Acceleration (m/s^2) (Avg)	1.0	1.0
Deceleration (m/s^2) (Max)	1.4	1.4
Deceleration (m/s^2) (Avg)	1.0	1.0

*Synchronous speed of LIM.
**Projected to be 44 kw. Measurement at the test track, however, has shown it to be 75 kw. See also p. 4-60.
***Used in case of safety-related failures as holding brake in stations.

PERFORMANCE (Continued):	DC Motor	LIM
Emergency brake deceleration (m/s^2)(max)	2.75	2.0
Maximum jerk (m/s^3) (for propulsion)	2.0	2.0
Maximum jerk (m/s^3) (for passenger)	0.8	0.8
Maximum uncompensated lateral acceleration (m/s^2)	1.0	1.0
Maximum grade acceleration	7.5%	15%
Headway	50 seconds	
Dwell (Erlangen spec)	20 seconds, average	

GUIDEWAYS:	
Form	Overhead beam; support 9.4 m high; vehicle bottom clearance = 4.7m; ℄ of vehicle 1.75 m from vertical support
Beam type	Slotted box beam
Beam height	1.125 m
Beam width	0.78 m

GUIDEWAY ELEMENTS:	
Minimum radius at maximum speed	80 m
Minimum radius reduced speed (31 km/h)	30 m (25m, @ 7.2 km/h in depots & turn loops)
Minimum spiral parameter	25 m
Maximum banking, degrees	8.50 maximum oscillation

GUIDEWAY ELEMENTS (Continued):

Interval between supports	30 m, tangent tracks; for curves see below

Spans for various curve radii, reduced speeds

Curve radius	Support span	Speed
25 m	15 m*	7.2 km/h
30 m	16 m	31 km/h
40 m	21 m	36 km/h
60 m	24 m	44 km/h
80 + m	30 m	50 km/h

*Only in depots, etc.

Type of switch	Fixed deflectors mounted in the track beam ensure that toggles are positioned when points are passed.
Supports	Steel or concrete

STATIONS:

Location	On-line (single or double channels)
Number of docking points	Site specific
Platform length	Depends on vehicle selection
Spacing	500-1000 m
Average dwell time	20 seconds
Ticket sales	Automatic
Passenger gates	Yes
Vehicles per hour	Site specific
Passengers per hour	Site specific (see page 4-10)

CONTROL AND COMMUNICATIONS SYSTEM:

Management Supervision:	(Automatic Vehicle Supervision/ Leitebene - AVS)
Direct vehicle control	No
Failure Management	Initiates action
Computers	Central computer, Siemens
TRAFFIC CONTROL:	(Automatic Vehicle Operations/Steuerebene- AVO)
Scope	Decentralized
Computers	One per station
Purpose	Direct control of up to 8 vehicles in stations and adjacent areas
Action	Start, stop, vehicle positioning, switch operation
Safety Control:	(Automatic Vehicle Protection Sichersebene - AVP)
Independent	Yes
Sensors	Block system, with short blocks, and sensors every 12 m
Fail-safe?	Yes
Action	Monitors vehicle spacing Monitors vehicle speeds Monitors switch safety
Data Transmission:	
Message form:	16-bit digital

- Each message includes vehicle I.D.
- Each message asks or reports position, speed.
- In stations, message includes door open/shut commands for both vehicle doors and station doors.

Modulation	Frequency shift keying (FSK), between 132 kHz and 121 kHz. (132 kHz = 0, 121 kHz = 1)
Vehicle contact	Vehicle polling and individual addressing of up to 8 vehicles per second
Accuracy	Parity checking of all messages
Duration	60 milliseconds, serial transmission one way-120 ms for query & reply

SAFETY AND RELIABILITY:

Escape system options:

- Push away or tow away of defective vehicle to the next station
- Passenger rescue by special vehicle belonging to the system or by auxiliary ground vehicle
- In tunnels safety walk-way
- Cloth-tube mounted in the vehicle floor

Station surveillance	Closed circuit TV in stations
Communication with passengers	Voice channels to and from vehicles and stations to central control
Passenger gates in stations	Yes

ENVIRONMENTAL STRESS:

Exterior noise: at 50 km/h measured at 7.5 m from vehicle	62-66 dbA
Interior noise: at 50 km/h	68 dbA
Air pollution	None directly emitted by vehicle

4.2 GUIDEWAY

4.2.1 H-Bahn Guideway System

4.2.1.1 General System Description - The H-Bahn vehicles are suspended from a bogie which travels along guide rails within an enclosed track beam (box girder). The track beam houses all the power, control, communications, and guidance equipment. The beam can be constructed in three ways:

a) thin steel wall with frame reinforcement,

b) full steel wall,

c) reinforced concrete.

The thin wall beam with rib stiffeners is the most economical selection and is the one being tested at Siemens' Erlangen site. The full steel wall beam is more expensive and is more suitable for short spans (about 15 m). The reinforced concrete beam is an option for locations where steel is not readily available, and it requires massive supports to carry the heavier beams.

The track beam is attached to steel or concrete support columns which are rectangular or round in cross section. Several support types are employed depending on the number of track lines and site conditions. The support columns are bolted or inserted into heads of either flat or deep foundations. The details of the various guideway components are discussed in the following sections.

4.2.1.2 Guideway Design Considerations - Since there are no specific regulations for transit systems like the H-Bahn system, the standards of the German Federal Railroads for steel railroad bridges were used as the main basis for design. The manufacturer's specifications for the various system components were also considered during design.

The following loadings are considered in the design of the H-Bahn system:

1) Steady or Dead Loads - This category includes the weight of the guideway structure as well as the weight of guideway equipment and materials, such as:

   - operating rails
   - brass rails (secondary component for linear motor)
   - power rails and supports
   - cables and conductors
   - instrumentation for control technology.

   The weight of equipment and materials amounts to 25 percent of the overall steady loads.

2) Traffic Loads - Traffic loads are the summation of the vehicle weight (7850 kg for the type 2/2 vehicle and the payload (66 persons: 8 per/m^2, each weighing 65 kg ≈ 4290 kg). The total weight of a vehicle is, therefore, 12,140 kg.

3) Drive and Braking Forces - Equal magnitudes of acceleration and deceleration forces are transferred by the linear motor (or the drive wheels when a direct current motor is used). In the case of linear motor drive, the forces act on the upper web of the carrier; in the case of frictional drive, they act on the lower web. For an acceleration/deceleration maximum of 1.4 m/s^2, these forces amount to 6000 N/vehicle (smallest vehicle). A spring brake loaded against the lower web can independently provide a 2.75 m/s^2 maximum deceleration (14,000 N/vehicle force).

4) Lateral Forces - Lateral forces of the order of 1/10 to 1/7 of the vertical loads are assumed for elevated railroads. This assumption includes consideration of skewed operation and its requirements for track clearance, tolerance, and of resulting wear.

5) Wind and Snow Loads - Stresses due to wind are assumed to be 2500 N/m^2 for an unloaded guideway and 1250 N/m^2 for the loaded case. Snow loads are not taken into con-

sideration, because the track beam is narrow and only minor accumulations are possible.

6) Thermal Effects - Additional stresses do not develop as a result of temperature changes. The expansion joints are dimensioned so that a variation of ±50°K is permissible when the rail is installed at or about 293°K.

7) Special Loads - A guideway span fully occupied with vehicles is considered as a special loading case. This load case represents the situation in which emergency braking results in several vehicles lined up behind each other along the span. This load is considered as a static load only.

4.2.1.3 Guideway Layout - In order to develop an optimal support span, all costs associated with guideway construction, transportation, assembly, and erection were examined. This span length, 30-35 m, is a structurally determinate system (carriers on two supports). A larger support span (>35 m) is possible when guideway support beams are reinforced.

A minimum radius of 30 m is used when laying out the system line. (A radius of only 25 m is permissible but only in storage facilities and turn-around loops.)

In order to achieve uniformity of the guideway with respect to the exterior dimensions, the support spans are approximately sized according to the curve radius as follows:

Curve Radius (m)	Support Span (m)
25	15
30	16
40	21
60	24
80+	30

The maximum possible speed is so reduced in curves having a radius $R \leq 80$ m that the free angle of swing is 14 degrees; with swing reduced to 8.5 degrees, the passengers are subjected to a residual lateral acceleration of 1.0 m/s^2. Based on these limits, the following speeds on curves are permissible.

Curve Radius (m)	Curve Speed (km/h)
30	31
40	36
60	44
80+	50

The transition from straight stretches to curves of different radii is accomplished by using transition curve sections called spirals. The dimensions of these transition sections are selected so that the resulting lateral jerk will be limited to 0.8 m/s^3.

The following guidelines are used:

a) The length of the switch support span should be approximately 21 m.

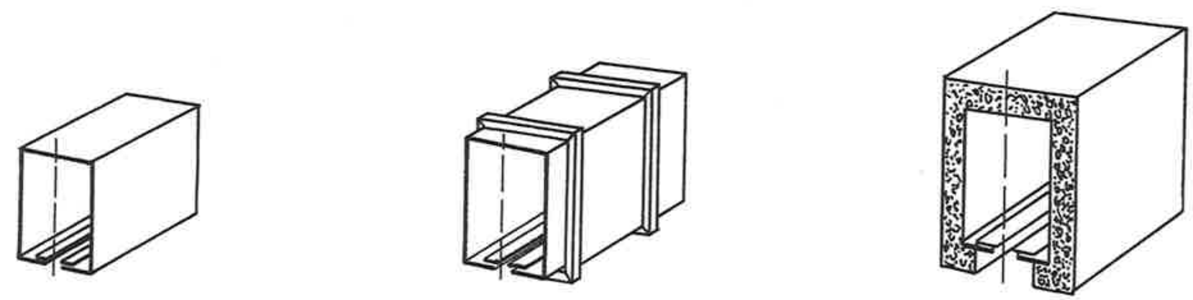
b) The lengths of straight stretches and curves will be in conformance with the previously given tables.

c) Local influences can affect the division of guideway span lengths; they should be adjusted so the resultant sections are equal in length.

d) If the curve lengths cannot be divided into economical support span lengths, the lengths should be extended into the transition or straight sections until the proper span lengths can be obtained.

4.2.1.4 Details of Guideway Track Beam - The track beam used for the H-Bahn system is of rectangular cross section and is slotted at the bottom. It is made of welded steel plates, thin-walled steel braced by steel framing, or sitecast concrete. (Figure 4-4).

In the interior of the steel beam, a brass plate, spot-welded to the underside of the top box beam member, serves as a reaction strip for the linear motor. The side walls carry the conductor rails which supply the vehicles with 3-phase electric power. The space above these rails accommodates the communication antenna,



	FULL STEEL-WALLED SUPPORT BEAM	STEEL-FRAMED SUPPORT BEAM	REINFORCED-CONCRETE SUPPORT BEAM
WEIGHT	155%	100%	400%
PRICE	120%	100%	65%

FIGURE 4-4. COMPARISON OF TRACK BEAM TYPES

active and passive elements of the headway and speed control systems, and the vehicle identification system. The bottom flanges of the beam carry the running rails for the main wheels. The running rails are fastened by clamps to the bottom plates of the track beam.

The box girder can be fabricated of steel or reinforced concrete; concrete the cheapest type, has a large cross section and requires more massive support columns. Two design variations are possible for steel-walled supports:

1) Steel members constructed of thin sheet metal supported by reinforcement frames spaced about 2 m apart.

2) Steel supports of heavy sheet metal with no reinforcement framing (primarily for short spans <15 m).

Both types fulfill the requirements of the specifications manual. Costs for the non-reinforced frame construction are 20 percent higher than those for the ribbed construction because of the thicker steel required. The interior cross-sectional dimension of the box beam is determined by the size of the drive unit. The beam for an H-Bahn not only has to be stable but must be dimensioned in a way that minimizes local deformations. These deformations are caused by carrying wheel loads, guide rollers, and the linear motor.

The clearances required for switching travel and those for mechanical and electrical safety needed for the running gear units and associated equipment also influence the inside dimensions of the track beam. The overall dimensions of the beam are approximately 780 x 1125 mm (for steel beams). Critical dimensions and allowable deflections are shown in Figure 4-5.

4.2.1.5 Details of Support Column Types - There are five basic configurations for support columns used for the H-Bahn system:

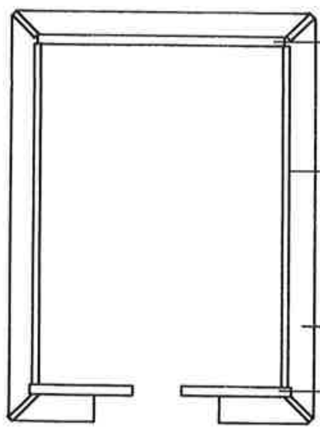
Type A - Inverted L-shaped columns for single-track lines

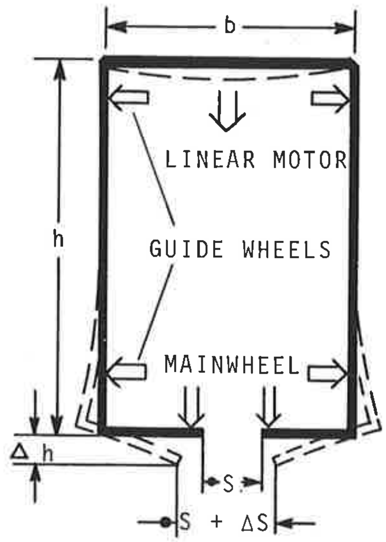
Type B - T-shaped support columns for double-track lines

Type C - Gantry supports for double- or multiple-track line

Requirements:

- Permissible spreading of slot	ΔS	=	5	mm
- Permissible deflection of lower chord	Δh	=	2	mm
- Total deflection of 30 m beam due to live loads	f max	=	50	mm
- Minimum envelope of necessary internal cross-section	b	=	780	mm
	h	=	1125	mm





Approximate Dimensions:

		Straight curve R = 60 m		Curve R = 30 m
- Plate thickness mm	Upper chord	20	20	20
St 52	Web	13	15	15
	Lower Chord	25	25	25
- Sections	Stiffening frames	160x70x8	160x140x10	160x180x10
	Spacing m	2	1.5	1.2
- Weight kg/m (including associated suspension elements)		600	825	900

FIGURE 4-5. TRACK BEAM DETAILS

Height (h)

- Track rail
- Lower points rocker wheel (incl. rocking travel)
- Lower points guide wheels
- Conductor rails
- Information equipment
- Upper points rocker wheel
- Upper points guide rail
- Upper guide wheels
- Clearance to top chord

Σ 1125 mm

Width (b)

- Slot width (suspension, emergency brake linkage)
- Running wheel width
- Lower points guide rail
- Guide wheel
- Necessary safety clearances for possible sideways running position

Σ 780 mm

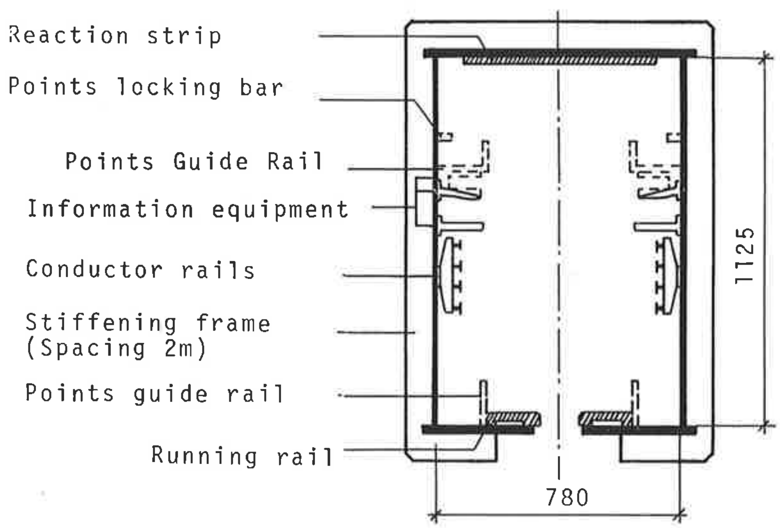


FIGURE 4-5. TRACK BEAM DETAILS (CONTINUED)

Type D - Inverted L-shaped support columns with two suspension points (Figure 4-6)

Type E - Pylon support for long spans and water crossings.

These support configurations can be constructed of steel or reinforced concrete and can be round or rectangular in cross section. Major considerations when choosing support columns are as follows:

1) Round cross sections are slightly lower in cost, since commercial steel tubes are available and round reinforced concrete columns can be economically constructed of spun concrete.

2) Steel support columns are constructed with foot plates which are easily fixed to the foundation head with anchor bolts. Reinforced concrete columns are joined to the foundation by inserting them into a sleeve in the foundation head.

3) Steel support columns are very slender and can be easily erected. Special design heights and cantilever lengths can be accommodated without major problems.

4) Reinforced concrete support columns cost about 30 percent less than steel and require no maintenance. Additional cost savings of 10 percent can be realized by using spun concrete supports. Reinforced concrete columns of various lengths of cantilever require additional form work. Also, concrete sections are much more massive than steel ones.

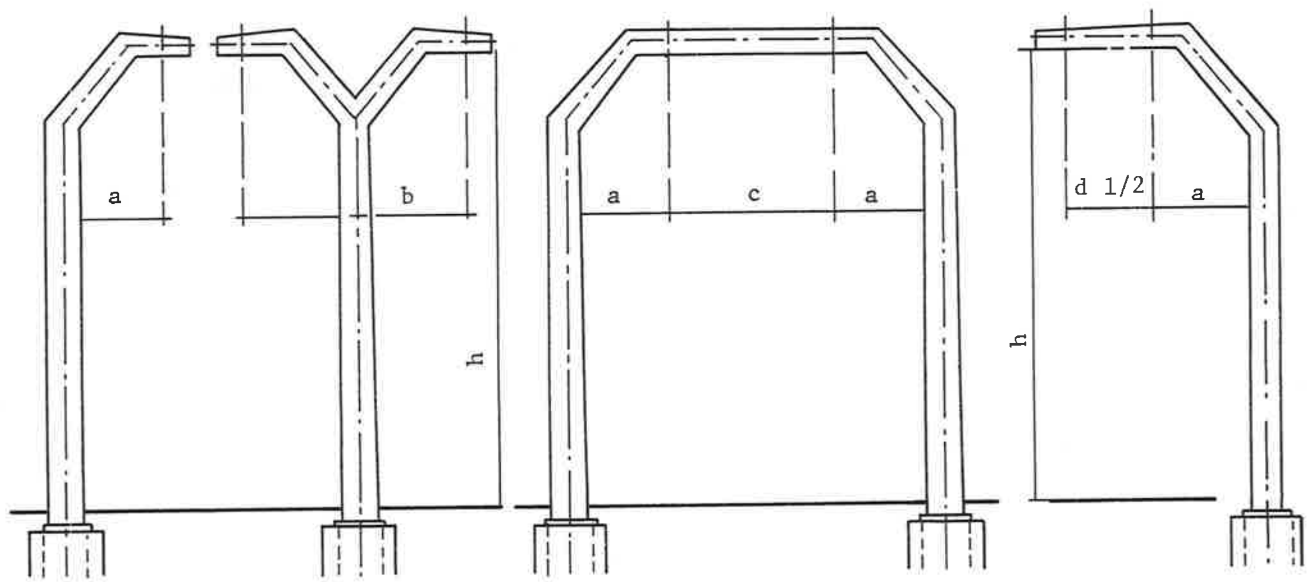
Typical dimensions for the various column types are outlined below:

Type A - Inverted L-shaped columns for single track-lines

a = 1.75 m (distance from inside edge of column to center line of vehicle)

h = 9.4 m (height of support)

X-Section = I (See Table 4-1)



In the form shown above, the support columns have the following "standard dimensions"

a = 1.75 m Minimum distance of track axis from fixed objects

b = 4.50 m Minimum distance between track axes of double-track lines with central support column

c = 3.50 m Minimum distance between track axes of double-track lines with gantry support colums

d_1 = 1.75 m Distance between points suspension centers (size of points opening)

d_2 = 3.5 m Minimum distance between track axis of double-track (sidewalk installation)

h = 9.40 m Minimum height for clearance between vehicle and roadway is 4.7 m in Germany.

FIGURE 4-6. TYPES OF SUPPORT COLUMNS

TABLE 4-1. CROSS SECTION OF SUPPORT COLUMNS

Dimensions / Type	Ht of Sup. Col h = 5.0/9.4/10.0 m				h = 12.0/13.8/14.5 m			
	$1.75 \leq b \leq 2.0$ m		$2.25 \leq b \leq 2.75$ m		$1.75 \leq b \leq 2.0$ m		$2.25 \leq b \leq 2.75$ m	
Steel □ A,B,C	I_u (mm) 700x(700)*	I_o (mm) 700x600	II_u (mm) 700x(800)*	II (mm) 700x700	II_u (mm) 700x(800)*	II_o (mm) 700x700		
D			III 700x(900)*	III_o 700x700			IV_u 800x(1000)*	IV_o 800
Concrete □ A,B,C	I_u 800x(1000)*	I_o 800x800	II_u 900x(1200)*	II_o 900x900	II_u 900x(1200)*	II_o 900x900		
Concrete ○ A,B,C	I_u 900ϕ	I_o 750ϕ	II_u (1050ϕ)*	II_o 900ϕ	II_u (1050ϕ)*	II_o 900ϕ		

*Dimensions in parenthesis are applicable for a cantilevel height of 10 m.

Taper = 10 mm/m - steel
20-30 mm/m - concrete
15 mm/m - spun concrete

Type B - T-shaped support for double-track lines

b = 4.5 m (centerline to centerline of vehicles)

h = 9.4 m

X-Section = I

Type C - Gantry supports for double- or multiple-track lines

c = 3.5 m (centerline to centerline of vehicles)

h = 9.4 m

Type D - Inverted L-shaped supports with two suspension points

a = 1.75 m

d_1 = 1.75 m for points suspension

d_2 = 3.5 m minimum distance of double-track lines.

4.2.1.6 Details of Support Column Foundations - Foundations for support columns can be of the types shown in Figure 4-7. Flat foundations can be constructed economically when the bearing stratum is found approximately 2-3 m below ground level. More space is required for flat foundations, but simpler equipment can be used. For a Type A support column of standard dimensions, the foundation would be approximately 4x6x2 m.

Where space is at a premium, deep foundations are generally used. Two types of deep foundations are 1) large, bored piles and 2) pile grillage. These foundations are about 15 m in depth and can be constructed much more quickly than the "flat" type. The pile grillage foundation is used primarily when the bearing stratum is at a greater depth than 15 m. The piles can be made of steel or reinforced concrete and are approximately 50-60 cm in diameter.

Basically, there are two types of foundation heads, sleeve-foundations for inserting support columns and flat-top heads for bolted connections. Flat-top foundation heads are cheaper than sleeve construction and more easily erected. They can be adjusted

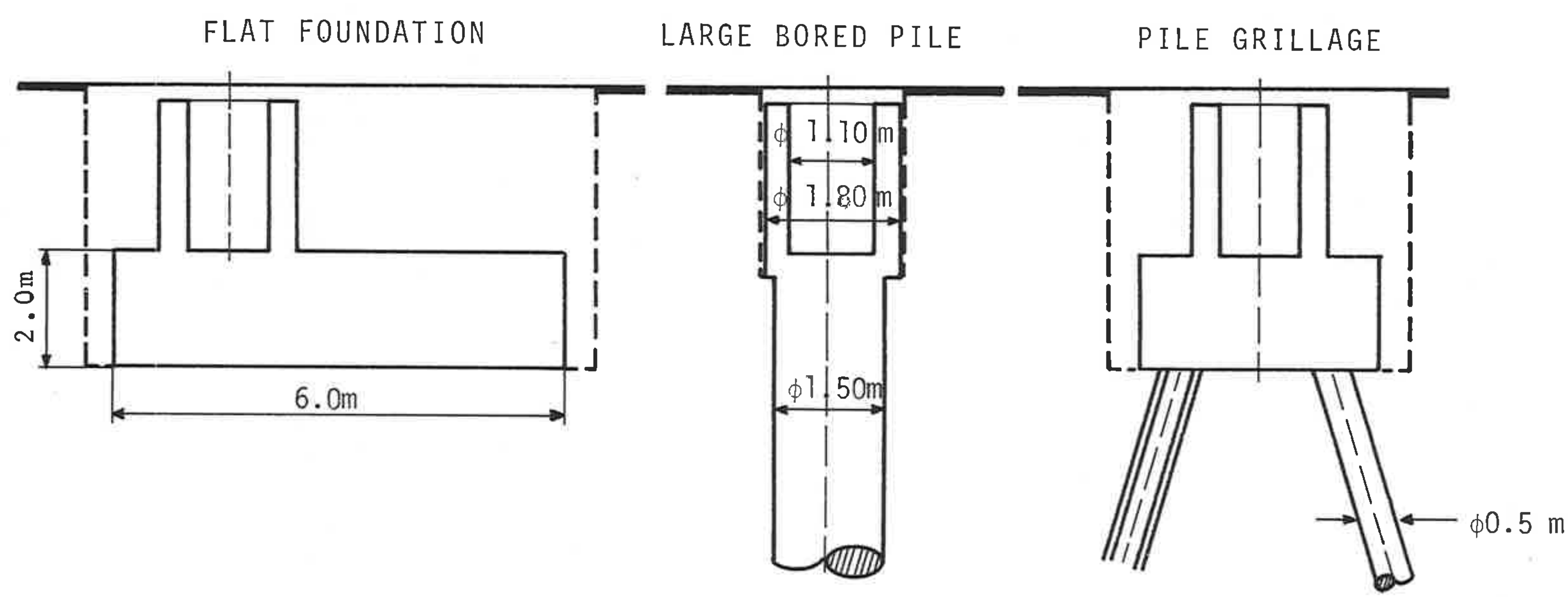


FIGURE 4-7. FOUNDATION TYPES

by means of anchor bolts which are cast into the foundation. Adjustments are made possible by steel plates which are mounted on top of a mortar bed on the foundation head.

For sleeve construction, the depth of the insertion is approximately 2 m and the top of the sleeve must be at least 30 cm below ground level.

4.2.1.7 Manufacture and Assembly of Guideway Components - In order to provide the tolerances necessary for proper operation of the running gear (1.5-2.5 mm), the guideway carriers and supports, if possible, can be mass-produced in advance at steel and concrete plants. In addition, the guideway carriers are fully equipped with reaction rails, transmitter, etc., at the time of fabrication; since this is done in a controlled environment, a high degree of accuracy is attained.

Work at the site is reduced to essentially the construction of infrastructures for clearing the right-of-way, pouring the foundations, erecting the supports, and mounting the guidebeam.

The reinforced concrete support columns are inserted into 2 m-deep foundation sleeves and setdown on a steel plate which has been built up to obtain the desired column height above ground level. No further vertical adjustments are required. The correct longitudinal and lateral position is obtained by using guys and flat hydraulic jacks. These can be removed 2 days after grouting the columns in the sleeves.

Steel columns are less massive and much lighter so that erection can be accomplished by securing them with anchor bolts. Because of the accuracy attainable with off-site manufacturing, only minor corrections are necessary. These are made by using wedges and jacks at the support foot plate; upon completion, the column can be loaded to design values.

The suspension brackets and clamping bolts needed for track-beam erection are preassembled at the factory. Two cranes are used to lift and position the beam to the support column cantilevers. The anchor plates, spherical washers, and nuts are then positioned and tightened. This entire process takes about 15 minutes. Final adjustment of the track beam is accomplished without any further crane assistance.

4.2.1.8 Maintenance and Repair of Guideway - The closed track beam serves to protect the internal workings of the H-Bahn system from weather and other external influences. The materials and finish of the track beam were chosen to keep maintenance costs down to a minimum. There are plans for a special mechanical attachment to be monitored by closed circuit television, which will clean and inspect the inside of the track beam. This cleaning will be required at regular, although infrequent, intervals. Open-sided sections of track beam provide access to the running gear for servicing. The running gear and vehicle are easily separated, permitting the easy separation of power equipment from the control and communications equipment and the removal of all electrical equipment for servicing. However, for normal maintenance and repair activities this separating feature is not required.

4.2.2 Guideway Switches

The switches of the H-Bahn system allow for safe merging and demerging of two track beams. The branches of a switch section consist of a transition track beam with a subsequent circular beam, or a transition track beam followed by a reverse or counter transition section.

When a vehicle enters a switch, the following occurs: the toggle devices attached to the ends of the bogie are pneumatically positioned for a left or right turn. The guide rollers affixed to the toggle arm are entrapped by the switch guide rails which are welded to the side walls of the track beam. The bogie or drive unit is thus guided through the switch to the proper branch or for merging to the main track beam. In order to prevent unintentional changeover of the switch guide rollers while a vehicle is in the switch, interlock rails positioned above the switch guide rails lock the rollers in the guide channel, until the switch has been completed.

Ramps, located at the approach of the switch, act as a secondary, or back up, switch system by mechanically pushing the toggle into the correct position should it be incorrectly positioned. For merging switches, the ramps are fixed; and for demerging, a pair of alternating ramps are provided. These adjustable ramps are controlled by the "safety level" of the control system. In the unlikely event that both the toggle device and ramp system are not positioned properly, the safety system will shut down before the vehicle reaches the switch.

When the drive unit enters a switch, the drive wheels opposite the direction of switching leave the running surface and freewheel above the slot in the track beam. The points, as they are called, are slanted to permit smooth degress and egress to the running rails. The slant of the opposite rail allows the free-running rail to come up to speed gradually, ensuring proper load distribution between carrying wheels. In emergency braking, the rail slant serves to shift the brake shoe to the opposite rail.

4.3 STATIONS

The design of H-Bahn stations is flexible enough to accommodate local site conditions and expected traffic volume. Modular units, which can be prefabricated, are designed to allow a variety of station configurations. Changes in traffic volume and required station capacity can be easily accommodated by adding the necessary station units. For normal scheduled operation and for off-peak limited demand service, no "off-line" track is required. If additional line capacity is required, however, a station can be served by a twin "on-line" track with switches located at both ends of the station area.

The stations can be constructed of steel or concrete depending on the local cost and availability of materials. The station exterior accents the use of glass with exposed aggregate concrete, stainless steel, or aluminum panels. The station interior is designed to require a minimum of maintenance with painted walls, non-skid rubber mat floors, and high-strength, molded plastic seating.

Passengers can enter or exit an H-Bahn station by stairs or by elevator. Since the "honor system" is used for German transit systems, there are no barriers or turnstiles to prevent patrons from entering the station at ground level. The stairways are sufficiently wide enough to accommodate two passengers moving in opposite directions. Glass windows along the stairwell and station lobby provide natural light and a feeling of "openness." Hydraulically controlled elevators (which exceed the minimum dimensions required for servicing wheel-chaired patrons) allow the elderly and the handicapped to gain access to the platform level. The station gallery is an open area designed with few interior supports and is well-lit. Ticket vending machines, e.g., those utilized for urban transit in Germany, can be employed for H-Bahn. The vending machines provide for single and multiple tickets, including tickets that permit passengers to change to other forms of city or local transportation. A route map displays the available lines to various locations and the appropriate fares. The patron deposits the fare to obtain a ticket for the desired destination and, as one possibility, inserts it in the ticket puncher (systems without punchers are also possible) which, in late hours, may control the demand option. Illuminated signs located above station doors indicate which line is arriving next.

Station doors are provided to prevent passengers from falling from the elevated platform and from approaching and contacting a vehicle before it has fully stopped. Locking clamps position the vehicle at the platform edge, reducing horizontal gap and vehicle sway. The vertical gap is controlled by a compensating suspension system which senses the weight of the vehicle, and in several seconds returns the vehicle floor height to about $\pm$10mm of the station platform level. The station and vehicle doors are triggered to open at the same time, after the incoming vehicle has come to a stop, and to close before it moves off. The sensors are infrared and the commands are given by the station computer. Stations can be equipped with closed circuit television and public address systems at the transit owner's discretion in accordance with pertinent regulations.

Each station is equipped with a station computer and data transfer equipment for controlling traffic in the vicinity of the station. The compact units are located in small rooms off the main lobby and are responsible for issuing commands and receiving signals from vehicles within its influence. Other mechanical and electrical equipment, such as that required for the heating and air conditioning systems, is also housed in separate station rooms.

A separate service area is normally available at stations to accommodate the power supply equipment needed for the station itself and its associated track sections, e.g., switchgear control equipment, and transformers.

4.4 VEHICLES

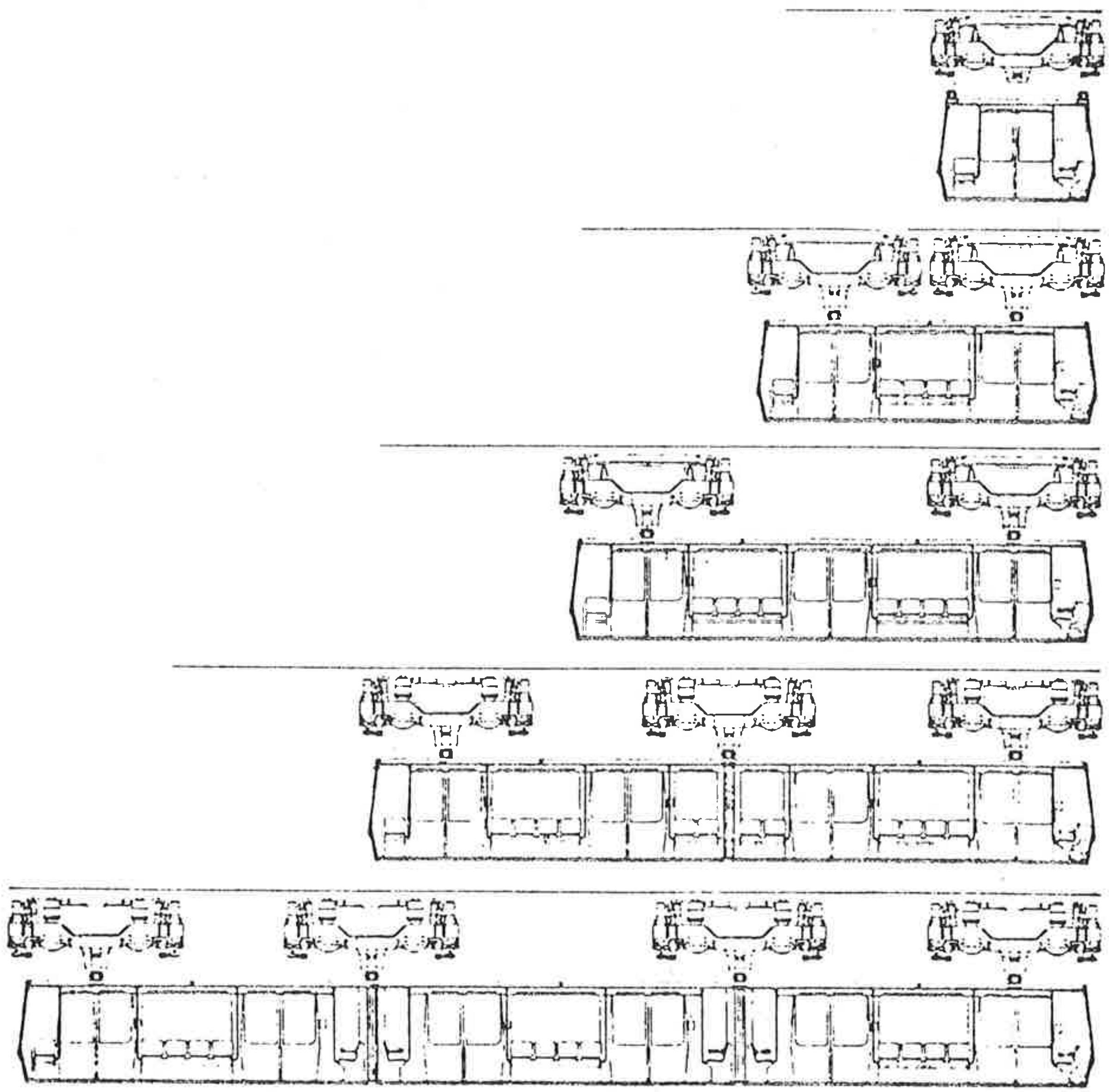
4.4.1 Vehicle System (Types and Capacities)

The H-Bahn system can be adapted to the travel demands of any local community, because it is designed so that a variety of vehicle configurations is available. These configurations are all derived from the smallest unit or cabin (vehicle). The size of the basic vehicle can be matched to the particular application so that it is possible, in the case of widely fluctuating traffic densities, to combine the vehicles into trains for rush hour service or to operate them as individual units during off-peak hours. If it is necessary to handle continuously dense traffic levels, vehicle consists can be used. Assuming a headway of 60 seconds, line capacities from 1000 passengers/hour to above 12,000 passengers/hour can be obtained depending on the vehicle configuration selected.

The smallest vehicle of the H-Bahn system, designated as 1/1 due to the one set of doors on each side, can accommodate eight seated and nine standing passengers, assuming four passengers/square meter of standing room. The biparting sliding doors allow a rapid, floor-level access to and from the station platform and coincide with the sliding doors on each station platform. Independent of the vehicle size or train formation, the door arrangement is kept uniform to match the station configuration. Vehicles with up to three doors on one vehicle side are constructed as a single-unit with either one or two truck-drive units. Vehicles with more than three doors must be multi-component articulated vehicles, in order to be able to corner properly. Such vehicles will then have three or more truck drive units. The end parts of the articulated vehicles are similar in construction except for the design of the linking elements. By using central parts, vehicles of arbitrary length can theoretically be designed according to the modular principle. For example, each section of the articulated vehicle is the same size as the meduim-sized unit of the non-articulated vehicle system. Figure 4-8 illustrates the various vehicle configurations and their respective characteristics.

The seating arrangement in the vehicles is predetermined by the door arrangements on each side (Figure 4-9). Starting with the 2x4 seat arrangement of the normal vehicle, the medium vehicle has an additional 2x4 seat arrangement between the doors, while the large cabin has an additional 4x4 seat arrangement. Other seating arrangements are possible. For example, there are five other seating arrangements for the medium-size cabin (2x2) which provide a different total passenger capacity as illustrated in Figure 4-10.

Special care was taken in the H-Bahn vehicle system design to standardize as many subsystems and components as possible. The uniform truck design, incorporating either a dc motor or linear motor drive and the electro-mechanical equipment for lighting, heating, ventilation, and information transfer, is common to all



Type Designation	Total Empty Weight (Kg)	Cabin Dimensions (mm) L	W	H	No. of Seats	No. of Standing Passengers (4 pass./m^2)	Total Capacity	Propulsion Rating (kw)pass./hr
1/1	4260	3450	2312	2300	8	9	17	54
2/2	7850	7545	2312	2300	16	25	41	108
3/3	9115	11640	2312	2300	24	45	69	108
4/4	12810	15735	2312	2300	28	70	98	162
6/6	18230	23925	2312	2300	38	111	149	216

FIGURE 4-8. H-BAHN VEHICLE FAMILY

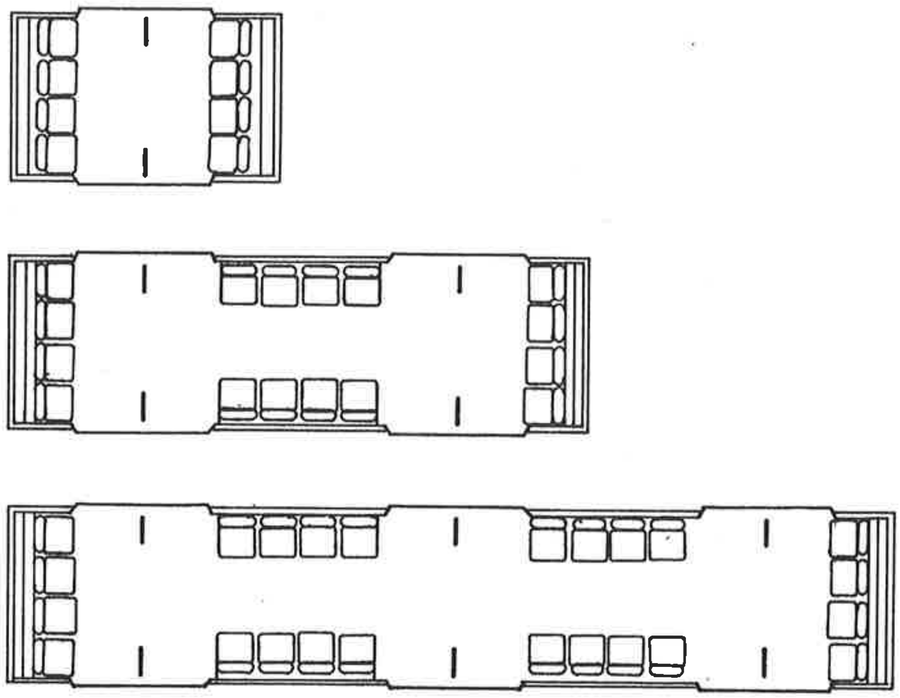
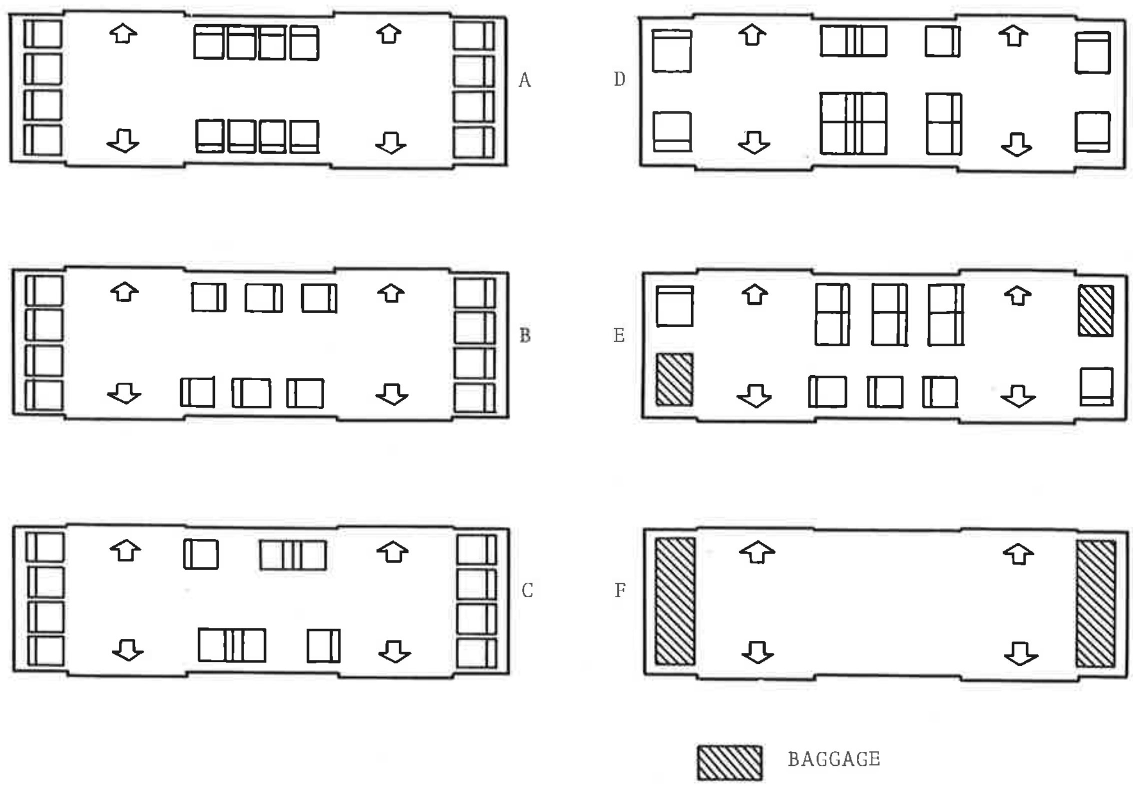


FIGURE 4-9. VEHICLE SEATING ARRANGEMENT



Medium Cabin 2/2

Version	No. of seats	No. of standing passengers (4 pass./m^2)	Total
A	16	25	41
B	14	28	42
C	14	28	42
D	13	24	37
E	11	28	39
F	0	56	56

FIGURE 4-10. ALTERNATE SEATING ARRANGEMENTS FOR THE MEDIUM VEHICLE - 2/2 (VERSION A - STANDARD ARRANGEMENT)

vehicles. This also applies to the vehicle suspension as well as to the pallets carrying the batteries, the battery chargers and the control and communications equipment.

The prime elements of the vehicle, i.e., the cabin, the truck, and the suspension system connecting the two are described in greater detail in the following sections. The cabin and the truck are constructed as two separate elements using different manufacturing methods. The truck is made of a welded frame on which the load-carrying double-flange wheels, the guidance wheels, the propulsion motors, and switch mechanism hardware are mounted. The trucks are connected to the cabins by a suspension system which passes through a slit in the guideway.

4.4.2 Vehicles

4.4.2.1 Mechanical Parts - Each body section consists of a floor, side walls, a roof, and one or two end walls. The payload is supported by the vehicle floor. At the closed end of each cabin section, the load is transmitted from the foor to the suspension elements via the pillars and top members of the two nearest doors. At the open end of the cabin section (articulated vehicles), the load is taken to the central universal joint in the floor and passes on to the coupling frame, which is connected to a truck unit at both its upper corners. The universal joints interconnecting the cabin sections and coupling frame allow a degree of relative rotation about the three main axes but prevent translational movement along these axes. Arrangement of the couplings in the vehicle floor is advantageous because the relative motion between the floors of the cabin sections and the part of the coupling frame forming the vehicle floor is very small. Connection of the two cabin sections with the coupling frame by separate joints halves the angle formed between the former and the latter when running through curves.

The small cabin (1/1) is made up of two self-supporting, plastic, sandwich components. The shells are of a light-core laminated construction in the form of two supporting GFK layers with a foam core. In contrast with the small cabin, the medium and large cabins are of light aluminum construction, which is more economical to produce for these vehicle sizes. The skeleton is covered with metal sheets on the outside and a plastic covering on the inside.

Suspensions - Pneumatic springs provide a high degree of passenger comfort. Each spring is fitted with a valve which enables compression to be kept constant, irrespective of the load. Separate control of the springs at either end of the transverse members stabilizes the vehicles against rolling. Positional stability of the body sections and the coupling frame is ensured by the method used to suspend them from the truck units. The coupling frame suspension also helps to stabilize the vehicles by means of springs located horizontally above the roof (Figure 4-11).

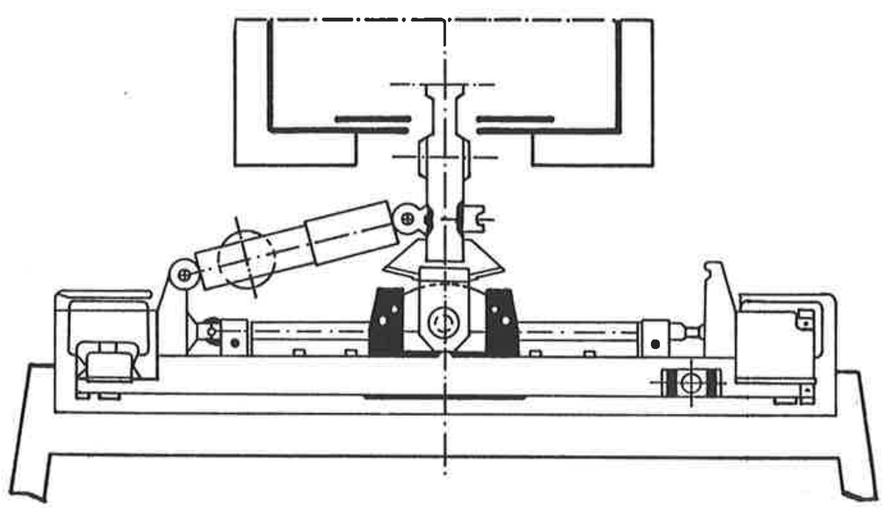


FIGURE 4-11. CABIN SUSPENSION SYSTEM

Seats - Plastic bucket seats are provided with the seat cushions glued in position. The heating/ventilating equipment and the control equipment are arranged under the seats. Access to the equipment is gained through hinged panels from outside.

Floor - The floor is covered with a non-slip plastic covering which turns up along the front of the seats. This permits easy cleaning.

Hand Posts - Railings are provided at the doors, and stanchions are located near each seat.

Windows - Non-opening windows made of laminated glass are used extensively on cabin walls and doors. The cabins are ventilated by fans with fresh air circulation. The windows can be fitted with ventilation flaps; removable windows with grills are possible for tropical environments.

Doors - Sliding doors are provided with rolling guides at the top and sliding guides at the bottom. The upper rolling guides are covered by a flap. The ventilation exhaust openings are located near the upper rolling guides. The doors are powered by electric, 3-phase motors.

Escape System - In case of an emergency which prevents the passengers from exiting the vehicle through the doors, the passengers can leave through a drop door in the vehicle floor. (This approach is the last resort for passenger rescue, usually passengers are rescued by other methods such as towing disabled vehicles to next station, etc.). The drop door is released by a signal from central control and as it is lifted by a passenger, a flexible fabric escape tube unfolds outward to the ground. The flexibility of the tube controls passenger descent to the ground (Figure 4-12).

4.4.2.2 Electrical Equipment: Lighting - Light fixtures above the sliding doors provide vehicle lighting. The fixtures are automatically operated by photo-electric switches.

Heating and Ventilating - The cabins are heated and ventilated by two electric heating fans rated at 1.5 kw each, mounted under each 4-seat bench. The fan drive motor is a maintenance-free single-phase motor. The heating is controlled by a vehicle thermostat. Vehicles with non-opening windows are provided with

FIGURE 4-12. ENTRANCE TO ESCAPE TUBE

an auxiliary battery power supply and a transformer for the fan to ensure emergency ventilation in case of a power failure.

Communications Equipment - Several communication panels, with a combined microphone and loudspeaker for intercommunication are installed in the cabins. This is effected with transmitter and receiver units, fitted on a pallet. The transmitting and receiving antennas are mounted on the running gear unit and the track beam. In driver-controlled systems it is also possible to use normal portable radio equipment for communication instead of the transmitting and receiving equipment with track-mounted antenna.

Information System - Information and communication equipment is arranged adjacent to the doors in the form of route diagrams, intercommunication equipment and emergency call buttons. Passengers can communicate with central control and be addressed by it. Magnetic memories are used for station announcements and dispatch.

Fire Alarms - In the event of excessive smoke, built-in fire alarms initiate a fire alarm signal at the control center or, with driver-controlled vehicles, on the control console.

Battery and Charging Equipment - To provide the control supply for the vehicle, the emergency power supply for communications equipment, and the emergency lighting and ventilation upon failure of the main supply, there is a 24 V battery system with associated charging equipment arranged on a pallet.

Manual Control Console - On H-Bahn systems operating with driver control (e.g., if required for articulated vehicle trains), a manual control console and a driver's seat are installed in the leading vehicles. The driver's seat is positioned to allow a view of the doors. A driver's cabin is fitted at each end of the vehicle to allow operation in both directions without terminal loops being necessary.

Vehicle Control - The control gear for the equipment described above is installed on a pallet. Plug-in controller modules accommodate the brakes and braking control for deceleration, normal running and entering, and positioning and stopping of vehicles at the stations.

Draw-Out Pallets - Equipment installation on draw-out pallets permits the pallets to be replaced, within a few minutes in the event of equipment failure by releasing the mechanical closures and disconnecting the electrical couplings. This considerably reduces downtime of the vehicle (Figure 4-13).

Door Drive, Door Control - The automatic sliding doors are moved by a 3-phase motor. The door control system opens and closes the doors. The door drive and control system for automatic door operation are easily accessible after lowering the cabin lighting unit.

Most of the equipment is mounted on pallets which are inserted under the seats from outside the vehicle. This method of installation, combined with quick-release plug connections, makes for easy servicing. Figure 4-14 shows the pallet bearing the data

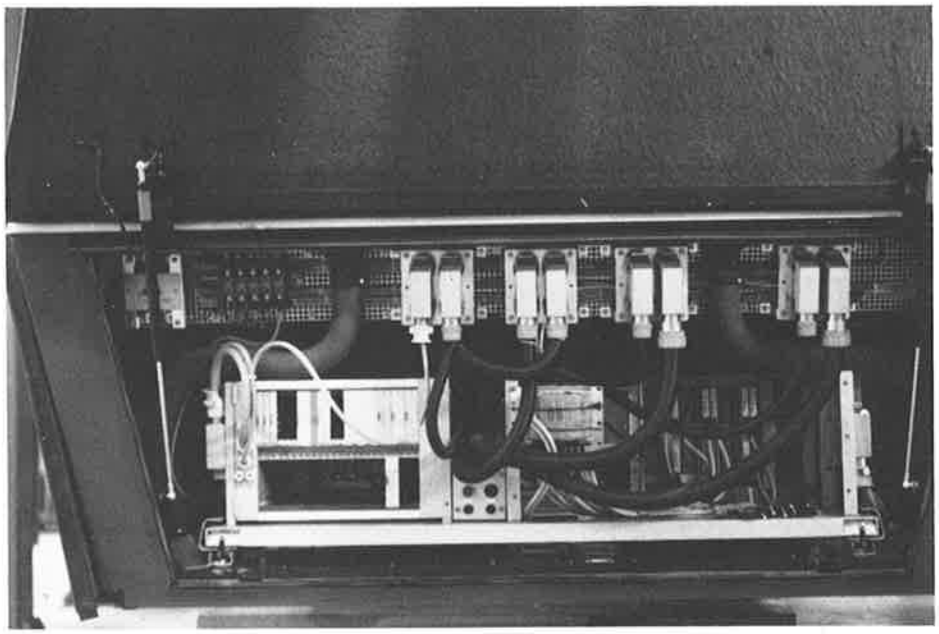


FIGURE 4-13. DRAW-OUT PALLET

transfer and communications equipment. Locating the main power equipment in the truck and the control and auxiliary equipment in the vehicle avoids the need for extensive power lines between the two, thus keeping the main voltage equipment separated from the cabin.

4.4.3 Truck Design

4.4.3.1 General - The truck units not only support and guide the vehicles, but also provide necessary traction and braking. As previously indicated, vehicles can be coupled together to allow several vehicles to be operated as a train. The truck units are independent (in their construction) of the type of vehicle - small, medium, large - and are therefore completely interchangeable.

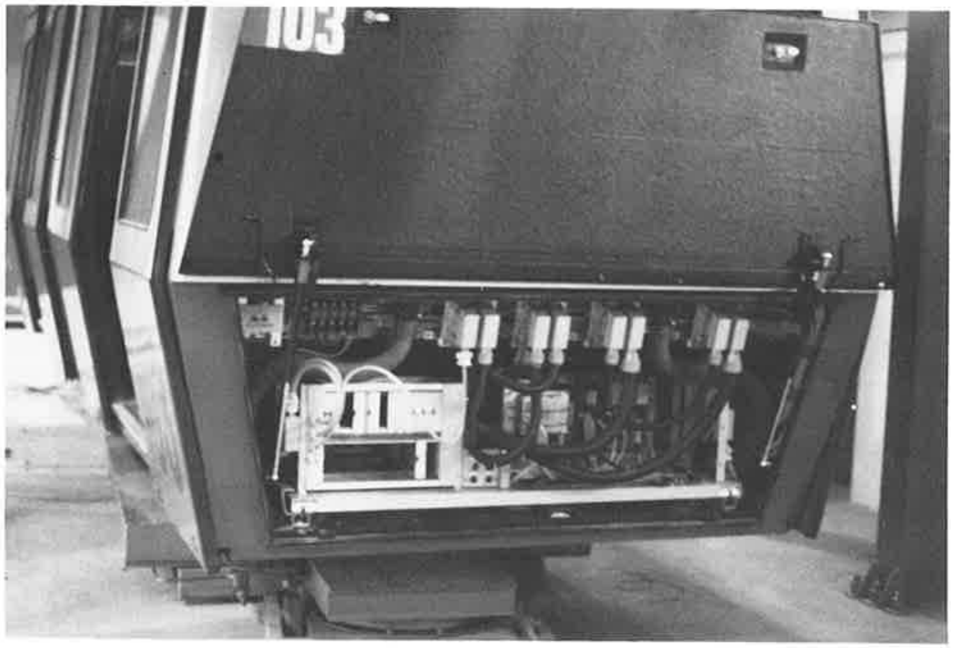
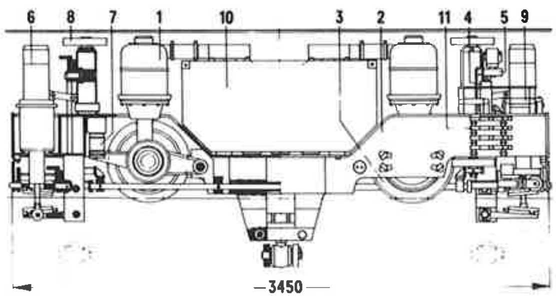
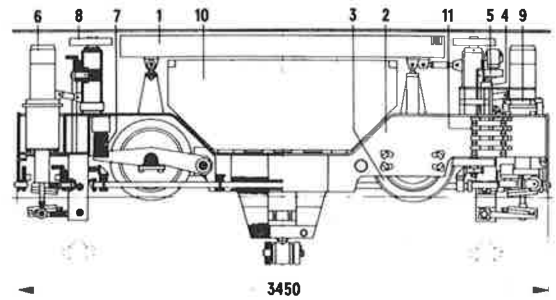


FIGURE 4-14. PALLET CARRYING DATA TRANSFER AND COMMUNICATION EQUIPMENT

Truck configurations differ only with respect to the type of propulsion, which can be optionally provided by rotary direct current motors or asynchronous linear induction motors as illustrated in Figure 4-15. Utilization of the same truck unit for either linear or dc propulsion was made possible by housing the electrical equipment in the middle area between the double-flange wheels. This results in the braking and steering equipment being located fore and aft of the load-carrying wheels - a disadvangage in terms of mass distribution. Each truck unit has two sets of double-flange wheels which use rubber tires to minimize noise. The wheels run on the lower girders on both sides of the guideway support slot as shown in Figure 4-16.





DC MOTOR DRIVE

1. DC traction motor

LINEAR INDUCTION MOTOR DRIVE

1. Asynchronous linear motor

2. Truck frame
3. Double-flange wheel
4. Actuator for toggel device
5. Toggle device for vehicle switching
6. Spring-applied brake
7. Main wheel suspension
8. Stablizing wheel
9. Communication equipment
10. Electrical equipment box
11. Current collector

FIGURE 4-15. TRUCK DESIGN

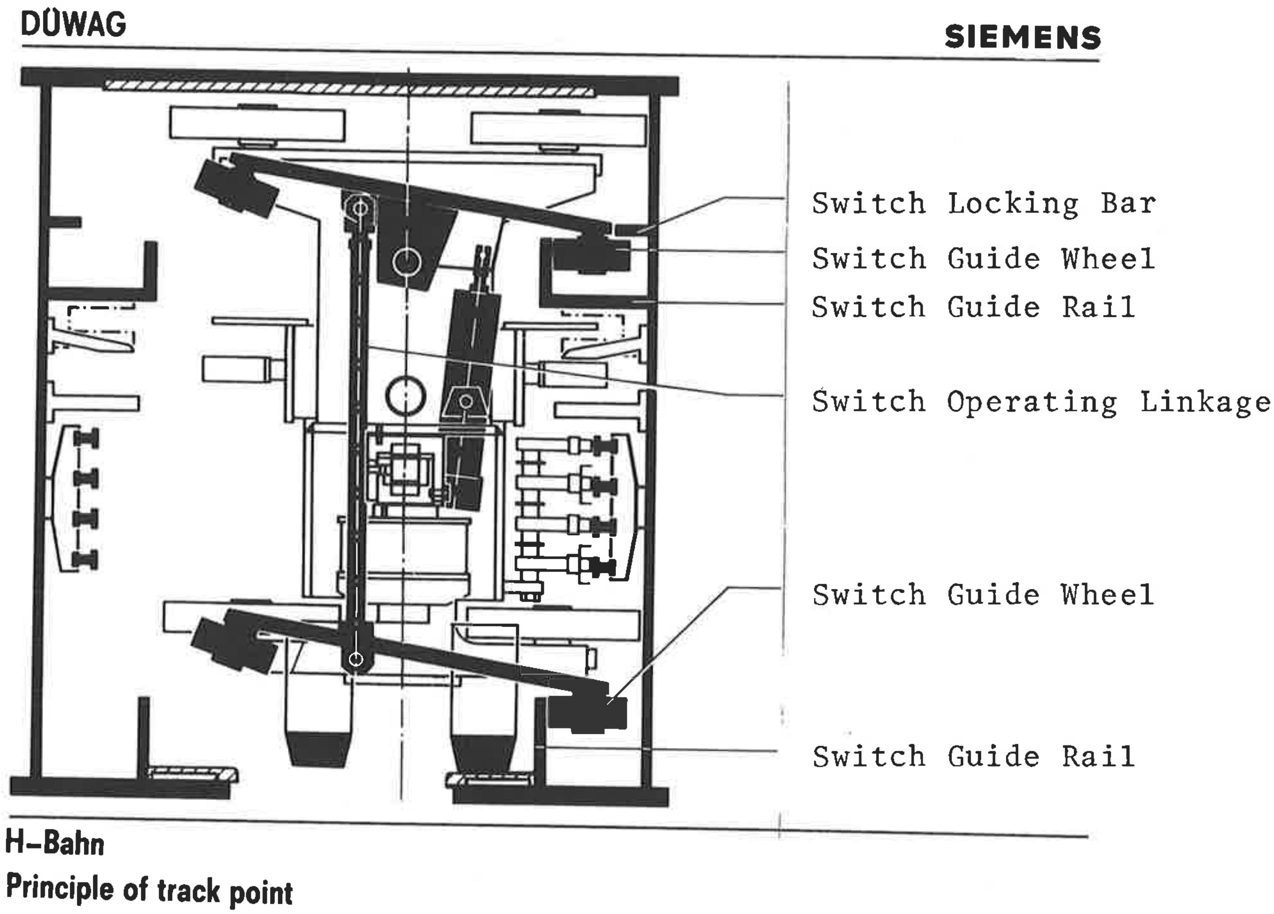


FIGURE 4-16. VEHICLE GUIDEWAY INTERFACE AT SWITCH LOCATIONS

As shown, the truck unit, when negotiating a switch, runs on one side of the guideway with one side of the double-flange wheels not carrying any load. The double-flange wheels are fastened in swing suspensions with an air suspension system between the truck unit and the vehicle. Spring-applied brakes located at the outer frame ends, and used for emergency braking, as well as maintaining stop position in stations, are electrically activated. The braking shoes contact both sides of the lower girder of the guideway. This eliminates any dependence on the friction between the wheel and rail.

4.4.3.2 Truck Unit with Linear Motor Propulsion - For those truck units using the linear motor, the 3-phase motor (primary part) is arranged along the top of the truck unit facing upward (Figure 4-15). It rests on two support columns over the double-flange wheels and is connected by links to the truck unit frame. The secondary part of the linear motor is formed by a reaction strip of 3mm-thick brass which is welded to the inside top of the track beam. The equipment associated with the main power circuit is housed in the electrical equipment box in the center of the truck unit.

The linear motor drive offers the advantage of not having to rely on the adhesion between wheel and rail and the associated effects on tire wear (tractive effort is provided without using running wheels as driving wheels). Vehicles using linear motors can climb grades up to 15 percent, which can be of significant value in laying out routes in hilly terrain. The linear motor is arranged such that the attraction force acting on the secondary part at high speeds reduces the load on the main running wheels. This also contributes to both noise and maintenance reduction.

Electrical power for the linear motor propulsion system is supplied from the 3-phase power rails (380v, 50 Hz at the test track, 660V, 50 Hz in future) via the current collectors to a reversible 3-phase ac controller with six thryistors in back-to-back connection aboard the vehicle.

The acceleration and deceleration level provided by either the linear induction motor or the dc motor, independent of vehicle size, is a maximum of 1.4 m/sec^2 with normal operation at 1.0 m/s^2 over a speed range from 0 km/hr to 50 km/hr. Maximum speed in normal operation provided by either drive is 50 km/h; the dc motor can provide 60 km/h if necessary.

4.4.3.3 Truck Unit With DC Motor Drive - With the dc motor propulsion, two 17 kW prototype traction motors per truck unit are used on the test track (27 kw for production), one arranged vertically above each axle, driving the main wheel via a 6.375 to 1 bevel reduction gear. The gearbox housings also act as suspension arms which resiliently support the main wheels. Forced-air ventilation is required for the dc motors; thus, two fans are mounted on top of the equipment box ventilating one motor each. The mechanical construction and overall dimensions of the truck unit are the same as those of the truck units using linear induction motors.

Grades up to 7.5 percent can be handled with a dc motor drive. The dc motor drives are more energy efficient than linear motors and have a lower reactive power requirement. They also have a better power/weight ratio with an added feature of being able to use regenerative braking. Electrical power for the dc motors is supplied by the current collectors from the 3-phase conductor rails. The input of the dc motors is controlled by a 6-pulse fully controlled thyristor rectifier bridge.

4.4.3.4 Switch Point - The switch point is an important element of the system. Its operation must be absolutely safe, i.e, automatically transmitted operating commands must be executed with certainty until the vehicle or vehicle units have passed the switch. Actuators in the switch operate jointly with equipment in the truck unit (Figure 4-16). The switch positioning device shown in the figure is a rocker assembly which can be brought into the right-hand position shown or into the opposite position by means of an actuator.

The positive action travel of the truck unit through switches is made possible by switch guide wheels attached to the truck unit. These are turned to the position corresponding to the desired directions of travel before coming to the rail switch. They engage the guide rails of the switch and take over the guidance of the truck unit while it passes through the switch. The switch guiding wheels prevent the truck unit from sliding off through one-sided operation of the drive wheels in the area of the switch gaps. The beginning and end of the switch guide rails are funnel shaped in order to guarantee the entrance of the switch guiding wheels with every possible position of the truck unit in the guideway (Figures 4-16 and 4-17).

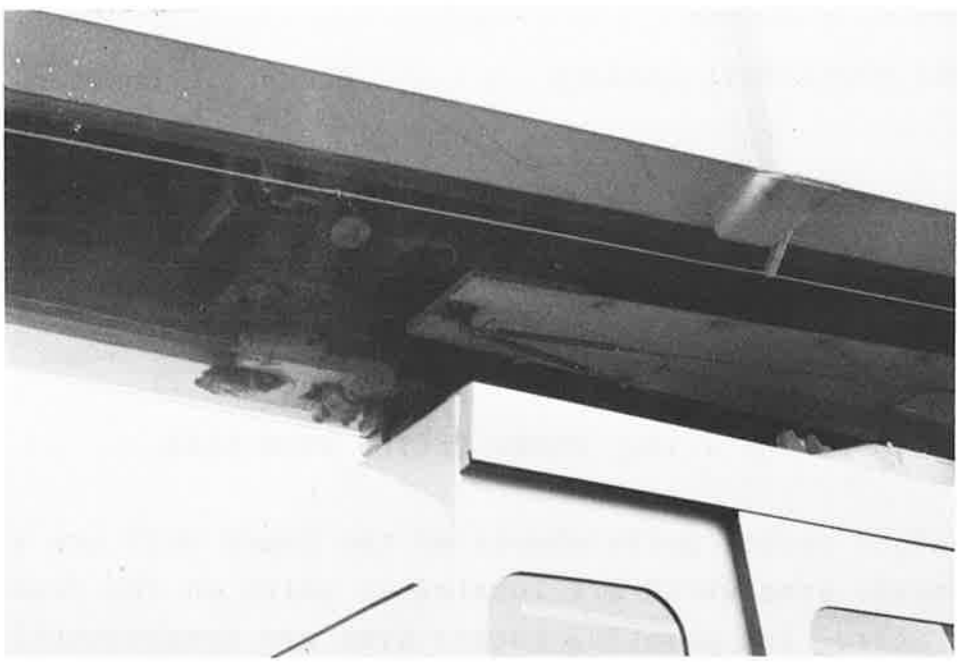


FIGURE 4-17. TRUCK UNIT IN SWITCH GAP

During travel through the switch, two of the four drive wheels leave the track redistributing the load to the two wheels on the side of the switch. This redistribution, as well as the possibility of a tilted position of the truck unit in the switch, due to worn switch guide wheels or construction tolerances, make it necessary to position the two load-relieved truck wheels vertically on the running surface of the track (Figure 4-18). In order to enable a jolt-free re-engagement of the unloaded carrying wheels, the rails in the vicinity of the wheel lead-in are developed as ramps.

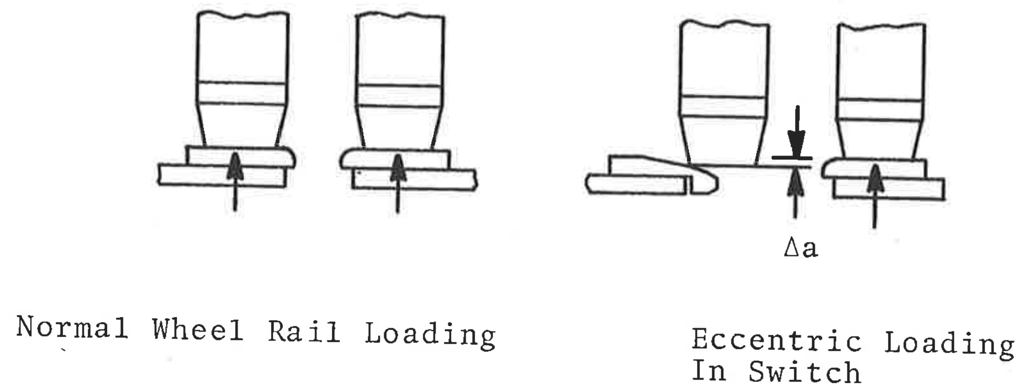


FIGURE 4-18. WHEEL RELIEF FROM LOAD

The eight switch guide wheels of the truck unit are arranged on four rocker arms which are located in pairs on the fronts of the truck unit. The pivoting rocker arms are synchronously activated by pneumatic actuating cylinders with the extreme position controlled electrically (Figures 4-19 and 4-20). The cylinder in the extreme position is at times without power. In case of power outage, the rocker is maintained in a steady end position by a spring system.

With branching travel, the selection of travel direction is determined by a switchable pair of deflector bars which are mechanically connected and mechanically interlocked at their end positions on the guideway. With joining travel, only one direction

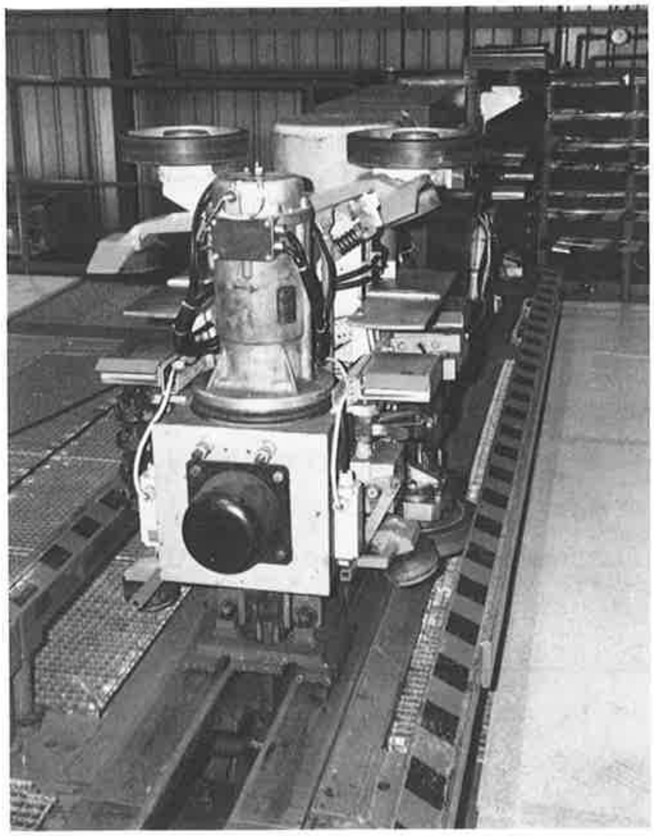


FIGURE 4-19. TRUCK UNIT FRONT SIDE

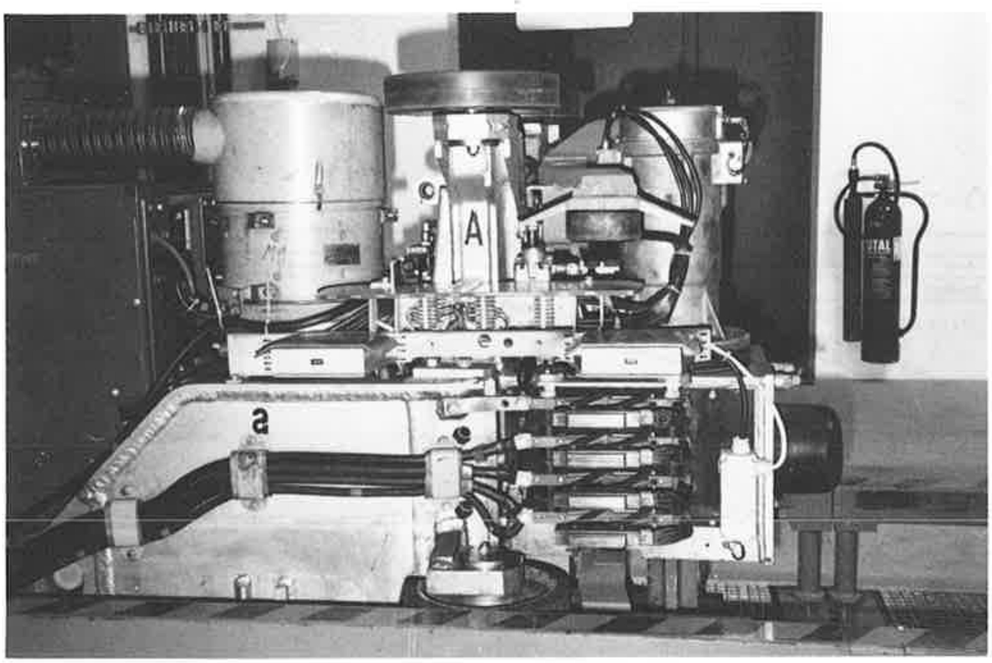


FIGURE 4-20. TRUCK UNIT SIDEVIEW

of travel is possible, and the deflector bar is fixed rigidly in the guideway (Figure 4-21). In the case of wrong positioning of the switch guide rollers, a sliding shoe attached to the rocker runs into the deflector bar and presses the rocker into the position corresponding to the selected or prescribed direction of travel. In addition, an overlap occurs between the safety lug on the rocker and the locking rail on the trackway. The locking rail mechanically prevents an undesired reversal of the rocker, i.e., when the sliding shoe has left the deflector bar, the rocker position is mechanically locked and remains locked during the entire travel through the switch (Figure 4-22).

4.4.4 Cabin/Truck Interface

The cabins are pendulum suspended for negotiating curves in the track (Figure 4-23). The system uses a compressed air activated regulating device. In order to obtain a high quality of comfort, an air spring is interposed between the suspension and the vehicle, which also assures level compensation at the platform for a loaded or an unloaded vehicle.

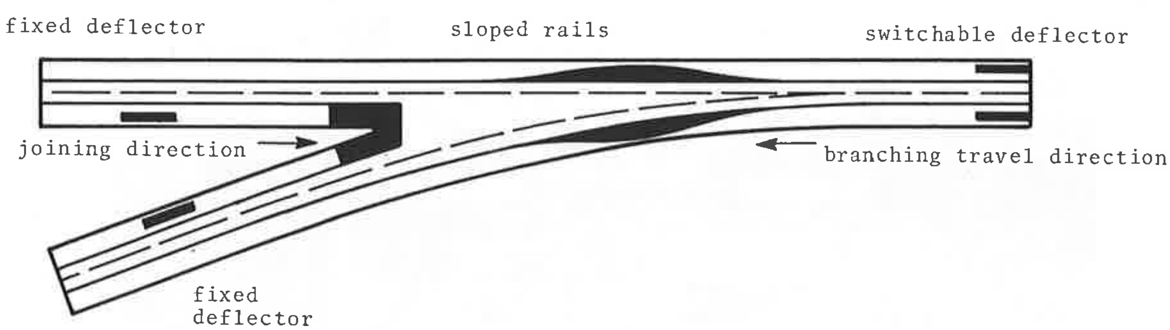


FIGURE 4-21. SWITCH AREA

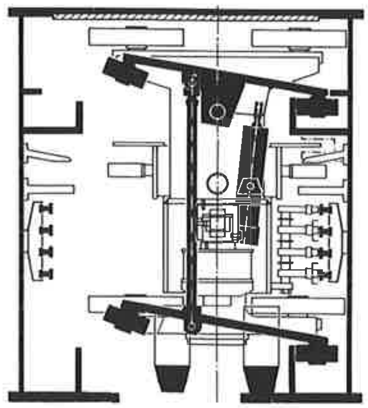


FIGURE 4-22. POSITION OF ROCKER UNDER THE LOCKING BAR

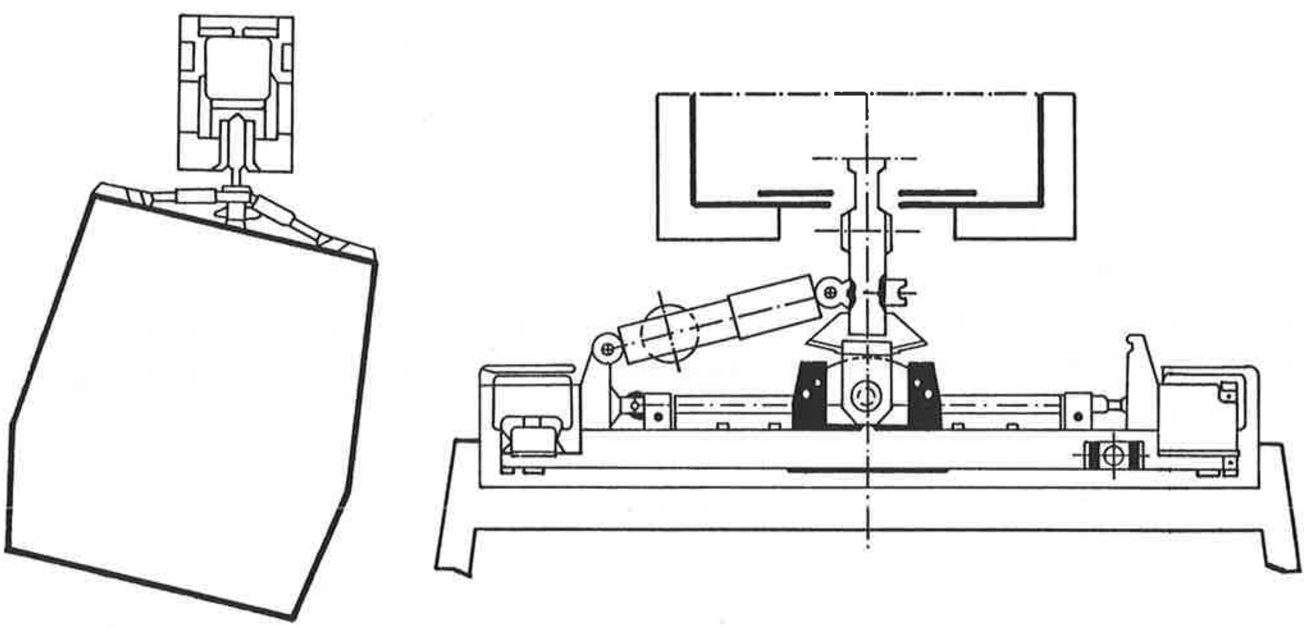


FIGURE 4-23. CABIN SUSPENSION SYSTEM

The vehicle has a jointed suspension extended from the suspension pins of the propulsion system downward through the roadbed slit from the roadbed carrier. While going through curves, the vehicle can compensate for centrifugal forces, because the center of the vehicle's gravity is below the suspension point. Pendulum oscillations are suppressed by horizontal dampers with the maximum oscillation defined by a mechanical halt. The dampers can be electrically locked in the center position of the vehicle and thus an inclined suspension of the vehicle can be prevented while on straight track.

Figure 4-23b shows the configuration of the suspension, including the secondary spring system with air springs. The dead weight of the vehicle is supported in the roof area, at the corners of the vehicle, above the side walls. Two air springs are arranged on a traverse, which is rotatably supported at its center in the suspension pin. The inner space of the traverses is configured as an additional air container for the air springs.

4.4.5 Propulsion and Braking

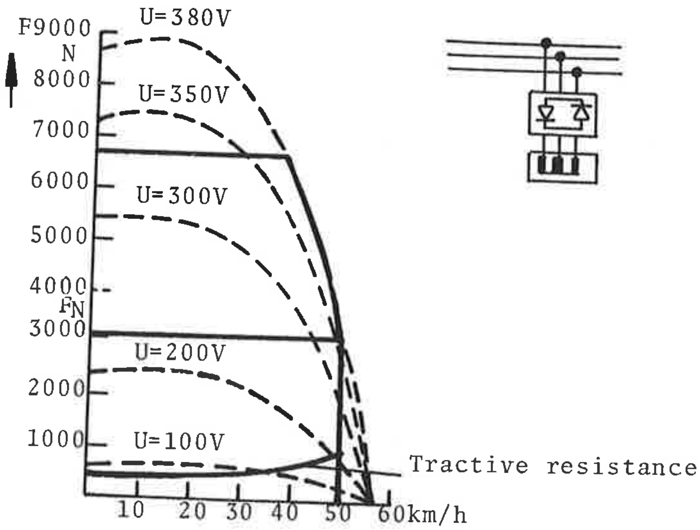
4.4.5.1 Requirements/Characteristics - Both the linear induction motor and the dc rotary motor are designed so that a maximum acceleration of 1.4 m/sec^2 and a maximum deceleration, also of 1.4 m/sec^2, can be achieved with all vehicles. On curves and at switches, the vehicle's free-running speed is limited by requirements of lateral ride comfort. At these locations, the vehicle undergoes controlled braking and, subsequently, controlled acceleration. The propulsion systems must be, therefore, designed for corresponding load changes, where adequate tractive power must still be available in the upper speed range. Figure 4-24 shows the tractive force-speed characteristics of both the linear and dc rotary drives w-ich also provide the service braking for the vehicles.

Since the linear motor drive is independent of wheel adhesion, the starting thrust is limited only by considerations of passenger comfort, i.e., maximum starting acceleration of 1.4 m/s^2 based on a 5200 kg vehicle weight per vehicle unit. The materials and the dimensions of the reaction strip are selected to render the tractive effort curve largely constant with the ac controller driven to full output (max voltage). The "synchronous speed" of the motor is selected at 59 km/h. This leaves an ample tractive reserve of approximately 3000 N at the maximum speed of 50 km/h (Figure 4-24).

Figure 4-24a applies to only one truck unit with two dc motors. The maximum tractive effort of 7000 N was based on an adhesion coefficient of μ=0.16 and a weight per vehicle of 4.45. The tractive effort of 4400 N at 50 km/h was based on an adhesion coefficient of μ=0.1. This operating point is attained at maximum starting current with 50 percent excitation. The tractive effort reserve permits a mean starting acceleration of 1.0 m/s^2.

4.4.5.2 <u>Advantages/Disadvantages of the Two Drive Systems</u> - Since the linear induction motor transmits its forces to the track by means of a magnetic field, it is absolutely "skid-proof." The motor has no rotating parts, and is virtually wear-free. At higher speeds, the selected overhead arrangement of the linear motor relieves the load on the carrying wheels. This helps reduce wear on wheel rims and, consequently, lowers maintenance costs.

The linear induction motor requires that certain contingencies be taken into account regarding dimensions. The upper chord of the track beam is used to close the magnetic circuit and serves as the secondary of the linear motor. In addition, throughout the entire length of track, a 3-mm-thick brass plate is necessary as a short-circuit bar. A large air gap must equalize the tolerances which occur as a result of track and vehicle manufacture, as well as a result of vehicle motions under different operating conditions. This large air gap causes a heavy demand for reactive power and



b) Running gear unit with linear induction motor drive

Vehicle weight 5200 kg

Motor type 1 TA 3322

U_{rated} = 380V line-to-line

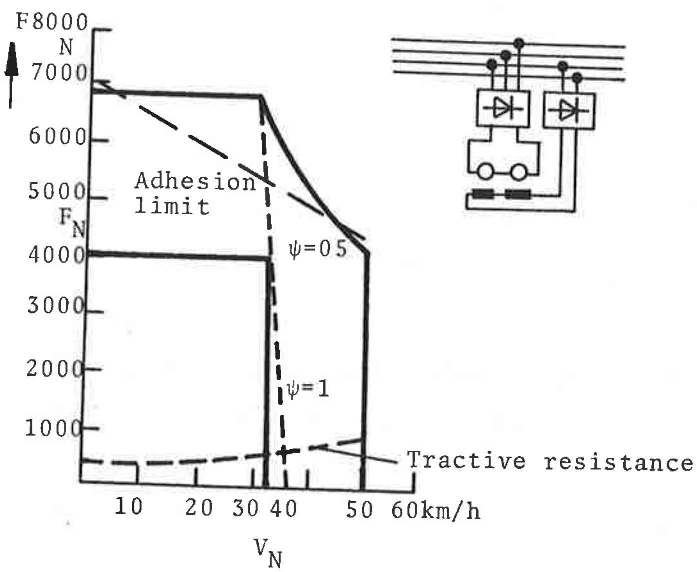
f = 50 Hz

Reaction system 20 mm Fe and 3 mm brass

$x = 33.3 \frac{Sm}{mm^2}$

$\delta_{magn.N} = 15$ mm

DC Rotary Motor



a) Running gear unit with two d.c. motors

Vehicle weight 4400 kg

Motor type 1 GV 1161

Gear ratio = 1:6.375

U_{rated} = 130 V d.c. per motor

Driving wheel diameter (new) 520mm

$\mu_{v=0} = 0.16$

$\mu_{v=50} = 0.10$

Linear Induction Motor

FIGURE 4-24. TRACTIVE FORCE VS SPEED

consequently lowers efficiency. These criteria considerably influence the size and weight of the machine.

By contrast, no demand for reactive power exists with the dc motor, and the demand generated by the control is less than with the linear motor. It, therefore, has a better power-weight ratio; in addition, regenerative braking is possible. Conventional drives are not quite maintenance-free, since wear occurs at the carbon brushes, the commutator, the bearings, the transmissions, and at the support wheels: the latter resulting from the transmission of tractive force to the rail. The dc motors also require outside ventilation.

If the acquisition costs for a linear motor drive are compared with those of a dc motor drive, the linear motor costs are nearly twice as high (Figure 4-25). The reasons for this are due to the above-mentioned disadvantages of the linear motor drives; the high specific costs of linear motors, since they are not yet being mass produced; and the expensive, high-power electrical equipment necessary to handle the high current. However, these differential costs can be justified to the extent that potential savings can be achieved in the track network because the linear induction motor can handle steeper gradients.

In summary, the suitability of a given drive for a particular application must be evaluated, both from technical performance and life-cycle cost viewpoints.

4.4.5.3 Asynchronous Linear Motor - The motor used at the experimental installation in Erlangen is a single sided short stator induction motor. The characteristics are given in Table 4-2.

The motor cross section is shown in Figure 4-26. The vehicle carries the stator laminations with the ac winding, while the guideway carries the short-circuit cage and the rotor yoke.

The stator is fastened to the traveling gear and has 13 poles. Its ac winding is fed with a frequency of 50 Hz (const.). At the planned maximum speed of 50 km/h, a pole division of 164 mm results.

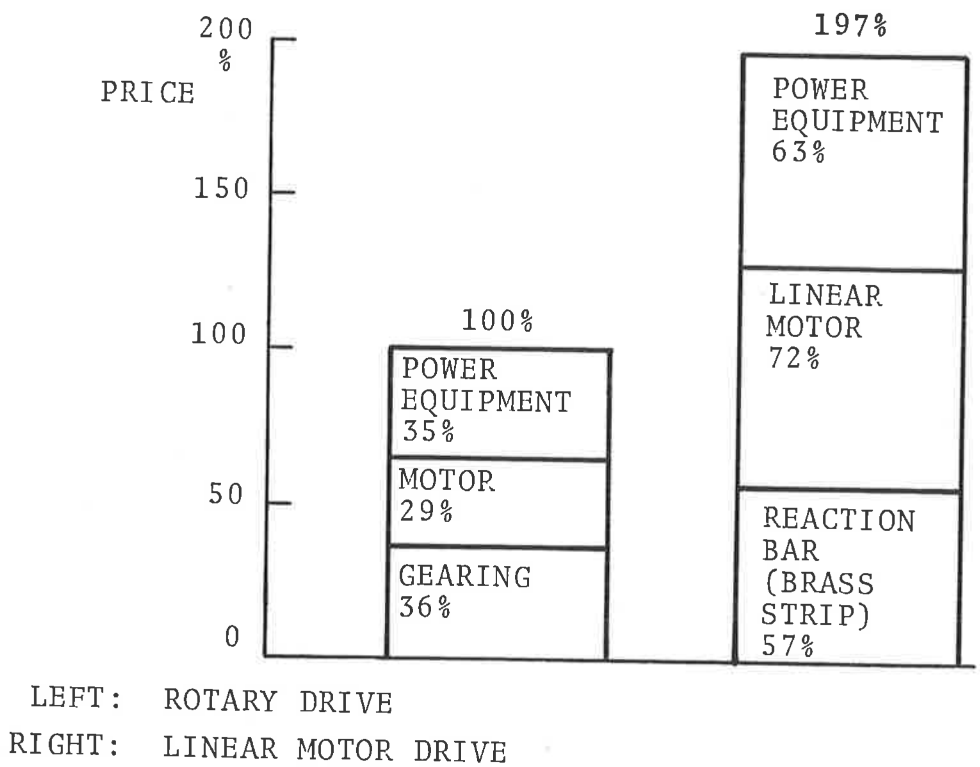
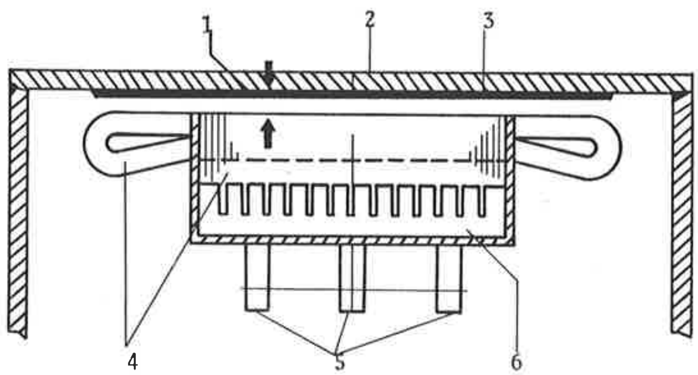


FIGURE 4-25. COST COMPARISON FOR VEHICLE DRIVES (TWO VEHICLES ON A 1 km SECTION)

TABLE 4-2. LINEAR INDUCTION MOTOR DATA

Motor Type 1 TA 3322	
Rated power	75 kw at 50 km/h
Maximum speed	50 km/h
Motor voltage (interlinked)	380 Vdc
Motor length	2200 mm
Motor width, total	630 mm
Motor height, total	150 m
Stator weight	840 kg



1. MAGNETIC AIR-GAP
2. MAGNETIC ROTOR YOKE
3. SHORT-CIRCUIT BAR
4. STATOR
5. MOUNTING ON RUNNING GEAR UNIT
6. AIR DUCT FOR STATOR BACK COOLING

FIGURE 4-26. INTERFACE OF ASYNCHRONOUS LINEAR MOTOR AND REACTION RAIL

The winding is designed as a double-layer winding. The grooves of the pole division at the two motor ends are only half-filled with conductors. The machine is self-ventilated; the outside air flow is used for cooling. The back of the support is alternately layered with laminated plates of various heights, so that cooling ribs are formed. A metal sheeting conducts the cooling air over this ribbed support back.

Speed is controlled by regulating the voltage. A 3-phase ac controller with six thyristors in back-to-back connection is used for voltage control as shown in Figure 4-27. Power is supplied from 3-phase conductor rails (1a, 1b) via the current collectors, main fuses and main contractor to a reversible 3-phase ac controller. The controller comprises five pairs of anti-parallel thyristors. Depending on which combination of three of these pairs is triggered, the linear motor develops forward, reverse, or reverse thrust (Figure 4-27).

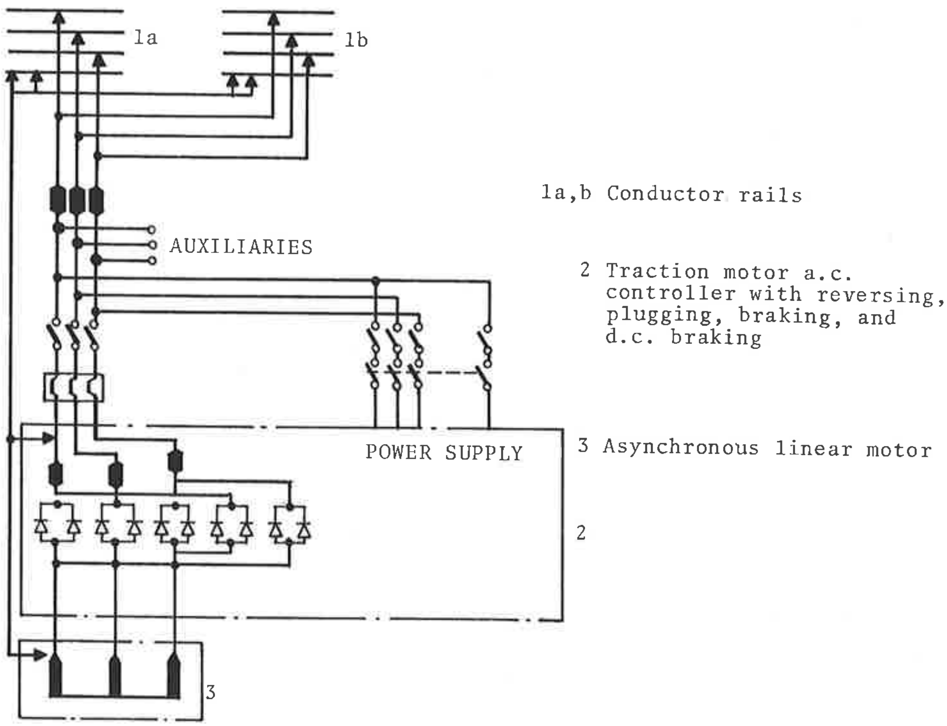


FIGURE 4-27. LINEAR MOTOR POWER CIRCUIT

Phase control is used to increase or decrease the controller output voltage and hence the thrust of the motor. When braking at high speeds, the motor is excited with dc by firing discrete thyristors in the controller (dc braking). At low speed, the controller switches over to plugging.

4.4.5.4 DC Rotary Motor: Erlangen Test Facility - The motor used at the Erlangen experimental system is a four-pole dc motor, designed for a rated armature voltage of 130 V. The motor characteristics are given in Table 4-3.

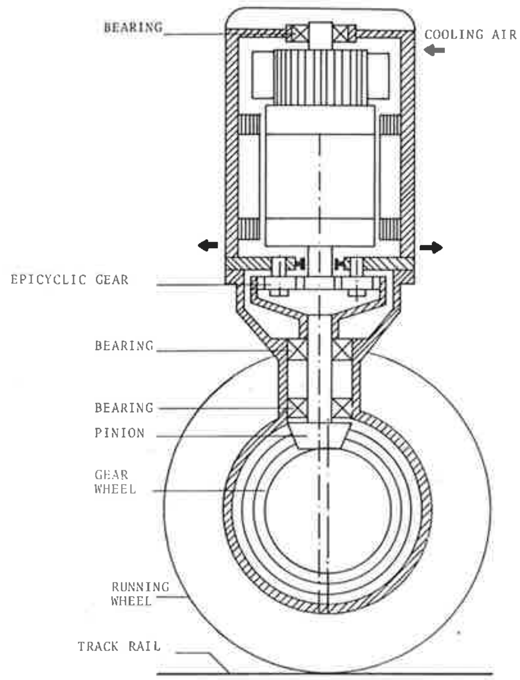


FIGURE 4-28. SCHEMATIC OF PROTOTYPE DC DRIVE UNIT AND SINGLE REDUCTION GEAR

TABLE 4-3. TECHNICAL DATA FOR PROTOTYPE DC ROTARY MOTOR

Motor Type 1 GV 1161	
Rated output	17 kw at 2200 rev/min
Maximum speed	4000 rev/min
Rated armature voltage	130 Vdc
Gear ratio	1:6.375
Weight of complete unit (motor and gearing)	197 kg
Frame diameter	278 mm
Height above running center	800 mm

The dc motor is affixed with a vertical shaft over the double gear drive (Figure 4-28). The round housing, of massive steel, serves as a support and as a return-circuit yoke for the magnetic flux. The motor is uncompensated. A pressed commutator is used. All windings are fabricated of lacquer-insulated ribbon wire. The armature leads are connected to the commutator laminations by means of electron-beam welds. The motor is externally excited. It is cooled through an external blower, whereby the cooling air is conducted to the motor on the top through a laterally affixed channel. The cooling air flows through the active components and then reaches the opening at the blower end shield. The end shield, the winding support, the commutator hub, and the covering cap are fabricated of light metal. The motor is flanged onto the drive housing. The torque is transmitted through a dog coupling from the motor shaft to the pinion shaft.

In the dc motor drive, the voltage is rectified and controlled by a thyristor bridge circuit (no contacts). The electric brake is of the regenerative type with a damping resistor and is controlled by the thyristor bridge circuit and the drive motor field. As shown in Figure 4-29, the power circuit up to the power control unit corresponds to that shown for the linear motor. The output of the two dc motors, whose rotors (m1, m2) are series connected, is controlled by a 6-pulse fully controlled thyristor rectifier bridge. The armature voltage may be varied from 0 to a maximum of approximately 400 V by phase control. The field windings (L3, L4) are supplied via a single-phase semi-controlled rectifier set and the reversing contractors. During braking, the main rectifier operates as an inverter. A damping resistor is fitted in the regenerative braking circuit to limit the braking current in the event of system outage.

Planned Production Design - These motors are designed for a rated armature voltage of 440 Vdc and will be used when the power supply is changed from 380 Vdc, 50 Hz, 3-phase to 660 Vdc, 50 Hz, 3-phase. (See Table 4-4.)

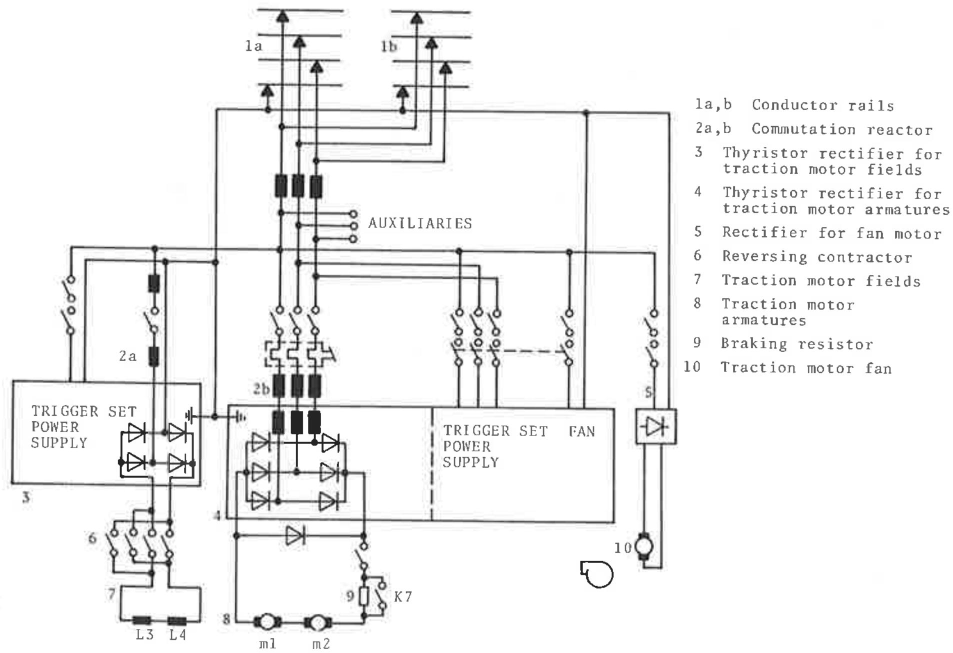


FIGURE 4-29. DC MOTOR POWER CIRCUIT

TABLE 4-4. TECHNICAL DATA OF PLANNED PRODUCTION UNIT

Motor Type 1 JO 0810	
Rated output	27 kw at 3630 rev/min
Maximum speed	6000 rev/min
Rated armature voltage	440 Vdc
Gear ratio	1:9.6
Weight of complete unit (motor and gearing)	215 kg
Frame diameter	278 mm
Height above running wheel center	790 mm

The available mounting space does not permit any significant enlargement of the unit. The best solution was found to be a motor with a higher speed, using a so-called integrated drive with a double-reduction gear (Figure 4-30). This solution dispenses with the lower motor bearing, the rotor being supported only by the upper bearing. The first reduction stage is in the form of an epicyclic gear. The sun wheel is part of the motor shaft and drives a hollow ring gear mounted on the bevel pinion shaft by way of the planetary gears arranged on a stationary carrier. The rotor is centered at the lower end in the region of the gearing. The second reduction stage is formed by the bevel gear. With this gearing concept, the rotary induction motor can be used in place of the dc motor.

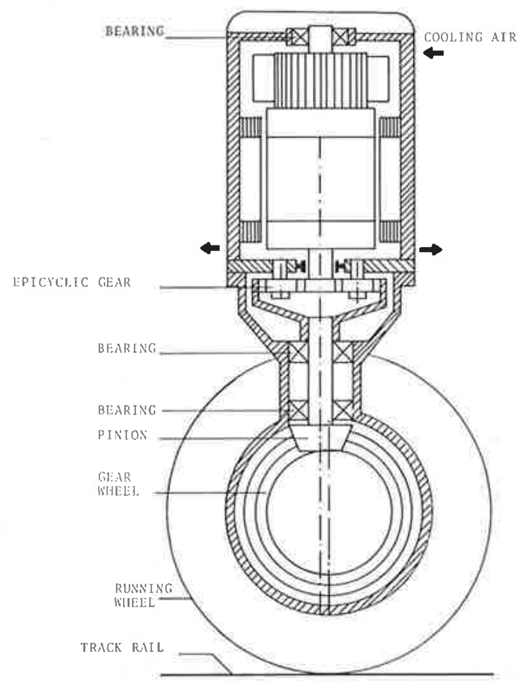
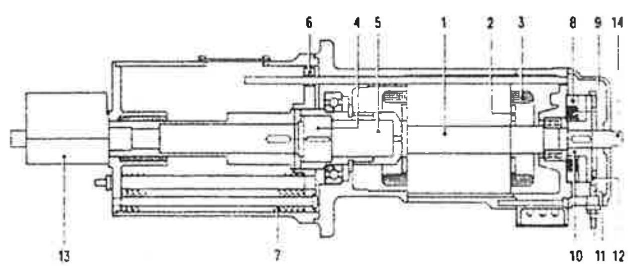


FIGURE 4-30. SCHEMATIC VIEW OF INTEGRATED DC DRIVE UNIT WITH DOUBLE REDUCTION GEAR.

4.4.5.5 Emergency Braking - A spring-applied brake is employed as an emergency and holding brake. The spring brake actuator consists of the spring brake and the electromotive rotary current (3-phase ac) drive. The rotary motion of the motor is transformed into an axial motion via a spring actuated and positive locking threaded spindle which is not self-locking. The buffer element transmits the brake force of the set of springs to the brake clasps (Figures 4-31, 4-32, and 4-33). The emergency brake holds the spring brake which is under tension in the disengaged position.

In the case of an emergency stop, the emergency brake is released by the zero voltage monitor. The release motor is switched to "brake" and the brake is brought to engagement. With the signal "brakes on," the motor is switched back to "release" and the torque regulated by the transistor regulator unit, so that the braking deceleration does not exceed permissible levels. Should the emergency brake control fail in the case of an emergency stop, a free-wheeling device in the spring brake actuator which protects the spindle from destruction takes over and ensures the full brake power does not build up suddenly.

1. hollow spindle
2. rotor of release motor
3. stator of release motor
4. } spindle nut
5. } with threaded spindle
6. spring plate
7. spring set
8. }
9. } holding brake
10. }



11. inductive transmitter
12. meter disc
13. buffer element
14. manual release device

FIGURE 4-31. SPRING BRAKE CYLINDER

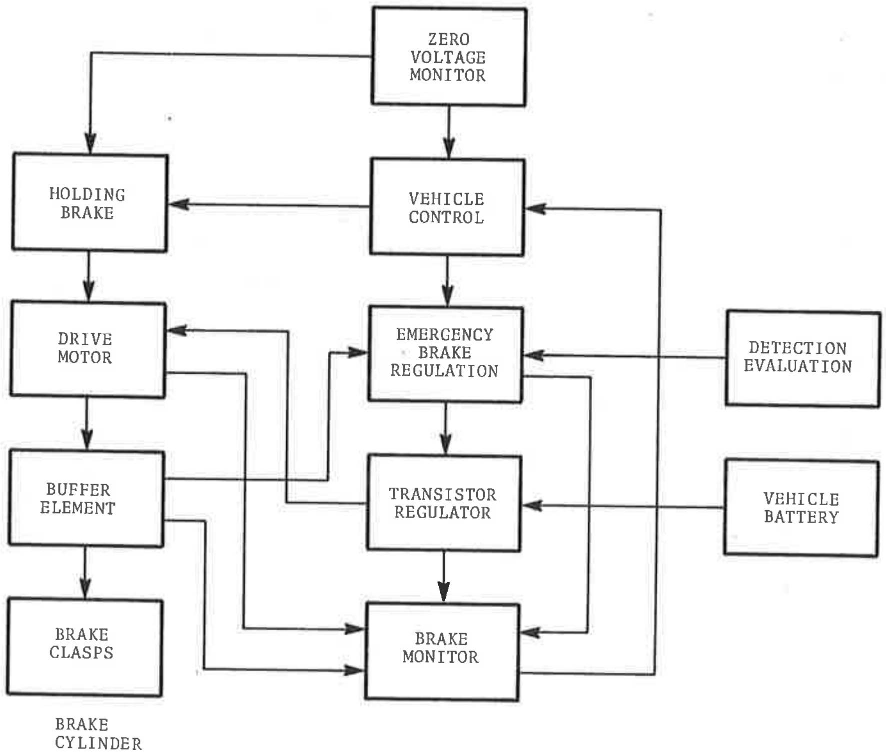


FIGURE 4-32. BLOCK DIAGRAM OF EMERGENCY BRAKE LAY-OUT

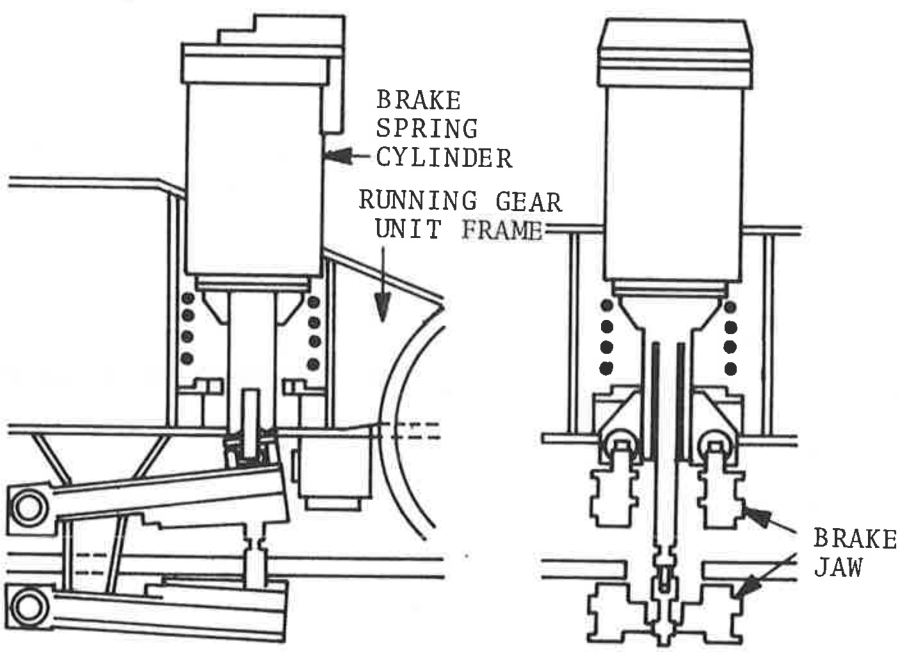


FIGURE 4-33. SPRING-APPLIED BRAKE

4.4.6 Vehicle Control

The H-Bahn vehicles may be controlled either manually by a driver or fully automatically. If manual control is used, the driver inputs the speed setpoint in the vehicle speed control equipment. Speed limit values are inserted locally to prevent the vehicle from proceeding too fast along any given section.

Vehicles can make better use of permissible speeds if the speed command is inputted from the track only. Then the driver's (conductor's) duties would only comprise opening and closing the doors at stations and giving an "all clear" signal for restarting. However, the H-Bahn was basically developed for use as a fully automatic, driverless system with the vehicles automatically controlled both on the track and in stations.

4.4.7 Vehicle Communication System

An essential requirement with fully automatic control is to provide a suitable communications system to inform passengers of the vehicle's position and destination. The H-Bahn system operates with a transmitting/receiving antenna in the track beam and corresponding antennas in the vehicle unit. Information coding techniques permit communication with one selected vehicle in the system and, if necessary, 2-way speech contact between a vehicle (passengers) and the control center.

4.4.8 Special Vehicles

Special maintenance and service vehicles are necessary in a large system for efficient servicing of the guideway supports and for guaranteeing high availability of the guideway. The service vehicle must be able to monitor (CC TV) the inside of the guideway and be able to clean the inside of the guideway. Another special vehicle is needed to tow broken-down vehicles, and it is expected to have an independent propulsion system, e.g., diesel electric. The vehicle will have an extenable catwalk, fitted with railways, used for passenger rescue, and be capable or performing on-the-spot maintenance on passenger vehicles and on the guidway. In addition, road vehicles will be equipped with hydraulic lifts for passenger rescue and/or guideway maintenance.

4.5 THE OPERATIONAL CONTROL SYSTEM OF H-BAHN

4.5.1 Concept and Philosophy

The overall structure of the automatic control system of H-Bahn is hierarchical and decentralized. A generalized block diagram is shown in Figure 4-34.

The supervision of the operational control system is accomplished by an Automatic Vehicle Supervision subsystem (AVS) also called Operational Control Level or Plane. AVS ensures that enough vehicles are in service to meet the traffic demands of the day. It also has several other functions that will be elaborated on later. The AVS does not have direct control over the vehicles, and its failure, while often degrading system operation, will not necessarily stop it.

Actual moment-to-moment vehicle control is directly exercised by the Automatic Vehicle Operation subsystem (AVO), also called Traffic Control Level.* In this subsystem, a computer in each station controls vehicles in and adjacent to that station. It issues commands for stopping and positioning of vehicles, opening and closing of doors, starting vehicles, and positioning switches in the guideway. The station computer also determines and monitors

*The AVO functions becuase of the cooperation between the station computer and the vehicle drive control-unit. It basically controls vehicle-positioning including headways, vehicle speed and switch functions on the vehicle as well as on the wayside.

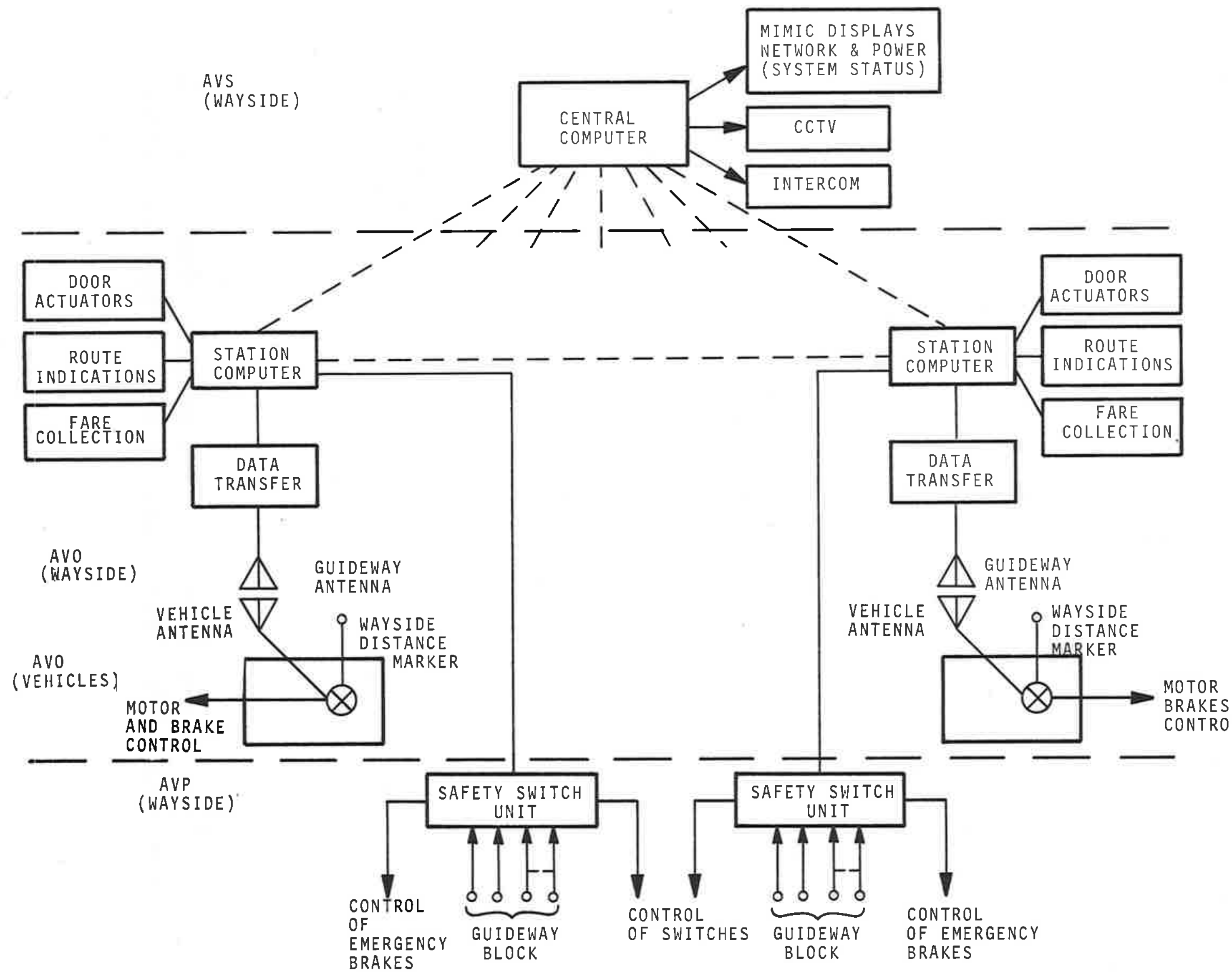


FIGURE 4-34. H-BAHN, GENERALIZED BLOCK DIAGRAM OF THE OPERATIONAL CONTROL SYSTEM

the switch settings for each vehicle in its sector and is able to reduce the guideway-generated nominal speeds when needed. Associated data transmission equipment transfers signals and commands between stations and vehicles and handles communication between passengers and control personnel.

If overspeeds, too short headways, or wrong switch settings are not corrected by the normal operation of the AVO for any reason, including failures, the ultimate safety of vehicles, i.e., ensuring freedom from collisions between them, is handled by the Automatic Vehicle Protection Subsystem (AVP), also called Safety Level or Plane. The AVP subsystem is designed to be fail-safe and is fully independent of both the AVS and AVO subsystems and involves no software. It is based on the block system with short block sections, and it monitors vehicle headways and speeds. If the headway between two vehicles falls below the safe distance or if the permissible maximum speed is exceeded, the AVP initiates emergency braking of the vehicle. The AVP also reacts to incorrect switch setting and switch interlocking.

The electronic unit responsible for detection and evaluation of potentially hazardous situations is of fail-safe design and construction. If any faults are detected, the vehicle is brought to a stop, greatly reducing the chance of a dangerous situation. The AVP is now being subjected to the stringent tests required of safety systems by the German Federal Railway.

The reliability of the operational control system is enhanced by the fact that the function of a failed station computer can be partically taken over by the supervisory computer, thus providing operational redundancy. This minimizes to some extent the effect of individual failures.

While total automation has been designed into the system, its actual application can be evolutionary. The safety system is present in all applications, but AVS and AVO can be applied completely or in part. Manually controlled operation with only AVP protection can be used if desired. The AVO can be specially set up for different applications. In the case of manual vehicle control without provision for monitoring along the track, its action is limited to handling vehicles at stations. In automatic operation, the dispersed computers handle the entire traffic flow in their respective areas. It is the intent of the developers to recommend the manually controlled system only where simplicity and economy are essential.

4.5.2 Operation Control

The structure of the various elements of the operational control system, their functions, and planned performance are described in this section. The way the system has been realized so far in the test environment at Erlangen is described in Section 4.5.3.

4.5.2.1 Automatic Vehicle Supervision (AVS) - As indicated in Figure 4-34, the AVS subsystem ("Leitebene" or Operational Control Level) consists of a computerized function and a central control monitoring function. The latter is to be operated by two controllers who observe the passenger flow in the stations by closed circuit television, the status of the vehicle and power systems by mimic boards or other displays, and provide an emergency intercommunication service for passengers.

Overall View - The supervisory computer is planned to provide overall network surveillance. It determines the vehicle density on the individual lines based on a daily passenger-load profile. It directs the station computers on such matters as door opening times, assures that sufficient vehicles are circulating in the system to meet the demand, and monitors the stationary equipment in the track beams and stations to ensure that they are functioning properly. The computer indicates when vehicles are due for servicing. It can also effect local adjustments in operating procedure, such as causing shorter stops in stations to allow a greater number of vehicles through in a given period.

The AVS functions are diagramatically shown in Figure 4-35.

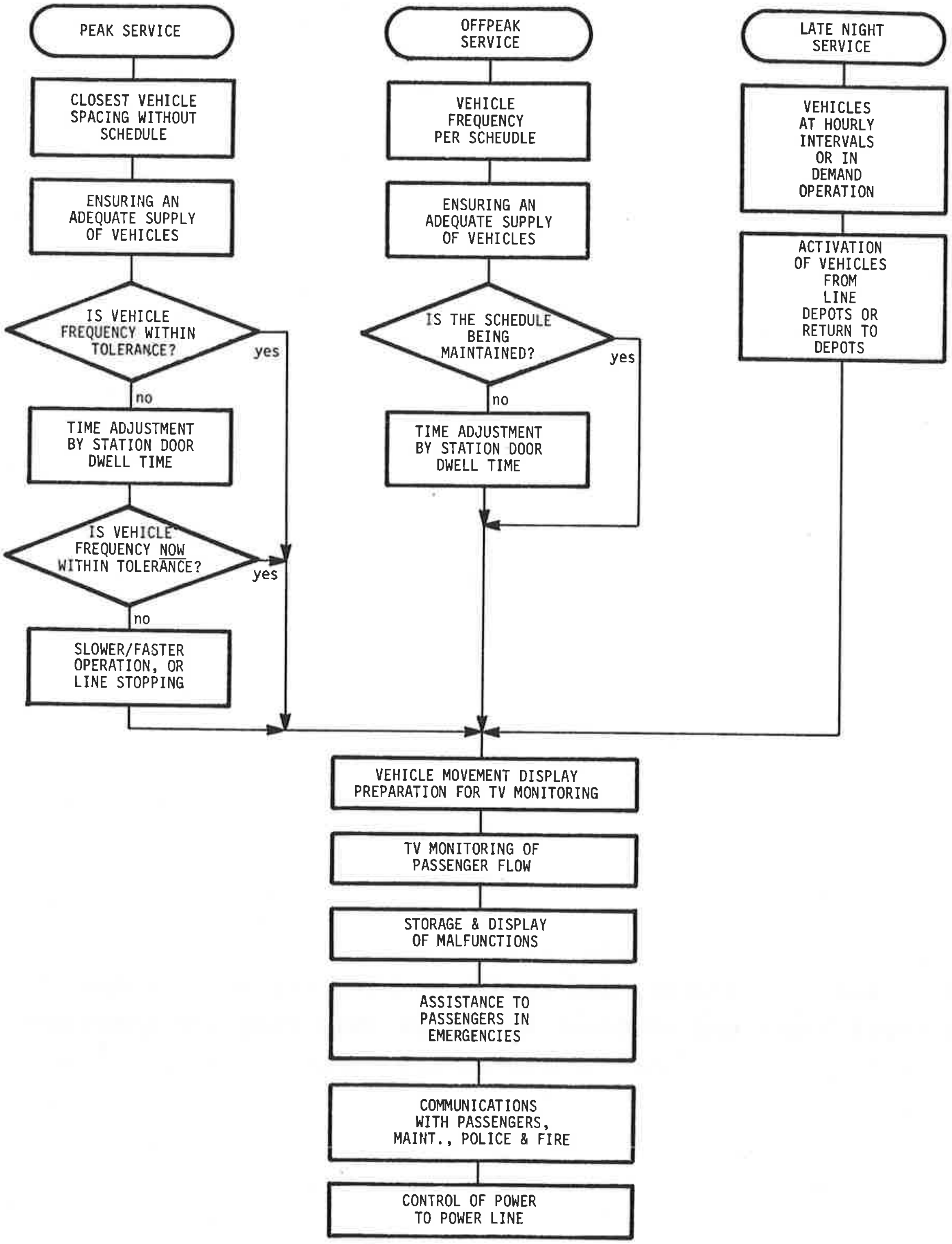


FIGURE 4-35. AVS FUNCTIONS

Control Center Function - The station computers report the operating and fault conditions at their locations to the central computer. The central computer evaluates these reports and displays them as visuals in the form of network diagrams and alphanumeric text.

Fault reports are given special attention and must be checked out by operating personnel once they have been noticed. Operators may order the central computer, by means of page printers and screen keyboards, to cause proper station or vehicle responses in the event of special occurrences or malfunctions. The input commands are converted by the central computer and transmitted via computer links to the station computers, which pass them on to the station equipment or the vehicles.

The equipment and software used for this purpose are standard Siemens products from the PR 300 process control computer series.

In addition to being responsible for operating vehicles manually in the event of malfunctions or special moves, operating personnel are also responsible for informing the passengers in stations and aboard vehicles of any malfunctions or detours.

Function of the Central Computer

1. Traffic Control

   a) Line data

   b) Scheduled operation, sequence, vehicles entering and leaving service

   c) Demand operation, minimization of waiting time, vehicles entering and leaving service

   d) Transfer functions from scheduled operation to on-call operation and vice versa

   e) Diversion to detour routes in the event of simple malfunctions

   f) Automatic forming of trains in stations and depots.

2. Operational Guidance

a) Tasks

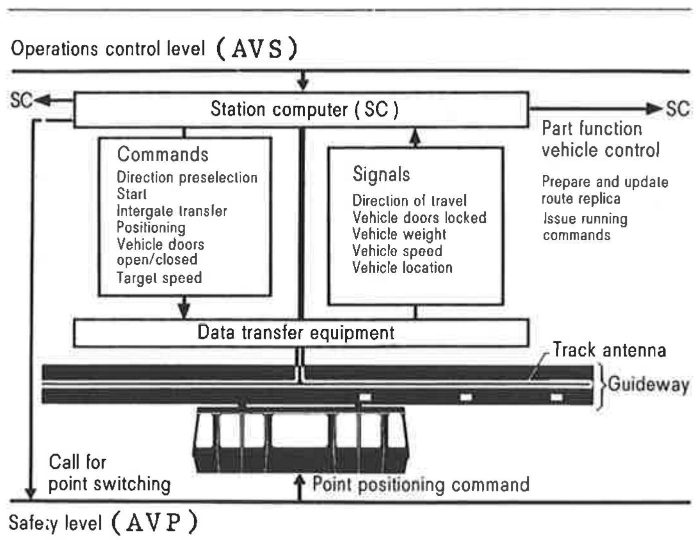
- Preparation of notices regarding operating states
- Preparation, announcement, and display of malfunctions in stations and vehicles.

b) Inputs

- Manual modification of line routing in the event of special load conditions
- Sending malfunctioning vehicles to the service area
- Closing defective stations
- Putting repaired stations back into service
- Remote control coupling in malfunctions (with inspectors on the spot)
- Remote control "cleanup" operation (after receiving the go-ahead from inspectors on the spot)
- Resumption of automatic operation after "cleanup."

4.5.2.2 Automatic Vehicle Operation (AVO) - The Automatic Vehicle Control subsystem ("STEUEREBENE" or Traffic Control Level as it is described in the German literature) consists of both wayside and vehicle-borne elements. If failures of any of these elements affect the commanded vehicle speed or headway, the independent safety system will detect and stop the vehicle (or vehicles) so affected. Hence, the AVO subsystem does not require fail-safe design and, in fact, the term has no meaning in the context of the AVO given the proper operation of the AVP.

Overall View - Basic AVO functions are block diagrammed in Figure 4-37. The dotted lines from the central computer (repeated from Figure 4-34) indicate overview only and not line control. Data flow is indicated in Figure 4-36.



Data flow at traffic control level for automatic vehicle control

FIGURE 4-36. TRAFFIC CONTROL LEVEL: DATA FLOW

Station Equipment - The stations contain computers and data transmission equipment, as well as fare collection, power supply equipment, and the URTL safety logic.

Computers - A computer is located in each station and has direct control over vehicles in the vicinity of that station, including movement both in the station and on the open track. In fully automatic operation, the vehicles are controlled with the programmed maximum limits to ensure punctual arrivals and departures. In the stations, the vehicles are slowed down, properly positioned with respect to the station doors, and stopped. The doors are opened, kept open for a predetermined dwell time, reclosed, and the vehicles are restarted.

The station computers obtain their inputs from other stations along the line as approaching vehicles pass through, and from scanners in the track.

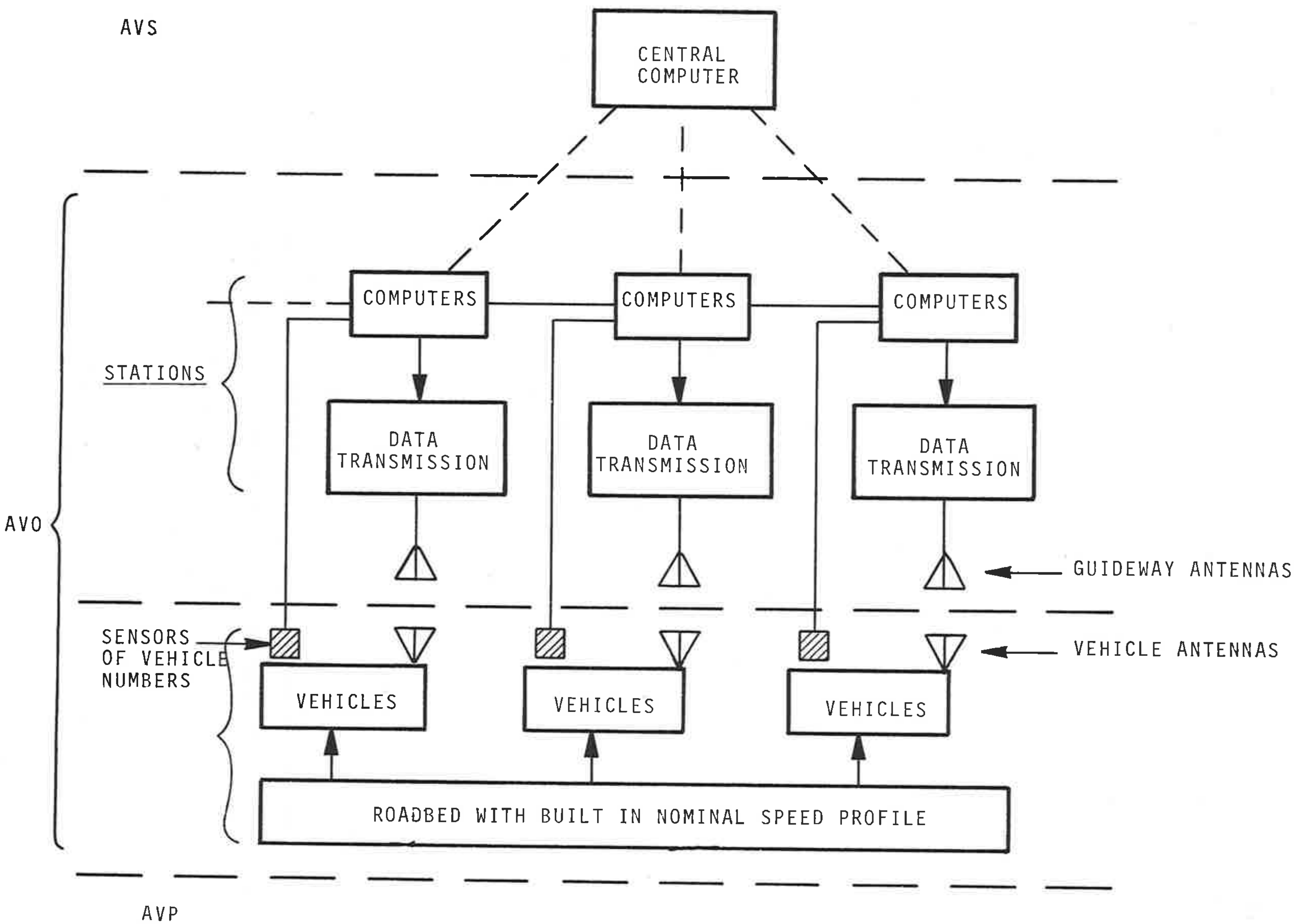


FIGURE 4-37. AVO BLOCK DIAGRAM

Data Transmission - The station computers can select other than nominal vehicle speeds through the data transmission equipment. Vehicles stopped in the stations are not given the start command before a sufficient headway to the next vehicle and proper switch functions ahead have been checked. The central computer intervenes only if faults occur or program changes are needed. If a station computer breaks down, however, the central computer can start any vehicle which has already stopped in the station. The other vehicles pass the station with the failed computer without stopping until it is fixed.

Automatic Drive Control - The drive of the vehicle is automatically controlled by the AVO system, and independently measured and monitored by the AVP safety system, or the "URTL." The AVP safety system only has to interfere under abnormal conditions.

The AVO system provides normal vehicle operation; for this, it is divided into a direct and an indirect part.

The indirect part is formed by the station computer and the data transfer system to the vehicles. This part controls the vehicles in the system by selecting lower than normal track speed limits, and controlling vehicle positioning, including headways and proper switch functions.

The direct control part is a passive limit speed profile installed in the guideway in connection with a vehicle detection device and the vehicle speed controller. The speed profile consists of permanent magnet dipoles.

At speed-restricted sections, such as at curves, and at changes of gradient and stations, the dipoles are mounted at close intervals on a profile bar installed in the track beam.

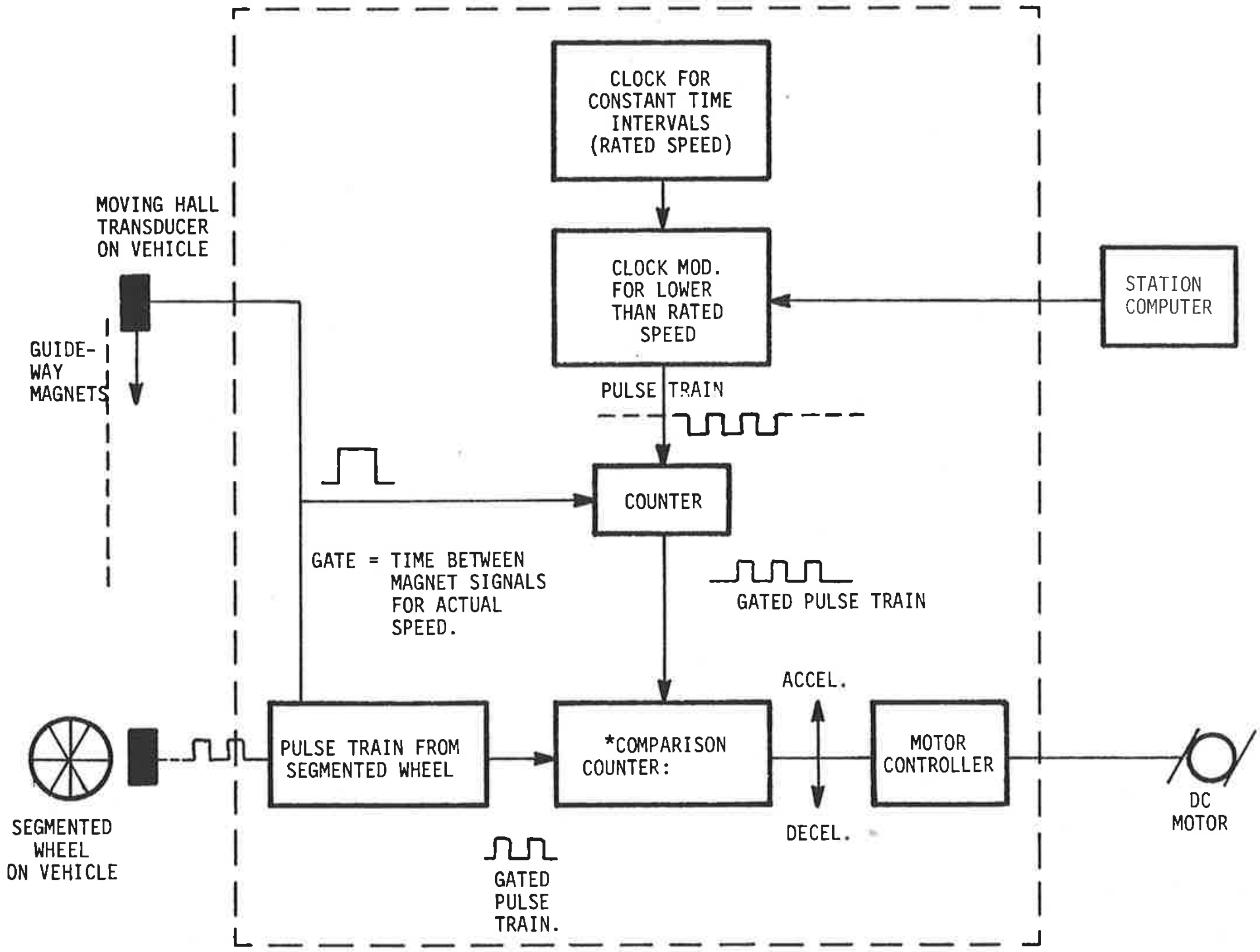
The manufacturer has paid special attention to this two-tier configuration of the AVO during system development. It permits emergency operation with the computer or the data transfer equipment out of action as long as the vehicles do not transgress the regulations of the safety level AVP, i.e., they do not travel too fast or too closely together. Speed restrictions continue to be invoked so that vehicles are operated at the appropriate speeds. As a result, the control unit is able to guide the vehicle according to the speed profile without external action. This is important, e.g., for passing stations with defective station computer. The vehicle-on-board-speed-controller of the direct control part is shown in Figure 4-38.

Each vehicle carries a Hall transducer which detects the time spacing of the magnets as the vehicle passes over them. The nominal speed is then calculated and sent to the onboard speed control. The vehicles use the passive point markers or magnets that are built into the guideway support to determine the highest speed required for any guideway section. This level may be modified downward by transmission from the computers to the vehicles over the guideway antennas. Such transmissions are selectively addressed to the vehicle or vehicles desired.

Vehicle On-Board Equipment - The functions of the vehicle speed control equipment are:

1) To receive the maximum nominal speeds at every point on the guideway as detected by the on-board sensors from the passive profile in the guideway;
2) To receive the speed modification commands, if any, sent by a station computer;
3) To override or reinterpret the guideway nominal speed, changing it to the lower commanded speed, if speed modification commands are received.
4) To directly control motors and brakes to keep the vehicle at the commanded speed, either directly as picked up from the guideway or as commanded by the station computer, as described above.

An electronic system translates the control signals into the necessary currents or voltages needed to accelerate or decelerate the motors or to actuate the brakes.



*if number of pulses from clock is greater than from wheel, accelerate

$(N_{pc} - N_{pw} = (+))$

or, if number of pulses from clock is less than from wheel, decelerate

$(N_{pc} - N_{pw} = (-))$

FIGURE 4-38. ON-VEHICLE DRIVE AND BRAKE CONTROL UNIT

Station Computer Operation - Figure 4-39 shows how a computer controlled vehicle ride is conducted from station n-1 through a merging switch to station n. It also shows how the vehicle travels through a branch, having stopped in station n and how it continues to the areas n + 1 or n + 2 with their corresponding stations.

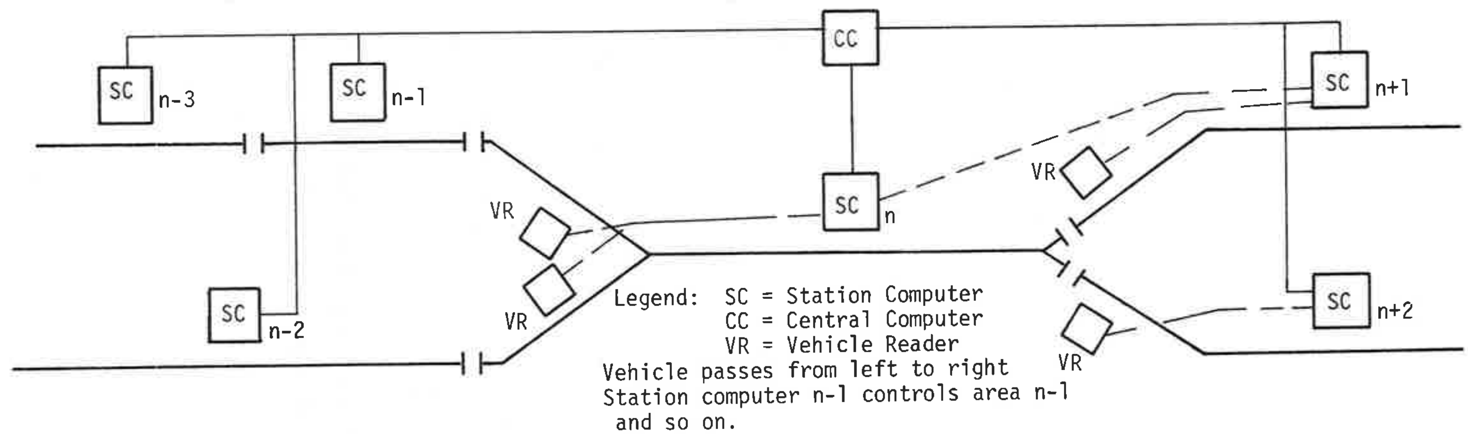
This figure is a drastic abridgement of two complex Siemens flow charts and is an expansion of Figure 4-37; it leaves out many of the details in the hope of better highlighting the functions. The process provides many check points, and at each reasonableness checks are made of the actions taken; a wrong action triggers a corrective action loop. No attempt is made here to analyze the effects of failure, because it would require much longer and more complicated failure modes and effects analysis. The control system is gradually being tested at Erlangen as the programming is completed; undoubtedly much debugging will occur over the next year.

4.5.2.3 Safety Control (AVP) - H-Bahn operation, whether automatic or manual, is protected from dangerous situations by the fail-safe Automatic Vehicle Protection subsystem (described as the "Sicherungsebene" or the Safety Level in the German literature). Its protective role is entirely separate from the dynamic control roles performed by the AVS and AVO subsystems already described, and it operates continuously to forestall dangerous conditions that might arise from overspeed, reduced headways, or improperly set switches.

The AVP is perhaps the most complex of the three control subsystems. Because of its importance and complexity, its elements will be briefly described before the subsystem operation as a whole is discussed.

These elements are:

a) The fail-safe safety sequential circuitry that evaluates sensor inputs, known as the "URTL;"



<u>Vehicle at Station n-1</u>

Prepares to go to Station n:

-check guideway availability

-check merging availability

-is all clear?

no — corrective action taken

yes — Vehicle in n-1 starts

Note: This is a much simplified version of data flow, showing only normal action. Many checks are made during each cycle. Corrective action loops are not shown

<u>Vehicle enroute to area n</u>

Enters area n

SC_{n-1} reports to SC_n

Vehicle detected in n by reader LE

CC and SC_{n-1} informed vehicle now held by SC_n

SC_n queries vehicle for reports

Velocities estab., and new velocity set, if necessary

Is station n available?

no — corrective action taken

yes — vehicle stopped in position in Sta. n

<u>Vehicle at station n</u>

Vehicle and Station door opened

Dwell time estab.

Waiting time passes

Doors closed and Locked

Weigh and report to CC

Check availability of guideway and switch

Can vehicle start?

<u>Vehicle enroute to area n+1</u>

Switch set

Demerge approved

Area change noted

SC_{n+1} queries veh. for reports

Is station n+1 available?

no — corrective action

yes — vehicle proceeds, and records erased from SC_n

FIGURE 4-39. COMPUTER-CONTROLLED VEHICLE OPERATION

b) The guideway block sensors mounted in pairs, mostly at 12 m intervals, the "BERO" sensors;

c) The high current signal relays that are switched by the URTL;

d) The fail-safe power relays, that switch power off the vehicles in emergencies.

Functions - In principle, the safety system is relatively simple. It consists of n blocks, each 12 m long. Each block is marked by an inductive transmitter which is normally energized by 24 Volts with an oscillator frequency of 60 Hz and which is triggered by the passage of a vehicle. Vanes on the vehicles, passing through the magnetic field, cause the actual triggering. Vehicle directionality is taken into account by having a pair of vanes on each side (sequence of triggering).

The generated signals allow the AVP subsystem to accomplish several functions:

1) Speed monitoring

2) Headway monitoring

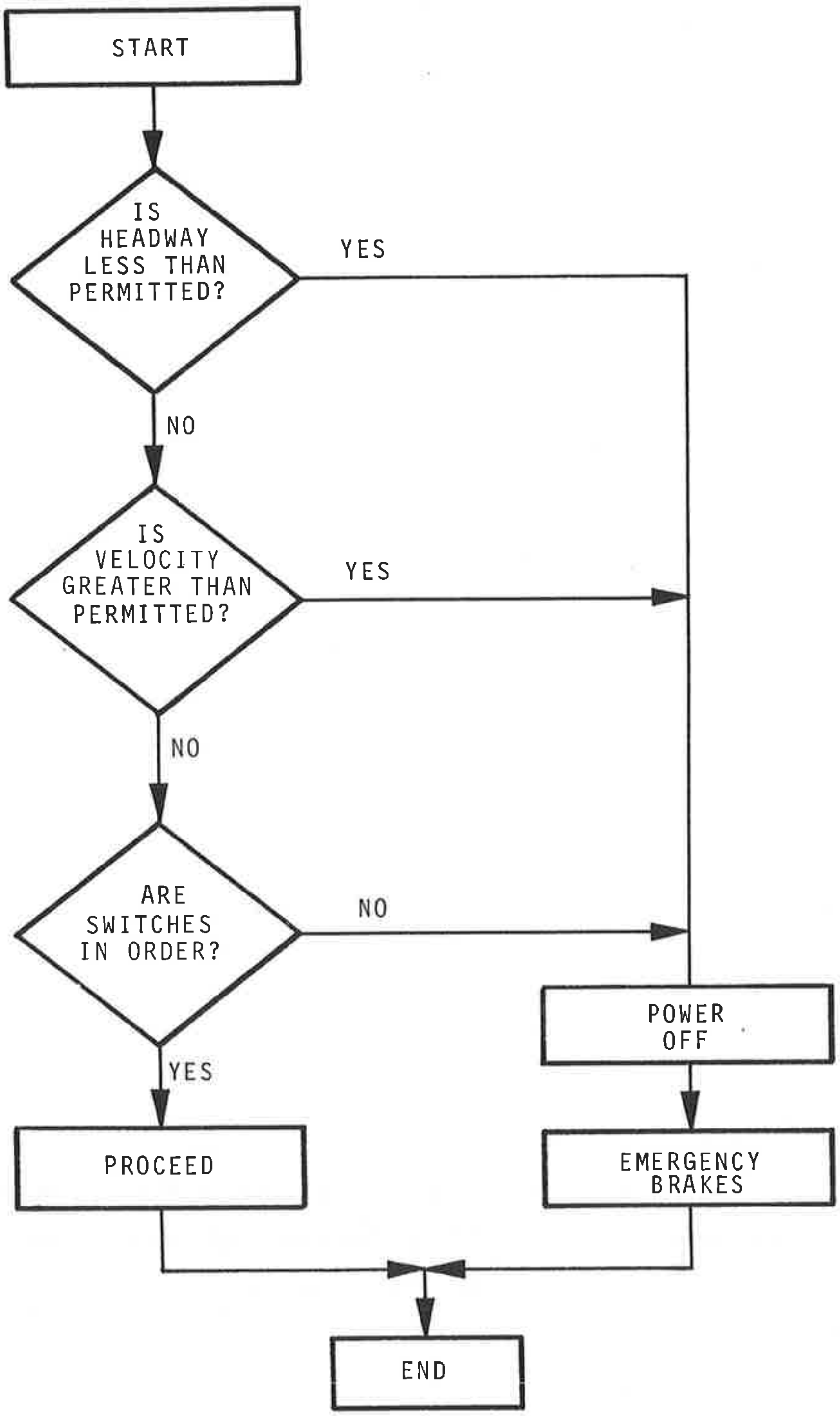
3) Switch position monitoring (not by "BERO"; monitoring by electrical contacts at the switchable deflectors).

If any of these conditions exceed the established limits for any location, power is cut off from the affected section of guideway activating the vehicle's spring loaded emergency brake.

Figure 4-40 shows the logical steps taken by the safety circuitry to accomplish the functions listed above. If speed, headway, or switch position is incorrect, the safety circuitry detects the error and stops the vehicles affected.

Safety Sequential Logic - This equipment receives inputs from all the safety sensors in its sector of the guideway, evaluates them and, in cases when safety is affected, switches power off.

This circuitry has been in the process of being designed and perfected by Siemens for several years. Although its use in H-Bahn will be its first application, it was originally intended



Note: If voltage is cut off, spring loaded emergency brakes are applied.

FIGURE 4-40. SEQUENCE OF SAFETY CHECKS

to be used by the German Federal Railways. It is commonly known as the "URTL" system, derived from the German for "Surveillance Resistor Transistor Logic." It monitors each step of its own operation, and it is fast, taking only 9 nanoseconds to check each step. As used in H-Bahn, any failure in the vehicle operational headways, any excess speed, any improperly set switch, or any failure in the URTL itself will cause removal of the power holding the power rail contractor closed, automatically causing application of the emergency brakes in the affected sector of track. The URTL was tested for 4 years, from 1974 through 1978.

The fail-safeness of this equipment has been investigated by Siemens Braunschweig and attested to by TÜV (Technischen Überwachungs Verein - Technical Surveillance Association). Siemens awarded the Technical University of Braunschweig a contract for further fail-safe analysis, and concurrently, TÜV is conducting a new study of the whole AVP subsystem. The consensus seems to be that the final equipment will be truly fail-safe, which means that any malfunction in one set of complex electronics will effect a power shut down in the vehicles under its control. Each station has one set of URTL equipment per direction; therefore failure of one URTL component will de-activate the station and all vehicles associated with it.

The URTL circuitry is made fail-safe by special integrated circuits (I.C.). Each circuit has two parallel channels handling the same information simultaneously, with each channel performing its function. If the subtraction of one output from the other leaves no signal, the result of one channel's functioning is passed on to the next stage. If a failure at any point has occurred in the I.C., one of the two channels is more likely to be affected and an error signal is generated, which will stop all vehicles in the section for which that particular URTL is responsible. It is recognized that identical failures are possible, and that they could give a false status check. This was one of the unresolved problems with the URTL at the time of the TÜV study. Development has occurred since then, and it is expected that this and other problems will be resolved. The studies currently being run will no doubt determine whether they have been satisfactorily solved, or if they haven't, that their probability of occurrence is so low as to be negligible.

"BERO" Sensors - The safety system detects vehicle speeds and headways using pairs of passive electrical sensors spaced every 12 m on full speed-lengths of guideway, and at 3 and 6 m spacings on curves and in stations - or about 200 per kilometer of guideway. A 5 km system would require nearly 1000 of these sensors.

Although they are energized by 24 Volts with an oscillator frequency of 60 kHz, they are passive only in that they put out no signal until a horizontal vane on the side of the vehicle cuts the magnetic field of a single sensor as it passes through the airgap (Figure 4-41). At this point, a current pulse occurs which is hardwired as an input to the URTL.

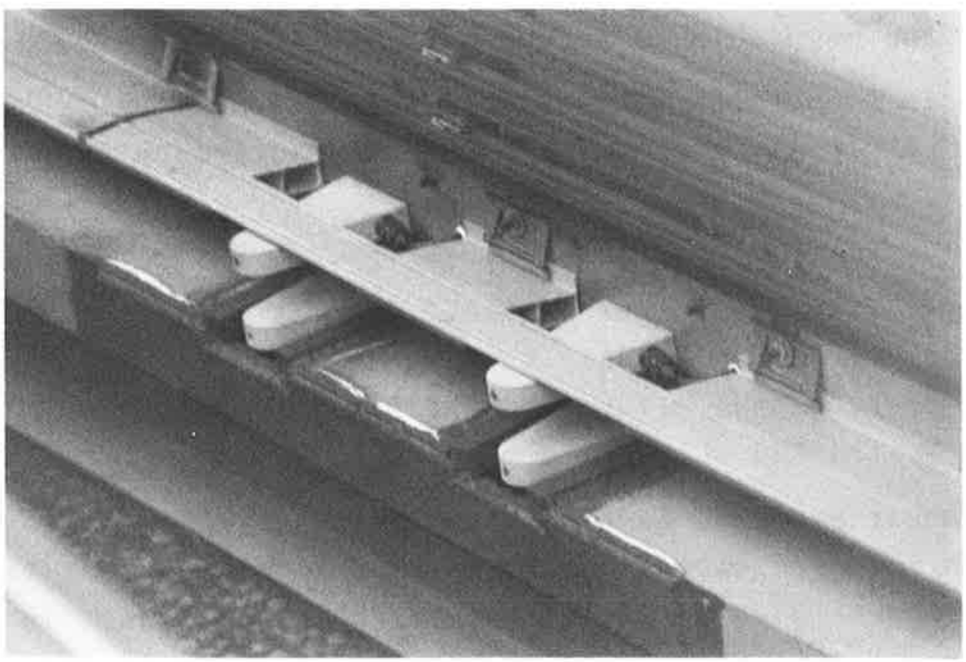


FIGURE 4-41. "BERO" SENSORS

Each vehicle carries a pair of vanes on each side of one bogie. The two halves of the sensor pairs are separated by 0.4 m and are spaced 12 m apart, except as noted above. Therefore, as the vehicle moves, each vane produces two sets of pulses at each pair of sensors. The URTL receives four pulses. The sequence and the intervlas of the pulses are used to supervise speed, headway, and drive direction. The maximum of the vehicle speed corresponding to the time needed to pass one vane through two sensors is deliberately set 15 percent higher than the speed the vehicle itself derives from the guideway magnets, thus giving a possible 15 percent tolerance between guideway speed and safe speed.

In summary, the safety system measures speed on the wayside, independent of the vehicle's on-board speed measurement; the URTL compares the stored safe speed at the point with sensor measured speed. If the latter equals or exceeds the safe speed, the URTL sends a cutoff signal to the current signal relay, de-energizing the power blocks occupied by the speeding vehicle.

Appendix A contains catalog sheets of the Siemens "BERO" sensors and the translation of the German description of how they work.

The High Current Signal Relay - For the safety system to be completely fail-safe, its power cutoff devices must also be fail-safe. These are of two kinds: the Siemens K50 relay, known as the high current signal relay; and the power switch, which is controlled by the K50 which also must be fail-safe.

In transit systems, in the United States, the safety system is based on the traditional block system. To ensure that the system is fail-safe, a so-called "vital" relay is used. In the opening mode of this "vital" relay the failure rate is low. With the removal of power from the vital relay coil for any reason, the relay opens.

The same function is provided in the H-Bahn safety system by the use of special relays between the URTL and the power cutoff switches (Figure 4-42). They have been used in railroad signalling for decades. Their use in H-Bahn is illustrated in the following figure, and they are described in more detail in Appendix A.

<u>Operation</u> - Upon detection of an error signal by the URTL, the sequencing in the circuitry stops, and all four relays open. In normal operation of the URTL, power is maintained on the power switch by one set or the other of the series relays. Each time a vehicle passes a sensor, one set is closed and the other is opened. Any interruption of this sequencing by any one of the four relays is immediately detected, and the closed relay pair is opened, causing the emergency brake to be set. It is not possible that both relays in series will stick, weld shut, or open simultaneously because of rigid mechanical coupling, moved by the armature (Appendix B). A form of redundancy is thus provided; and since

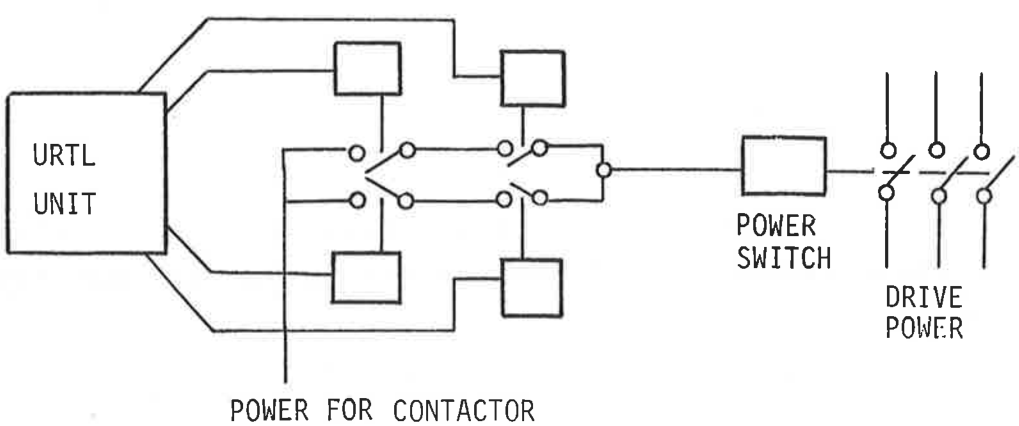


FIGURE 4-42. POWER SWITCHING IN SAFETY SYSTEM

the expected life of each relay is over two million cycles when properly applied, long, trouble-free life is likely. This constant sequencing causes contact wiping and permits immediate detection of any relay trouble.

The Power Contactors - The contactors that cut off power to the vehicle power rails are the last links in the necessary fail-safe chain. Their frequency of operation is much lower than that of the high speed signal relays, for they only operate to turn the system on and off and to cut off power when a dangerous condition is detected. They must be able to make or break the full power sector load without damage, and hence must have rugged contacts. They must also have a very low failure rate in the opening mode, and this is ensured by the spring assisted contactor opening.

The contactors used are 3-pole, Siemens Type 3WE22. Two springs are provided for each contact. The factory guarantee for the contactors is 20,000 cycles of operation, and the lifetime of the contact opening springs is said to be 35,000 cycles. Reliable shutoff is possible with only three springs, giving a 100 percent redundancy to the springs.

Switches of the same type are used in nuclear power stations, cable cars, and ships. Each contactor is individually tested. TÜV (Technische Überwachungs Verein) has tested this contactor and affirms that it is adequate for the purpose and that contactor redundancy is not needed. Normal preventive maintenance will include periodic inspection of the contact assist springs for breakage.

Overall Safety System Operation - As indicated in Figure 4-40, the safety system has three main functions: velocity checking, headway monitoring, and switch position checking. The latter includes the assurance of merge safety.

Maximum Speed Monitoring - This has already been described in connection with the BERO sensors (c.f. Section 4.5.2.2).

Headway Monitoring - The URTL is fed by the signals from the 12 m safety blocks. It stores and sorts out all the signals delivered by the vehicles (resulting from the vanes on the bogies triggering the BERO sensors, as described earlier), and checks the number of free blocks behind each reporting vehicle. If the number is less than the established limit, it will sense this, and stop all vehicles in the power sector. For full speed vehicles (16 m/sec), this limit is 12, 12-m blocks, or 144 m. In station areas additional BERO-sensors can reduce this limit, and the lowest vehicle speed is 1 m/s.

At a station with a waiting vehicle, the one following can approach to within 3 m, but cannot move again until the restored lead vehicle has advanced at least 6-12 m blocks ahead.

Merging and Diverging - The adjoining and merging lines are checked at each merge event. There is also a headway monitoring between a vehicle and the merge which is prepared for the switch run of the other branch. One or the other of the merging vehicles will be stopped or slowed until the spacing on the merged line is proper for the speed of the lead vehicle.

Switch Safety - The direction desired for each vehicle is ordered by the station computer of this area. The station computer sends messages to the URTL and to the Hall generator, which causes the toggle in the vehicle to be set as the vehicle passes by. The URTL checks the message and sends an order to the ramps. The ramps return a "completed action" signal to the URTL, which if not received, causes the URTL to cut off power to the approaching vehicle, making it stop. The toggle returns no feedback signal, for if it is not properly set it will be forced into the right position by the ramps on the guideway. The sensor on the vehicle reports this malfunction to the central computer, which responds by ordering the vehicle to head for maintenance.

Further details of safety system operations can be found in the annotated Siemens diagram in Appendix B. Figure 4-43 presents an overall block diagram of the safety circuitry. The sensor signals are stored and checked for validity. The vehicles in the system present their speeds, and block occupancy, and

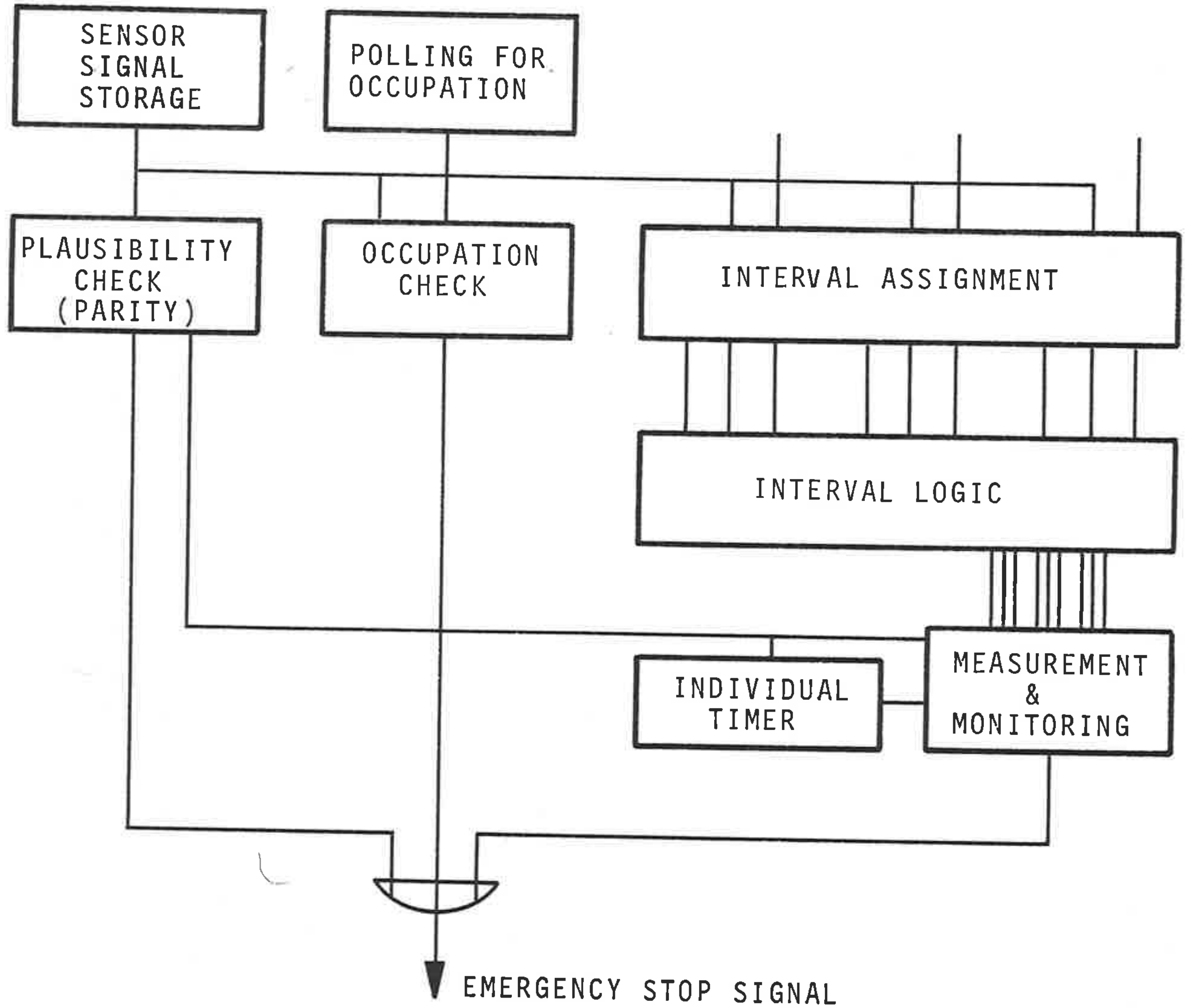


FIGURE 4-43. SAFETY CIRCUITRY DIAGRAM

switch settings are checked. The outputs of all these checks are, in effect, ored together; any unsatisfactory check will precipitate an emergency stop.

4.5.2.4 Communications - The data transmission system links station computers to vehicles, and vice versa, by means of guideway antennas coupled to vehicle-borne antennas. Figure 4-44 is a block diagram of this equipment.

This system uses a 16-bit digital message, sent by frequency-shift keying, using 121 kHz and 132 kHz. Accuracy of transmission is checked using a parity bit. Each vehicle has an individual address in the system and the station computer can be linked with one or several vehicles. Frequent performance testing is built into the system. It is planned that the guideway antenna will be mounted inside the guidebeam in a plastic carrier.

The same carrier frequency transmits voice communications, both from and to the vehicle. Station announcements, emergency calls, emergency announcements, information on malfunctions and directions to the passengers may be transmitted.

4.5.2.5 Failure Management - It is planned that operating vehicles will automatically report a number of possibly hazardous conditions to the operators at central control, who will respond with preplanned actions. These are reported over the communications system, of course, but are highlighted here because they are not routine, but unique responses to unique conditions.

Failure Categories: Three are established with action indicated:

- I Breakdown on guideway or emergency brake application;
- II Major component failure - vehicle proceeds to next station and stops;
- III Secondary component failure - vehicle goes to maintenance shop at end of day.

Failure Types: The various failure conditions, their categories of action, and the detection means are tabulated in Table 4-5.

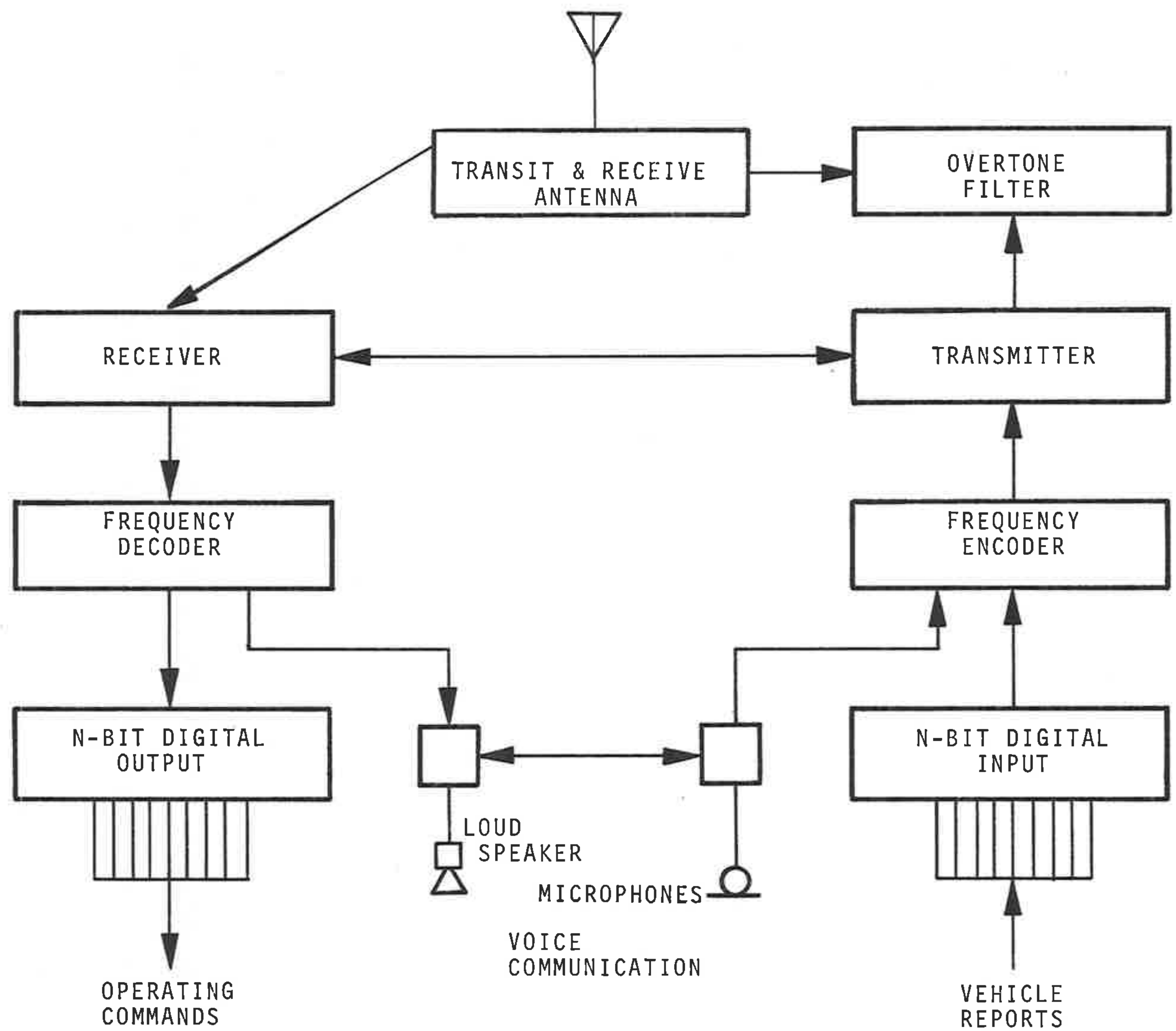


FIGURE 4-44. COMMUNICATIONS SYSTEM DIAGRAM

TABLE 4-5. FAILURE DETECTION SCHEME

CATEGORIES OF ACTION

CONDITION	I EMERGENCY BRAKE	II STOP AT NEXT STATION	III STOP AT MAINTENANCE	DETECTED BY
Fire		√		On-Board Sensors (2, ionization)
Motor Hot		√		On-Board Sensors
Motor Warm			√	On-Board Sensors
Vehicle Switch Activated By Ramp			√	On-Board Sensors
Lighting or Heating			√	On-Board Sensors
Overspeed	√			"BERO" Sensors In Guideway
Headways Too Small	√			"BERO" Sensors In Guideway
Switch Malfunction	√			Sensors in the Switch

4.5.3 Hardware Realization

Maturity - A good fraction of the equipment now used in the Command, Control and Communications subsystem was already developed by Siemens and its suppliers for other applications, and can be considered mature. A tabulation, supplied by Siemens, follows, showing the various elements of the CCC system hardware, the proportion of each that is a final design in production, the proportion that is new, and the manufacturer (referring to the test track in Erlangen).

AVS Subsystem

Central Computer	tried, final design	- 90%
	new	- 10%
	manufacturer	- Siemens
Monitoring Center	manufacturer	- Siemens (design would be site specific)

AVO Subsystem

Station Computer	tried, final design	- 100%
	manufacturer	- Siemens
Vehicle Sensor	tried, final design	- 10%
	new and prototype	- 90%
	manufacturer	- Siemens
Vehicle Positioning Stop Unit	tried, final design	- 50%
	new and prototype	- 50%
	manufacturer	- Siemens
Doors and Docking Unit	tried, final design	- 50%
	new and prototype	- 50%
	manufacturer	- Siemens Baumgartner Switzerland
Ticket Unit	tried, final design	- 100%
	manufacturer	- AEG Kassel

AVO Subsystem (Continued)

Ticket Punch and Line Call Unit	tried, final design	- 50%
	manufacturer	- AEG Kassel
	new and prototype	- 50%
	manufacturer	- Siemens
Line Indicator	tried, final design	- 100%
	manufacturer	- Krueger Hamburger
Speed Profile	new and prototype	- 100%
	manufacturer	- Siemens

AVP Subsystem

Safety Unit	tried, final design	- 20%
	new and prototype	- 80%
	manufacturer	- Siemens
Block Sensor	tried, final design	- 90%
	new and prototype	- 10%
	manufacturer	- Siemens
Electric Switch Unit	tried, final design	- 10%
	new and prototype	- 90%
	manufacturer	- Siemens
Communications Subsystem	tried, final design	- 50%
	new and prototype	- 50%
	manufacturer	- Industronics Wertheim

Reliability Effort - As mentioned earlier, little formal reliability analysis was done on the hardware. At the test track, the effects of failure on the system's operation have been minimized in several ways:

1) If a station computer fails, vehicles passing through its zone can continue uninterrupted, for they are monitored for safety by the independent AVP system, and derive their speed commands from the guideway profile. They will, however, bypass the station where the failure occurred.

2) The critical element in the safety system, the URTL, has been extensively studied by several organizations. TÜV critiqued it thoroughly in 1975. The Siemens Braunschweig organization likewise critiqued it and the fail-safe operation of the URTL was thoroughly described in "URTL - An Electronic Fail-Safe Logic for Railroad Signalling," by H.J. Lohmann. Currently further fail-safe analyses are being conducted by the Technical University of Bräunsweig.

Need for Redesign - It is likely that in a production system the communcations equipment would be redesigned.

Maintainability - Rapid failure detection, location, and repair were considered key points in the design of the wayside equipment.

1) Each station is equipped with a central failure box, to which is brought all the failure indication signals from the station equipment.

2) The box sends a summary failure message via the station computer to the central computer, where it is displayed to the operator.

3) The operator can then dispatch a service man to the station to repair the trouble.

4) The service man is led by the lights on the failure box to the defective subsystem, and by module indicators to the defective module, which in most cases can be rapidly replaced with a spare module.

Costs - All units put into a production system will be of production, not prototype, design. Siemens believes, using only equipment in production or ready for production will allow them to obtain reliable products at the least cost. Some specifics on expected costs are presented in Section 6 of this report.

4.6 FARE COLLECTION

The method and equipment for passenger handling and fare collection are largely a function of the applied operating concept.

For H-Bahn, scheduled operation with stops at every station is planned. In addition, during off-peak hours the passenger can summon a vehicle for the route desired (Demand Operation).

In both cases, the equipment and graphics required for passenger handling in the stations are essentially the same as those which are used today in modern European public transit. Figure 4-45 shows, for example, one possible arrangement for the station.

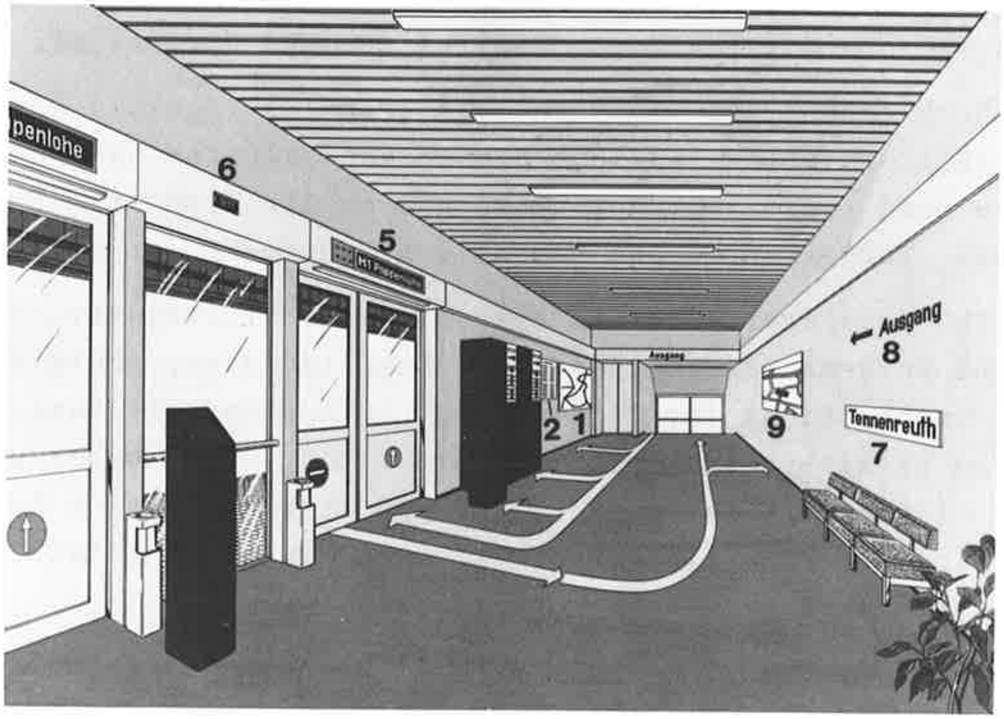
As the passenger gets off the staircase or elevator, he enters the information and passenger-handling area, where the diagram, instructions for determining the appropriate fare and use of the ticket-selling machines are found. The number and terminus of the next route are displayed at each station by a route indicator. The ticket-canceling machines are located in front of the doors at which the cars stop.

The equipment in the stations will be designed to suit the specific conditions and situation of the user. For example, the ticket-canceling machine and automatic ticket-selling machines, route diagrams, and so forth can be mounted elsewhere if the operator desires. For application in other countries the specific station equipment can be used.

For operation according to a fixed schedule, all conventional ticket types now used in public transit may be employed. Single-ride tickets and multiple-ride tickets can be canceled. This will not be necessary for those who have passes or are transferring from other transit modes, and hold tickets that have already been canceled. In a European setting, roving inspectors will check to be sure that all fares have been paid. In America, turnstiles would be installed.

For the "demand" mode, in which passengers summon the vehicles, the ticket-canceling machine is equipped with a keyboard enabling the passenger to indicate his desired route (Figure 4-46).

At the Erlangen Test Facility, the vehicle-summoning system is presently combined with the ticket-canceling machine. The passenger must cancel the ticket before a vehicle can be summoned for



KEY:

1 - route map
2 - information on fares and use
3 - automatic ticket-selling machines
4 - ticket canceling machine and route calling equipment
5 - route indicator
6 - clock
7 - station name
8 - exit sign
9 - station environment orientation diagram

FIGURE 4-45. H-BAHN PASSENGER STATION INTERIOR LAYOUT

FIGURE 4-46. CANCELLING MACHINE WITH KEYBOARD

the desired route and then the journey can begin. This means that tickets which the machine cannot read or cancel, such as passes, cannot be used making it necessary to use single-ride tickets during off-peak travel hours. A provision is also made for controlling vehicle-summoning functions by the keyboard alone, making it completely independent from the need to cancel the ticket.

The decision as to whether a design incorporating the Demand Mode operation for off-peak hour operation, should be implemented at all, and if so, in what form, remains as a choice for the future operator.

Route Operation on a Fixed Schedule

This type of operation will be used for most of the day, and particularly during peak travel hours.

The basic operating mode for the H-Bahn collection system is quite similar to that used throughout public transit systems in the Federal Republic of Germany.

Since all conventional ticket types may be used, i.e., single-ride and multi-ride tickets, passes, or transfers, fare collection can easily be incorporated into an existing transit fare structure. This means that the automatic ticket-selling machine and ticket-cancelers that are presently in use may be used for H-Bahn as well. However, locating ticket-canceling machines, in the stations, directly in front of car entrances can lead to delays in passenger interchange. If passenger interchange is in fact influenced adversely by this arrangement, the operator may choose, for example, to locate the ticket-canceling machine next to the automatic ticket-selling machine. In present-day public transit practice, tickets are not normally canceled in the station but rather aboard the vehicles themselves. The H-Bahn manufacturers indicate that the canceling machine can also be mounted aboard the vehicle.

However, it is also possible to sell tickets or passes that have already been canceled by stamping them, as is done for example, in Hamburg. Multi-ride tickets cannot be used; this means that ticket-canceling machines can be completely eliminated.

Demand Mode of Operation

This mode of operation would be used exclusively at off-peak hours, responding to rider requests.

Ride requests made by the passenger can either be connected to the ticket-canceling system (as is the present arrangement at the test facility), or they may be designed to be independent of the canceling facilities. In both cases, random checks will be necessary, since even if the tickets must be canceled in order to request a vehicle, one cannot rule out the possibility, for example, that several people will travel on only one ticket or non-transferable tickets will be misused.

By linking the ticket-canceling machines and the route request facilities, protection is provided against misuse of the route request facilities. This means, however, that the tickets which are used must be cancelable or "readable" by the ticket-canceling machine. If H-Bahn is integrated into an existing public transit network, the existing ticket system may not be adaptable. Persons who are transferring or other passengers who do not have usable tickets will then have to buy a valid ticket before they ride H-Bahn. As in the case of the "Dial-A-Ride Bus," people with tickets entitling them to travel at off-peak hours can obtain an additional ticket for summoning vehicles.

In the type of ride request system which is completely independent of the ticket-canceling mode, there is admittedly no protection against misuse of the ride request system; however, a fare system which is already being used on public transit systems can be easily adopted. The keyboard for route requests is then located in the vicinity of the automatic ticket-selling machine, in conjunction with a route diagram.

4.7 OPERATIONAL SUPPORT

4.7.1 Power Supply

The power supply facilities for an H-Bahn system can be broken down essentially into the following main components:

- Medium-voltage supply
- Substations to feed the traction current
- Power rail system
- Individual power supplies for the stations
- Remote-control facilities.

Survey

The dc motors and asynchronous linear motor drive are available for H-Bahn vehicles (see Section 4.4.5). In both types of drive, the vehicles are powered by four power rails (Phases R, S, and T; midpoint conductor Mp) with 3-phase voltage of 660 V, 50 Hz. When the dc motor drive is used, the 3-phase voltage is rectified by a fully controllable 3-phase bridge circuit and supplied to the traction motors. At the same time, the motor armature voltage can be adjusted with the 3-phase bridge, thus controlling the speed of travel. When the linear motor drive is used, a 3-phase voltage control is used as the final control element, controlling the motor voltage and, hence, the speed of the vehicle.

The power rails are fed by substations, which may be located in the [passenger] stations. The substations are connected to a medium-voltage network (~20kV). For the proposed network in Erlangen, the substations have an anticipated load rating of 400 or 630 kVA.

The switchgears at the substations (for example, motor-driven power switches) are monitored and controlled by a remote-control system from central control. A special branch is provided in the traction current substations to supply energy to the stations.

Medium-Voltage Power Supply and Substations for Traction Current Feed

To supply (medium) voltage to the substations, the feasibility study at Erlangen found it advantageous to use a separate ring cable for H-Bahn, connected to the city medium-voltage network at two transfer points. If the city network consists of several independent subnetworks, the transfer points can be located in different ones. During normal operation, the ring cable is supplied from one transfer point. If this transfer point or the associated part of the urban network fails, the power supply switches over to the second similarly designed transfer point. In the event of a total system failure (failure of the high-voltage network), the ring cable makes it possible to feed individual substations with an emergency power supply system located at a central point. This makes it possible to clear the vehicles off the line one section at a time, allowing the passengers to disembark at the next station. The H-Bahn ring cable can be installed on top of guideway supports in order to avoid having to bury it. The transmission cables for the control system, also mounted on guideway supports, must then be shielded appropriately. If necessary, transmission cables can be mounted on the sides of the supports.

In addition to the standard solution using the ring cable, there are other ways of connecting substations, e.g., by providing power directly from the city medium-voltage network. Because of the voltage level currently in use (380 V, 3-phase), it is not possible to use low-voltage feed with house connections. Moreover, the connected power which would then be available would not be sufficient.

With the abovementioned direct connection of individual H-Bahn substations to the closest urban medium-voltage distribution station, the investment for the medium-voltage ring cable, which would otherwise be required, is eliminated; however, there are several problems which offset this advantage:

- If the urban medium-voltage network consists of separate subnetworks (island networks), a connection between adjacent subnetworks through the power rail system between two adjacent substations should be avoided to prevent, for example, undesirable equalizing currents between two subnetworks due to different power factors in the island networks.
- In the event of cable breaks or other loading shedding, power source security is less than in the ring cable solution, because the substations are integrated into the overall urban network.

- The cost of energy is largely determined by the amount of energy and the corresponding peak consumption value for a specific period of time. The measurement points are normally located at the feedpoints between the urban network and the H-Bahn network. This offers advantages for indirect connection, since extreme peak loads in the ring cable from one substation would be offset by lower loads on other substations.

On the basis of experience gained so far, a direct connection may be advantageous, especially in certain cases, e.g., small H-Bahn installations. As far as connecting the H-Bahn network to the urban network is concerned, a determination must be made in each individual case as to whether the installed power lines in the urban transformer stations are sufficient or whether expansion will be required.

In order to decide which type of feed will be selected, subsequent users will have to weigh operating aspects against the necessary investment for each of the two solutions. Local power supply companies will have to be involved in this decision-making process. In addition to the choice of the type of feed, planning will also depend upon the layout of the network, the size of the vehicles, vehicle loading schedules, and station siting.

Within the framework of the feasibility study, a preliminary design for power supply facilities was drafted for an H-Bahn network in Erlangen. The ring cable solution was given preference. In order to increase safety and reliability, the ring cable supply system is redundant, using two transfer points from the urban medium-voltage network which can be selected optionally. The largest possible distance between substations depends on the voltage drop expected in the power rails. It was found at Erlangen that with a power rail voltage of 660 V, substation intervals of 1400 to 1800 m are feasible. This means that substations can be provided at every second or third station if we assume an average distance between stations of 500 to 600 m. This means that with bilateral power rail feed (normal operation), five trains of two dc motor-driven vehicles of the 2/2 AE type can be operated simultaneously; with unilateral feed (for example, if one substation fails), two trains can start without exceeding the maximum permissible variations in operating voltage of +10 percent to -24 percent of the rated voltages as established by VDE 0115.

As a rule, substations are located at every second or third station. The power rails are also interrupted at stations which are equipped with traction current substations (Figure 4-47).

With a feed area of this type, feed comes bilaterally through the substations. This ensures that if one substation fails, power supply to the corresponding feed sections can be assumed by the two adjacent substations.

An additional power rail break is located at the station which is between two adjacent current substations. Under normal conditions, these additional breaks are bridged by coupling switches.

Because the safety system triggers emergency braking by disconnecting the traction voltage, the system is divided into individual feed areas. This division is site specific.

Power Rail System

The power rail for phases R, S, and T as well as the midpoint conductor Mp are mounted at the sides of the guideway supports. (See Section 4.2.) Power rail segments 7.5 m long are pre-assembled with corresponding insulators and spacers and then mounted on the guideway supports (Figure 4-48). Using the same design for operation (scheduling, train length), the load on the power rails in the case of vehicles powered by dc motors is less than in the case of vehicles powered by linear motors. This is essentially due to the smaller efficiency η and power factor cosine ϕ, which are less for linear motor drive than for dc drive. In H-Bahn systems with dc motor-powered vehicles, it is sufficient to mount the power rails on one side. The power rails are mounted on both sides only in the vicinity of switches. For linear motor powered vehicles, it may be necessary to locate the power rails

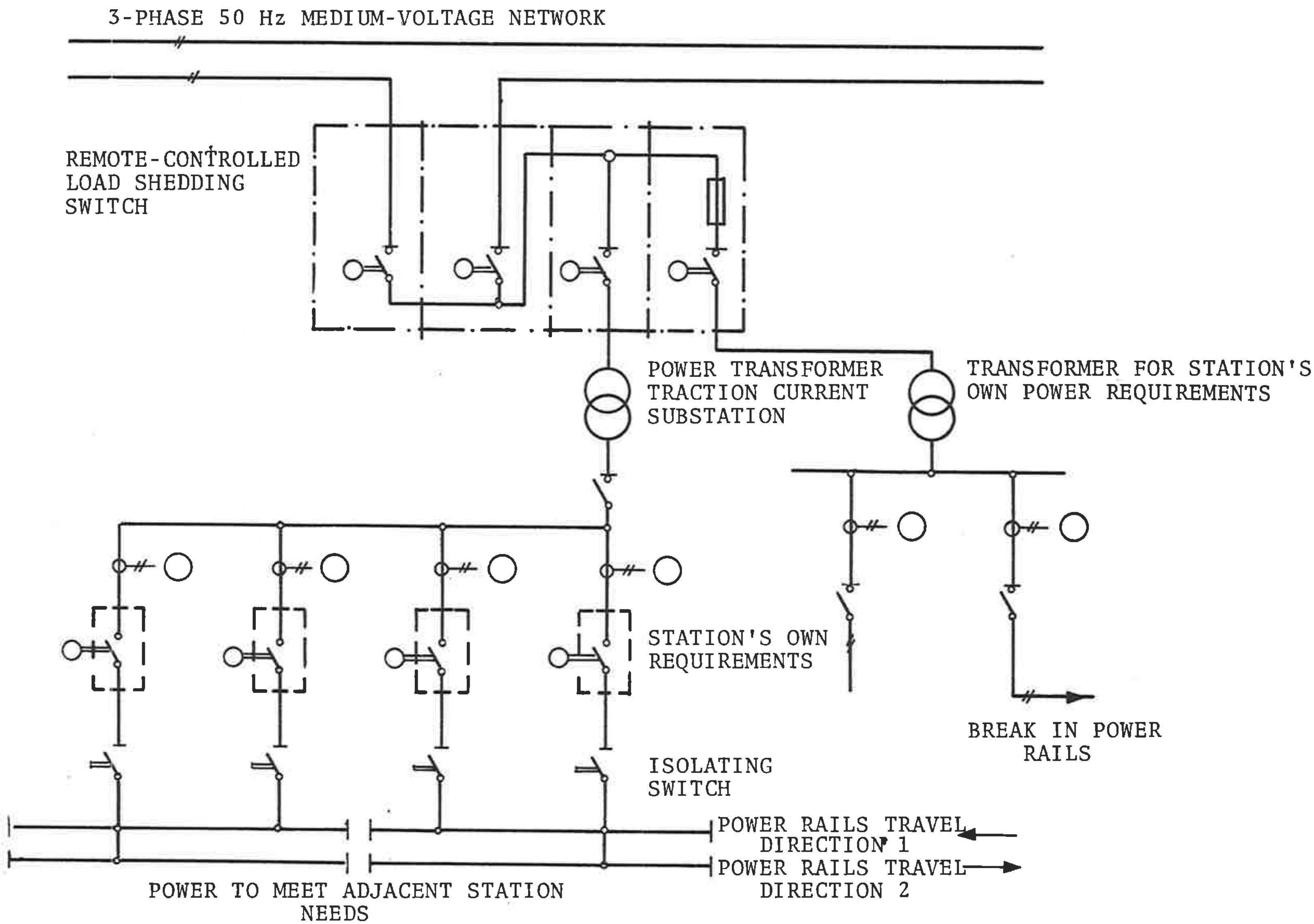


FIGURE 4-47. POWER DISTRIBUTION DIAGRAM FOR SUBSTATIONS

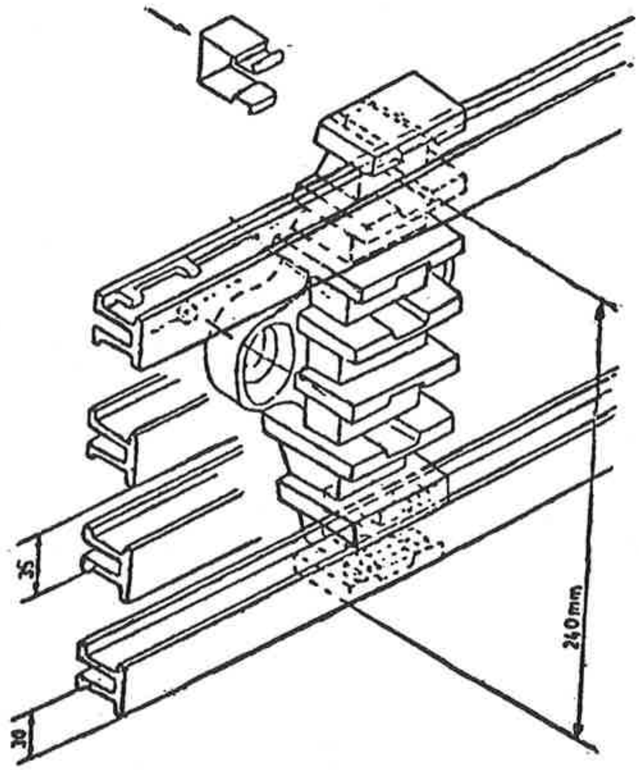


FIGURE 4-48. POWER RAILS AND INSULATORS

on both sides or to increase the power rail cross section. This depends upon the load on the power rails and must be studied in each individual case.

At the Erlangen Test Facility, the power rail cross section is 353 mm^2 for each rail with bilateral power rail installation and a traction voltage of 380 V, 50 Hz 3-phase. The power rails are designed and dimensioned for operation with linear motor powered vehicles. The rails are made of copper. Operating tests conducted thus far on the H-Bahn vehicles at the Erlangen Test Facility, with the profile shown in Figure 4-49, reveal no problems with current pickup between the power rails and the current collectors. With the existing power rail/current collector system, life tests conducted thus far indicate that the power rails would last a minimum of 10 years.

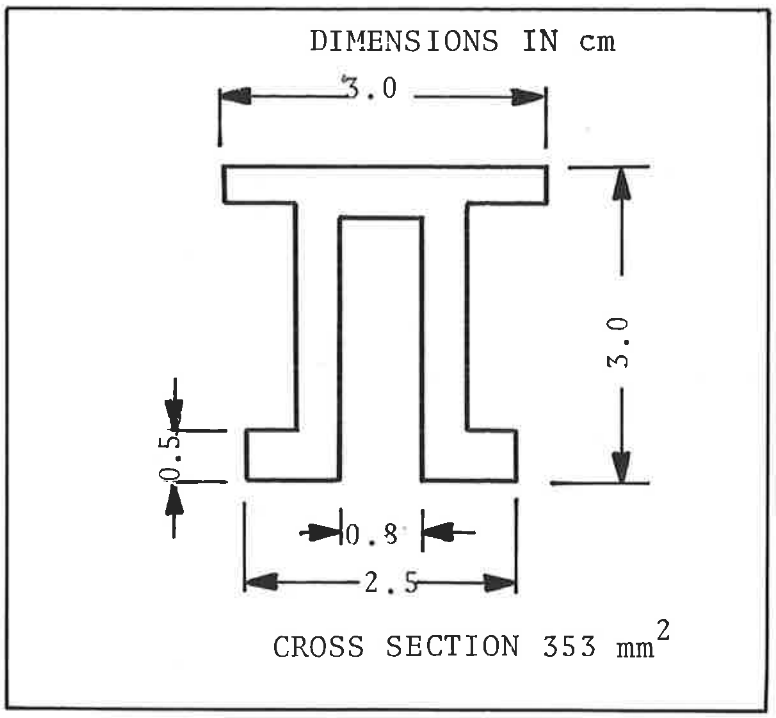


FIGURE 4-49. ERLANGEN POWER RAIL PROFILE

The midpoint conductor Mp serves simultaneously as a protective conductor. This is permissible in accordance with VDE 0115. The midpoint conductor is grounded in the foundation. In addition, it is connected at each stop with the platform at the stop and with the guideway support. Connecting it to the station platform prevents potential differences from developing between the vehicle and the stop. Connection to the guideway support is a connection to the lightning protection system. Lightning protection is provided by electrically conductive links between the foundations of the uprights and the individual guideway supports. A special lightning grounding system is required for special foundations.

It is necessary to check for short circuits. This includes monitoring ground faults.

Meeting the Power Requirements of Individual Stations

Separate 3-phase current distribution systems are necessary for meeting station power requirements. In stations where a traction current substation is already located (see Figure 4-47), the station's power requirements are met by a load-shedding switch from the medium-voltage network. A transformer is used to transform the medium voltage to 0.4 kV voltage to supply the station. This individual power requirement transformer can also supply an adjacent station through a 400 V cable. In addition, the station can also be connected to the urban 380 V network, if needed as an auxiliary power supply in the event of a failure in the ring cable. Furthermore, a design has been developed, similar to the one at the test facility, for an emergency power supply system using batteries, in case (for example) emergency lighting or communications with control center is required. The station doors will remain functional.

Separate protected power supplies are planned for the URTL safety system as well as for the station computers. The design of the URTL independent power supply system has also been the subject of studies to develop a fail-safe design for elements critical to safety. In the station computer, in the event of a power outage, the data are protected by a command to store them if the voltage falls below a certain value.

Remote-Control System

The switching equipment at the traction current substations is normally monitored and switched by a remote-control system from the central control point. The switch status of the switching equipment to be monitored is displayed on data display equipment. Remove control is via a keyboard. In order to maintain remote monitoring or remote control independent of the line voltage, an emergency power supply is provided at each substation and at the central control in order to be able to cover the line downtime in the event of network failure. In this case, the existing emergency power supply at the stops will be used.

4.7.2 Vehicle Storage

Storage areas in an anticipated network are to be built in a way which minimizes the operating power required to put the cars into service and to take them out. These storage facilities are generally located at the ends of lines and at junctions. The available space plays a role in this decision.

Various designs are possible for storage areas. The most important ones will be described below.

The Ring and Off-Line Storage Facility (Figure 4-50) can be located either at the end of the line (line terminal, with loop), or at a central point in the system, possibly in connection with repair and maintenance facilities.

In the ring storage system, by contrast with off-line storage, both the vehicles entering service and those leaving it serve the station. The ring storage system requires more space than the off-line storage system.

The central storage system (Figure 4-51) is preferably used on two-track lines, not at the end of the line but along the line.

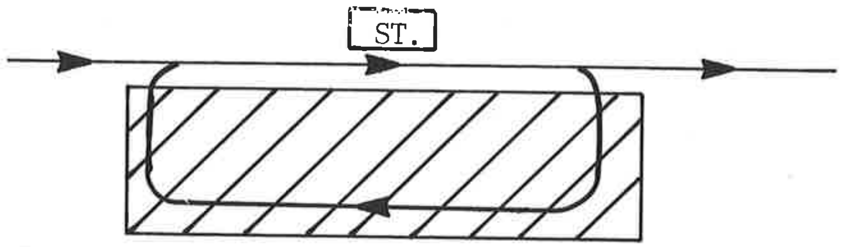


FIGURE 4-50. RING AND OFF-LINE STORAGE FACILITIES

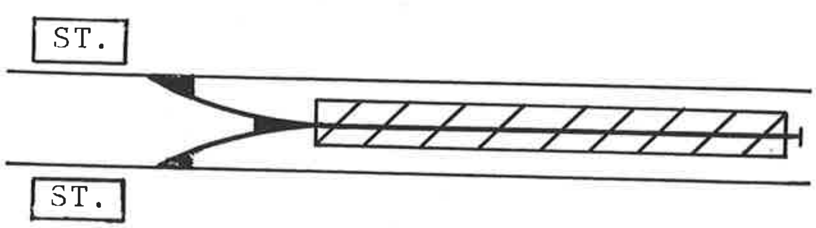


FIGURE 4-51. CENTRAL STORAGE TRACK

Stub-end and pull-off storage facilities (Figure 4-52) are preferably located at the ends of the line, with a turn-back track.

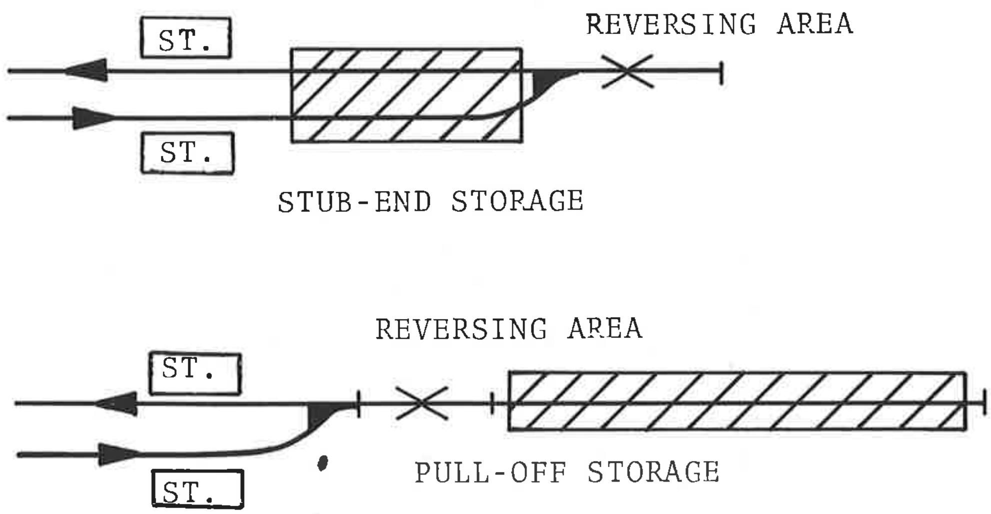


FIGURE 4-52. TYPICAL STORAGE FACILITIES

In the pull-off mode, vehicles being taken out of service at the end of peak travel hours are parked in the storage area and are put back on line only at the beginning of the next peak travel hour. The vehicle reversing area is located in front of the storage area.

The turn-around storage track can be referred to as a "push-through" storage area. In contrast to the "pull-off" storage area, the storage area is located between the station and the reversing stub. This means that there is no longer any distinction between vehicles which are merely turning back and those which are being stored. The vehicles being taken out of service push all of the "parked" vehicles up one space. The leading vehicle is used for this purpose.

If the storage track described above, possibly with maintenance and repair facilities, is also to be used by lines without a direct line connection to the storage track, connecting tracks running as directly as possible to the junctions with those lines can be planned. Plans so far have called for maintenance and repair facilities to be located at the central shop facility. On the other hand, daily cleaning of the interiors of the cars will be handled by providing one storage area on each line with catwalks.

Vehicles in service during off-peak hours can also be stored on the running rail in the vicinity of the end of the line after they go out of service.

Since the vehicles required for off-peak-hour service are stored on the running rails, the number and capacity of the storage facilities are determined by the additional vehicles required for peak hour service, by the service vehicles which are kept on hand as an operating reserve, and by the storage areas which make it possible to take malfunctioning vehicles out of service.

The number of vehicles available for service, therefore, depends on the schedule for the morning rush hour and the off-peak hours.

Depending on the type of storage facility, consideration must be given to providing additional space for turning vehicles. The length of one vehicle's storage space consists of the length of the vehicle over the couplers and a space of 0.9 m between every two cars. The cars to be stored on a line or a part of a line are generally distributed uniformly over the storage areas at the ends of the line.

Figure 4-53 shows a pull-off storage facility planned within the framework of the feasibility study for Erlangen for nine vehicles of the 2/2 AE type.

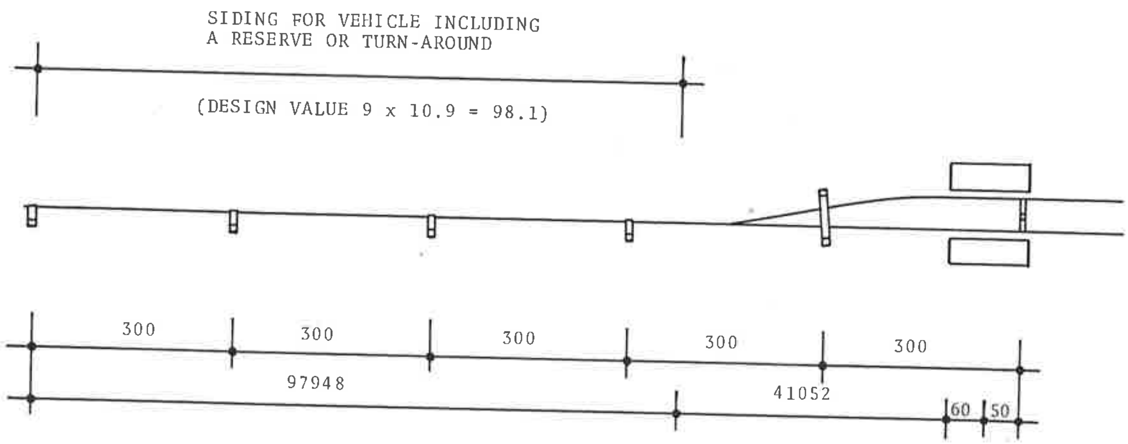


FIGURE 4-53. PROPOSED ERLANGEN STORAGE FACILITY

4.7.3 Maintenance, Repair, and Cleaning

Since early 1978, long-term tests have been conducted at the Erlangen Test Facility. From the results, we can draw some conclusions about the long-term behavior of the system, especially vehicle components. On the basis of the data provided on the lifetime of parts subject to wear as well as on the reliability of components, technical improvements were made where necessary reducing the cost of maintenance and repair. In addition, information has been obtained providing an idea of the necessary volume of maintenance and repair work.

One goal of further development is a system for rapid fault recognition during operation and simple and rapid methods of maintaining and repairing all subsystems.

Vehicles

Test results are available in the form of up-to-date data on the work and intervals to be expected for vehicle maintenance, as developed within the framework of the feasibility study at

Erlangen for vehicle type 2/2. This study included both experience with H-Bahn test operation and maintenance-related information from the Federal German Railways and Public Transit Systems. In the case of H-Bahn, the following maintenance work intervals have been estimated.

Routine checks		
"Check-out"	every	7 days
T 1 periodic inspection	every	12,500 km
T 2 periodic inspection	every	25,000 km
T 3 intermediate inspection	every	250,000 km
T 4 complete inspection according to Bo-Strab	every	500,000 km
Unusual damage		
00 minor damage	every	4 months
01 damage to mechanical parts	every	100,000 km
02 damage to electrical parts	every	2 years

Check-outs are performed on check-out stands. Visual checks of the current collectors, brake linings, and mechanical brakes are also carried out. Then the vehicles are cleaned externally.

Periodic check T 1 will cover components such as traction motors, control, charging equipment, and vehicle suspension. Check T 2 will include work on mechanical parts, and at 25,000 and 50,000 km the wheels will be adjusted to equalize the wear of the rubber tires; the wheels are replaced at 100,000 km.

Check-up T 3 involves visual checks which are the same as those in T 2; in addition, worn parts in the running gear, brakes, and switch contacts are replaced.

Complete check T 4, performed according to Bo-Strab takes into account operating safety including brakes, electrical equipment, and running gear.

Minor damage repairs include replacing burned-out light bulbs and correcting defects in fans.

Damage group 01 covers problems with mechanical elements, brakes, and drive; while damage group 02 covers problems with automatic control and information and transmission systems.

For simple vehicle maintenance and rapid elimination of faults, all of the important parts of the vehicle equipment must be replaceable in the shortest possible time by an exchange system. For this purpose, the equipment for drive and brake control, vehicle ventilation and heating, batteries with chargers, emergency braking assembly, and command and control equipment are all assembled into modules and mounted in an interchangeable chassis or on plug-in boards.

Running wheels, guide wheels, and drive motors with their transmissions are also designed for rapid replacement.

Other assemblies including air compressors, braking resistors, etc. are mounted so that they are readily accessible on the vehicle roof.

If a defect develops in a vehicle during its trip, the nature of the fault must be recongized as soon as possible. An appropriate reaction will reduce problems related to operating faults and keep them within certain limits.

At the present time, a fault-recognition unit is being developed. As soon as a defect occurs on a vehicle which is in service, it is reported over the data transmission system. This initiates a reaction which is adapted to the particular kind of defect. Depending on the nature of the problem caused by the defect, a distinction is made between three fault classes at the present time (Table 4-6). (See also Section 4.5.2.5 and Table 4-5).

Shops

In an anticipated network, the maintenance, repair, and cleaning work which needs to be done only once for each system is performed at a central shop. This simplifies work procedures. All of

TABLE 4-6. FAULT CLASSIFICATION

Fault Case	Example	Defect	Reaction
Fault case 1	Switch rocker defective	Safety affected	Emergency brake application
Fault case 2	Overheating of the motor	Reliability affected negatively	Vehicle goes to the next station
Fault case 3	Illumination and heating defective	No negative effect on vehicle's ability to operate	Vehicle goes to the end of the line and then into the maintenance facility

the main routes are, therefore, connected together by the shortest possible operating distances. These should be arranged so that they can be used as bypasses in the event of problems with operation and, in emergencies, can be used to form extensions of the routes.

The maintenance and repair facility is equipped with special open-design guideway supports (vehicle stands), which allow access to the running gear components such as drive, current collectors, and wheels (Figure 4-54).

The assemblies mounted on the vehicle roof are also readily accessible by removing the floor grid at the workstand.

Functional testing and damage detection will be carried out at automatic check-out test stands; design for them is currently being done. Check-out tests to identify problem areas are planned for both the electronic systems and the parts which are subject to wear including dc motor brushes Defective parts are either replaced or repaired at the repair facility.

In general, the running gear and the car body are not separated from one another for maintenance work. If this is necessary in exceptioncal cases, the car is lowered onto a dolly and the running gear is lifted out of the repair stand by a crane.

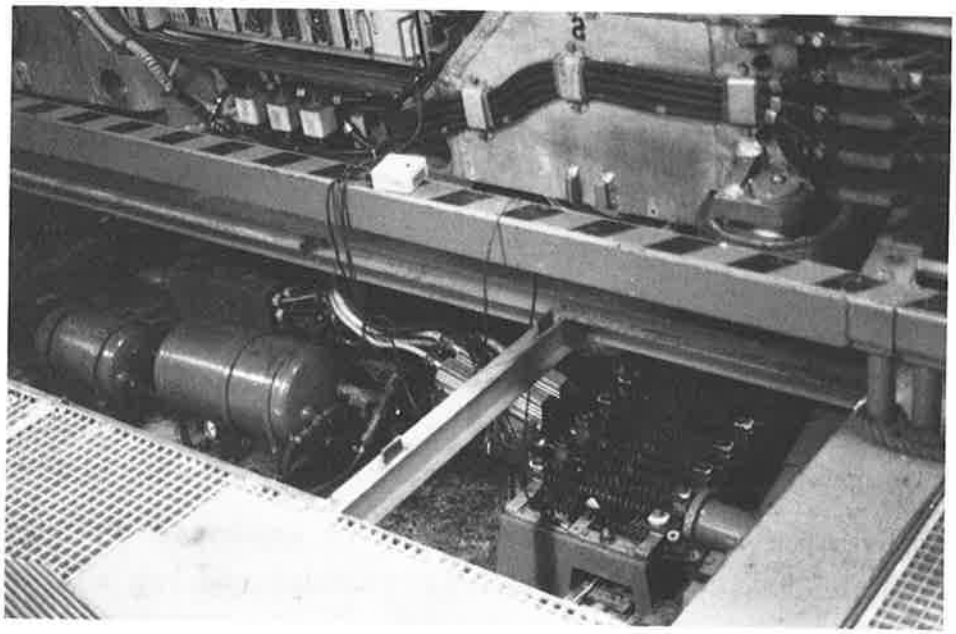


FIGURE 4-54. 'RUNNING GEAR IN MAINTENANCE AREA

In addition to regular inspections and repairs, a facility associated with the shops performs wet cleaning of the cars. The car exteriors are cleaned once a week, as a rule, in a fully automatic washing facility; and the car interiors are wet-cleaned by machine once a week. Additional dry interior cleaning of the cars is carried out once a day at the vehicle storage areas.

Within the scope of the feasibility study for Erlangen, a maintenance and repair facility was set up at the test track (Figure 4-55) complete with all necessary equipment, at a central point in the network. The maintenance intervals given above were used for the vehicles.

The building is designed for maintenance and repair work on a vehicle fleet consisting of 115 cars including a shop reserve of the type 2/2 AE vehicle, each car running 84,000 km a year.

The 2-story design reduces the floor area requirements of the shop.

The building measures 43 m by 36 m in area. The ground floor primarily houses offices, storage areas, and the paint shop, as well as the electrical and electronic shops, together with a set-up area for checking out equipment. The shops for mechanical and electrical components are located upstairs (Figure 4-56). The vehicles travel on a guideway support to reach the bogie maintenance area which is also located on the second floor.

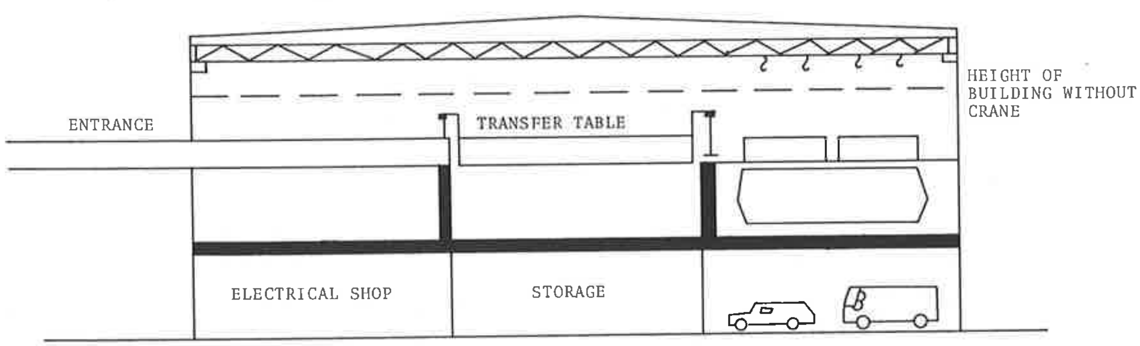


FIGURE 4-55. ERLANGEN MAINTENANCE FACILITY

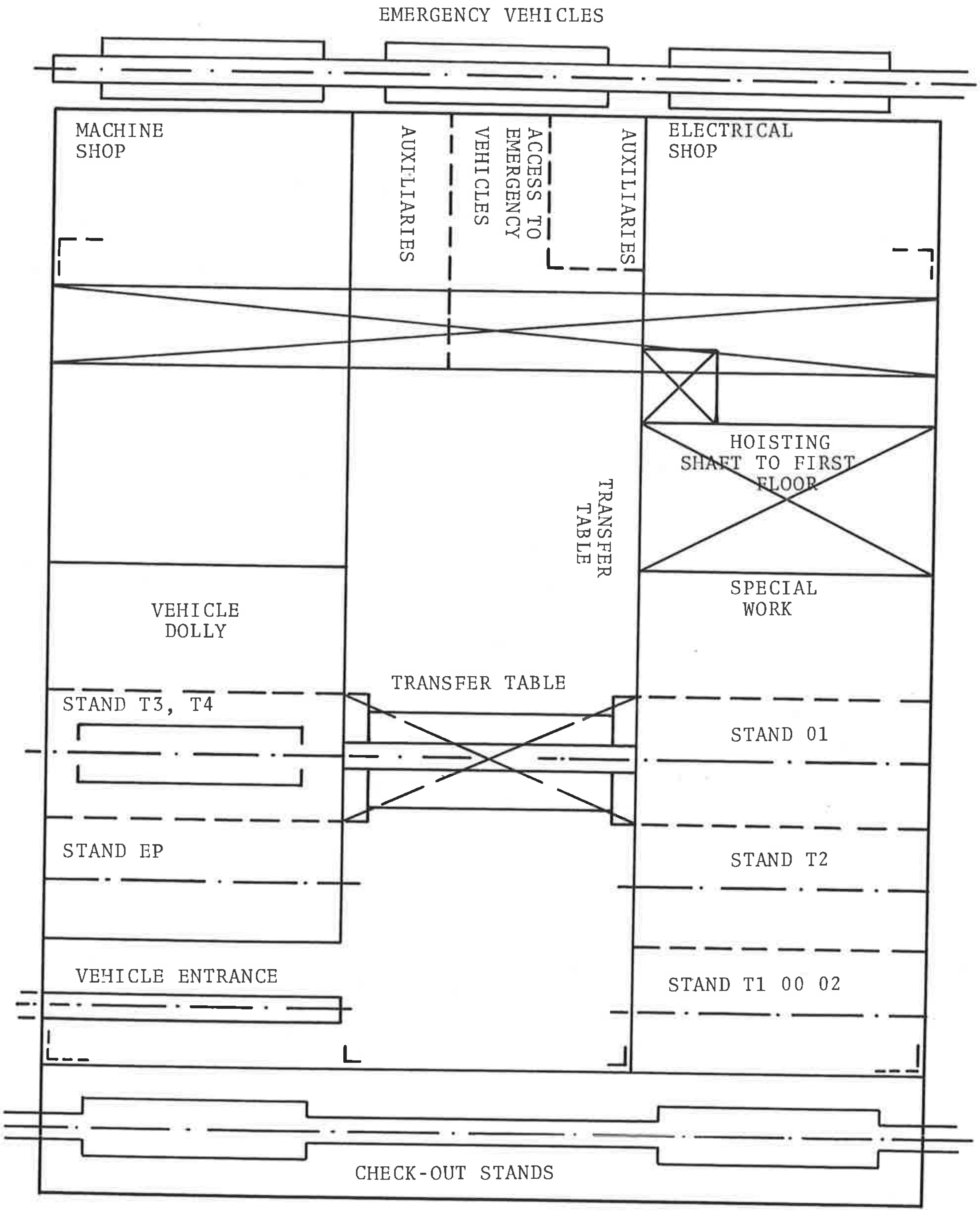


FIGURE 4-56. ERLANGEN MAINTENANCE FACILITY (SECOND FLOOR)

A work stand located about 3.4 m above the ground floor is located near the guideway support. This stand is slotted, so that the running gear is above the slot and the vehicle suspension passes through it. The car itself is accessible from the ground floor. After being checked out, the vehicle continues traveling in the same direction over the connecting guideway supports and leaves the building; no repairs are carried out. The vehicle then travels over a separate guideway support to the shop. The work stands are located opposite one another. The vehicle moves from one to another over a transfer table which is designed as an open guideway support able to move laterally.

Guideway Maintenance

In contrast with the readily accessible components of the vehicles, equipment parts that are located inside the box girder guideway supports, with slots in the bottom, are less easy to reach. Except for the adjustable ramps in the switches, other parts of the guideway equipment such as power rails, signal sensors, etc., require relatively little maintenance and repair. The power rails need to be replaced only once every 10 years in the least favorable case. No measurable wear was found at the test facility after the first 100,000 km of running.

The 400 Bero and Hall signal sensors at the test facility were installed in the spring of 1979, and have only failed once.

Installation of an unmanned vehicle equipped with television cameras is planned for inspecting these parts; this vehicle would travel inside the guideway and examine the equipment optically and electrically.

The guideway support is dimensioned so that engineers can carry out the replacement tasks. At the Erlangen Test Facility, the guideway is accessible through manholes constructed in the top of the guideway, one at each support, approximately 37 m apart. The internal guideway supports are also accessible through openings in the switches.

In addition, a manned emergency vehicle has been developed, so far specifically for the test facility, from which work can be carried out inside the guideway supports (Figure 4-57). Similar vehicles will be provided for larger scale installations.

Experience at the test facility has shown that abrasion of the carbon brushes, power rails, and the wheels in connection with moisture on the guideway can build up a slippery coating. To counteract this, materials with low abrasion will be used from now on. In addition, the guideway is cleaned on the inside. A vehicle with provision for automatic internal cleaning of the support is currently being developed.

Station Components

Thus far, a process has been developed for the maintenance and repair of components at the stations; it was developed within the framework of a planned installation for Berlin.

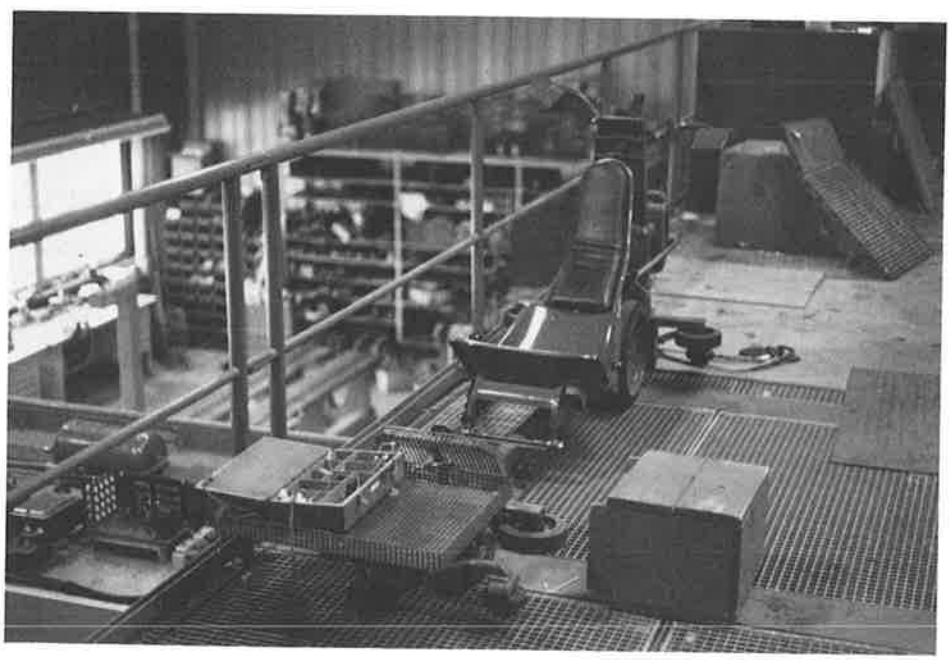


FIGURE 4-57. VEHICLE USED FOR INSPECTION AND MAINTENANCE OF BEAM INTERIOR

Equipment located at the stations such as computers, safety switching equipment, docking equipment, door-control, and passenger-handling equipment, i.e., automatic ticket-selling machinery and route indicators can be turned on or off remotely by operating personnel at the control center. In addition, these devices can report their operating status to the control center: ON, OFF, or DEFECTIVE.

Any fault reports which come in are passed on by the operating personnel to the maintenance department for correction. The maintenance personnel have a central switchboard at the station from which the operating status or fault reports of the individual devices can be ascertained.

The individual devices are largely constructed as plug-in units. By changing the plug-in PC boards, the maintenance personnel can rapidly pinpoint the location of the defect. The safety switching system is designed to detect its own malfuctions. (See Section 4.5.2.3.)

In addition to unscheduled maintenance when needed, the units are also given regular preventive maintenance. Such maintenance involves cleaning the equipment, replacing air filters and ventilating fans, and replacement of circuit-breakers or limit switches according to a predetermined schedule. Preventative maintenance favors not only safety but also availability of the operational guidance system.

Although the parts of the equipment which are located in the guideway are less accessible because of the closed design (by comparison with the vehicle components) there probably will be fewer maintenance and repair costs since none of the parts move, execpt for the switch ramps. The power rails are characterized by low wear and according to the current state-of-the-art, should not have to be replaced more than every 10 years. Thus far, there has been only one failure among the signal sensors at the test facility.

As in the case of the vehicles themselves, the stations have had a system designed for rapid fault-recognition and elimination. The possibility of being able to recognize and correct defects quickly favors the availability of station components, especially control elements, as does preventive maintenance. Preventive maintenance additionally reduces the probability of situations that affect operation as a result of equipment failures.

4.7.4 Auxiliary and Rescue Equipment

In the event that a vehicle is stalled out on the line, provision is made to stop the following vehicles by a signal from the guidance system to the stations. This prevents the vehicles from becoming backed-up out on the line.

One design provides for pushing or towing the stalled vehicle to the extent that it is moveable. This can be accomplished either by using the following vehicle (Figure 4-58) or by using a special work vehicle.

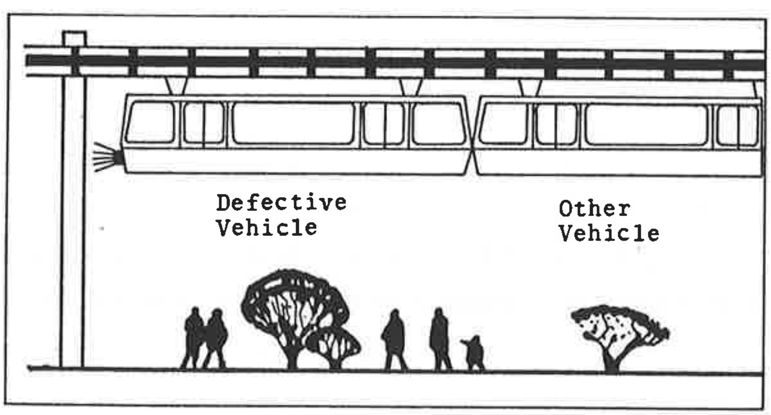


FIGURE 4-58. MOVING A DEFECTIVE VEHICLE

However, it is not possible for the operating vehicle following the disabled vehicle to approach the disabled vehicle automatically, since the safety system would trigger emergency brake application once the safety interval had been exceeded. The defective vehicle is therefore first reported to the operating guidance system; the operating personnel can then shut off the safety system in the appropriate section of the line. The following vehicle can then be moved up to the defective vehicle (with the operating personnel taking responsibility for safety) and coupled to it. It is then controlled manually using a portable control panel. After coupling is complete, the appropriate safety switching system, etc., is turned on again to protect the further travel of the helper train.

With operating instructions being supplied to and from the computer system at the control level, the helper train is then driven at reduced speed to the next station where the disabled vehicle is removed from service.

When a special vehicle is being used for pushing or towing, the latter is also controlled. The defective car can be repaired on the spot or made moveable by this auxiliary vehicle. Such special vehicles are equipped, as a rule, with a drive, e.g., diesel electric drive, which is independent of the system.

The coupling part for two vehicles at the test facility is now being built and will be delivered and tested in 1980-1981. The couplings are heatable for use in winter and links the control circuits and the mechanical parts.

If it is necessary to rescue passengers from a stopped vehicle, it can be done by using special vehicles belonging to the system or auxiliary ground vehicles or a cloth tube mounted in the floor of the vehicle to permit the passengers to escape. Provision is also made for providing a safety area in accordance with Bo-Strab (escape route) for lines in tunnels.

An emergency vehicle designed to operate on the system is not yet running at the Erlangen Test Facility. Such a vehicle would be equipped with extendable catwalks, fitted with railings, to rescue the passengers (Figure 4-59).

Doors must be openable from outside in order to transfer the passengers. An appropriate handle for this purpose is provided and is accessible only to operating personnel.

Ground emergency vehicles are equipped with hydraulic lifts (Figure 4-60).

To avoid serious emergencies resulting from fire, non-flammable materials of low toxicity are used in the cars. This is intended to provide sufficient time for a disabled vehicle to travel to the next station so that passengers may be evacuated to safety. If this is not possible, the vehicles are equipped with an elastic tube to permit the passengers to escape. At the Erlangen Test Facility, the rescue tube has been installed in all of the vehicles (Figure 4-61). After the passengers have used

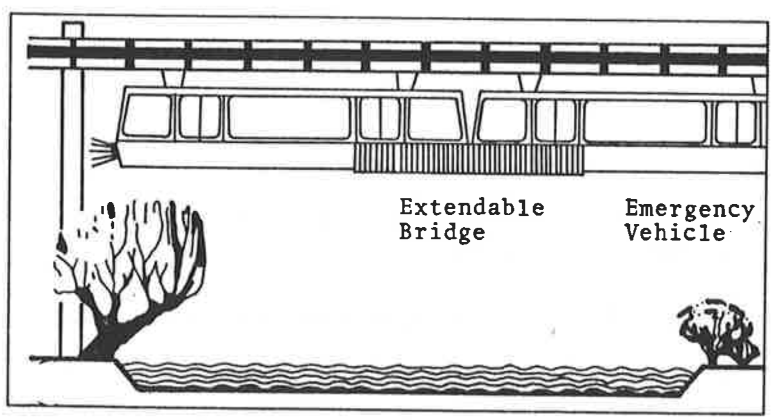
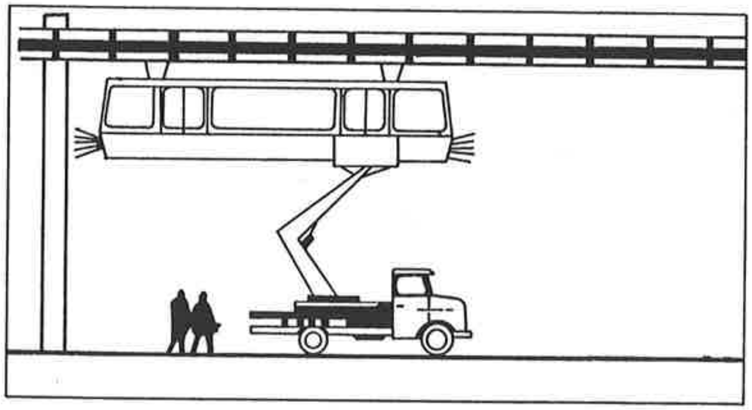
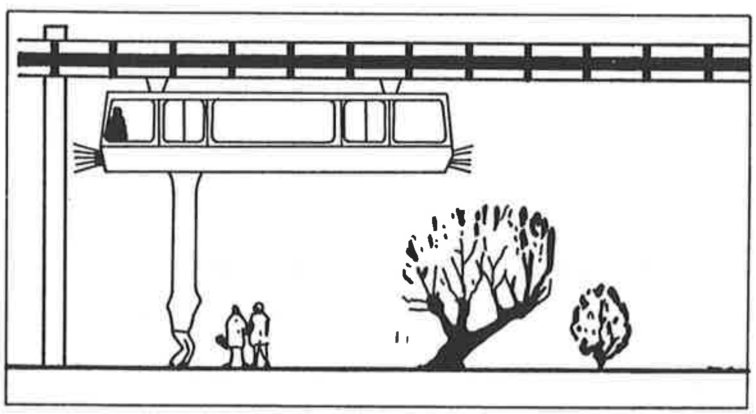


FIGURE 4-59. EMERGENCY VEHICLE WITH EXTENDABLE CATWALK



Emergency Vehicle Fitted with Cherry-Picker Basket

FIGURE 4-60. EMERGENCY VEHICLE OPERATING FROM THE GROUND



Rescue Tube

FIGURE 4-61. EMERGENCY EXIT

the 2-way communication system to request that the lock on the hatch be released by the control center, the hatch in the floor can be opened manually.

After the hatch has been raised, the elastic tube, stored in the cabin floor, falls down out of the vehicle. Upon raising the hatch cover, instructions on use of the elastic tube, with pictures and symbols showing how to leave the car at once are revealed. The passenger leaves the car through the tube in the floor. The elasticity of the tube ensures that the passenger reaches the ground at reduced velocity. The rescue tube has demonstrated its functioning ability in tests conducted at heights as great as 20 m. (Rescue tubes of this kind are also used by the fire department.) Consideration has been given to making the rescue tube with a variable length so that it can be shortened to the necessary length in emergencies.

4.8 THEORETICAL CAPACITY

The capacity of a perfectly operating H-Bahn network, with a fixed vehicle and/or train size, depends upon the capacities of the following elements:

- line (including switches)
- stations
- turn-arounds

The minimum operating headway on a line is determined by the element with the lowest throughput or, when several routes operate jointly over the same line, by the load imposed on that system element by vehicles operating on other lines.

The system elements with the lowest throughputs are generally the on-line stations. On the basis of time required for braking, loading, and unloading and acceleration to line speed, a normal operating headway of 50 seconds is possible with normal station dwell periods. In the case of operation over a section of beam, common to two lines or unusual numbers of passengers, the section can be a performance restriction, and must be studied in detail. This can be accomplished (for example) within the framework of a simulation of the entire network (Section 4.10). The criteria which are critical to the capacity of the individual components are discussed in the following paragraphs.

Capacity of the Line

The operating concept designed by the manufacturer plans for the vehicles to operate at a scheduled operating top speed V_{line} of 13.9 m/sec (30 mph). At this speed, the minimum operating headway on the line is about 10.5 seconds, corresponding to 12 small blocks in the safety system, each being 12 m long, for a total of 144 m. This vehicle spacing includes the operating times for normal line switches. This vehicle frequency must be taken into account, for example, when several routes operate over the same section of line.

Capacity of Stations

In regular service, the vehicles generally travel according to a fixed schedule. The stations are designed as on-line stations; therefore, stops at the stations require dwell times which reduce the capacity of the line.

The shortest possible vehicle spacing which determines the capacity of a line is composed of the time lost at stations Δt_V, which is constant with zero-fault operation, and the passenger exchange time at the stations which see the heaviest use, Δt_{max}.

The time lost at stations using the example of a train composed of three Type 3/3 vehicles (total length approximately 36 m, capacity of 69 persons per vehicle (24 seated and 45 standees), calculated at 4 persons/m^2, see page 4-132 (Figure 4-62). The type-dependent times are marked +. The time lost at stations for zero-fault operation is governed by the boundary condition that the leading vehicle has left the stop (stop clearing point = S_F) when the following vehicle reaches brake application point S_{Bw}. After passing point S_{Brl}, the vehicle is braked to a stop

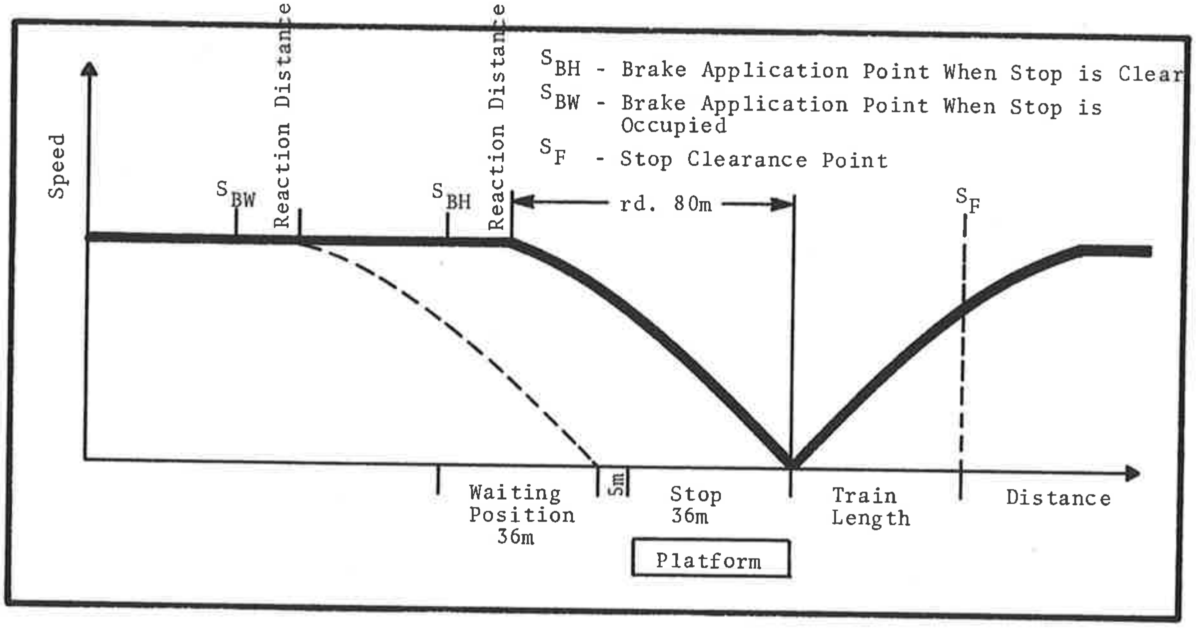


FIGURE 4-62. CRITICAL PARAMETERS DETERMINING STATION CAPACITY

at the station with a deceleration $b_{average} = -1\ m/sec^2$. If the train reaches the line marker S_{Bw} before the previous train has left the station, its speed will be reduced, possibly to zero, so that the vehicle stops at a "waiting point" 5 m outside the station until the preceding train has cleared the station.

The time lost at stations (without "docking") is based on the assumption that the vehicle is braked to a stop at the station as follows:

Travel time between markers S_{BW} and S_{BH} $\frac{41\ m}{13.9\ m/sec}$	= 3.0 sec (+)
Brake reaction time	= 1.0 sec
Service braking time	= 11.5 sec
Positioning time	= 2.0 sec

Time required to open and close doors = 4.0 sec

Door check and starting time = 2.0 sec

Time required to clear the station = 8.0 sec (+)

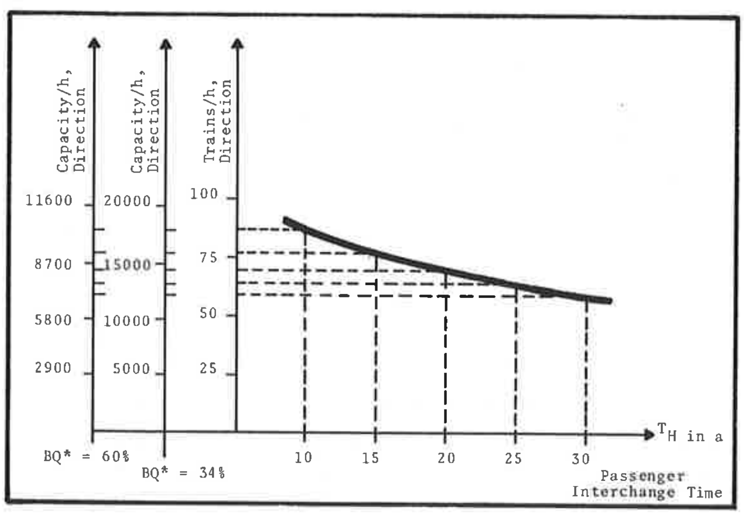
Total time lost at the station t_v = 31.5 sec

Application of mechanical clamps to prevent vehicle sway is included in the positioning time. Thus, the shortest permissible train interval for continuous operation on the line will be

$$\Delta t_{min} = 31.5 \text{ sec} + t_{Hmax},$$

assuming operation of a train composed of three Type 3/3 cars.

Figure 4-63 shows the maximum vehicle capacity (F_{trains}/h, direction) and the maximum capacity (No. of passengers/h,



BQ* = Seats/Vehicle Capacity

*Note: This ratio is used frequently herein as a measure of the quality of service offered to the passengers.

Vehicle Type 3/3, V_{max} = 50 km/h

FIGURE 4-63. H-BAHN STATION CAPACITY

direction) and therefore the line capacity which is a function of the passenger interchange time for a given type of vehicle.

Measurement of passenger interchange times performed at the test facility using passengers familiar with the system (corresponding to peak travel times) yielded the following figures for a Type 2/2 vehicle, per person and per vehicle door.

Exiting per door	Seconds	Entering per door	Seconds
1st to 5th	0.8	1st to 5th	0.6
6th to 11th	0.7	6th to 9th	0.7
12th to 16th	0.6	10th to 14th	0.8
17th to 20th	0.5	15th to 17th	0.9
		18th to 20th	1.0

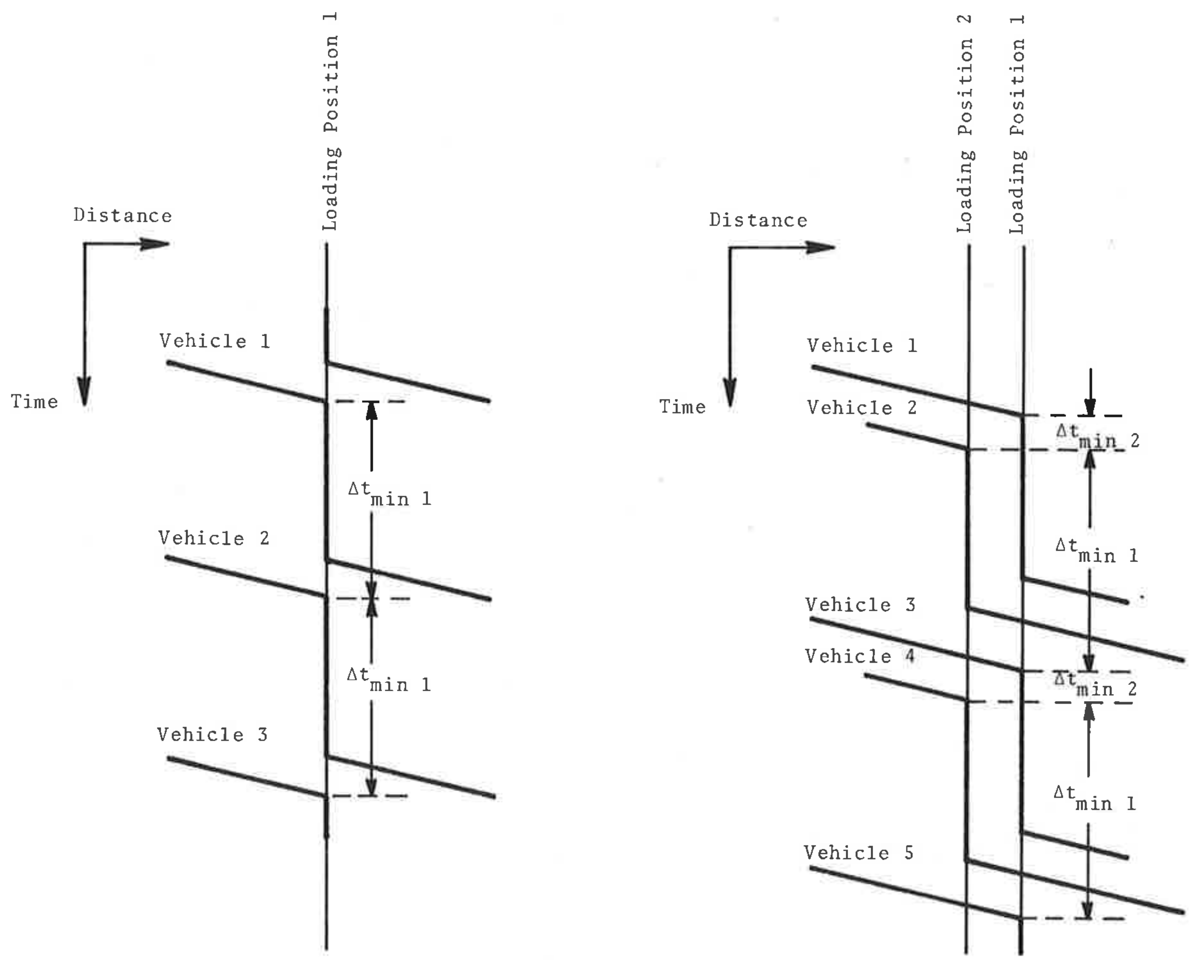
Therefore, within 20 seconds, 16 passengers can leave through each door and 16 can enter. Based on the Type 3/3 vehicle, this means that 60 percent of all the passengers can enter and leave. This is a realistic design basis.

The stopping capacity for 3-car trains of Type 3/3 vehicles is 70 trains per hour in each direction, for a time of 20 seconds spent at the stop, as indicated by Figure 4-63. The train intervals roughly correspond to the 50 seconds given above. If all 69 seats and standee spaces are utilized (BQ = 34%), the capacity is about 4,500 passengers per hour per direction (maximum).

Because of the time required to handle the vehicles and passengers, the stations are the components with the lowest capacity; because of this the train intervals generally will be no shorter than 50 seconds approximately.

The train intervals, by comparison with the minimum vehicle spacing on the line of approximately 10 seconds, offers a reserve factor of 80 percent and about 40 percent for turn arounds. The station capacity can be doubled if the on-line stations are replaced by "double on-line stations" for a given vehicle size and number of stops. However, double on-line stations take up much more space and are more expensive. Such stations make sense when one line section is used jointly by several routes, and there are only a few stations on the jointly used section.

Another way of increasing the capacity of on-line stations is to increase the number of loading positions for vehicles. In Figure 4-64, a simplified diagram shows operational changes at two stations "a" and "b."



Distance-Time Diagram.
Station "a." One Loading Position

Distance-Time Diagram.
Station "b." Two Loading Positions

FIGURE 4-64. CHANGES IN STATION OPERATION

Station "a" has one loading position, and station "b" has two. Vehicle 2 can enter station "a" only when vehicle 1 has left the loading position. The vehicle capacity is two vehicles every 2 x Δt_{min}.

In station "b," vehicle 1 goes to loading position 1, and vehicle 2 goes to loading position 2 after time Δt_{min2}. At time $t = \Delta t_{min1} + \Delta t_{min2}$, the vehicle leaves loading position 2, so that vehicle 3 can go to loading position 1. In this case, the vehicle capacity is two vehicles per $t = \Delta t_{min1} + \Delta t_{min2}$. In contrast with a station design with one vehicle loading position, the vehicle capacity increases as Δt_{min2} becomes smaller than Δt_{min1}. The value of Δt_{min2} has not yet been established by the manufacturers. They are waiting for the results of tests being performed at the H-Bahn Test Facility in Erlangen.

<u>Capacity of Turn-Arounds or End Loops</u>

The capacity of turn-arounds, like that of stops, is described by the shortest possible train interval.

The boundary conditions for zero-fault operation is that the following train may not pass line marker S_{BW} before the train ahead has reached line marker S_W. Otherwise, the following train is braked and held at the waiting position outside the switch area (Figure 4-65).

The time lost t_{vk} is as follows:

Time to travel between line markers	=	6.0 sec (+)
S_{BW} and S_{BH} $\frac{82\ m}{13.9\ m/sec}$	=	1.6 sec
Brake reaction time	=	1.0 sec
Service braking time	=	11.5 sec
Changeover time and start signal received for travel in reverse	=	2 sec

Time to clear the stop and switch area = 12.5 sec (+)

Time loss at turn-around totals t_{vk} = 33.0 sec.

Therefore, the shortest possible train interval for continuous operation with turn-around is:

$$\Delta t_{Kmin} = 33 \text{ sec.}$$

Therefore it is shorter than the vehicle interval established by the station, and does not result in further limitations of capacity.

4.9 NETWORK CONFIGURATION

The primary factors governing network configuration are the traffic demand and the forms of operation to be used. Typical

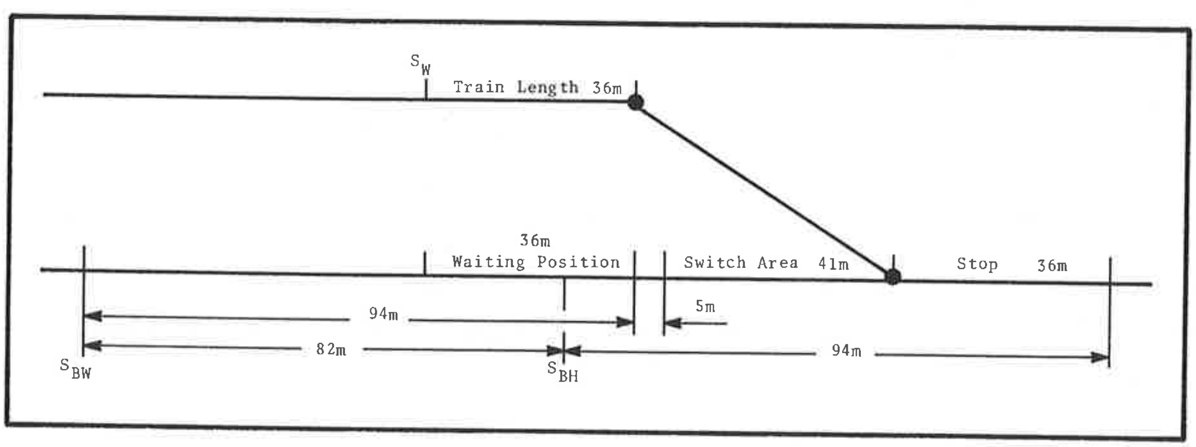


FIGURE 4-65. H-BAHN: CRITICAL PARAMETERS FOR CAPACITY OF A TURN-AROUND FACILITY FOR A TRAIN OF THREE TYPE 3/3 VEHICLES

tasks to be performed by an H-Bahn system include the following:

- total coverage for medium-sized cities;
- use as a feeder system to existing transit systems;
- serving satellite communities and connecting them to the inner-city transit system.

The type of operation used by H-Bahn is a line operation according to a fixed schedule with on-line stations. The network is generally laid out to fit this type of operation. It is also possible to have demand operation in evening hours; however, this type of operation has no effect upon the network design.

4.9.1 Network Elements

In laying out an H-Bahn network, almost all of the elements of conventional network models are used.

A standard design of fixed guideway support is used. However, the supports can be made shorter as in the case of suspended vehicles, to bring them down to ground level or into a tunnel. Critical factors to be considered before introducing the guideway into existing built-up areas are routing constraints such as space requirements, maximum incline and maximum descent, and curve radii. See Section 4.2.

For line junctions or crossings, crossovers have been proposed within the framework of the Erlangen Feasibility Study. However, network expansions are also possible, as provided in the planning study for Hamburg-Farmsen. Figure 4-66 shows a line divergence by using crossover as well as network extension.

In contrast with a crossover, network expansion offers additional turn-around facilities for the connecting lines. However, more construction materials and space are required. The transitional arches required for the switches mean that with a layout having R_{min} = 40 m, the minimum loop diameter will be 100-120 m. In congested built-up areas, the loop might have to

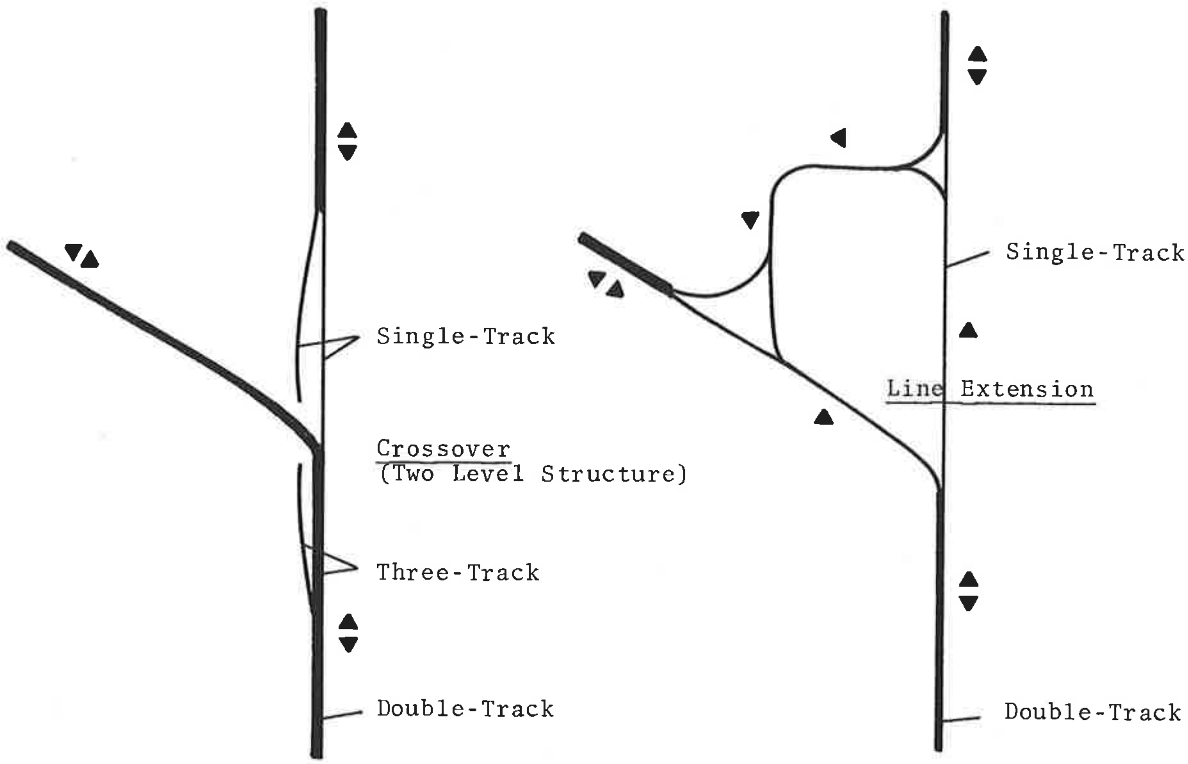


FIGURE 4-66. LINE DIVERGENCE USING CROSSOVER AND NETWORK EXTENSION

go around a block of buildings. As the network is expanded, several routes might operate jointly on one section of line; therefore, network expansion is critical to capacity and hence the dimensioning of vehicle frequency for the total line operation.

Level line crossings and junctions can also be made with the aid of special guideway supports (for crossing angles up to 20°), since it is only in this range that the gaps produced by the slot in the guideway can be bridged (Figure 4-67).

Questions relating to control, safety, capacity, and cost must be studied before such level crossings and switches can be utilized.

The stations on the H-Bahn network should provide adequate coverage to the areas to be served. One way of evaluating this is to consider the maximum line distance to the next station for a passenger is 200-300 m. This means that the average station spacing is about 500-600 m.

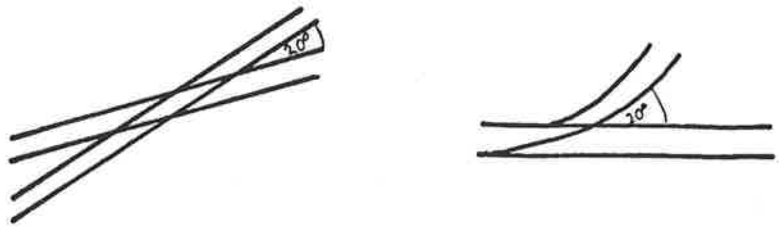


FIGURE 4-67. CROSSING AT-GRADE AND SWITCH

4.9.2 Network Designs

The H-Bahn network can have a radial or axial network design, corresponding to the configurations of the main traffic arteries of the city (Figure 4-68).

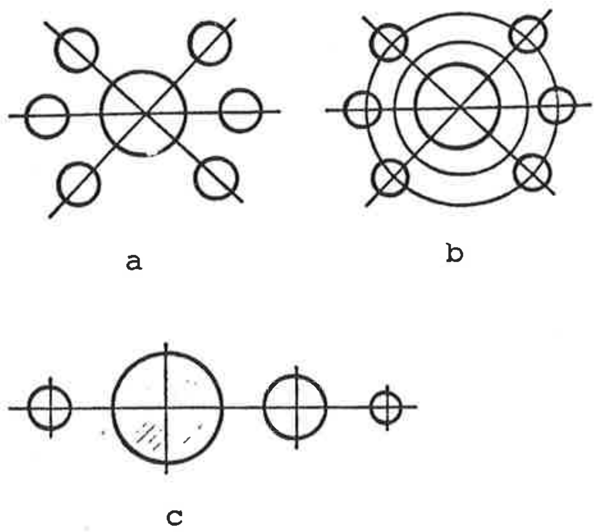
Taking into account the types of buildings located in the inner-city areas, which are usually densely developed, these areas can be served by either a ring, tangential, or diametrical design (Figure 4-69).

By using routes which run separately, the likelihood that the total network will be disabled is reduced, and the flexibility of various types of operation on the individual lines is assured.

When there is limited space available, lines with heavy service must be superimposed; it may be necessary to run main routes over a single section (Figure 4-70).

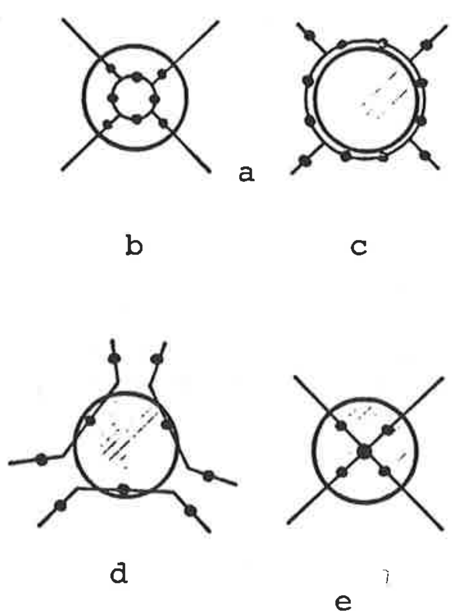
At the end of the line, a service and reversing loop or a cutback or dead end station can be provided (Figure 4-71).

Transfer facilities will be provided at line interchanges. In designing a network, therefore, it is important to ensure that the passengers can reach their destinations either directly or by changing cars only once. By using a triangular network structure, any stop can be reached by transferring once (Figure 4-72).



a - radial network; b - radial network with rings; c - axial network.

FIGURE 4-68. NETWORK STRUCTURES

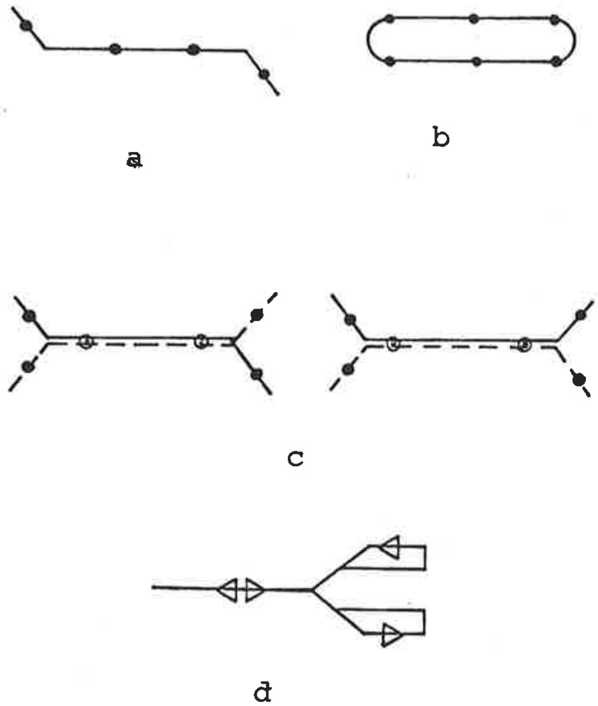


KEY:

a - service ring; b - inner; c - outer; d - tangential service;

e - diametral service with central interchange point.

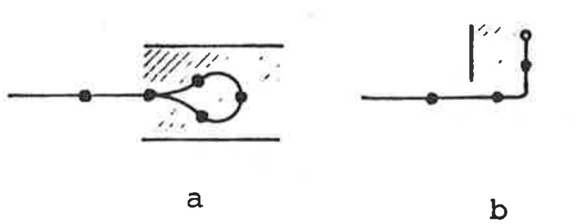
FIGURE 4-69. WAYS OF SERVING INNER CITIES



KEY:

a - separate line; b - ring line; c - overlapping lines; d- split line.

FIGURE 4-70. LINE DESIGNS



KEY:

a - service loop; b - stub end with reversing loop

FIGURE 4-71. DESIGN OF TERMINALS

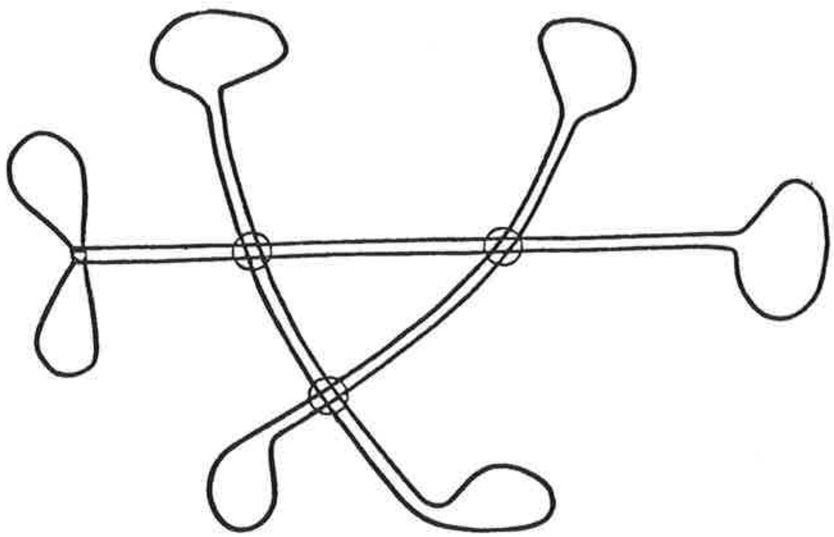


FIGURE 4-72. NETWORK WITH TRIANGULAR STRUCTURE

For maintenance and repair of vehicles, as well as for vehicle cleaning, it is necessary to have a central service facility with lines connected to it with the shortest possible service trackage. The shop buildings can also be used to store vehicles, in conjunction with suitable storage tracks at the ends of the lines.

If a demand type of operation is used, it may be necessary to locate additional stations on the lines to meet passenger demands quickly and to minimize passenger wait time.

4.9.3 Erlangen Network Design

Within the scope of the Erlangen Feasibility Study, an H-Bahn system with bus feeder lines was studied.

Preliminary studies yielded a radial axial network as the basic design for the Erlangen H-Bahn network. After a gradual process of improvement and evaluation, the proposed network now consists of three main lines which will operate largely independently of one another. Lines B and C merge in the inner city (Figure 4-73). Line A is tunneled beneath the railroad station and the city center.

Any of the 50 stations on the 30.4 km network can be reached by transferring once. (Turn-arounds are provided on all the lines reducing travel time during peak hours.)

4.9.4 Evaluation and Selection of Network Alternatives

Within the framework of an application study for an H-Bahn system, several network alternatives are generated by an extensive evaluation carried out to determine the best configuration. Evaluation of improvements are carried out in accordance with traffic, operations, economics, and urban design considerations. Evaluation can rely, for example, on a listing of evaluation criteria, cost-effectiveness considerations (to determine the level of H-Bahn service to be provided to outlying areas) and

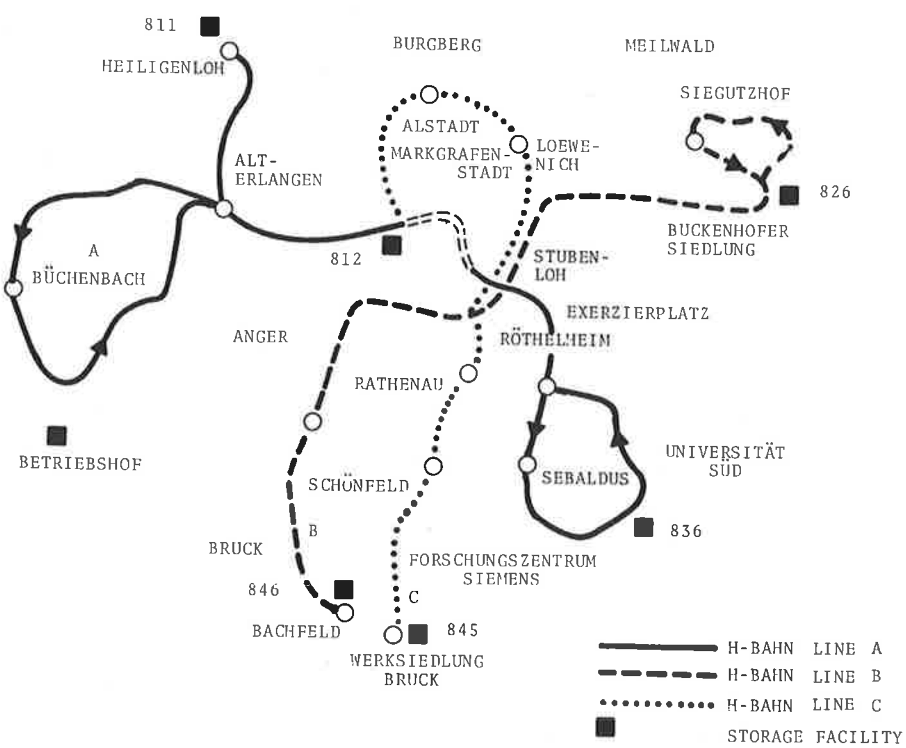


FIGURE 4-73. ERLANGEN NETWORK

dynamic simulation (Section 4.10). Detailed studies in these directions have already been undertaken within the framework of feasibility studies. The Erlangen H-Bahn Feasibility Study involved, for example, a gradual evaluation, selection, and improvement of network alternatives.

During the first stage, the theoretical possibilities for line operation and connection were established. On the basis of these studies, alternative possibilities were proposed in the second stage, covering the service demand on the main lines. These possibilities were developed further in the third stage, and one of the alternatives was subjected to a rough cost-effectiveness analysis.

The following can be used to evaluate network alternatives:

- Service criteria (line density, number of stops, etc.)
- Operating criteria (average distance travelled, etc.) and
- Network loading criteria (average loads on the line or at specific stops, etc.)

While the service criteria are independent of the anticipated traffic demand, the two other groups of criteria provide information on the anticipated traffic relationships. The basis for this is the adjustment of projected flows to the corresponding network alternatives.

4.10 DYNAMIC SIMULATION

Dynamic simulation of H-Bahn operation has been carried out for the original design of point-to-point demand travel and for line operation according to fixed schedules.

Using the concept of point-to-point demand operation, in addition to simulating operations on the entire network, a number of individual tests were conducted on network elements such as junctions and stations. Special attention was given to studying vehicle flow merging at junctions.

Network operation was simulated for the cities of Erlangen and Hamburg-Farmsen. In Erlangen, H-Bahn was viewed as an urban transit system in a medium-sized city; in Farmsen it was viewed as a feeder to the mass transit system of a large city. Studies were conducted to determine the average waiting time, the average operating speed, and the average car loading. The number of cars varied and the effects of a limited number of intermediate stops by comparison with point-to-point travel without stops was observed.

The simulations showed that the idea of point-to-point demand operation with constant line speed is practical using the operating guidance technology and switch control that have already been developed.

The results of these simulations lost their value when a transition was made to the concept of line operation according to a fixed schedule. In that mode the line speed becomes variable.

For this design, the Studiengesellschaft Nahverkehr (Urban Transit Study Association) carried out a dynamic simulation of an H-Bahn network for the city of Karlsruhe (263,000 population) within the framework of the "Study of Operation in Urban Public Transit Networks."

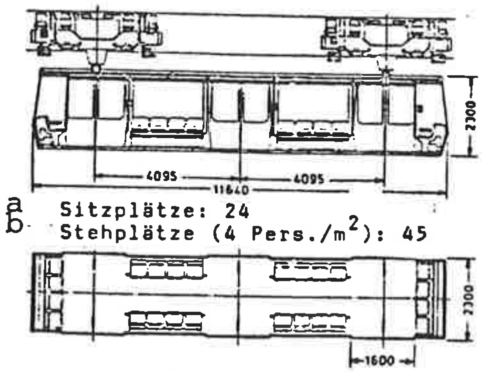
This study dealt with an H-Bahn network having a route 45.2 km long and a line 52.1 km long with a total of 67 stops. For the type of service that would be provided, there would be an average of 168,000 riders and 875,000 person-kilometers per day; in other words, 61.3 million riders would travel 319.7 million person-kilometers per year. Simulations were run for a basic design and six variations (Table 4-7 and Figure 4-74).

In basic design, as well as in the other operational variations, the results of the operational simulation indicated stable operating behavior as far as stop time variations and increased ridership were concerned.

TABLE 4-7. CHARACTERISTICS OF STUDY ALTERNATIVES

TEST VERSIONS	TEST SUBJECT	PARAMETERS					
	For variations see values enclosed in squares	Vehicle type	Maximum speed	Ride quality in dimensioning cross section (BQ value)[1] for 10-min. peaks of: Peak travel time in %	Off-Peak travel time in %	Eve. travel time in %	Increase in traffic as % of basic concept
Basic concept	Operational development in accordance with manufacturer's design	3/3	50	60	90	100	100
Type 1 Type 2	Changes in operational dimensioning	3/3 3/3	50 50	[50] [40]	90	100	100
Type 3 Type 4	Changes in maximum line speed	3/3 3/3	[60] [40]	60 60	90	100	100
Type 5	Change in ratio between seats and standees	[3/3 KA]	50	60	90	100	100
Type 6	Capacity	3/3	50	[35]	-	-	[135]

[1] $BQ = \frac{\text{available seats}}{\text{passenger load}}$



Data (Planning Case Karlsruhe, vehicle Type 3/3):
L/W/H = 11.9 m/2.3 m/2.3 m (car),
69 passengers (24 seats, 45 standees),
Weight (empty) 7420 kg,
Rated drive power 68 kW,
Top speed 60 km/h,
Maximum acceleration 1.4 m/sec^2,
Service braking 1.25 m/sec^2,
Maximum grade 7.5%

KEY:

a - Seats: 24; b - Standees (4 persons/m^2) 45

FIGURE 4-74. TYPE 3/3 VEHICLE

In Variants 1 and 2, BQ, the service quality (number of seats divided by the number of passengers) was reduced. In other words, more passengers were carried for the same number of seats. By contrast with the basic design, this simulation showed an increase in the intervals and a decrease in the passenger demand.

Also in contrast, Variants 3 and 4 varied the maximum speed. The simulation showed that as the speed increases, vehicle demand drops. At the same time, vehicle power consumption increases. The cost of the increased energy is more than compensated by reduced capital and maintenance costs (resulting from higher speed, hence fewer vehicles).

The use of a fictional vehicle was employed in Variant 5 in order to study the effect of service quality upon cost and attractiveness. This vehicle known as 3/3 KA, has 32 seats and room for 30 standees by comparison with 24 seats and room for 45 standees in the Type 3/3 vehicle. The simulation showed that the vehicle demand and the annual capacity decreased.

In Variant 6, a 35 percent traffic increase was compared with the weekday average and evaluated in terms of its effect upon operation. The simulation results showed that this increase in traffic could be handled without changing the schedules. However, this increase meant that the allotted space for seated passengers and standees was overloaded (BQ or service quality was 34 percent).

Conclusions:

Conversion of point-to-point demand operation with synchronous operating speed to line operation according to a fixed schedule assumes an extensive conventional operating concept.

In planning an H-Bahn, dynamic simulations must be carried out in order to dimension the stations, vehicle size and number, operating reserve, scheduling, and so on. In addition, the effects of malfunctions that might occur should also be simulated in order to get some information about suitable countermeasures (network changes and/or reactions). Dynamic simulation could also be used to answer the question of whether, in a given application, it makes sense during evening hours to use line-demand operation (vehicles only on demand), or whether it would be better during evening hours to continue line operation according to a fixed schedule, with vehicles coming at appropriately longer intervals, for example, one train every 10 minutes.

4.11 OPERATION UNDER ADVERSE WEATHER CONDITIONS

In severe winter weather, H-Bahn has fewer operational problems than most other AGT designs. The major advantage is the use of a slotted box beam to house the bogie and associated equipment. Inside the beam, switch components, power and signal rails, and communications equipment are sheltered from the ill effects of snow, ice and wind. Snow and ice accumulations are limited to the tops of track beams which have no equipment critical to system operation.

Operational experience has been gained at the test track in Erlangen. In the harsh winter of 1978-1979, with extreme cold periods and heavy snow accumulations, the operation of the test facility continued as usual. The protection afforded by the closed track beam had a positive effect on performance parameters such as dependability, availability and availabile traction for propulsion and braking.

The life-cycle costs of components with the beam would also be expected to be lower than for similar components on a channel guideway system (e.g., susceptibility to corrosion). Snow and ice removal from the guideway is not necessary; therefore, its operating costs should be lower than those for other AGT systems. Guideway switches are free of ice and snow and their operation is unaffected.

Snow accumulation on vehicle roofs does not create problems for the operation of brake resistors, but air compressors and other vehicle roof-borne equipment might be affected by adverse weather. Drainage ports are provided to prevent rain from accumulating, but snow and ice are free to cover these vehicle components. Although no problems have been experienced to date, Siemens indicated a cover could be fabricated if operational problems occur.

The box beam, as mentioned earlier, is well protected against the direct influences of inclement weather. In low temperatures, however, condensation can form along the top chord of the beam, and drops onto the running rail where tire filings and power collector fibers can combine with the condensation to form a slippery surface. Siemens and Düwag have, however, chosen new tire and brush materials which reduce shedding, and they are developing a cleaning device which will be used to clear the running surface.

Thermal heating of the beam may produce high temperatures within the beam which may affect the performance of electtical components and hamper manual maintenance efforts of maintenance personnel. The Erlangen test facility is not subject to extreme temperatures from solar heating, but H-Bahn's application in warmer climates where internal beam temperatures might be excessive, may require additional ventilation or insulation.

Wind effects on system operation and structural integrity have been sufficiently considered by Siemens in design and by field testing of carrier beams. The system can tolerate a 125 kg/m^2 force with a live load and twice that amount for the unloaded condition. Some sway will be experienced in vehicle operation at moderately high wind speeds, but its effects will be tempered by the vehicle suspension system.

4.12 FEASIBILITY STUDY FOR H-BAHN AT ERLANGEN

4.12.1 Introduction

In 1974, the city of Erlangen directed a group of transit experts to prepare a feasibility study for an H-Bahn to be built in Erlangen. The task was funded by the Federal Ministry of Research and Technology. On the basis of the study results, and following an intensive discussion by the responsible authorities, the City Council in autumn 1979 approved the construction of an H-Bahn pilot installation.

The background for the study was the anticipated future expansion of the total traffic volume as the result of an increasing city population, together with increasing travel. However, the increase in passenger-car use will result in a further decrease of the services provided by urban public transit. Approximately 80 percent of total automobile traffic, if the quality of current urban transit modes were to remain at its present level, will develop in the form of individual, private car use on the streets. This would result in further deterioration of an already unsatisfactory traffic situation and would have a deleterious effect upon the quality of life, especially in the inner city area.

The increase in the traffic share of public transit which would be expected from the construction of an H-Bahn system could constitute an important contribution to the improvement of these conditions.

The crux of the study was to plan, on a theoretical basis, the implementation of an H-Bahn and to determine the consequences of its construction. With the aid of cost-effectiveness analysis, the costs and social benefits were determined.

In addition, it was decided to study the question of whether a bus system would cost less than an H-Bahn and weather it would be equally useful. For this purpose, a comparative bus system was investigated, which would have the same degree of attractiveness as the H-Bahn.

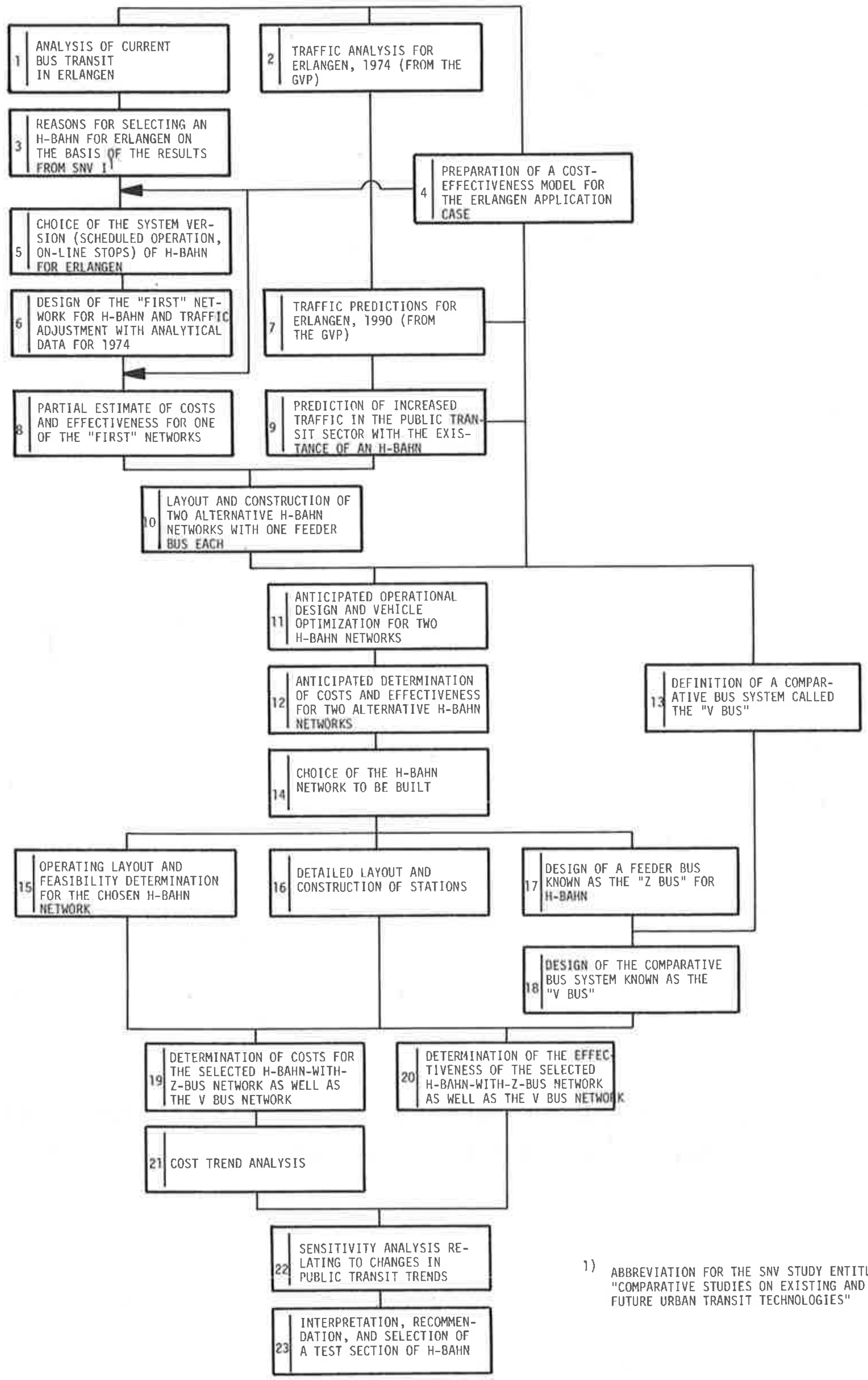
The course of the study is shown schematically in Figure 4-75.

In the following sections, we have presented the results of the study as they apply to selected subject areas. A survey is provided of the Erlangen transit district, the traffic development, the selected H-Bahn network, and the operating design. The results of the investment and cost calculations as well as the effectiveness determinations are discussed. The details of the Erlangen project will be described as well.

4.12.2 Erlangen Transit District

The city of Erlangen is located on the northern boundary of the Nürnberg-Fürth-Erlangen metropolitan area. Approximately 100,000 people live in an area about 77 km^2 (1974). By contrast with the general trend in the Federal Republic of Germany, the population is increasing and this increase is anticipated to reach 10 percent by 1990 bringing the total population to about 110,000 inhabitants. Approximately 68,000 jobs are expected to be available in the urban area in the same year. Moreover, there are approximately 12,500 students at the University of Erlangen.

The focus of activity is located east of the Regnitz River, in the inner-city area, and in the boundary areas which touch on the inner city. Most of the inner-city traffic is concentrated on a few main roads which have correspondingly high traffic levels, and which essentially radiate out from the inner city. Each day 45,000 persons come into Erlangen from the surrounding areas and leave the city at night, while only about 18,000 persons cross the city limits in the opposite direction.



1) ABBREVIATION FOR THE SNV STUDY ENTITLED "COMPARATIVE STUDIES ON EXISTING AND FUTURE URBAN TRANSIT TECHNOLOGIES"

FIGURE 4-75. FEASIBILITY STUDY

The public transit system in Erlangen consists of an inner-city bus system, while the traffic-generating areas located outside the limits are served primarily by regional bus services and the commuter trains of the Deutsche Bundesbahn (DB).

In the feasibility study for Erlangen, it was demonstrated that inner-city traffic could be taken over by H-Bahn in conjunction with a feeder bus system. The H-Bahn urban transit system would connect the focal points of the activity centers to correspond to the main traffic flows and would serve the inner city. The feeder bus system would connect to the H-Bahn system areas located around the boundaries of the city which are not receiving any service now or are receiving only unsatisfactory service. The regional buses and commuter trains of the DB would also be retained in the H-Bahn plan as supplementary systems, particularly commuter service.

4.12.3 Traffic Prognosis

The H-Bahn traffic estimate for 1990 has been prepared. In the target year, a total of about 348,000 trips per workday are predicted for the total traffic level (motorized public and private transit). The results of the traffic prognosis and traffic distribution calculations are summarized in Table 4-8.

If H-Bahn were built, the public transit share of the total daily traffic of 90,400 trips per workday would be 26 percent.

By contrast, if a conventional bus system were retained, like the one currently in operation in Erlangen, there would be only 68,000 public transit trips per day in the target year of 1990. The higher user attractiveness of H-Bahn over a conventional bus means that under the boundary conditions of the traffic prediction, there would be a desirable shift of riding from private cars to public transit.

As a result, the burdens imposed on the city by automobile traffic (as a result of pollutants and noise, for example) can be reduced. Construction of parking spaces for cars not in use could be reduced, and the available sites, of which there are only a limited number in any case, could be put to other uses.

TABLE 4-8. PROJECTED TRAFFIC DISTRIBUTION FOR H-BAHN IN ERLANGEN, 1990

Type	Parameter	Value
Total daily traffic (private cars + public transit)	Trips/day	347,800
Public transit alone	Trips/day %	90,400 26
Inner-city traffic (private cars + public transit)	Trips/day	198,200
Public transit alone	Trips/day %	62,600 32
Incoming traffic (private cars + public transit)	Trips/day	46,200
Public transit alone	Trips/day %	7,900 17
Outgoing traffic (private cars + public transit)	Trips/day	103,400
Public transit alone	Trips/day %	19,900 19

4.12.4 H-Bahn Network and Operating Design

The H-Bahn network which was used as the basis of the cost-effectiveness analysis included a feeder bus network. The basis for laying out the network is discussed in detail in Section 4.9. Because of the problems involved in incorporating the elevated guideway in the historically developed inner city, a radial line about 700 m long will be built in-tunnel in the city center.

Table 4-9 shows important characteristics for the selected H-Bahn network which are pertinent to the Erlangen application.

TABLE 4-9. PARAMETERS OF H-BAHN NETWORK

AREA	Category	Parameter	Value
TRANSIT NETWORK	Track length	Track km	54.3
	Route length in tunnel	Route km Route km	30.4 0.71
	Switches	Each	50
	Stops	Each	50
	Stop density	Number/route km	1.7
	Average station spacing	m	590
TRANSIT INCREASE	Performance	Rides/day	83,900
		10^6 rides/year	26.0
		Passenger km/day	274,200
		10^6 passenger km/ year	85.0
	Average length of ride	Passenger km/ride	3.3
	Average line loading	Passenger km/day, route km Direction	4,510
	Peak hour factor	%	15.3
	Maximum line cross-sectional loading		
	Line A Line B Line C	Persons/h, direction Persons/h, direction Persons/h, direction	3,270 1,590 1,660

On the basis of a vehicle optimization program intended to minimize vehicle costs with predetermined boundary conditions pertaining to operating standards, the Type 2/2 AE vehicle was selected (see Figure 4-76).

This type of vehicle has the following characteristics:

- Seats	20
- Standees (0.25 m^2/person)	36
- Total number of passengers	56
- Car length	9.25 m
- Total length over couplers	10.0 m
- Doors per side	2

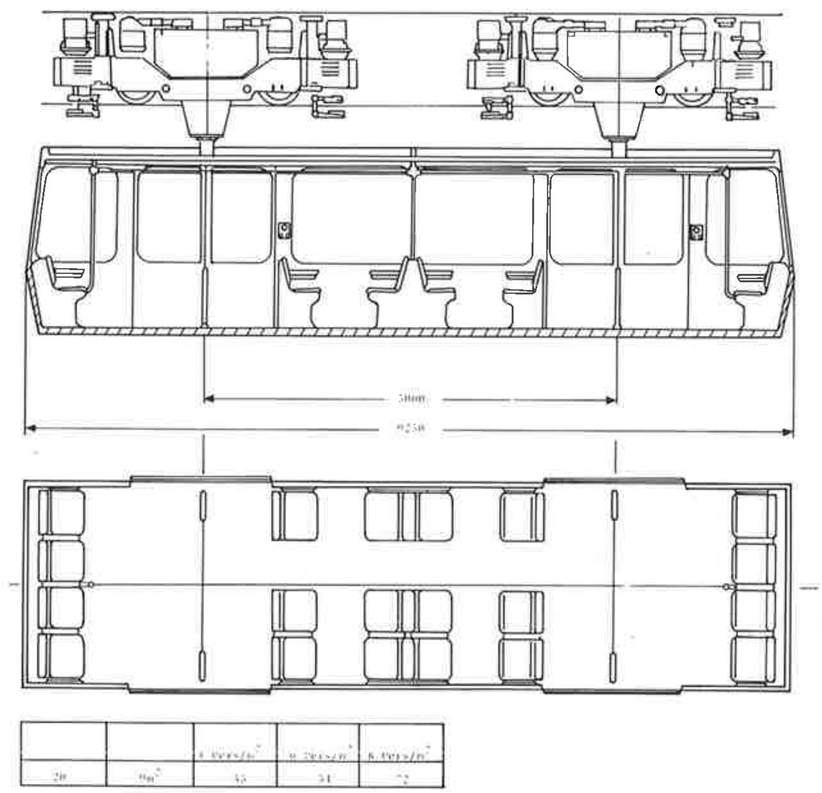


FIGURE 4-76. TYPE 2/2 AE VEHICLE

The operating layout was developed for this type of vehicle. During the peak ten minutes of the peak service hours, all seats and standee spaces are available. Train intervals are between 80 and 100 seconds. Operation will involve using both two-car trains and single units.

Table 4-10 summarizes important data on operating planning.

4.12.5 Cost Results for H-Bahn

The bases for the investment and cost calculations as well as their results are discussed in detail in Section 7.

Building H-Bahn for Erlangen would involve investment of about 431 million DM (1976 price level), and this investment would be spread out over a 3 to 4 year period beginning with detailed planning.

Once operation began with an average ride length of about 3.3 km, depending on the transit mode selected, different specific total costs would result. The specific total costs would vary, at an interest rate of 6 percent between 0.80 DM/trip ($.32) (with funding) and 1.55 DM/trip ($.62) (with completely outside financing.) The operating costs will not be covered. They amount to 0.42 DM/trip ($.17). The percentage of the total costs, with complete outside funding, amounts to about 30 percent (see Table 4-11.)

Effectiveness determinations have shown that the attractiveness of H-Bahn for riders is much greater than can be expected for conventionally designed bus systems. Therefore, we did not compare H-Bahn costs with the costs of the bus system operated in Erlangen within the scope of the study because of the problems involved, of a methodological nature, in comparing urban transit systems with different levels of rider attractiveness. Instead, we attempted to determine whether an "imaginary" comparative bus system with the same level of attractiveness as H-Bahn would show lower

TABLE 4-10. DESIGN PARAMETERS ERLANGEN NETWORK

Parameter	Dimension	Value
Vehicle type	-	2/2 AE
Vehicle capacity	Passengers	56
Seats	Passengers	20
Standees	Passengers	36
Maximum number of vehicles required,	Units	115
From these spare-vehicles (operational, maintenance)	%	8
Average speed on the line, peak hours	km/h	23.7
Vehicle spaces/track km	Spaces/track km	125
Length of operation on work days	h	19
Peak hours	h	4
Off-peak hours	h	15
Late-night operation	h	-
Operating cost	Vehicle-km/day	26,000
	10^6 vehicle-km/year	9.4
Average vehicle performance	Vehicle-km/vehicle, year	81,800
Average vehicle occupancy	%	16.1

TABLE 4-11. ESTIMATED COSTS FOR ERLANGEN H-BAHN (i = 6%, 1976 PRICE LEVEL)

Type of Cost	Dimension	Costs with Public Subsidy		Costs with Complete Outside Financing
		With Connecting Funds	Without Connecting Funds	
Specific total costs	DM/trip	0.80 ($.32)	1.04 ($.41)	1.55 ($.62)
	DM/person km	0.25 (.10)	0.32 (.13)	0.48 (.19)
Specific capital costs	DM/trip	0.39 (.15)	0.62 (.25)	1.14 (.45)
	DM/person km	0.12 (.05)	0.19 (.08)	0.35 (.14)
Specific operating costs	DM/trip	0.42 (.17)	0.42 (.17)	0.42 (.17)
	DM/person km	0.13 (.05)	0.13 (.05)	0.13 (.05)

or higher costs. A study of this problem revealed that a comparative system designed to be as attractive would be out of the city's financial reach in view of future cost trends for the years following 1985; indeed it would be more expensive than H-Bahn plus the feeder bus system. Conventional transit modes were assumed in this study.

4.12.6 Summary and Analysts Recommendations

The investigations conducted within the feasibility study indicate that the public transit system in Erlangen would be improved by introducing an H-Bahn system.

The H-Bahn has the following points in its favor:

- Higher attractiveness relative to the conventional bus,
- Few adverse environmental effects (low noise, no exhaust fumes).

The attractiveness of H-Bahn will result in a shift of rider demand to public urban transit. Preliminary estimates indicate that in 1985 approximately 86,000 riders will use the H-Bahn system each day (including the feeder bus system). This prediction represents an increase of about 30 percent over the predicted ridership of a conventional bus system.

The high level of H-Bahn attractiveness would then make it possible to implement traffic diversion measures to limit the use of private cars and thereby enhance the quality of life in Erlangen's inner city. This means, for example, the establishment of pedestrian zones and the elimination of existing parking areas. These measures are bound to result in an increase in ridership on transit systems, so that H-Bahn operation will become more cost-effective.

In order to reach final conclusions about the proposed H-Bahn system as a new means of public transit, this system should be tested under actual operating conditions transporting the public in a pilot project. This pilot project would be part of the proposed total network.

It should:

- include important traffic links between residential and commercial centers;
- include as many structural components of the total network as possible,
- be structurally incorporated into the urban pattern, and
- be integratable into the overall network for public transit in Erlangen.

The analysts propose a line about 8 km long running from the western part of the city across the valley of the Regnitz River into the inner city and then on to the southern part of the town. During the test operation period, simultaneous studies should be implemented to study the traffic, operation, and engineering performance of H-Bahn, and the relevant usage and cost figures that have been extrapolated. The decision to expand the pilot section into a complete network will follow evaluation of test operation.

The analysts have therefore decided to recommend that an H-Bahn pilot line be built in Erlangen.

4.12.7 Current Status

In the summer of 1978, a request to construct an H-Bahn demonstration line was presented to the Erlangen authorities. Approximately 90-95 percent of the required investment of nearly 200 million DM would be made available by the Federal Ministry of Research and Technology as well as by the State of Bavaria. In discussions held in the City Council, objections were raised to the planned routing of the line because of the cost to the city, the effect upon the appearance of the city, and the alleged years of inconvenience caused by the planned construction of the inner city tunnel. Those who favored H-Bahn pointed out, in particular, the opportunity to achieve a considerable improvement in the public transit area, reduce the burden imposed on the city by the use of private cars, and the resultant improvement in the quality of life in the urban area. They stressed the environmental pollution caused by the existing urban transit system. In particular, they hoped that, by connecting the western part of the city to the inner city by means of H-Bahn, a four-lane expressway (expected to cost 30-50 million DM) could be eliminated. However, the latter point was strongly opposed by the transportation policy of one of the political parties. Of the 49 members of the City Council, 26 voted against the construction of the proposed line in the autumn of 1978.

In the autumn of 1979, another application was filed with the City Council for constructing an H-Bahn test route. This request was based upon a revised design for the overall H-Bahn network. The cost of an H-Banh system with a feeder bus system was compared with a conventional bus system, whose capacity was increased 50 percent over the present level. The cost comparison revealed that the proposed H-Bahn/feeder bus network would be more economical than an improved bus solution; in other words it would show a lower deficit. The demonstration line, derived from the H-Bahn network, is about 6 km long. It requires an investment of approximately 140 million DM. The Federal Ministry of Research and Technology declared that it was prepared to pay 75 percent of the investment cost. Another 15-20 percent would be paid by the State of Bavaria. The remainder would be covered by the city of Erlangen and the Siemens Company. In addition, the Federal Ministry of Research and Technology was prepared to cover 75 percent of the deficit in operating costs for two years in the demonstration facility.

In October 1979, by a 26 to 21 vote, the City Council adopted a basic decision to construct an H-Bahn pilot facility, on the condition that the city's contribution would be reduced by special arrangement with the State of Bavaria. In addition, the proposed routing would be investigated once more and described in detail before a final decision would be made on the exact route the line would follow.

At the present time, a working group under the direction of the city of Erlangen is devising additional, alternative routings for the demonstration line. The working group is composed of representatives of the city of Erlangen, the Erlangen Public Works Department, VAG Nürnberg (the transit operator), and Siemens. The decision on the exact route to be adopted will be developed on the basis of comprehensive cost and traffic-load analyses. The urban environmental effects produced by the routing play an important role in this design effort. The choice of the route will not be made before the end of 1980.

At the same time, organizational and legal questions are under study in conjunction with the construction and operation of the demonstration facility. These include the following:

- the establishment of a construction and operating authority and a definition of their goals;
- preparation of a planning and authorization proceeding, and determination of the organization which would receive the subsidy.

As yet, these structures have not been fully worked out; although it is expected that the facility will commence operation in 1984/85.

4.13 Selected Application Studies and Planning Cases for H-Bahn

In addition to the feasibility study conducted for H-Bahn in Erlangen, other studies of possible applications of people-movers have also been carried out in cities with different traffic situations. What follows is a survey of a selected group of planning cases from which the range of possible H-Bahn applications can be drawn. The specific planning case, the transit role played by H-Bahn, and the nature and the purpose of the study are listed in Table 4-12.

With the exception of the Karlsruhe study, these studies were all intended to provide information to be used for making decisions on the implementation of a people-mover in each specific application case. In the case of Karlsruhe, exclusively theoretical studies were conducted to determine the operating behavior, etc.,

TABLE 4-12. H-BAHN - SELECTED PLANNING CASES

Planning Case	Traffic Problem	Type and Purpose of the Study
Berlin/Spandau	Urban distribution system with connection to a high-speed rail system	Planning application study, preparation of a decision on the use of a people-mover in Berlin
Berlin/Märkisches Viertel	Urban distribution system with connection to a high-speed rail system	Planning application study, preparation of a decision on the use of a people-mover in Berlin
Karlsruhe	Total coverage for the city, with feeder buses	Basic investigation of a specific planning case, study of the operational pattern of H-Bahn by simulation, including development of bases for planning and decision making
Hannover	Service to fair-ground	Feasibility study, investigation of the possibility of using people-movers at the Hannover fair-ground
Dortmund	Service to the University with connections to outlying University complexes	Planning and application study, preparation of a decision on the use of an H-Bahn in Dortmund

of H-Bahn using operation simulation, from which general planning and decision guidelines were derived.

Building on the results of the planning application study in Berlin (Spandau and Märkisches Viertel), additional studies were conducted for this application case, e.g., to determine the choice of people-mover routes that could be built. At the present time, the governmental authorities in Berlin have not made a decision concerning the construction of a people-mover, but one is expected in the near future. Also, no decision has been made as to which particular system is to be employed to connect the fairground in Hannover.

In the summer of 1979, it was decided to build an H-Bahn pilot route on the grounds of the University of Dortmund; the decision was made by the responsible authorities of the State of North Rhine-Westphalia and the Federal government.

In addition, numerous preliminary investigations of H-Bahn have been carried out by R&D firms for other cities both in Germany and abroad. A few of these cities are Düsseldorf (linked to the fair-ground), Milan (connection to an industrial area), and New Delhi (feeder service to a commuter railway line).

It would be going beyond the scope of this section to present detailed results. The following survey is therefore limited to operating, network, and traffic data for the applications listed in Table 4-12. Section 7 provides an overview of the costs for Berlin and Karlsruhe.

4.13.1 Berlin Test Area: Spandau

In the planning study for the use of people-movers in Berlin, the western test area was defined as being the northern part of Spandau. In 1976, approximately 80,700 people lived in the total area of the test district, measuring 14.2 km^2. For the planning year 1982/83, it was estimated that the number of people living there would decrease to approximately 75,800.

The distribution of the residential and work areas, service areas, and shopping districts as well as destinations outside the area under study (schools and jobs) has resulted in heavy traffic flows toward the old town of Spandau; transfer stations are planned in that location in order to transfer passengers between the people-mover and the Berlin subway system. The traffic flows are largely determined by traffic that travels beyond this particular area and, to a lesser degree, are increased by the inner-city traffic flows centered on the old city.

The goal of H-Bahn in the Spandau test area is to serve the entire traffic district for local traffic as well as to connect the residential and work areas to the old town of Spandau, and to provide transfer stations to permit passengers to transfer to the Berlin high-speed rail network.

The H-Bahn network proposed for the Spandau test area is shown in Figure 4-77.

4.13.2 Berlin/Märkisches Viertel/Wittenau Test Area

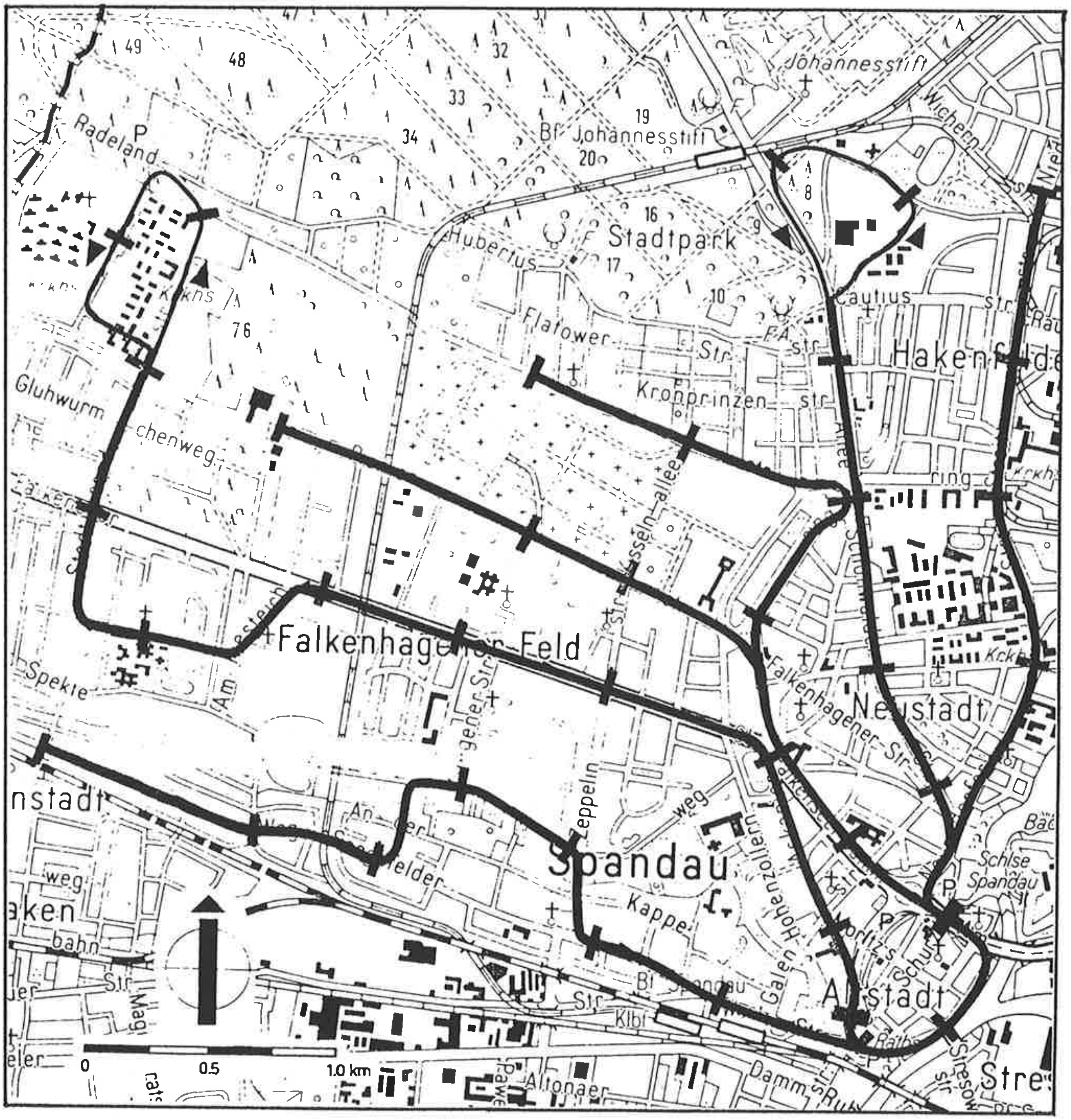
This test area essentially consists of Märkisches Viertel and Wittenau.

The total area of this district is about 11.6 km^2.

Approximately 72,100 inhabitants are forecast for 1982/83.

The test area shows a homogeneous structural classification, with low-density residential areas, high-density residential areas in newly built-up districts where high-rise structures are found, and industrial areas in the western part of the test district. There are also service and shopping districts.

A characteristic feature of the test area is the traffic which goes beyond the district itself, resulting in heavy, channeled traffic flows toward the planned people-mover/subway transfer stations at the edges of the test area. In addition, there are local traffic flows resulting from trips within Märkisches Viertel itself.



a

b

c

d

KEY:

a. Large peoplepmover lines and stops

b. Transfer stations

c. Double-track sections

d. Single-track sections

FIGURE 4-77. H-BAHN NETWORK FOR BERLIN/SPANDAU

The Märkisches Virtel/Wittenau test area is one in which the primary purpose of H-Bahn, in addition to connecting Märkisches Viertel with the adjoining areas, is to link Märkisches Viertel to the Berlin subway system for handling commuter traffic. Hence, in both test areas the H-Bahn will serve primarily as a feeder and distributor for the rapid transit system.

The proposed H-Bahn network for the test area is shown in Figure 4-78.

The traffic forecast (Figure 4-78) for the two application cases in Berlin was calculated for the year in which the system would begin operation, 1982 or 1983. In the Spandau test area, a daily total of 83,400 rides is expected, while the daily total rides for Märkisches Viertel would account for 69,400 trips on the public transit system. Studies of traffic breakdown could not be carried out because sufficient data on traffic patterns were not available.

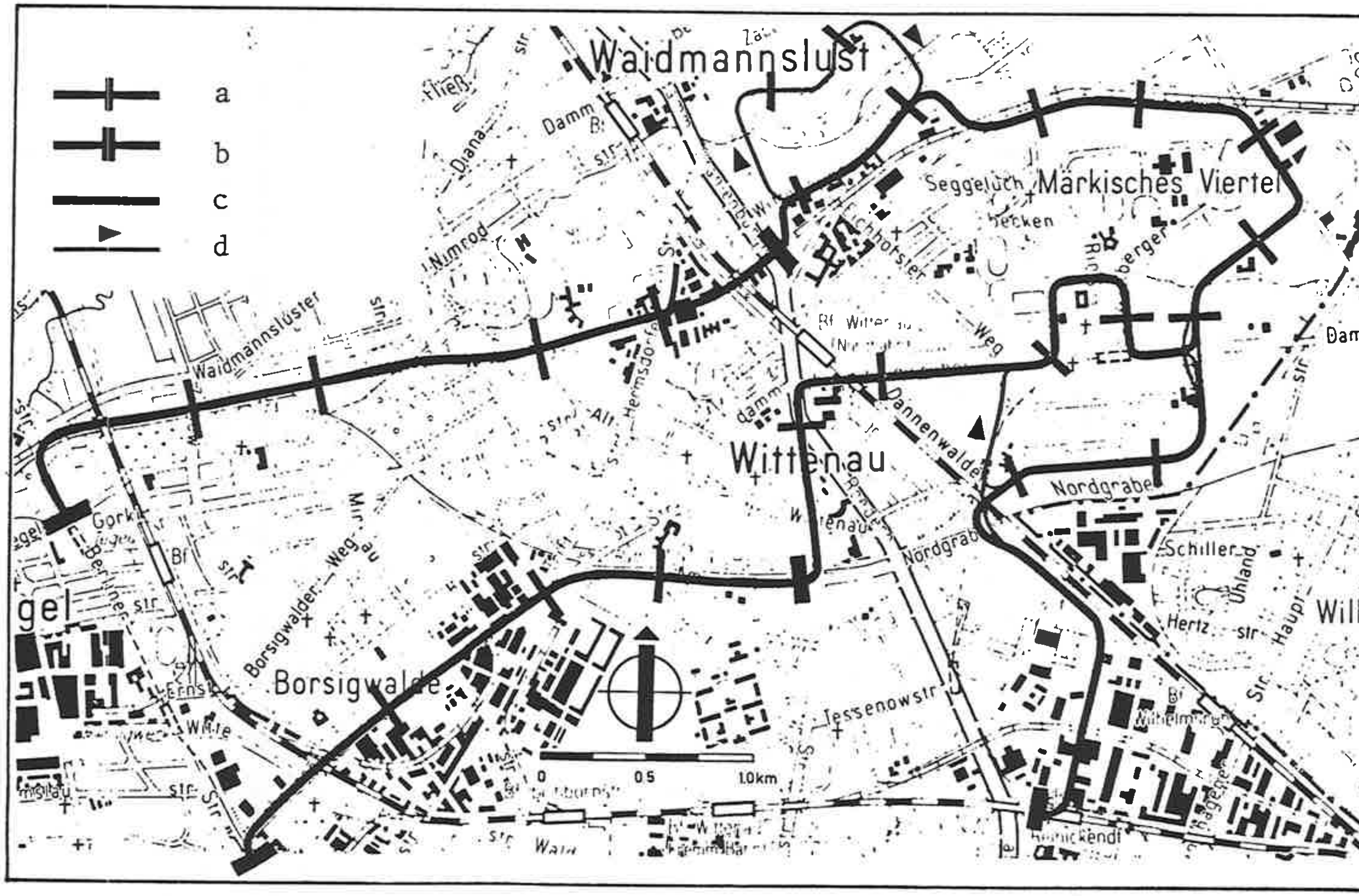
In both test areas, travel in and out of the district predominated, while traffic within the district played a subordinate role.

If an H-Bahn were built in Berlin/Spandau, it is estimated that 95% of all trips by public transit would be on H-Bahn; the corresponding figure for Märkisches Viertel is 92%.

4.13.3 Karlsruhe

The goal of the Karlsruhe study differed from the goal of the other studies. Their purpose was to gather data to be used in deciding whether or not to construct a people-mover. At Karlsruhe, only theoretical studies were performed with the assistance of available traffic and structural data, to determine operating behavior, etc., of an H-Bahn using the example of a concrete planning case.

The city of Karlsruhe is characterized by a monocentric urban structure, with an elongated downtown area (Kaiserstrasse) and residential axes extending radially out into the surrounding districts. This residential structure, with its historic buildings and urban pattern which must be protected, allows only a little



KEY:

a. Large people-mover lines and stops
b. Transfer stations
c. Double-track sections
d. Single-track sections

FIGURE 4-78. H-BAHN NETWORK IN BERLIN MÄRKISCHES VIERTEL flexibility for new designs of transit networks. The traffic flows into the inner city from the residential axes are concentrated on the east-west axis, so that very high cross-sectional loadings occur here. This, coupled with a slight increase in traffic outside the collecting axes, has resulted in a dual transit system in Karlsruhe.

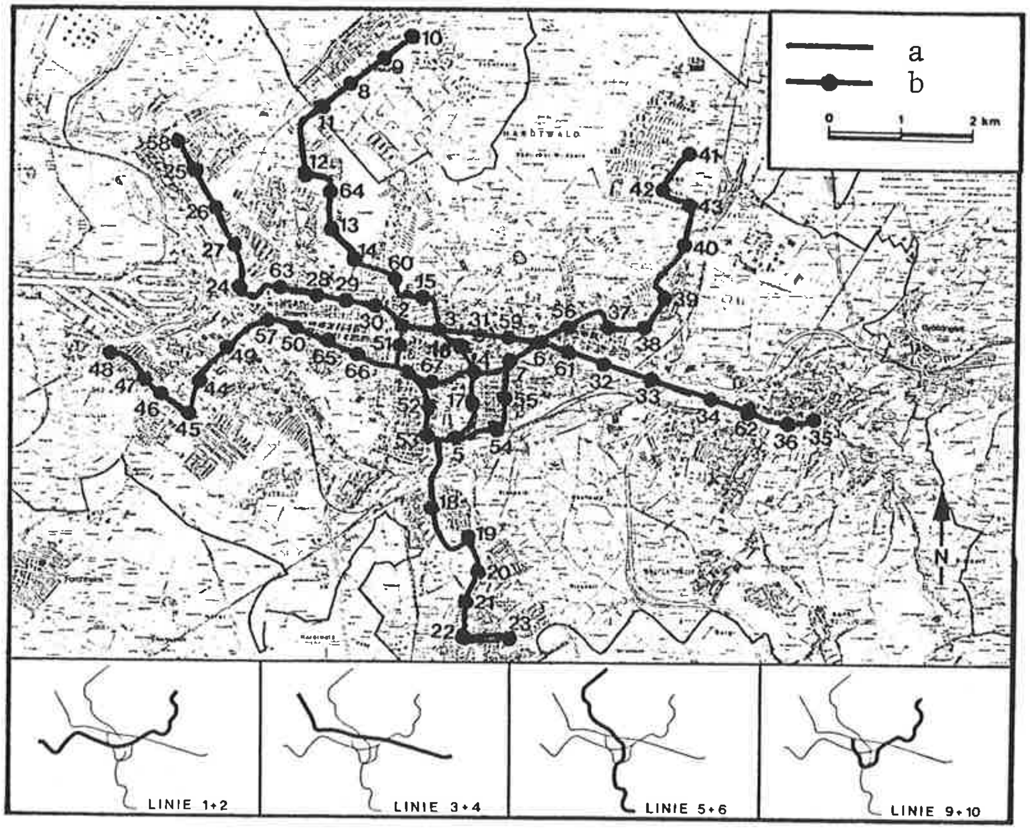
With a total area of about 173 km^2, including the urban area itself and the associated districts outside the city, the area served by the transit system is about 160 km^2.

At the present time, the city of Karlsruhe is served by a streetcar system combined with a complementary bus system and a suburban railway known as the Albtalbahn. The surrounding districts are also served by the Deutsche Bundesbahn (Federal German Railway), which is linked to the inner-city public transit system at the main railway station. In 1977, the network of the Karlsruhe Verkehrsbetriebe carried about 160,000 passengers every day.

In this study, researchers proceeded on the basis that the H-Bahn urban transit system in Karlsruhe would replace streetcars and assume their transport function (Figure 4-79). Therefore, as the main system in Karlsruhe, it has the purpose of serving the inner city and connecting densely populated residential areas directly with activity centers such as shopping areas, recreation areas, schools, services, and jobs most of which are located in the inner city. A suitable bus system and (in the south) the Albtalbahn would supplement H-Bahn and serve primarily as feeders.

Calculations aimed at predicting traffic levels and traffic breakdowns, taking into account the attractiveness of H-Bahn and an increase in mobility, show that in planning H-Bahn for 1990 there would be a mode split of 34.3% by contrast with 26% in 1977. The combined H-Bahn/bus network, including the feeder systems, would carry approximately 223,000 passengers every workday, with a total of about 198,000 traveling on H-Bahn.

On the basis of the operating layout structured according to the manufacturer's design, the influence of the following



KEY:
a. line
b. stops

FIGURE 4-79. H-BAHN NETWORK, KARLSRUHE

parameters on operational developments, costs, and system utilization were studied for Karlsruhe:

- changes in operating dimensions
- changes in maximum vehicle speed
- changes in seat/standee ratio in the vehicle.

In addition, performance tests were carried out.

The results are discussed in Section 4.10. They may be summarized as follows:

- The operating characteristics of the system are stable in all of the investigated operational variants, by contrast with variations in time spent at rest and increased traffic.
- The efficiency of the system is sufficient.
- An increase in maximum vehicle speed from 50 km/h to 60 km/h would have a positive effect upon both costs and utilization.

- The ratio between seats and standees in the vehicle can have a considerable effect upon costs and use, and should be optimized for all application cases.

4.13.4 Hannover

In the Hannover study the implementation of a people-mover system for serving the fairground (approximately 1 km^2) was studied. The people-mover was intended to replace the existing vehicles now in use, which are forced to use the roads.

The traffic flows on the fairground were used in the study to develop a network with a total length of about 9.3 km.

Calculations of traffic demands indicate that on-line loading at peak hours would be between 2,000 and 10,000 riders/h in each direction. In order to handle these demands, plans were made to use vehicles with a maximum of 4 cars per train and a vehicle capacity of 40 to 50 passengers, corresponding approximately to vehicle Type 2/2.

The results of the study indicate that traffic problems on the fairground could be handled by automatic people-movers. The implementation of a people-mover system was therefore recommended by the analysts.

4.13.5 Dortmund

The feasibility of an H-Bahn system on the grounds of the University of Dortmund was studied, with the system serving as a link between parts of the University located considerable distances apart. The study was carried out by the University of Dortmund. In predicting traffic levels between two sections of the University, it was decided that the average figure for 1980/81 would be approximately 4,000 riders/day or 2,000 riders/day each direction. It was expected that there would be a basic load figure for the system which would consist of job-related trips by University employees. The basic load would have an irregular peak-hour flow superimposed upon it, caused by the beginning and end of classes and visits to the cafeteria at noon. Therefore, both possible types of H-Bahn operation were studied; the on-line and on-demand types of service. By connecting the H-Bahn to an S-Bahn station (high-speed rail network), the user potential can be increased. Calculations in this connection are not presently available.

The study was based upon a single-track line about 1.2 km long with two stations. Shuttle operation with 2 trains of the Type 2/2 vehicle were planned (capacity of 41 passengers, motor drive).

In 1979, it was decided that the responsible authorities of the State of North Rhine-Westphalia and the Federal German Government would construct this facility. An H-Bahn operating authority will soon be established. The facility should be complete by 1982. Investments amounting to about 13 million DM (1976 price level) will be 75 percent covered by the Federal Ministry of Research and Technology and 25 percent by the State of North Rhine-Westphalia.

4.13.6 Tables Summarizing Important Parameters of Application Cases

In Table 4-13, we have summarized, for each application case, selected parameters on the transit network, traffic increase, and operating design, to the extent these data were available. The required investments for H-Bahn installation are given as well.

TABLE 4-13. SUMMARY OF KEY PARAMETERS FOR H-BAHN APPLICATIONS

Parameters			Application Case				
Category	Item	Dimension	Berlin Spandau	Berlin Märk. Viertel	Karlsruhe 1)	Hannover	Dortmund
Transit System	Route length amount in tunnel	line km line km	27.3 -	22.6 -	45.2 5.2	4.0 -	1.2 -
	Length of track	track km	50.2	40.6	96.7	4.0	1.2
	Switches	number	45	32	69	7	2
	Stops, avg. distance between stops	number meters	41 670	27 830	67 770	12 330	2 1200
Traffic Increase	Transport capcity	rides/d 10^6 rides per yr.	78,800 25.1	63,600 20.2	198,800 61.3	These data were not determined because of the special application case, "fairground" (operation only on a few days a year).	4,000 These data were not included in the study. Studies will be conducted when the system is operational.
		Person km per day	204,400	299,100	1,031,300		
		10^6 pers. km/year	65.0	95.1	319.7		
	Avg. length of ride	person km/ride	2.6	4.7	5.2		
	Avg. line loading	person km/day, route km/ direction	3,740	6,600	11,400		
	Peak load factor	%	10.5	10.5	13.2		
	Maximum cross-sectional loading on the line	persons/hr, per direction	min. 300 max. 1,400	min. 800 max. 1,400	min. 2,600 max. 3,500		
Operation	Vehicle type	-	2/2	2/2	3/3	2/2	2/2
	Vehicle capacity Seated Standing	passengers passengers passengers	41 16 25	41 16 25	69 24 45	41 variable	41 16 25
	Max. vehicle requirement	units	76	73	232	24	2
	Operating and maintenance reserve	%	8	8	14	-	-

TABLE 4-13. SUMMARY OF KEY PARAMETERS FOR H-BAHN APPLICATIONS (Continued)

Parameters			Application Case				
Category	Item	Dimension	Berlin Spandau	Berlin Märk. Viertel	Karlsruhe 1)	Hannover	Dortmund
Operation (Continued)	Max. speed	km/h	50	50	50	36	50
	Avg. operating speed	km/h	26	29	30	18	39
	Hours of operation on workdays	h	21	21	20	11	10
	Operating capacity	Vehicle km/day 10^6 vehicle km/year	27,500 9.3	26,200 8.9	97,800 34.0	1,500-4,500	
	Avg. vehicle capacity	Vehicle km/vehicle, per year	122,500	120,960	146,600	see note above	see note above
	Avg. vehicle occupation	%	17.0	26.1	13.6		
Investments	Required investment for entire installation	Millions of DM	336	282	869	41	13
Price	Price level		1978	1978	1977	1978	1976

1) test version 2

5. SYSTEM OPERATIONAL DEPLOYABILITY ASSESSMENT

In this section of the report, the H-Bahn system is reviewed and assessed in regard to the important characteristics involved in the operation of a public transportation system, i.e., its technical maturity, safety, reliability, maintainability, cost-saving features and human factor features. Also included is a review of the development approach and philosophy used by the system developers and of the test program used to develop and validate the design. The statements included reflect the technical opinion and judgment of the assessment team and are based on a 2-week visit to the test site and discussions with technical and management staff from both Siemens and Düwag.

5.1 DEVELOPMENT ASSESSMENT

5.1.1 Development Approach/Philosophy

Two important factors that affect the technical maturity of a complex system, such as an automated guideway transit system, are the degree to which: (1) conventional/proven technology is utilized in the design approach and, (2) the design is tested and verified during the development process in an environment and configuration representative of actual operation.

One positive aspect of the H-Bahn development approach is the apparent philosophy, on the part of the system developers, to utilize conventional, state-of-the-art concepts and technology whenever feasible. In contrast to extending the state-of-the-art in automated systems through innovative concepts and new hardware, the H-Bahn approach has been one of combining existing technology with emphasis on simplicity and flexibility with extensive testing. In designing the system, both Siemens and Düwag have utilized standard specifications, techniques, and design concepts. Standard civil engineering practices, specifically the requirements of the German Federal Railway, have been used in the guideway design along with conventional materials such as steel and concrete. Vehicles have been designed in accordance with existing rapid transit vehicle specifications. The design of the command and control system is quite conventional and straightforward, using to a large degree a modern technology safety system recently developed for the German Federal Railway. Thus conventionality of the design approach is evident.

With this level of dependence on conventional approaches and hardware, the emphasis during the development program should be focused on hardware integration and its performance in situations representative of revenue operation. Important also is the development and testing of new hardware and its interface with the rest of the system. To what extent this has been done is addressed in the following section and in the subsystem areas of Section 5.2. Generally speaking, the system developers have relied on extensive testing throughout the development program to evolve and mature their design. Although the earlier test facilities were geared primarily toward vehicle and guideway development, the test facility of Erlangen provides a good basis for checking out the integration of the three major subsystems (vehicle, stations/guideway, command and control) and for validating the technical design for revenue operations. With its three stations, its 1.4 km of guideway, six vehicles, maintenance facility, central control facility, maximum speed capability, and other features, the Erlangen facility offers an environment quite representative of public operation. (Figure 5-1.)

5.1.2 System Test Program

A prime area in the development of the H-Bahn system is the test program, which has been underway since 1973. Focusing initially on the hardware design for the vehicle propulsion system, tests were carried out in Berlin on a 170 m straight section of track using steel rails and a modified rail vehicle. The purpose of the test was to evaluate the initial concept of a linear synchronous motor. Vehicle speed is a function of the electrical line frequency, with a 3-phase single-sided primary winding in

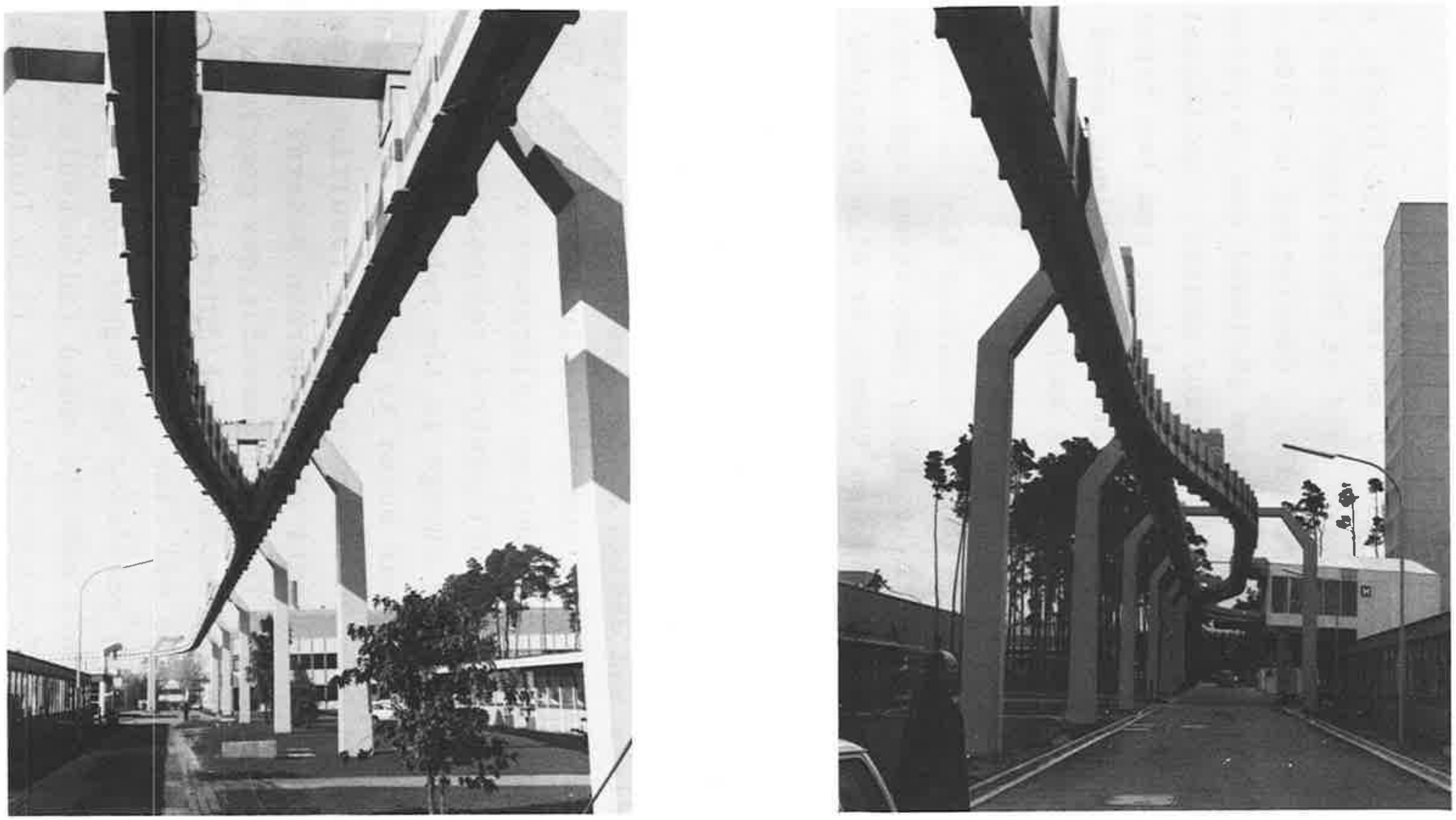


FIGURE 5-1. ERLANGEN TEST FACILITY

addition to an exciter winding on-board the vehicle, and a reaction system on the guideway. The basic performance data associated with this motor was collected and evaluated.

Based on the experience gained at the Berlin track, a prototype site was constructed during 1974 at Düsseldorf, and these were conducted during 1975 and 1976. Consisting of 150m of guideway in a Y configuration, the system included one 16-passenger cabin, one switch and a wayside control center. At Düsseldorf guideway construction utilized steel columns and two types of beam design - full and trussed steel walls. The maximum speed obtainable on the Düsseldorf track was 36 km/hr.

The Düsseldorf facility provided the first opportunity in the development of the H-Bahn system to evaluate the performance of prototype designs for the three major subsystems and the electrical and mechanical interfaces between them. It also provided a basis for evaluating alternative design approaches for reducing system noise and system wear. The system operated through a wayside control center which controlled vehicle speed and position through a prototype hardwired control system.

Major findings and design changes resulting from test programs at Berlin and Düsseldorf are summarized in Table 5-1. The need for tightly controlled construction tolerances for the guideway due to air gap and ride comfort control reasons was determined from the test program. The change in the vehicle propulsion system from a synchronous linear motor to an asynchronous linear induction motor was made on recommendations resulting from studies made by scientific consultants of the German Federal Ministry for Research and Technology. These recommendations concluded that future development should emphasize scheduled line operation which would eliminate the off-line sections required for acceleration and deceleration resulting in higher top speeds and the requirement for a variable vehicle speed (adjustable from zero to maximum velocity). Synchronous drive is no longer feasible under these conditions; hence, an asynchronous linear induction

TABLE 5-1. TESTING HISTORY SUMMARY TABLES

(10 pages)

H-Bahn Subsystem:	Operational Guidance Technology Components: Data Transmission
	Guideway Component: Rail Joint
	Guideway Component: Support Suspension
	Vehicle Component: Switch Points
	Vehicle Component: Point Drive
	Vehicle Component: Suspension
	Vehicle Electrical System Component: Current Collector
	Vehicle, Stopping Point Component: Door Drive

H-BAHN SUBSYSTEM: OPERATIONAL GUIDANCE TECHNOLOGY COMPONENTS: DATA TRANSMISSION (1 of 2)

	STAGE I	STAGE II	STAGE III
PRELIMINARY TESTS	Berlin test track	Berlin test track	
Test	EMV tests Functional tests of the DÜ design	Functional testing of the coupling procedure EMV test	
Goal	Determination of applicability of the DÜ in the vicinity of the linear motor and third rail as regards data and speech traffic	Determination of whether capacitive or inductive coupling is advantageous	
Results	Instrument logic, transmission, and reception are functional.	Capacitive coupling owing to excessive noise level not suitable for speech traffic	
Recommended Measures		Installation of a linear high-frequency conductor for inductive tapping	
FACILITY TESTING	Düsseldorf test facility	Erlangen test facility	Erlangen test facility
Test	EMV test in a guideway support	EMV test in a guideway support with modified linear motor and current conductor arrangement	EMV test Noise radiation testing with externally mounted antenna system
Goal	Determination of applicability in a closed box girder type support	Determination of applicability in a box girder with a new geometry	Determination of usability Long term tests

H-BAHN SUBSYSTEM: OPERATIONAL GUIDANCE TECHNOLOGY COMPONENTS: DATA TRANSMISSION (2 of 2)

	STAGE I	STAGE II	STAGE III
FACILITY TESTING (Continued)			
Results	Antenna system in the guideway support can be installed below the upper flange of the girder. Interference caused by vehicle electrical system.	Antenna system next to power rails on the side walls of the girder very sensitive to interference	Antenna system functional Noise radiation near the limit set by the German Post Office Total system protected against noise
Recommended Measures	Noise suppression on vehicle drive	Mounting of Antenna system beneath the guideway girder support	Detailed improvement to reduce noise radiation

Conclusions: Use of components for actual installation feasible.

H-BAHN SUBSYSTEM: GUIDEWAY COMPONENT: RAIL JOINT

	STAGE I	STAGE II
PRELIMINARY TESTS	Düsseldorf Facility	Düsseldorf Facility
Test	Use of rail joint with a diagonal cut and adjustable expansion joint length	Testing a joint with a displaceable filler (operated using sloping surfaces and surfaces and springs)
Goal	Determination of suitability as a transition element for steel wheels with flanges	Determination of smooth operation so that the actual joint remains continuous even with variations in the support gaps
Results	Suitability only for small expansion joints (support length up to 15 m) in conjuction with steel wheel at the Düsseldorf facility	Good function in the support expansion direction (rise in temperature). Development of cracks in the opposite direction
Recommended Measures	Construction of a joint with a displaceable filler	Construction of positive guides for both operating directions
FACILITY TESTING	Erlangen Facility	Erlangen Facility
Test	Use of positively actuated filler	In preparation: installation of a design easier to install and maintain
Goal	Determination of suitability for expansion distances of ± 20 mm and noise travel with rubber wheels in a long-term test	Determination of equally satisfactory function with reduced installation and maintenance cost
Results	Good function very precise installation (cost) necessary	
Recommended Measures	Structural improvement to simplify installation: self-supporting crossing design	
Conclusions:	Including the improvements still to be made, the problem of joint-free crossings for rubber wheels appears to be solved.	

H-BAHN SUBSYSTEM: GUIDEWAY COMPONENT: SUPPORT SUSPENSION		
	STAGE I	STAGE II
PRELIMINARY TESTS	Düsseldorf Facility	
Test	Use of a support suspension with 2 bolts on each side of the support (bearing blocks bolted under supports)	
Goal	Determination of function and feasibility of installation and adjustment	
Results	Poor function on the slide bearing side; costly adjustment	
Recommended Measures	New design	
FACILITY TESTING	Erlangen Facility	Erlangen Facility
Test	Use of a support suspension with intermediate frame	In preparation: use of a suspension with a reduced height
Goal	Determination of improved function and simple installation and adjustment	
Results	Engineering requirements satisfied; relatively unsuitable appearance due to the anchor bolts used	
Recommended Measures	Further development of design	
Conclusions:	A suspension design with limited height exists which will completely meet the technical requirements.	

H-BAHN SUBSYSTEM: VEHICLE COMPONENT: SWITCH POINTS

	STAGE I	STAGE II
<u>PRELIMINARY TESTS</u>		
Test	Mechanical point connector Function test	
Goal	Determination of functioning ability	
Results	Choice of a design	
Recommended Measures		
<u>FACILITY TESTING</u>		
Test	Function test: determination of switching force and switching time during operational switching and forced switching	
Goal	Determination of functional ability, strength, and safety during operational and forced switching	
Results	Sufficient functioning ability and strength, but too elastic in forced switching	
Recommended Measures	Elimination of the mechanical point connector Drive and monitoring of each individual point group	
Conclusions:	The drive of each point group independently has been proven reliable in a long-term test.	

H-BAHN SUBSYSTEM: VEHICLE COMPONENT: POINT DRIVE		
	STAGE I	STAGE II
PRELIMINARY TESTS		Pneumatic positioning cylinder
Test		Function test, with sudden loading even contrary to the switching direction
Goal		Determination of functioning ability during operational and forced switching
Results		The pneumatic cylinder satisfied all the function tests and safety requirements
Recommended Measures		
FACILITY TESTING	Electrical point setting cylinder	
Test	Function test: determination of switching forces and switching times during operational and forced switching	Function test, safety test
Goal	Determination of functioning ability and safety during operational and forced switching	Determination of reliability in a long-term test and safety during forced switching against applied pressure and at maximum speeds
Results	Sufficient functioning ability and safety for operational switching; Defective positioning cylinder (jammed push-rod) during forced switching	Functional ability, reliability, and safety were demonstrated. Use of the pneumatic cylinder in all vehicles
Recommended Measures	Choice of a pneumatic positioning cylinder	
Conclusions:		

H-BAHN SUBSYSTEM: VEHICLE COMPONENT: SUSPENSION		
	STAGE I	STAGE II
PRELIMINARY TESTS		
Test		Determination of natural frequencies on the spring test stand
Goal		Determination of calculated natural frequencies
Results		Natural frequencies can be determined so that a new suspension could be installed in a 2/2 vehicle at Erlangen
Recommended Measures		
FACILITY TESTING		
Test	Function test: determination of frequencies for the three coordinate directions and the swing angle, long-term test	Function test: determination of frequencies for the three coordinate directions and the swing angle, long-term test
Goal	Determination of functioning ability and reliability as well as ride comfort	Determination of functioning ability as well as ride comfort
Results	Car suspension too hard in all three planes	Determination of reliability in long-term test; demonstration of good ride comfort under all operating conditions
Recommended Measures	Development of a new car suspension with a wobble stabilizer	
Conclusions:		

H-BAHN SUBSYSTEM: VEHICLE ELECTRICAL SYSTEM COMPONENT: CURRENT COLLECTOR (1 of 2)

	STAGE I	STAGE II
PRELIMINARY TESTS		
Test	Testing of a leaf spring current collector on a roll test stand, on which, in addition to normal operation, situations involving the current collector coming into contact with and moving away from a power rail, as well as power rail impacts, could be simulated.	Testing of an articulated current collector on the roll test stand with the same prerequisities as in Stage 1
Goal	The current collector including the slider must be mechanically and electrically functional for bidirectional operation. The current collector must operate reliably for at least one year, in other words for approximately 7000 hours of operation or 100,000 km.	Same goal as in Stage 1, with special emphasis on joint wear
Results	Both the unilateral and bilateral current collectors were set vibrating by impacts and when coming in contact with and leaving the third rail. In the case of the bilateral current collector, bidirectional travel was not possible.	With the articulated current collector and a separately sprung slider, an operating time of 5 years was simulated on the roll test stand; approximately 60 million impacts and 1.5 million movements to and from the third rail were simulated. No problems or damage resulted.
Recommended Measures	On the basis of these results, the experiments with the leaf spring current collector were suspended.	On the basis of these results, the current collectors were installed at the Düsseldorf test facility.

H-BAHN SUBSYSTEM: VEHICLE ELECTRICAL SYSTEM COMPONENT: CURRENT COLLECTOR (2 of 2)

	STAGE I	STAGE II
FACILITY TESTING		
Test	Testing of articulated current collector at the Erlangen facility in daily test operation	Testing the modified current collector with the new slider
Goal	Satisfactory performance under actual operating conditions and determination of desired maintenance interval	Function test and long-term operation test
Results	Under experimental operating conditions, it was found that the sliders left the third rail at an angle.	The current collector with the new slider design has thus far satisfied all requirements in long-term tests
Recommended Measures	Modifications to the slider, choice of a new mounting	

Conclusions: The current collector can be used in its present design.

H-BAHN SUBSYSTEM: VEHICLE, STOPPING POINT COMPONENT: DOOR DRIVE		
	STAGE I	STAGE II
PRELIMINARY TESTS		
Test	Testing a door drive mounted on the platform (linear motor), with one mechanical and one magnetic clutch, lock, and unlock system for synchronous opening and closing of the platform doors and the driveless vehicle doors	In contrast to the preliminary tests in Stage 1, in Stage 2 an arrangement was tested in which the platform and vehicle doors were equipped with a single drive. Synchronous opening was triggered by means of an electrical command.
Goal	Testing under conditions resembling those in actual operation	Testing under conditions resembling those in actual operation
Results	Both systems are ready for installation as indicated by test results	On the basis of the test results, this system is likewise suitable for installation.
Recommended Measures	When used under experimental conditions, improvements to detail will be necessary	Installation and testing of this system at the Erlangen test facility
FACILITY TESTING		
Test	After the preliminary tests, the arrangement with a magnetic clutch lock and unlock system was tested at the Düsseldorf facility	Equipment of the vehicles and stations at the Erlangen test facility with their own door drives, transmission of synchronized door opening commands by an infrared system
Goal	Proving and function test under conditions resembling those in actual use	Function test and long-term test
Results	The system is considered ready for use on the basis of the operating tests	System ready for use
Recommended Measures		
Conclusions:	The results of the long-term tests must be in before we can make any statements about the lifetime and maintenance intervals.	

motor or a dc motor should be used. In addition, a design change occurred in the switching mechanisms on-board the vehicle and in the guideway due to the change in the vehicle drive concept.

With the experience gained at Düsseldorf and the resulting design changes, a new and larger test facility was constructed on the grounds of the Siemens Corporation in Erlangen during 1976. Using various design approaches for the guideway and stations and updated designs for the vehicle and the command and control systems, the facility provided an extensive and realistic environment for system performance and integration testing. The first vehicle (Veh. #101) arrived in December 1976 and testing began in January 1977 to determine static and dynamic deflections of the guideway beams. Since that time, five additional vehicles were delivered during 1977 and 1978, bringing the total number of vehicles at the facility to six, two with dc motor drive and four with linear induction motor drive. (Figure 5-2.)

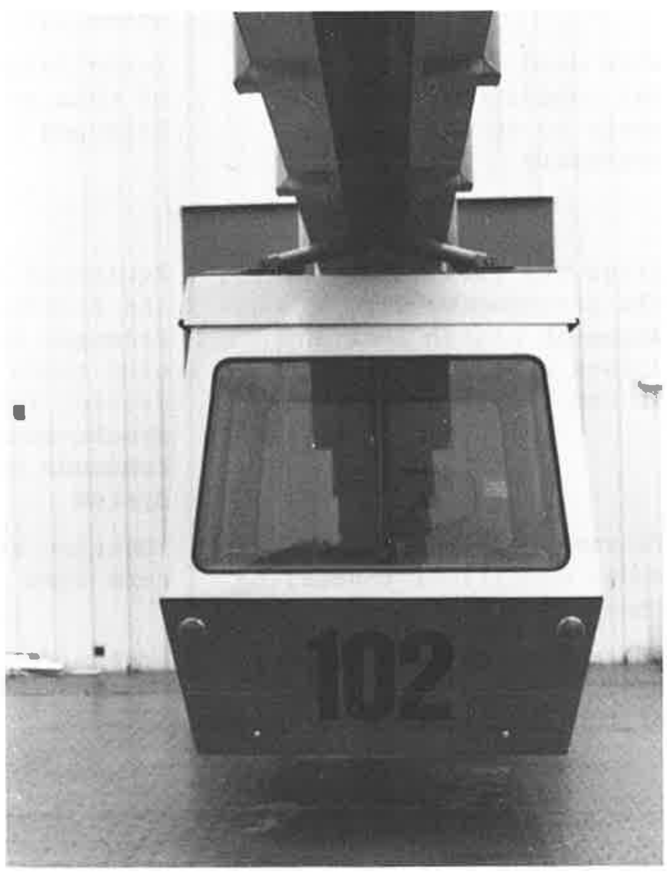


FIGURE 5-2. H-BAHN VEHICLE (TYPE 1/1 VEHICLE)

Table 5-2 shows the schedule of testing at the Erlangen facility since early 1977. The prime emphasis of the tests during 1977 and 1978 was on the mechanical and electrical performance of the dc drive and linear induction motors, the interface between the vehicle, guideway, and wayside, and the data transmission between the vehicle and the control center. In particular, the following tests were conducted:

- Electrical operating tests, with rotary drive and linear induction motor drive
  - Recording of operating parameters
  - Heating tests
  - Electrical power consumption
  - Recording of parameters
  - Recording of influential and interference parameters.
- Ride quality, noise, with rotary drive and linear induction motor drive
  - Vibrations and accelerations
  - Front-to-back vibrations
  - Lateral accelerations
  - Jerking
  - Rocking of the vehicle
  - Interior noise in vehicle during operation
  - Vehicle noise measured at specified distances under different conditions.
- Braking tests, operation through switches, with rotary drive and linear induction motor drive
  - Recording of service brake characteristics
  - Recording of emergency brake characteristics
  - Determination of response time and delay
  - Determination of limiting values.

TABLE 5-2. TIMETABLE FOR H-BAHN TEST TRACK AT ERLANGEN AS OF JULY 12, 1978

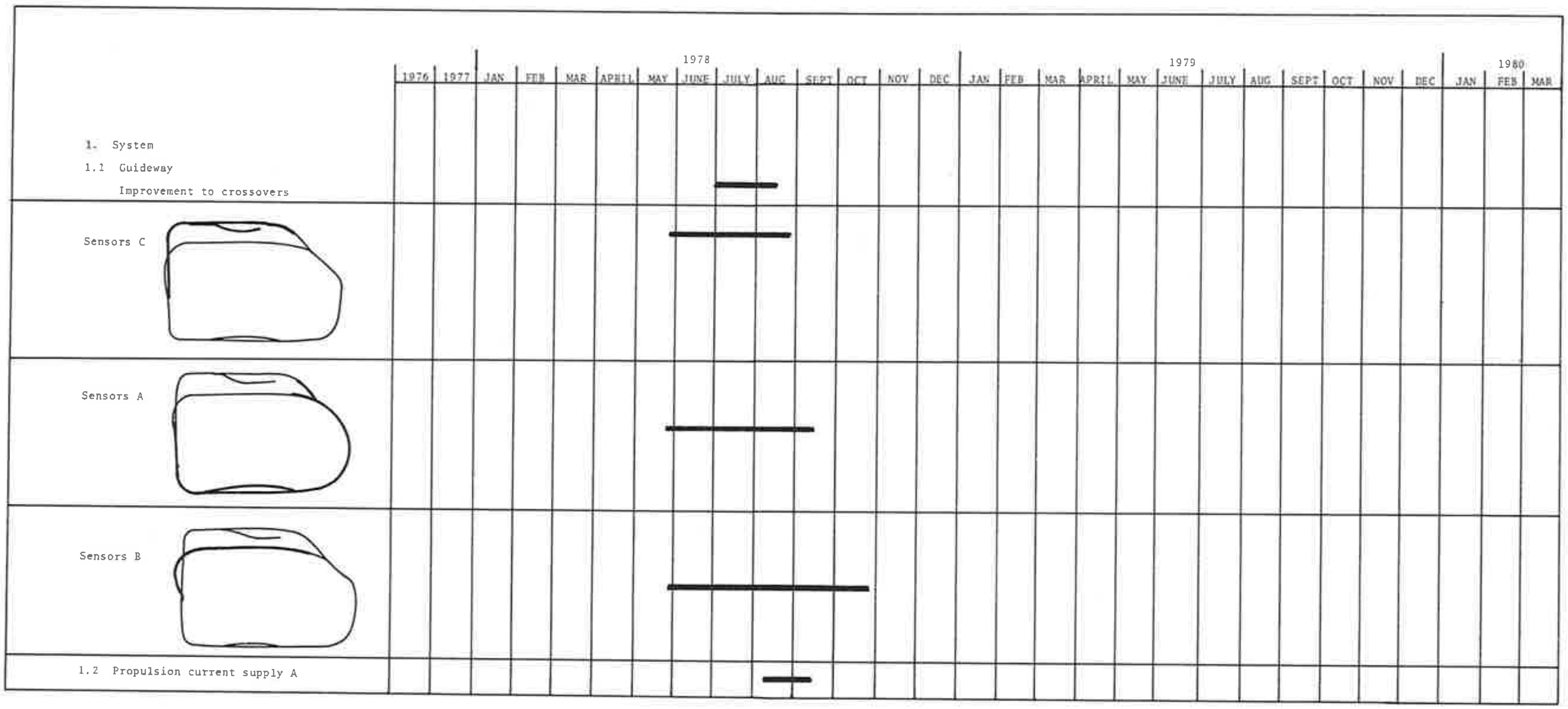


TABLE 5-2. TIMETABLE FOR H-BAHN TEST TRACK AT ERLANGEN AS OF JULY 12, 1978 (CONTINUED)

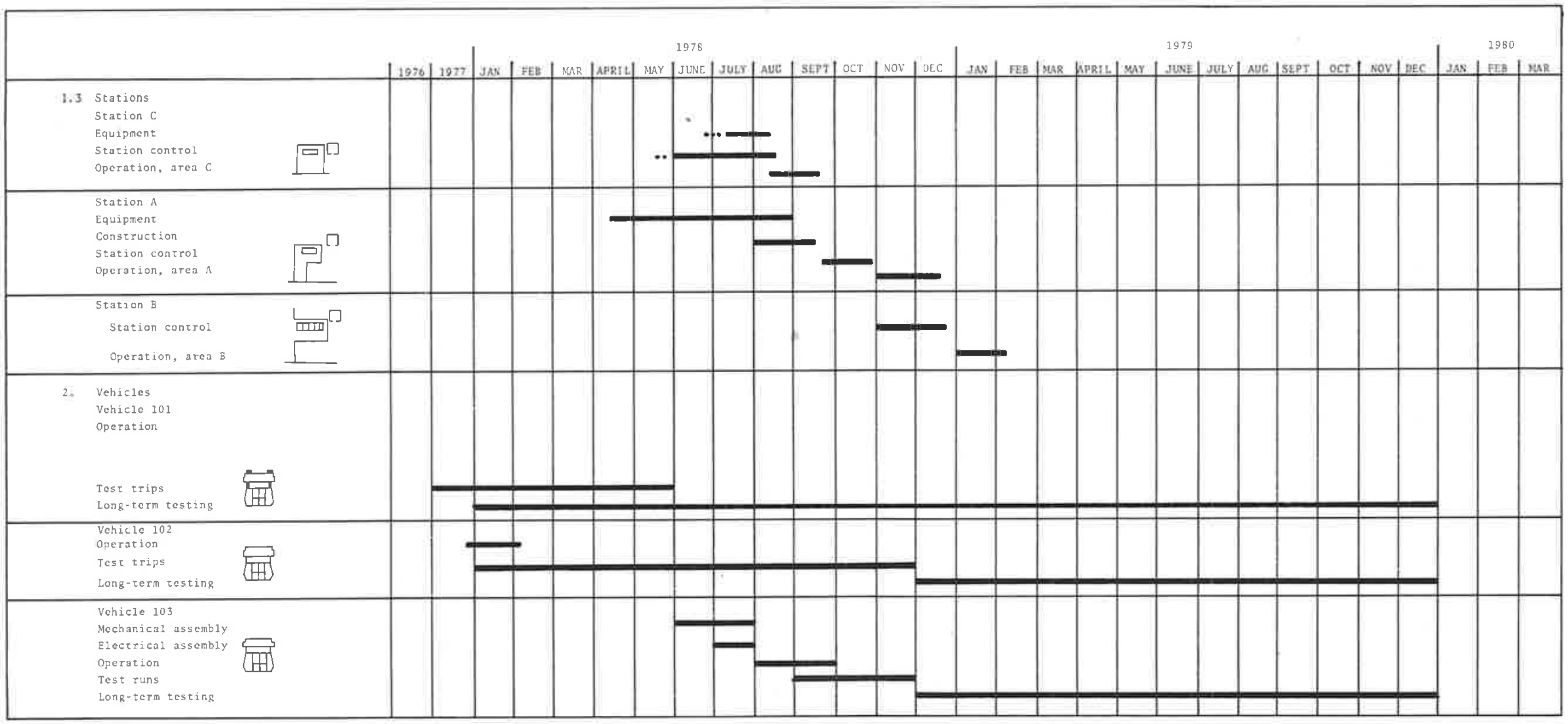
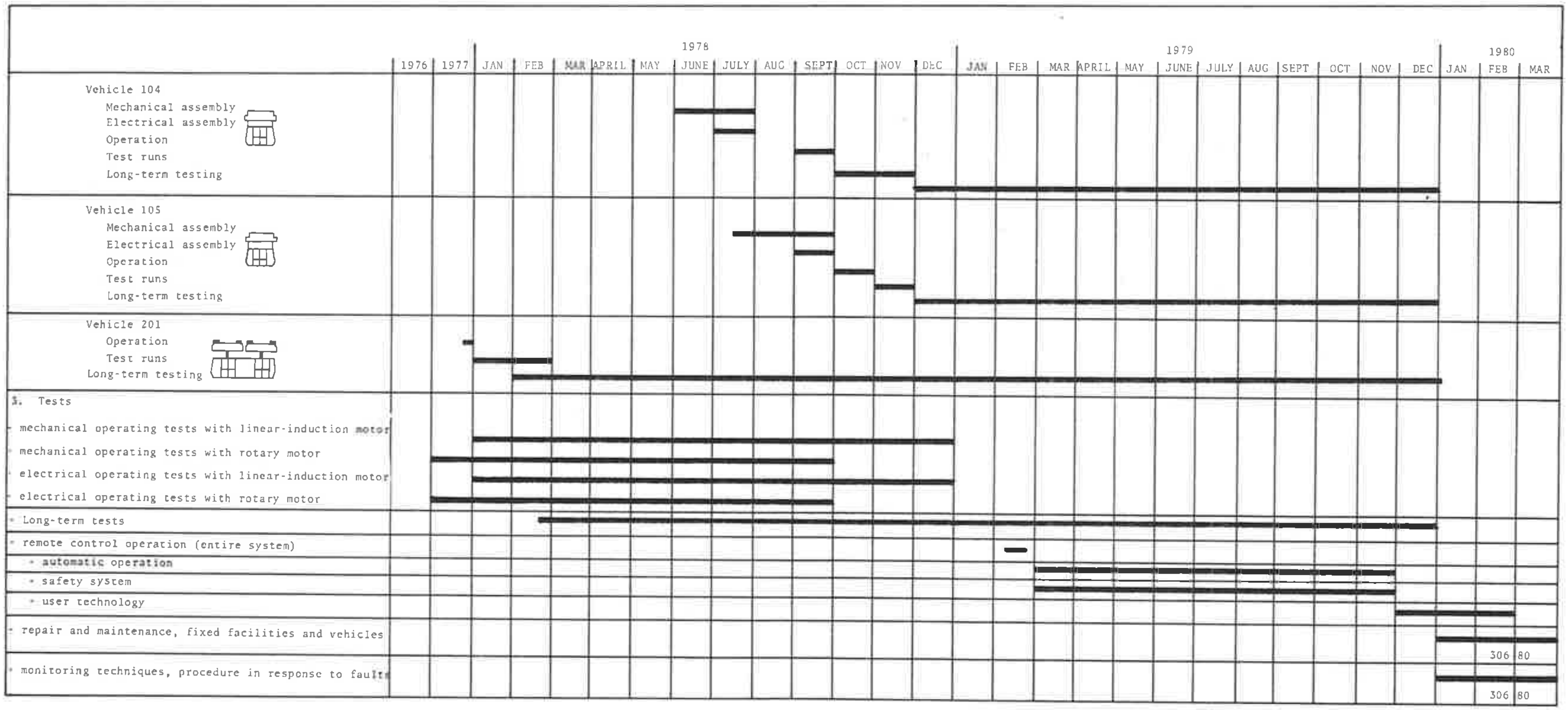


TABLE 5-2. TIMETABLE FOR H-BAHN TEST TRACK AT ERLANGEN AS OF JULY 12, 1978 (CONTINUED)



- Safety system tests
  - Individual testing of equipment
  - System tests on the safety level
  - Determination of response criteria on the safety level (vehicle spacing, vehicle speed, operation of switches)
  - Determination of emergency brake reaction time in vehicles.
- Data transmission tests
  - Individual testing of modules
  - System testing of elongated and isolated transmission facilities
  - Measurement of the effect of electromagnetic interference on high frequency transmission.
- Measurements on guideway supports (30 m beams, curved beams, switches, steel and reinforced concrete supports)
  - Correction factor for vibration
  - Bending of supports
  - Changes in the cross section of the guideway support
  - Ground vibrations near the support foundations.

At the time of the assessment, endurance tests were being conducted on the two dc drive vehicles at the planned rate of 15 hr/day to determine reliability and wear. The following tests were included:

- Long-term tests

  Reliability determination

  - Drive equipment
  - Control device
  - Brakes
  - Heat and ventilation.

  Wear measurements

  - Current collectors
  - Brake linings
  - Wheel tires

- Guide and switch rollers
- Motor brushes.

Until early 1979, vehicle operation was primarily through either manual control or remote control under manual direction. With station computer software being checked out at one station in early 1979, limited automatic operation under computer control was possible. With the other two stations scheduled for completion of software checkout by late spring, it was anticipated that total automatic operations of the test track would begin in early summer of 1979. With the capability available, system level testing under computer control focused on multi-vehicle operation for both normal and abnormal conditions. In addition, the interface between the computer and the "user technology" (fare collection, signage, etc.) can be validated. The following tests are planned, with some already partially complete at the time of the assessment:

- <u>Operating tests; user technology</u>
  - Individual testing of equipment for operation
  - Testing joint operation of equipment
  - Remote controlled operation (under the control of personnel)
  - Computer tests
  - Remote controlled operation (under computer control)
  - Checking monitoring and guidance systems
  - Checking operating procedures
  - Starting and ending operation, "deadheading" to storage areas
  - Individual testing of equipment for user technology
  - Cooperation of equipment for user technology with the computer
  - Tests with passengers.

As shown in Table 5-2, endurance testing on each vehicle will be conducted over a lengthy period of time, at least until 100,000 km of operation have been accumulated per vehicle.

5.2 TECHNOLOGICAL ASSESSMENT

During the past several years, the H-Bahn development program has culminated in the emergence of an extensive test track facility with six vehicles, three stations and a maintenance center. Though no H-Bahn systems are operating in revenue service at this time, the test facility is providing valuable experience in operating and maintaining the system. In this section of the report, the system at Erlangen is first reviewed at a concept level and then looked at from the perspective of eventual deployment in revenue service. Issues such as technical maturity, safety, reliability, maintainability, and cost-savings are addressed. Section 5.2.1 provides an overall summary at a system level and addresses issues involving more than one subsystem; Section 5.2.2 addresses each key subsystem.

5.2.1 System Assessment

Concept

The H-Bahn system concept of providing various sized vehicles suspended from guideways in a scheduled mode of operation appears to be a sound approach. The modular concept of vehicle configurations offers flexibility without severe cost impact. The enclosed track beam precludes the need for snow and ice preventive or removal measures and significantly reduces the imapct on the environment of noise and electromagnetic interference generated by the vehicles. In spite of frequently spaced manholes throughout the beam, access to wayside hardware for maintenance or replacement is somewhat impeded; nevertheless, a special vehicle is being developed for inspection of and minor repairs within the track beam. The command, control and communications (CCC) system is relatively conventional in concept, but because of the significant number of wayside components needed to carry out these functions, it is heavily dependent on hardware reliability for trouble-free operation. The demand option during off-peak hours seems to provide a relatively low-cost way to gain more efficient operation at those times. Its full effectiveness needs to be determined and evaluated in a revenue service operation.

Maturity of the System

The technical maturity of the design is a strong factor influencing the evaluation of the H-Bahn system. Therefore, it is important to review to what extent conventional and proven technology has been used in keeping with the overall philosopy of the developer and the implementation of the concept design. Use of conventional technology does not eliminate the development effort entirely, but certainly is a factor, along with a thorough test program, in minimizing the amount of effort required to bring the design concept to maturity. For those areas of the system where new designs and concepts are being utilized, the amount and type of testing of these new designs are important in evaluating the maturity of the system. The last factor to be discussed is the degree to which the total system has been tested in a configuration and environment that is representative of revenue service. Though conventional technology may be utilized at the component and/or subsystem level, the hardware interfaces and environment unique to the H-Bahn concept must be verified and proven through an extensive test program. The following comments summarize the findings on technical maturity:

a. The design philosophy of using conventional approaches and/or proven technology was actualized, to a large degree, during the development program. The prime exceptions are the use of a linear induction motor and its controls, the switches and the operations, and the traffic control areas of the CCC subsystem.

b. Testing and evaluation of several design alternatives have been carried out during the development program, particularly on the vehicle and guideway subsystems, and improving its maturity.

c. Extensive testing has been conducted during the development program, both with new hardware components and with conventional hardware in new configurations. More testing needs to be done, and is planned in the following areas:

- System integration tests under automatic control operation
- Endurance/reliability testing at a system level and with final design configurations
- Testing under abnormal conditions (anomalies).

Safety

Overall safety of the H-Bahn system has been addressed by the system developer through a fail-safe approach to the design and through general safety practices and features. Detailed safety analyses such as failure mode and effects analysis or a fault-tree analysis have not been accomplished to date on the entire system or on each major subsystem. At the present time, an analysis of the fault types and their effects based on stringent Federal Railroad requirements is being carried out by TUV Rhineland for safety-related components. Although developed in accordance with the strict safety standards of the German Railroads, use of the URTL safety logic in the H-Bahn system would be its first operational application.

Remarks on Rescue System

Auxiliary and rescue devices for H-Bahn are provided for different applications and already exist, in part, at the test facility.

If a stalled vehicle cannot reach the station under its own power, rescue can be accomplished by either pushing or pulling the vehicle to the next station (depending on the situation), by using the vehicle which follows it or by using a special vehicle. When special on-line vehicles are used, the passengers can be transferred from their inoperative car to the station. Ground-based special vehicles offer another method of escape. In the tunnel, the safety space can be used as the escape route. In special emergencies, such as fires, the vehicle must travel to the next station or the rescue tube can be deployed.

The nature and extent of the rescue equipment to be deployed will depend upon:

- the tolerance time until rescue is initiated
- the usability of a given system on a given section of line
- the probability that an emergency will occur.

Individual studies will have to be carried out for each individual H-Bahn application.

It is expected that in an H-Bahn network, with an appropriately designed and laid out rescue system, the passengers will be able to be rescued within an acceptable time frame.

Nevertheless, when using a trailing vehicle to push or pull, care should be taken to ensure that operating personnel reach the on-line station where the defective vehicle is located. The time required for the operating personnel to arrive, the disconnection of the safety level, the bringing together of the vehicles, the coupling, and pushing to the next station after the safety-switch system has been reactivated, must all be taken into account.

When using a special vehicle to push or pull the defective one or to rescue passengers, the defective car must be reachable. In other words, the approach path to be traveled by the special vehicle in the network must be clear to enable the rescue vehicle to reach the defective car in a tolerable amount of time. The location of the special vehicle in the network is important in this regard, as well as the time it will require to reach the defective car.

If the passengers are to be rescued first, using the special vehicle, equipment with extendable rescue catwalks plays an important role in joining the vehicles; depending on the catwalk arrangement, a defective vehicle can be reached over the same guideway member or over the parallel guideway.

When transferring passengers over the extendable catwalk, the unilateral loading can result in a lateral displacement of the vehicle and, hence, of the catwalk. By using some special device; the tilted position could be limited.

A combination vehicle for use in the system is anticipated as an auxiliary vehicle either to make a cabin operable or to push or pull it away if stalled; it will also be used to rescue the passengers. For forming trains, using a larger emergency vehicle with the necessary carrying capacity is also possible.

Use of ground emergency vehicles assumes that the location can in fact be reached by such a vehicle.

If tunnel escape routes are to be used, passengers must be able to open the vehicle doors in emergencies. The locks, like the rescue tube, could be released by a signal from the control center.

If particularly rapid rescue is necessary, as in the case of a fire, the fire detectors in the car will report this to central control. With the use of nonflammable materials in the vehicle, passengers should have sufficient time to reach the next station assuming the level of toxicity from the nonflammable materials is not excessive.

In the unlikely event that two emergency situations occur simultaneously, the rescue tube lock is designed to be released. But problems may arise if the tube is used to rescue certain groups of passengers such as the elderly, the handicapped, and children, and difficulties may also become apparent if the distances to the ground vary or if the vehicle is trapped over a waterway. In the event of a fire, it is questionable whether all passengers could escape. Therefore, further tests will have to be conducted on the rescue tube design and any modifications should be tested as well.

The proven feasibility of using rescue chutes assumes that such a system could be developed for special H-Bahn application. The question of whether the rescue tube would be adequate as a means of rescue also depends upon the probability that a dual accident would occur. Sufficient testing of all rescue systems discussed will assure public safety.

System Availability/Reliability/Maintainability

Although several good reliability practices and features have been incorporated into the design, a detailed reliability analysis allocating and specifying reliability requirements and goals for each subsystem has not been conducted. Using theoretical analysis is viewed with a certain skepticism by the manufacturer of the H-Bahn. Their approach is more of accumulating test experience and resolving problems as they occur. By October 1979, 100,000 km had accumulated at the Erlangen test facility with another 500,000 km planned. Thus, sufficient experience with the system should be obtained in order to evaluate system reliability and determine improvements necessary for revenue service. One area needing further attention and evaluation is the scheme for taking care of disabled vehicles. Some concepts have been discussed (see Section 4.7.4); actual testing at Erlangen of these methods will be performed in 1980 and 1981.

Maintainability features of the H-Bahn system appear to be very good, particularly with respect to the vehicle. Hardware accessibility was a dominant threme in laying out the vehicle design and the maintenance center. The use of pallets for the vehicle auxiliary and control equipment, in addition ot an open (rather than enclosed) track beam in the maintenance center, allow for direct access to every major vehicle component. In contrast, the inside of the track beam and the wayside hardware located there are not easily accessible. Manholes are provided at each support (max. 37 m spacing) for access/egress to the enclosed structure. Although the inside of the beam is not easily navigable, most of the wayside hardware is passive equipment, except for the switching ramps. Thus, it is expected that frequent maintenance will not be necessary. The current test program at Erlangen, however, will be the proof of this. Inspection of the inside condition of the beams and inside the beam-mounted equipment is being considered by using Television (TV) mounted on the bogie of a special vehicle. This concept will be implemented and evaluated at the test track.

The cost of maintenance and repair is strongly affected by component reliability, wear-resistance, accessibility, and interchangeability. In addition, if preventive maintenance is carried out too infrequently or "deferred" to save money, equipment defects are more likely to occur and lead to operating faults. High reliability and wear-resistance will increase system availability, reduce the required vehicle reserve, limit the size of the repair shop and the maintenance crew, reduce time required for maintenance and repair, and in the final analysis, reduce total operating costs.

The need to achieve the lowest practical costs for maintenance and repair must therefore be carefully considered. Measures contributing to low maintenance costs and to infrequent operating defects can be instituted with good engineering, and are suggested in broad terms by Table 5-3.

Often a compromise must be made between the quality and the cost of a component; for example, instead of using a material which is particularly wear-resistant but costly, it is possible to select something which will be much more reasonably priced but will have a shorter lifetime.

In making this decision, the operating costs for personnel and parts, which will be made necessary by the more frequent replacement intervals, must be taken into account as well as such points as availability, vehicle reserve, and the size of the repair shop. Additionally, the anticipated increase in the cost of the part (material) and for maintenance personnel must be taken into account.

TABLE 5-3. MEASURES FOR ENSURING LOW MAINTENANCE COSTS AND HIGH RELIABILITY

	For Low Maintenance	For High Reliability
Long Maintenance and Repair Intervals	Use of wear-resistant materials, low maintenance components	Use of components with high reliability for transit systems. Use of the smallest possible number of components
Few and Short Operating Malfunctions	Timely maintenance by correct establishment of maintenance and wear intervals on the basis of maintenance schedules	Redundant design, rapid detection of defects, and reaction by a device for real time fault detection
Simple and Short Maintenance, Repair	Simple interchangeability of components as a result of easy accessibility and the use of plug-in boards Setting up a well-organized repair facility with an automatic check-out system; Personnel training	

In the case of H-Bahn, many of the measures outlined have either been provided already or are in the course of being provided.

In order to reduce maintenance expense, the lifetime of parts subject to wear is increased by improving materials on the basis of long-term test results; the wheel and power/rail/current collector materials fit into this category.

The requirements of high component reliability and low repair costs have been considered and met by the manufacturer in the extensive use of conventional and proven technology in H-Bahn. Conventional transit mode experience was integrated into H-Bahn development by involving experts in railroad engineering and searching for applicable data in existing comprehensive literature on conventional railways.

Reliability analyses have not yet been carried out, but the overall system and its individual components have undergone development since early 1978 in long-term testing. Any defects that have cropped up have been evaluated and have resulted in overall system and component improvements. This procedure means that most of the system's problems will have been worked out prior to its being put into practical service.

The reliability and number of individual components are critical to the repair time needed for the system and, consequently, to system availability as a whole. For example, by using a redundant component design, system reliability can be increased, thereby reducing operational disturbances. Nevertheless, an increase in the number of components resulting from redundancy will lead to an increase in component failures and maintenance effort.

The maintenance and repair intervals established thus far are based upon experience gained at the test facility during operations through the year 1978, as well as from experience with conventional transit modes. Further long-term testing at the test facility or at the first demonstration facility will provide additional necessary experience on the failure rate of the components and the lifetime of parts subject to wear. Test and demonstration operation is therefore particularly important. Evaluation of the data obtained will provide additional information, especially for operation in complex networks, on the following:

- Maintenance intervals and maintenance schedules, maintenance strategies for central control
- Operational system realiability and availability
- Necessary vehicle reserve
- Design of realtime fault recognition and handling of malfunctions by central control
- Type and number of checkout facilities
- Size and equipment of maintenance and repair facilities
- Personnel training for maintenance and repair
- Costs of maintenance and repair.

Corresponding information could be gained by reliability analysis. Using theoretical analyses exclusively is viewed with a certain skepticism by the manufacturer of H-Bahn. The manufacturer prefers to perform practical test analyses of the test results and to make modifications to the system or repeat tests if necessary, in order to gain the proper information.

In order to handle short-term temporary malfunctions on the vehicles, a fault-recognition system has been developed for H-Bahn. At the present time, a hierarchy of three fault classes has been developed.

Experience with automatic people movers in the United States has shown that such a system is very important for realtime fault-recognition. A vehicle which is not completely reliable is therefore taken out of service rapidly and cannot cause further problems in operation.

Low cost maintenance and repair is recognized as an important developmental goal of H-Bahn technology. Command and control units in easily replaceable modules, guideway components which are readily accessible at the shops through open guideway supports, simple interchangeability of components mounted on the vehicle roof, as well as a rapid fault-detection system designed around automatic check out stands, and an especially short maintenance and repair time are expected for the vehicles.

Nevertheless, this says nothing about the frequency of required maintenance and repair work, which depends on the number and actual lifetime of parts subject to wear, the number of the components, and their reliability. As mentioned above, these facts should be determined by further operating experience or by reliability analyses.

Cost-Saving Features of H-Bahn

Among the predominant, potential cost-saving features of the H-Bahn system is the guideway design. Its sleekness and narrow cross section minimize the amount of material required for fabrication, land use, and right-of-way costs. The enclosed track beam concept precludes the need for snow and ice removal equipment and labor, or for a permanent snow/ice preventative system. The life of wayside components enclosed by the beam should be enhanced with protection from the natural environment, thus reducing life-cycle costs. Prefabricated construction offers potential significant cost and time savings in the construction and installation of the guideway. In addition, the linear induction motor design option for the vehicles provides the capability to accommodate grades as high as 15 percent, thus permitting more cost-effective guideway layouts of the system.

The vehicles can easily maneuver the tight curves on the guideway because of the speed control system. This allows the guideway pattern to be flexibly fitted into a city's layout; right-of-way costs can then be minimized. Costs can also be reduced by "on-demand" line operation for off-peak hours, thereby eliminating the cost associated with operation of empty vehicles.

5.2.2 Subsystem Assessment

5.2.2.1 Vehicle - In assessing the H-Bahn vehicle's design and performance, the technical maturity of the vehicle and its safety, reliability and maintainability are addressed. The technical maturity of the vehicle is evaluated in terms of incorporated conventional/proven technology in the design and the degree of testing that has been performed on new hardware at a system level.

Technical Maturity

In reviewing the vehicle design in terms of incorporated conventional/proven technology, one positive aspect of the developer's approach was to guide the design toward proven technology by using specifications derived from other transit properties. For example, "Recommendations for Rolling Stock of Rapid Transit Systems," (VOV 6.030.1, June 1969 edition with supplement) and "Load Assumptions and Safety Factors for Rail Vehicles," (2nd edition, Light Weight Vehicle Construction, 1970/71, No. 14) are among several documents used in defining the technical requirements of the H-Bahn vehicle.

Commonality of the vehicle's design with other transit vehicles is illustrated by the use of aluminum construction which is a standard construction material used by the light rail industry, for the medium and large size cabins, and by the use of nonflammable material for seats which has been further developed and is now being used for conventional transit systems. Also, the air/rubber spring suspension system and the "power-off relay with springs" emergency brake concept are design approaches used on light rail systems in Germany. The 130 V-dc drive motors that propel the two dc drive option vehicles at the Erlangen test facility have been used previously for the Siemens Electric Car produced by Volkswagen. However, a larger motor (440V dc) will be used for operational deployment in the H-Bahn system.

In some cases, hardware used in the H-Bahn vehicle design has received extensive usage in non-transportation related applications or has been the result of extensive tradeoff analyses and tests early in the H-Bahn development program. The tube escape system has been used to some degree in existing buildings under emergency conditions and by the fire department in some areas. Though the bogie (truck) design and structure are unique to H-Bahn, much of the electrical and mechanical equipment is conventional technology. The 24V batteries for onboard power are commercially available, while the passenger communication system uses conventional technology commonly used, e.g., in remote-controlled crane operation. The infrared system used to activate the vehicle doors is a result of an early tradeoff study that evaluated several mechanical and optical systems. Used extensively for remote control of televisions, the infrared system has been specially modified for the H-Bahn application to terminate precisely aimed command signals. Both the copper material for the power collectors and the solid rubber-on-steel support wheels for the bogie, are a result of tradeoff studies that evaluated several materials and configurations.

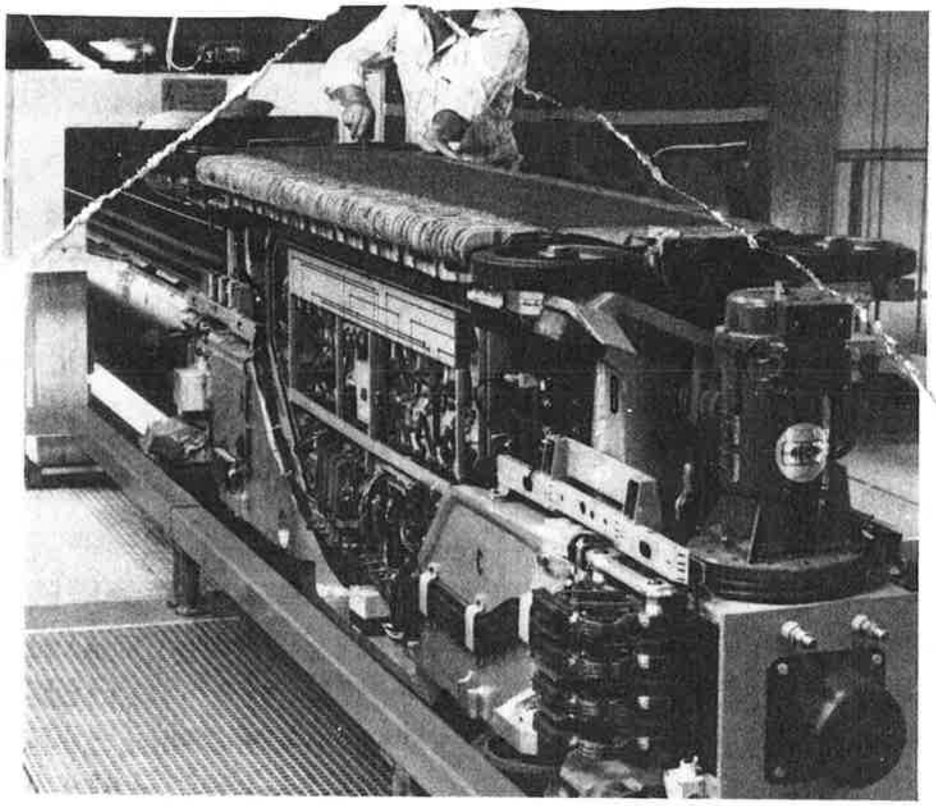
To the extent that conventional technology and design approaches are incorporated into the H-Bahn vehicle, the vehicle development program should and has, to a large extent, focused on the interfacing and integration of this technology and on those designs and hardware which are new. The fiberglass small cabin, the onboard switching system, the bogie structure, and the linear induction motor are key vehicle subsystems which were new designs and, therefore, required and received extensive testing.

Though fiberglass material had been used before for various vehicle parts the concept of a totally fiberglass structure was new and needed verfication in terms of structural adequacy and flammability. Extensive fatigue testing was conducted on the small cabin. Two million cycles at 30 percent maximum load were applied along each axis without any major problems. Some torsional testing was also conducted. Meanwhile plans have been prepared for crashworthiness testing to take place. Flammability tests on the cabin material and the seat material have been conducted in accordance with German specification DID 3102 with successful results. In the case of the onboard electro-mechanical toggle device that is used for proper positioning of the switch wheels, the design has evolved from a three-phase ac motor-activated device to a pneumatic system, which has operated reliably to date over approximately 270,000 switch cycles during the vehicle test program. In addition, as a test of design durability, over 1000 switch cycles at vehicle speeds of 50 km/hr were performed using the backup system of mechanical ramps in the guideway as the forcing function for the switch against the air pressure of the toggle switch cylinder.

Though utilizing, to a large degree, conventional mechanical and electrical hardware, the bogie structure design is new and requires verification of structural adequacy in the H-Bahn operation enviornment. The mileage accumulated on all the bogies to date in the vehicle test program (approximately 100,000 km as of October 1979) has provided some operational experience with the bogie; additional mileage (500,000 to 600,000 km) will be obtained during the remaining portion of the test program.

The vehicle subsystem to receive the most attention during the development program was probably the propulsion system, which included the dc motor and ac linear motor (Figure 5-3). The linear motor initially was designed as a single-sided, linear synchronous motor. It was first tested at a small (170 m) test track in Berlin in 1973 and then later at the Düsseldorf test facility during 1975 and 1976. Valuable information was gained relative to the basic performance of the motor, namely air gap sizing, power factor, force levels, etc.

The experience gained by the German Federal Ministry for Research and Technology from their studies brought about a change from a synchronous linear motor to an asynchronous linear induction motor (LIM). This was done to allow scheduled line operation



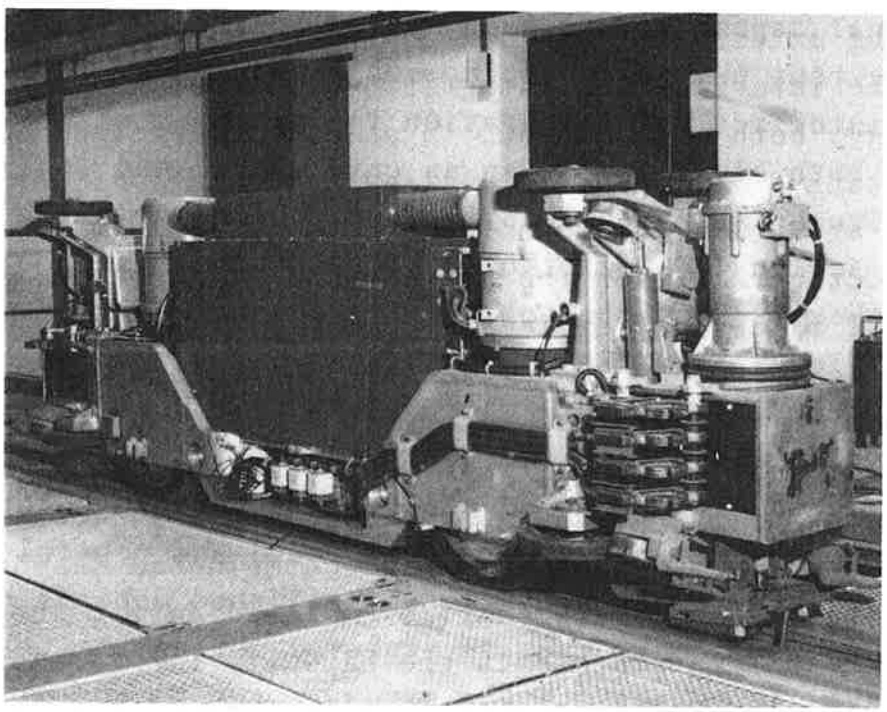


FIGURE 5-3. LINEAR AND DC H-BAHN TRUCK DESIGNS

with variable speed and because a variable frequency power source was necessary to vary the speed of the synchronous motor and thus the vehicle. (With an asynchronous motor, speed variation can be effected through voltage control.)

The LIM has been under development since 1976. At the time of the assessment, four of the six test vehicles used at the Erlangen test facility were equipped with LIMs. Total mileage accumulated during the test program through September 1979 on vehicles equipped with linear induction motors (LIM) amounted to 25,000 km; these tests indicated that the LIM is performing satisfactorily, and that the experience to date has been important in reducing the technical risk involved in using this type of propulsion system. Fears that continuous acceleration in stations could loosen the reaction rail during long-term operation have not been realized. Some problems have occurred with the reaction rail due to extreme acceleration conditions caused by a vehicle being accelerated several times with the brakes on, but these have been resolved. More endurance testing is planned for LIM vehicles.

One final aspect of assessing the maturity of the H-Bahn vehicle is the extent that the development program has focused on and tested the interface and integration requirements of the vehicle technology, both old and new, in an environment and configuration representative of an operational system. In considering the test programs at Berlin and Düsseldorf, the 100,000 km accumulated through October 1979 on the vehicles at Erlangen and the planned additional mileage of at least 500,000 km (test program objective is to collect 100,000 km per vehicle), should provide sufficient experience to validate the interface between the various components of the vehicle and between the vehicle and other key subsystems such as the guideway and the command and control subsystems. The extent to which this is accomploshed depends on the configuration of hardware that is employed during the test program and how closely it represents the hardware for an operational deployment. The Erlangen test facility provides a system configuration for testing the vehicles that is representative of an operational deployment to a significant degree; for example, the facility encompasses on-line and off-line stations, switches, computer-controlled operation, maximum vehicle speed capability, maintenance facility, and other features. There are, however, a few configuration factors regarding the vehicle and its interfaces which need further evaluating and, perhaps testing prior to system deployment for revenue operation. These are as follows:

a. Mileage and experience, to date, on the vehicles at the Erlangen test facility have been accumulated with a feeder voltage from the power rail system of 380V 3Ø, 50 Hz. The feeder voltage planned for an operational system is 660V, 3Ø, 50 Hz. The change in voltage level does not affect the overall design of the power supply and vehicle equipment. The necessary switching equipment for 660 Vac is all off-the-shelf equipment, and its functional reliability has been proven. This change between the vehicle and power distribution system interface will be demonstrated prior to its operation in revenue service.

b. The change above also affects the sizing of the dc drive motor which has been at 130V during the development program, but is planned for 440V for the operational deployments. The large motor has already been developed as a traction motor and, therefore, only requires certain basic tests which could be carried out at the test area. Since the drive wheels and the transmission have been adapted from the traction motor design, the larger motor can be used without significant risk.

c. Though a mechanism linking two or more vehicles together for trained operation is planned, and has been ordered, there has not been any testing at the time of the assessment with this feature. Though the H-Bahn system can operate without this feature, it does provide good flexibility during peak-hour traffic and could be a key marketing feature of the system, once tested and verified. It is planned that couplers will be delivered, installed and tested in 1980 for two vehicles.

d. The vehicle interface with the recently changed antenna of the data communications system could use more test and evaluation, since the antenna design and location was changed only a month or two prior to assessment. If a new antenna system is to be designed for installation inside the track beam, test and evaluation at system level would be required prior to revenue operation. Provision has been made for these tests and the Federal Ministry for Research and Technology has promised financial support for this work.

e. The passenger evacuation system design has received only limited testing to date. Considering that the tube or "sock" design will be used only as a last resort, and that the main emphasis of the H-Bahn design has been on other approaches like preventive measures, particularly with respect to fire safety, the limited testing does not represent a problem. However, more testing with the "sock" design would be useful in understanding the capability and constraints of the approach.

In summary, there is an inherent level of maturity in the H-Bahn vehicle that is implied by nature of the conventional technology and previously proven hardware used in the design. Also, extensive testing has been conducted on those parts of the design which are new. The key factor toward reaching overall maturity of the vehicle is the additional testing and evaluation required in those areas, previously mentioned, that have a bearing on operational deployment. With this completed, the H-Bahn vehicle should play a reliable role in the operation of the H-Bahn system.

Vehicle-Safety/Reliability/Maintainability

In addition to the technical maturity of the H-Bahn vehicle, other issues such as safety, reliability, and maintainability of design have been addressed. In regard to safety, conventional approaches have been used in the vehicle design. Safety-glass windows, door safety edges, provisions for emergency lighting and communication, and an interlock between the door open/close status and propulsion power are just a few. Fire alarms are provided on each vehicle, although they only serve to send the vehicle to the next station, if activated, rather than allowing the doors to open. Though general safety studies have been conducted on the vehicle design, a detailed component-by-component failure modes and effects analysis has not been undertaken to ensure that the design is fail-safe under all conditions.

Similarly, a detailed reliability analysis allocating quantifiable design levels of reliability to each vehicle component has not been conducted. Nevertheless, the vehicle has been designed using general reliability practices such as redundancy, fault identification, extensive design tests and analysis of failure data in order to make appropriate changes. The current 15 hr/day operation of the vehicles until 100,000 km is accumulated on each vehicle is providing a good failure data base for evaluating reliability. Log books are being maintained and reviewed at the test facility for developing such a data base.

System availability is enhanced by the use of redundancy in some areas of the vehicle design. The toggle-switch system is situated at the front and rear of each truck (bogie) with either system being able to negotiate a turn if the other is not working. Except for the small vehicle which has only one bogie, redundancy on propulsion power is provided in the larger vehicle designs, which incorporate a minimum of two bogies. If propulsion power is unavailable on one bogie, adequate power is provided by the remaining bogie(s) to move vehicles at reduced speed to the next station. Vehicle direction is also reversible which provides flexibility in vehicle maneuvering during abnormal situations. With more than one door being provided on each vehicle, redundancy ingress/egress is available.

The attention given to vehicle maintainability is significant, particularly in regard to accessibility of the hardware. Control and auxiliary equipment mounted on pallets are located under the seats and are easily accessible from outside the vehicle. Quick-release plug connections are provided for easy removal. Location of the power equipment in the truck and the control and auxiliary equipment in the cabin avoids the need for extensive power lines between the two. Non-use of the slotted box surrounding the guideway running surface within the maintenance facility allows for easy and total access to every major component of the vehicle. Equipment such as the air compressor, brake resistors, etc., located on the recessed roof of the vehicle, are also directly accessible and, in fact, are entirely unprotected from the environment, raising some concern as to their resistance to moisture.

A diagnostic facility also contributes to the concept of efficient maintenance. At the present time, a fault recognition design is being developed for vehicle equipment and for the data transmission system which can transmit three different types of faults in the vehicle to the central control. These faults are then encoded into a collective report and transmitted. There are three different collective reports (fault types):

Fault 1: This report is transmitted as a collective report in the event of failure of the components on the TF unit which are necessary for operation. Fault recognition causes the vehicle to go into emergency brake application.

Fault 2: This report is given as a collective report in the event of failure of components which are not absolutely necessary for operations, but the vehicle must be taken out of service as soon as possible (for example, at the next stop).

Fault 3: This report is given as a collective report in the event of failure of components which are not absolutely necessary for operation. The vehicle can remain in service until the scheduled end of its trip.

5.2.2.2 Overall Guideway System - The principle behind a suspended vehicle has been used in Germany and Wuppertal and for the Cabintaxi system, and in the U.S. for the Jetrail and Monocab Systems. The H-Bahn guideway manufacturers, using very basic, sound, civil engineering practice, have produced an elevated guideway system suitable for urban integration. The guideway components are designed and constructed of proven materials, using conventional construction in accordance with the regulations of the Federal German Railways which are recognized internationally as being strict.

Reinforced concrete and structural steel are used for the fabrication of track beams and support columns. No new or untested materials are utilized for guideway fabrication, but the nature of vehicle support subjects the track beam and columns to a different load environment than bottom supported systems. Because the success of this design concept hinged on the development of a track beam which was sufficiently stiff and offered a variety of column types which met site specific needs, a comprehensive test program was necessary. The testing effort at Düsseldorf and now at Erlangen has done much to refine, design, and evaluate alternatives and options.

The track beam has been redesigned since the extensive test program in Düsseldorf. There, steel truss and full-steel-wall track beams were evaluated for rigidity (resistance to deflection), noise, vibration, and protection from the elements, as well as construction tolerances and overall guideway appearance. The lessons learned formed the basis for design of the Erlangen track beam which cost effectively utilizes a thinner cross-sectional steel beam stiffened by reinforcing ribs spaced along the beam length. Further refinement of track beam design will be minor. Siemens is contemplating removal of the running rails, using the bottom web of the beam as the running surface. No major changes are contemplated or appear necessary.

Some testing of support columns, foundations, and column heads suspension has been conducted, but design changes to these components have been minor and are based mostly on experience gained in construction and fabrication of supports for the Erlangen test track. Problems encountered in fastening track beams to column heads were identified and a redesign of the mounting arrangement has been completed. This new suspension will permit simpler installation and adjustment of the track beams.

Various versions of the columns have been installed for evaluation at the test track at Erlangen (Figure 5-4). Measurements of their stresses and deflections, especially in those with excessive cantilever, are being accomplished to bear out design computations, but little refinement appears necessary.

Track Beam -- The design of the track beam allows for maximum protection from the environment. Since the beam is a slotted box girder, rain, snow and wind, etc. have little affect on system components such as power rail switches and running surfaces. (Figure 5-5.) The only weather-related problem with the track beam configuration seems to be condensation. On occasion, water droplets accumulate on the inside face of the top plate, drip onto the running rails, and combine with brush fibers and tire filings to form a slippery surface. Siemens is aware of this problem and plans to correct it with a brush system to keep the running rail clean. If a brush system can be mounted to the front of the bogie this problem should be mitigated.

Thermal heating of the track beam is another environmental condition which could be a problem. The steel track beam surface, in arid climates can theoretically experience high temperatures. Expansion joints are therefore provided to reduce the probability of track buckling. Measurements of interior beam temperatures at the Erlangen facility have proven to be only slightly greater than the ambient temperature, but in warmer climates, high intensive temperatures and humidity values might affect the performance of electrical components.

The steel-walled beam with rib bracing appears to offer more than the full steel and concrete beam alternatives. Besides being the only beam type tested extensively, the beam can be fabricated using a constant cross section, and by varying the rib spacing; the desired stiffness can be attained this way. A major cost-saving feature of the H-Bahn track beam is that it can be constructed of standard sizes, off-site, and can be transported

FIGURE 5-4. EXAMPLES OF STEEL AND CONCRETE SUPPORT COLUMNS

FIGURE 5-5. INTERIOR OF TRACK BEAM

to the site of erection (Figures 5-6 and 5-7); however, the overall guideway cost is affected by the distance the track beams must be transported from plant to construction site. Prefabrication of guideway components allow for increased quality control tolerances. Construction experience at Düsseldorf and Erlangen revealed how critical quality control is for guideway erection and adjustment. Disruption of traffic and site disturbance are also reduced by track beam prefabrication, since site work is limited to excavating, pouring the foundation, and column and track beam erection.

Access and maintenance of the H-Bahn track beam is accomplished using the manholes located atop each section of track beam

FIGURE 5-6. TRACK BEAM PLACEMENT

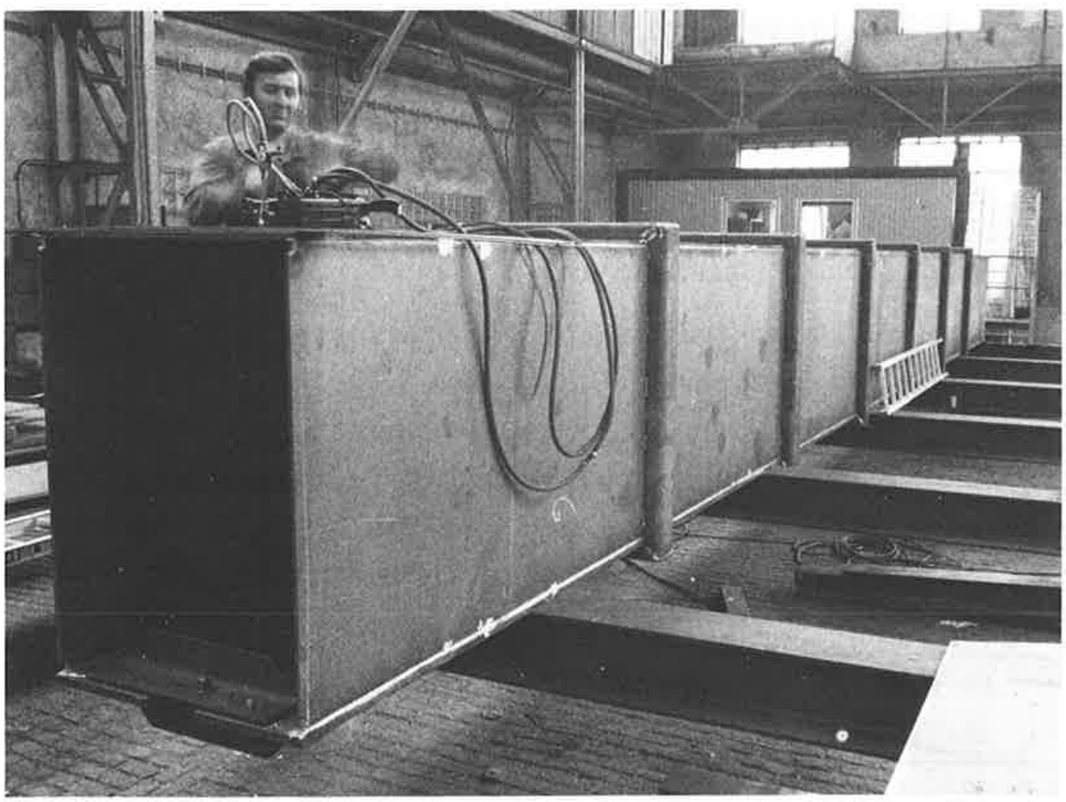


FIGURE 5-7. PREFABRICATION OF TRACK BEAM

and by openings at the switches. Access can also be gained where the track beam enters the maintenance facility. Work area within the beam is very limited, and for major repairs or replacement of power rails, etc. system downtime might be significant; however, incidents of this type are not expected to occur frequently. (Replacement of the power rails is expected to happen no less than every 10 years.) A vehicle which can be driven inside the beam is planned for operational service. A troubleshooting system utilizing a CCTV camera mounted on the front of a bogie is being considered for detecting problems and monitoring maintenance operations. Maintenance of the track beam exterior, will require touch-up painting approximately every 10-15 years and complete repainting every 20-30 years, unless CorTen steel is used. Siemens has tried CorTen, but the rusting has not stopped and drippings have stained the concrete beneath the guideway. (According to a bulletin issued by the Federal Ministry of Transportation dated, April 28, 1973, weatherproof steel may no longer be used for bridge construction.)

From a safety viewpoint, the H-Bahn system has the advantage of having the power rails located in a sheltered area within the beam. The closed beam configuration also provides much better protection from foreign objects than most supported systems, although there is a remote possibility that objects could be tossed into the beam from beneath.

Clearance problems for H-Bahn vehicles are the same as those for other suspended systems. The bottom side of the vehicle is normally 4.7 m above street level so it cannot be damaged by normal vehicles. Only oversized vehicles (which usually require special permits) must be considered and can be safely accommodated by instructing operators of the potential hazard. (Figure 5-8.)

<u>Columns and Foundations</u> -- The H-Bahn system requires a narrow right-of-way and can be integrated to almost any urban situation including installation over median strips, sidewalks, roadways

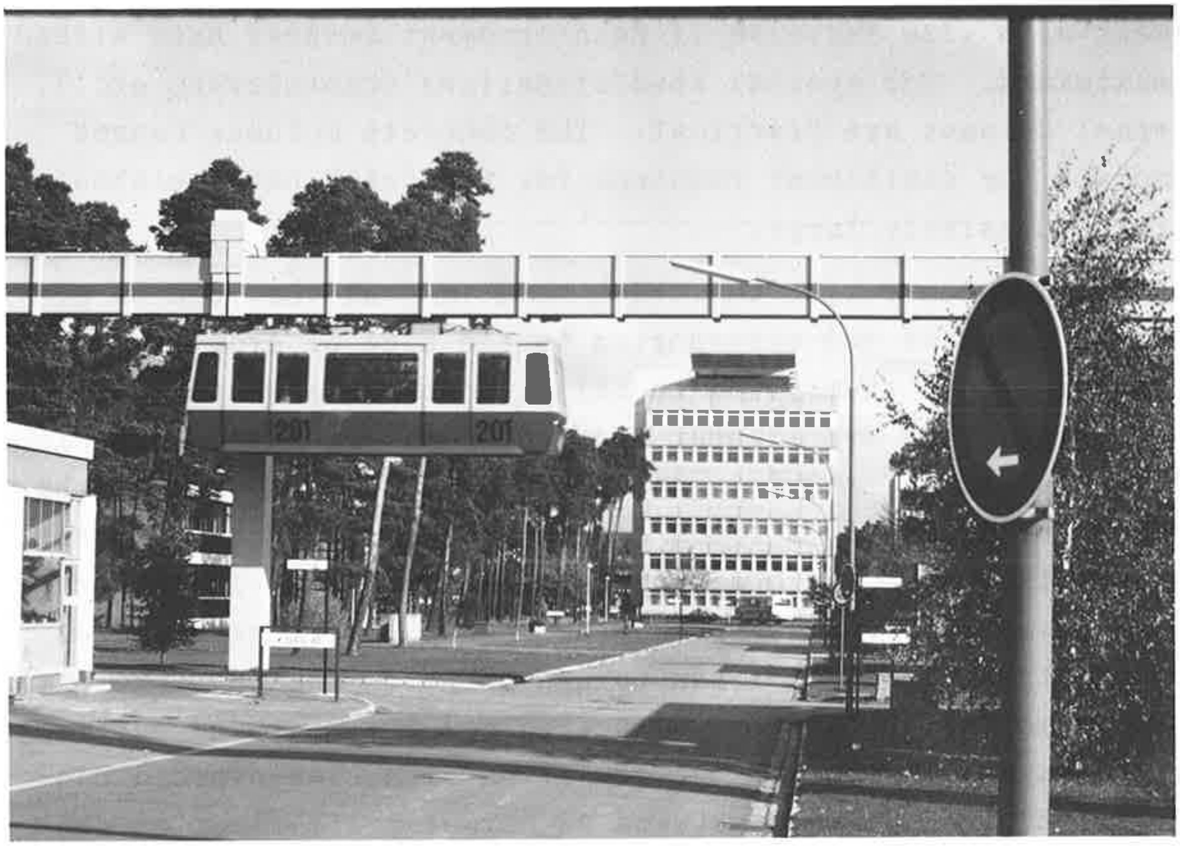


FIGURE 5-8. INTERSECTION OF H-BAHN AND ROADWAY

and walkways. The support columns, which come in several shapes and are fabricated of either steel or concrete, have been successfully demonstrated at the Erlangen test track. The columns are designed using standard specifications for rail-road-bridge construction in Germnay and their design appears to be rather conservative. For example, columns located in local traffic areas are designed to withstand an impact of 100 tons and all others a minimum of 25 tons. The support columns, as mentioned before, can be constructed of steel or concrete and there are some definite advantages to each. The steel columns have smaller cross sections and, therefore, can be utilized most anywhere. To accommodate impact loadings, the steel column walls need only be made thicker, while the concrete columns require additional reinforcement or a size increase if reinforcement amounts have already been maximized. For special load situations (cantilever, etc.), only steel columns are practical. The concrete columns cannot accommodate the cantilever required for two track beams without becoming excessively large.

The columns are like the track beam in that they can be prefabricated off site and transported to the site of erection. Steel columns lend themselves to this type of construction more so than concrete; they are lighter and can be fabricated in one piece. Erection is simple, requiring only bolting of the column to the foundation head, and full loads can be applied immediately after fastening; therefore, site disruption is minimized. The concrete columns, however, are massive and the spinning process utilized for fabrication is only for the column proper. The concrete uprights are molded by centrifugal action and the mast and outtrigger must be preassembled at the factory or on site. Reinforced concrete uprights can be manufactured as normal prefabrication concrete parts in one piece, but transportation costs of either type of concrete column are greater than for steel uprights. This, coupled with the increased time and effort needed for erection of concrete columns in sleeve foundations, tends to negate the cost advantage that concrete has over steel.

Column maintenance is a function of whether steel or concrete is used. Concrete columns do not require any maintenance, but steel columns require some painting approximately every 10-15 years.

To protect against rust, it is expected that the outsides of the guideway supports will have to be given a touch-up coat of paint every 10 to 15 years and a complete coat every 20 to 30 years. According to the headquarters of the Federal German Railway System, these intervals can be achieved with appropriate preparation (sanding, priming, etc.). There is also a corrosion-proof paint coat on the inside of the guideway. Only one paint coat has been put on at the test facility, and it has not yet been necessary to touch it up. It is not known how often and to what extent rust-proofing will have to be applied to the interiors of the guideway supports in a future installation designed for long-term operation. It must be determined how water condensation precipitates inside the guideway supports, and how it can be avoided.

On the basis of long-term tests and the testing of vehicles designed for inspection, cleaning, and maintenance which are now being developed, further information will be available on guideway maintenance and repair.

5.2.2.3 Switches - The H-Bahn switching system is a new design; hence, its level of maturity is a function of the test cycles conducted at the Erlangen test track. By the time testing is completed, the primary toggle device will have been cycled 270,000 times, and the mechanical ramp cycled 1000 times at 50 km/hr (for test purpose only). To date, use of the mechanical ramps on the test track has not been necessary. The switch system design is considered fail-safe; continued testing of both the rockers and switch ramps will increase confidence in its safety and reliability.

Unlike the earlier switch design at Düsseldorf, the present switching system is compatible with both dc rotary and linear induction motors (LIM). This independence allows for greater flexibility in specific H-Bahn system designs. Safety and reliability are the key points or factors in evaluating a switching system. The rockers or toggle has several features which help develop confidence in it. The pneumatic toggle on the vehicle which receives its command from central control, must be in the full left or full right position, thus, preventing the situation where the toggle would fail to enter a switch wheel channel because the toggle wheels were in a balanced or neutral position. The use of a positive retention rail and two toggle switches per bogie also adds to the safety of this system. (Figure 5-9.)

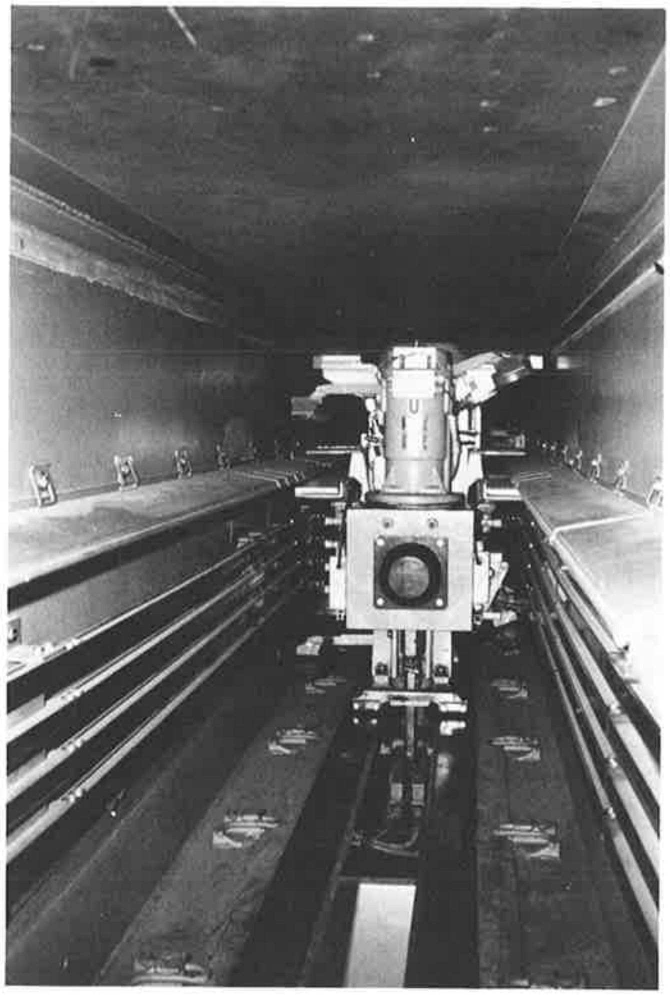


FIGURE 5-9. TOGGLE-SWITCH IN TRACK BEAM

The reliability of the switch ramp system will help ensure that the switch system will fail safe. Because the ramps for the merging condition are fixed with no moving parts, no problems or failure potential is apparent. However, for demerging operation, the ramps, like the toggle device, must receive a signal in order to position them in the left or right mode, but are not active in normal operation. Only if the position of the toggle on board the vehicle is not corresponding to the switchable ramp is the toggle forced by the ramp to the other position. The correct position of the switchable ramp (referring to its proper end-position as well as the vehicle-headways on both switch branches) is insured by the safety level (AVS). The safety of the demerging operation therefore corresponds to the high safety of the URTL system (see Section 5.2.2.5).

Finally, the possibility of a foreign object being tossed or introduced into the switch rail or ramp mechanism is remote but possible; testing of this condition would be advantageous. Also guidelines for fencing requirements based on beam height, etc., should be established to minimize outside intrusion.

5.2.2.4 Stations - At the present time three stations are in operation at the Erlangen test facility. (Figures 5-10 and 5-11). For this reason, the assessment study is based on their features and the preliminary design layouts for the proposed revenue system in Erlangen.

Station design for the H-Bahn system is intended to be flexible; that is, usable in elevated, at-grade and subgrade service, for single line and multiline traffic, and on-line or off-line service. An attempt has been made to employ modular design so stations can be sized according to line capacity.

Selection of materials for use in station construction are based on criteria such as low initial cost, reduced maintenance, fire resistance and vandal protection. The superstructure of stations utilizes conventional materials (steel and concrete) to produce attractive stations which are designed with efficient management of available space. The extensive use of glass within the stations creates a feeling of openness and increases the perceived security of patrons. Regular glass is used in conjunction with handrails as an alternative to using safety glass; but if desired, safety glass could also be installed. This feeling of openness extends itself to stairways and elevators where thin vertical windows extend along the entire length. The use of

FIGURE 5-10. H-BAHN STATION INTERFACING WITH EXISTING BUILDING

FIGURE 5-11. H-BAHN VEHICLE ENTERING STATION

hydraulic elevators has several advantages including a smaller space requirement for equipment, and insurance that the elevator cab will slowly return to the ground level should a mechanical problem or power failure occur, thus excluding the possibility of someone getting trapped inside the elevator between floors.

Stations have been designed to be accessible to the elderly and handicapped (E&H) by means of elevators and ramps. No obstacles which would prohibit E&H movement about stations were observed. Elevator controls, emergency phones, fare collectors and fire fighting equipment were conveniently located. Siemens/Düwag is testing an automatic positioning device that would limit the station-to-vehicle interface by no more than ±10 mm; this height differential is compensated for by the tilting step of the station platform. The use of mechanical clamps and a hinged platform to position a vehicle in a station provided the stability needed for safe passenger ingress and egress.

Station maintenance has been minimized by careful selection of materials. Floors are covered with non-slip rubber matting which can be easily mopped or hosed down, seating is of molded high strength plastic, and walls and doors are of painted metal. The computer units and other station equipment are easily accessible for maintenance, since they are located in locked cabinets off the main lobby.

The emergency exits were clearly marked, and the maximum distances to them were within the 30 m distance required by German standards. No sprinklers were installed in stations, but fire extinguishers were available corresponding to German requirements.

Fare Collection

Fare payment is normally not controlled by turnstiles in the Federal Republic of Germany. Instead, roving inspectors carry out spot checks. If a passenger without a valid ticket is found, he must pay an increased fare as a fine; at the present time this fine amounts to 40 DM (approximately 20 U.S. dollars) in Hamburg and Munich. Likewise, the H-Bahn will not have any turnstiles; however, they may be installed if the operator so desires.

Experiences with urban transit systems in the United States indicate that, despite close security, the number of persons riding without paying their fare is very high. Station entrances are generally protected by turnstiles; there is no experience with free and uncontrolled access to public transit systems. Therefore, for U.S. applications, various types of controlled access and egress methods, such as turnstiles, can be installed.

Also in the demand operation mode, if not turnstile-controlled, misuse is possible. Only practical operation in a sample installation will reval the extent to which misuse happens and the extent to which this can be prevented , e.g., by station TV. The following information represents experience with Dial-A-Ride bus systems in Germany:

- The novel idea of summoning rides using a keyboard did not pose any difficulty for passengers.
- After the penalty for misuse was abolished (the ride request used to cost 0.50 DM approximately 25 U.S. cents), the number of improper ride requests in the Lake Constance area rose sharply.

Demand mode ride requests will be initiated only in off-peak hours; hence the Dial-A-Ride experience with misuse, even if repeated in H-Bahn, will not be serious. In the U.S., the problem should be minimized.

The developers have not addressed the methodology of automatic fare collection specific for a U.S. environment.

5.2.2.5 Command, Control, and Communication (CCC) - This subsystem consists of four elements, described fully in Section 4: Communications Network, Supervisory Control, Traffic Control and Safety System. This assessment section will review the features of the system from the points of view of:

- Maturity of System
- Maturity of Components

- Technical Risks (if present system design were built)
- Reliability, Maintainability, and/or Cost.

Overall CCC System -- It is a truism of design that a system is more than the sum of its parts. Any assembly of system elements combined for the first time to perform a system function, whether the assembly is made of proven, mature parts or not, will not be of itself mature until it has been tested in all its modes, modified as test results demand, and run long enough to show consistent and repeatable performance within its nominal specification limits. The H-Bahn CCC system, now being tested at Erlangen, is such a system assembly.

In common with several existing and operating AGT systems, the H-Bahn CCC system performs, among others, the following functions:

a. It assures safe spacing between vehicles by means of discrete, fixed guideway blocks; the normal headway expected in use will be 50 seconds, although a minimum of 10 seconds is possible.

b. It controls speed along the guideway in a predetermined manner, and speed can only be modified downward.

c. It operates the vehicle system in a scheduled manner most of the time.

d. It can operate in a demand mode during lightly loaded times of day.

Architecturally the control system is also similar to some existing systems:

- It is hierarchically organized.
- Operating control and safety control are independent.
- Safety control is fail safe and responds safely to failures both in itself and in other control functions.

Though conventional in concept, however, the CCC, as implemented by the developer, utilizes hardware and software in a configuration unique to the H-Bahn system. Some of the hardware elements, such as the computers, guideway sensors, and URTL logic have been used in other applications, and can be considered mature. The software is new; thus, although proven components are used in command and control, their use together in a system is new.

For two years, the developers of H-Bahn have therefore devoted a major amount of time and effort in the test program at Erlangen to accelerating the growth of their control system and hastening its maturity. They intend their system to evolve, with lessons learned at each phase of the testing being fed back to correct troubles found, until they have a control system that is capable of operating in day-to-day service in a predictable and reliable manner.

The need to test new components such as the guideway antenna, and speed and safety sensors is clearly recognized. Extended testing of the entire vehicle system under complete automatic control is expected. Logs are being kept of all tests, including a record of all failures that occur.

This system is feasible and should work satisfactorily without much risk after the planned tests are carried out. Close attention must be given to analyzing the system's weak points and correcting them during the tests; elements of a reliability program, which will increase the length of relatively trouble-free operation should be implemented. (See the Recommendations Section for details.) The latter is particularly important, especially for the block and speed sensors, for many are mounted throughout the system. Approximately 400 sensors have been operating at the test facility for 9 months without any failures. If one sensor fails, however, operation at reduced speed is possible until the repair is made. Repairs are simple, with replacement accomplished by removing the old and plugging in a new part.

In the sections that follow the four elements of the CCC system will be reviewed separately for their performance in the four areas listed earlier.

1. Communications or Data Transmission Network:

Maturity of System -- FSK data transmission is a commonly used method for data transmission to moving vehicles. The system concept is thus relatively conventional. Its realization, however, is probably not too matrue. The equipment now used at the test track is not made by Siemens; later it is planned to replace it with Siemens equipment, which in turn will require some debugging.

Maturity of Components -- The antenna is still experimental. It was originally mounted inside the guideway beam, but transient signals from power rail/power pickup arching were excessive, and the antenna has been relocated outside the beam, where it is now a continuous wire, mounted on insulators below the beam. If Siemens had to build a system tomorrow this would be the antenna used. Development of a more noise-immune antenna is proceeding, and it is expected that in a system production model the antenna would be positioned inside the beam.

Technical Risk -- The system seems to be straightforward and conventional and should offer low risk of not being satisfactory. The present maximum rate of vehicle polling by station computers is eight vehicles per second. Thus the nominal minimum spacing between vehicles at full speed (50 km/hr) is 144m or 10 seconds. However, due to station dwell-time requirements, a headway of 50 seconds is usually expected giving a reserve factor of 5:1 to compensate for minor delays and breakdowns (see Section 4.8). Average station spacing is assumed to be approximately 500 m.

Reliability -- The data transmission system seems to be a good choice for H-Bahn. With extensive testing still to come, it will become mature. A particularly good feature of the entire system is that vehicle drive does not depend on a continuous flow of commands over the data system. Though the station computer might be defective, the vehicle can continue its drive by track speed.

2. Supervisory Control

Maturity of the System -- The supervisory control element ("Leitebene") as planned is not radical or particularly innovative, as has been described earlier. Its realization as an H-Bahn element, however, will require almost totally new software for the standard Siemens computers used. Naturally any system deployment would require a data base for control tailored to the site, but the basic programs would be the same, for they would perform the same supervisory tasks.

The control software is defined and specified, but its programming has not yet been done. The fact that the concept will work has been proven by the fact that a human operator standing in for the central computer has been operating the test track. The operators may be said to have been exercising "fly-by-wire" control over the vehicles. It is not expected that the central control will be operating automatically until 1980.

Maturity of Components -- The components of central control, for any deployed system, will be mostly standard and proven, as was stated earlier. The computers are standard Siemens series 330 process computers, and the software for generating the control displays already exists; only the operating control software remains to be written.

Clearly, if any system were sold in which computers other than Siemens own product were demanded by the customer, much reprogramming would be necessary.

Technical Risk -- The risk of failure in the realization of supervisory control seems low; the work still to be done is primarily software programming, and not software design. Nevertheless, to program a set of software so that the result is reliable and failure-free is no small task and requires much time and money.

Reliability and Maintainability -- The supervisory control hardware will be made up of mature elements, which should be adequately reliable. Some theoretical reliability calculations have been made; tests currently underway will establish their level of reliability. Siemens clearly understands the need for rapid diagnosis and repair in vehicular equipment, and how to achieve it. A rapid maintenance service for the computers already exists. Studies have been conducted of repair time, and have yielded quantitative data on intervals for preventive maintenance for the specific application at Erlangen.

3. Traffic Control Element ("Steuerebene")

Maturity of the System -- This element, which provides moment-to-moment line control for the system's vehicles, is quite straightforward in concept. Some of its hardware and all of its software are new. On the vehicle, the Drive and Brake Control Unit (DBCU) is a special electronic package that receives wayside signals and translates them into control signals for the motors, doors, and brakes.

Station computer software was being debugged at the time of the assessment. For a period of eight months in 1978, it had been tested in a simulation mode, using central computer software to simulate the vehicle. Since early 1979 testing with the actual vehicles has been progressing. At the time of the assessment, final software debugging was far enough along for Siemens to confidently have all the station computers and several vehicles operating automatically by June 1979.

Maturity of Components -- Standard Siemens process computers are used in the stations. Existing designs of permanent magnets are installed in the guideways as a speed-profile, and the Hall transducers used for the markers basically are stock items.

Technical Risk -- Enough has been done at the test track to prove that the traffic control system works, and there is a high probability that the control element in a deployed system can and will work as planned. The rate at which confidence in it will be built up during the next year will depend on how fast the program can be debugged, and how soon the full fleet of six test vehicles can be run simultaneously and automatically on the test track. Automatic operation with three vehicles will be demonstrated.

Reliability, Maintainability, and Cost -- The traffic control system, which was partially working at the test track in the spring of 1979, requires many wayside parts, whose individual reliabilities must be much higher than the desired system reliability. Part failures must also be easily detected and located to minimize system downtime. The need for short times to repair the many guideway components, has been taken into account; and many passive elements, such as the guideway permanent magnets, which are both easy to change and inexpensive, have been used.

4. Safety System ("Sicherungsbene")

Maturity of System -- The safety system was described earlier. Of all the elements of the CCC system, its hardware is probably the most mature, as it was designed for the German Federal Railways, beginning in 1968. It was tested over a period of four years, and has been accepted as fail safe by the railways. It is described in some detail in the Siemens literature. It is entirely hardwired and requires no software. It is known as the "URTL" equipment, and is designed and built by Siemens.

The entire safety system, of course, is more than the URTL equipment, one set of which is located with the station computer in each station. The entire system includes two passive safety sensors for each 12 m block along the guideway, switch ramp actuators in the guideway, and vital relays that finally cause the system to fail safe by cutting off the power to sections of the distribution system. The URTL has not yet been used in revenue service; an H-Bahn usage would be the first.

Maturity of Components -- The URTL, as was designed for the Federal Railroads, was modified for H-Bahn use. Nearly 30 percent of the printed circuit cards in this version are special. Thus, the apparent maturity of the system may be deceptive. The safety unit changes must be proven out at the test track. The URTL electronics has been under development for several years for railroad applications, and its design was thoroughly analyzed for reliability. Because of its redundant components and constant comparison of parrallel channels, it can detect any failure of its own parts. Its signals the failure and removes the actuating output signal, causing relays attached to the output to open (see Section 4).

The BERO sensors (magnetic switches designed for limit switch application), which are placed in pairs every 12 m along the beam, are standard Siemens products slightly modified mechanically to increase the spacing between the legs. This change was necessary because of the need to allow the vehicle's mounted vanes more vertical dynamic movement to pass through the sensor legs. The changed version has become a Siemens standard product. Its durability is the same as the original standard type.

The Hall transducers used as markers in the stations and at switches are also standard products, and hence are mature. Other parts of the system are new and peculiar to H-Bahn: the settable ramps for the switches are new, and they have been working as planned. Their reliability will be evaluated as the tests proceed. There has been only one failure among the 400 BERO sensors, within a 3/4 year of operation, and none among the Hall Transmitters. Both were designed for industrial environments, such as Rolling Mills.

Technical Risk -- The risk associated with using a large electronic system to process the outputs of safety-critical malfunction sensors would usually be considered high. According to all the available literature on the H-Bahn safety system, the URTL system has been designed so that any internal failure in its own circuitry will drop its output to zero, thus causing the entire section of power rail served by the station in which it is located to have its power removed. Test data is not presented, but extensive analysis done by the Technical University of Braunschweig and by the Siemens Braunschweig Division have convinced both the German railways and the Siemens project team that the URTL is fail safe and, hence, is a valid control element for a safety system. The railways have certified that a safety certificate could be granted.

Reliability, Maintainability, and Cost -- It is to be hoped that the URTL shows a long Mean Time Between Failure (MTBF). The extensive test program will demonstrate how well the system does work in simulated revenue service and how truly effective the rapid diagnosis, replacement, and repair features of the URTL really are.

No fault can be found with the decision to use the URTL, since the URTL is the most mature element of the control system; it has been extensively tested and analyzed, and is a Siemens product. Nevertheless, doubt remains as to the overall efficiency of the safety subsystem because of the way the safety shutoff is effected, i.e., by cutting off power to a sector of the track.

The URTL section is estimated to require about 2 percent of the system investment in the Erlangen application.

5.2.2.6 Power Distribution - The power distribution system at the test truck is somewhat simpler than would be needed in a deployed system, as is self-evident. The design and details of a real life system would be site specific. However, although the distribution of power would be at 660V, 30, 50 Hz, the test track installation was designed for 1000 volts; hence, a changeover from 380V to 660V would pose no problems.

A most important interface exists, however, between the power and command, and safety systems, for the transit system fails safe in the event of a safety critical failure when the affected section's power is removed.

Power to each section of the power rails is fed through a relay which is held closed when the system is "go," and is de-energized by the safety system when any overspeed, illegally reduced headway, or inoperative switch condition is detected. In other words, the system fails safe by removing power selectively from the power rail section or sections in which a safety critical failure has occurred.

Fail safe power cutoff would de-energize the guideway between stations, the average spacing of which would be about 600 m in a deployed system. In most cases one vehicle would be affected by an emergency stop. The contactors and relays, which are described in Section 4.5.2.3 under "safety control," are stated to be fail safe by TÜV. A full description of the power system is contained in Section 4.7.1.

The important parts of the H-Bahn power supply systems (power feeders and substations) will be made redundant for revenue service. This will be done to provide a high level of reliability in the H-Bahn urban transit system. In contrast with a non-redundant design, the probability of vehicle stoppage due to power problems is reduced. Bilateral feed of traction current in the corresponding power rail sections is ensured, if one substation should fail, with the two adjacent substations being able to take over the task of supplying the power to the affected power rail sections. If the high-voltage transfer station should fail, a switch can be made to a second high-voltage transfer station. In the event that the state power supply totally fails, the vehicles will be run to the next station using a central emergency power supply. The emergency power supply is dimensioned so that even the last section of the line can be cleared during a period of time tolerable for passengers.

The power supply to the stations, like the traction current supply, is made redundant. If the individual power supply at a station should fail, the equipment can be switched over to the city's 380 V low-voltage network. Additionally, in the event of a total line failure, emergency power supplies are provided for the safety system and station computer. The station doors will remain fucntional with a floating battery. The battery will also operate an emergency lighting system. A floating battery is also provided in the vehicle as an emergency power supply in the event of interruptions in the traction current. It supplies power for emergency lighting, communications with central control, data transmission, vehicle ventilation, and fire detection systems for about two hours. In accordance with VDE Regulation 0115, all system components capable of carrying current, are grounded, especially the guideway supports, the vehicles, and the station platforms. This provides protection against lightning and avoids potential for electric shocks. (A monitoring system to detect short circuits is provided. It includes ground faults.)

The dimensioning of the substations, feed cables, and power rails, with a predetermined train length and predetermined train sequence, is influenced significantly by the choice of drive, be it linear or dc motor. When dc motor drives are used, the substation wiring, the feed cable cross sections, and the power rails can be made smaller than when linear motor drive is used. Hence, in each specific application, the type of drive must be determined before the power supply system is designed. The power rail/current collector system is currently undergoing long-term testing at the H-Bahn test facility and is being improved. At the present time, according to the manufacturer, a lifetime of at least 10 years is expected for the power rails. The sources for this estimate are the operating values of the H-Bahn network provided for the city of Erlangen. This result supports efforts for low maintenance cost and short interruptions in operation (availability). The protected arrangement of the power rails inside the guideway supports ensures that the traction current will be available even in extreme weather conditions. Even in the harsh winter of 1978-1979, there were no operating problems at the test facility caused by defects in the power supply.

No studies are available yet on starting inrushes, especially when linear motors are used. Provision is made for doing this in further testing at the H-Bahn test facility.

5.3 HUMAN FACTORS ASSESSMENT

5.3.1 Introduction

This section reviews the interface between the passengers and the system. Those things that affect any passenger traveling the system - noise, security, safety, aesthetics - are considered in Section 5.3.2. These are followed in Section 5.3.3 by separate human factors assessments of the major subsystems - the vehicle, the guideway, the stations, and the command and control subsystems.

The larger question of community acceptance of AGT systems was recognized in 1975 as being very important, and the Federal Ministry of Research and Technology of West Germany ("MORT") - Bundesminister für Forschung und Technologie (BMFT), in German - authorized the Battelle Institute of Frankfurt "to study the feasibility of involving citizens in application planning for people movers and in developing a practicable citizen participation model." Two case studies were performed in the city of Marl and in the city of Erlangen. The latter was carried out in parallel with, but separate from, the Erlangen H-Bahn feasibility study, which was also sponsored by MORT.

At Erlangen, Battelle developed and put into effect a program of citizen participation, which apparently was successful. Of the participants, 74 percent felt that it was appropriate. The "planning game" which was an integral part of the program, provided both information and a chance for the participants to absorb or learn it. The program also seemed to have been aimed at the potential H-Bahn users. It developed some valuable guidelines beyond the H-Bahn experience, and the Battelle report should be useful to many planners.

5.3.2 System Assessment

The test track at Erlangen presents a small version of an operating system, and because it is a test track, as many of the options for a real system as possible have been installed for comparison. Guideway constructions and finishes of various kinds have been installed; three forms of stations are used; and various approaches to guideway aesthetics are tried. Details of these will be described in the assessment sections.

This section will review the system as a passenger might see it in a typical trip from origin to destination, both when the system is operating properly and when troubles occur.

Normal Operation - The test system will be operating in a fully automatic manner in a year or two. It is assumed that this will show the same characteristics as a deployed system. A typical passenger trip should include the following actions:

1. The passenger enters the enclosed lobby of the station, and, if it is elevated, has a choice or walking up the stairs, which are illuminated and glassed in to enhance customer personal safety; or he has a choice of calling the elevator, which is hydraulic and hence self-recovering in the unlikely case of failure. Presumably a map or other directions would be posted in the station entrance, although these were understandably not evident at the test track.

2. On reaching the vehicle level, the passenger sees an active and very visible sign over the station platform door announcing what train is coming next (Figure 5-12). Tickets can be obtained from the automatic vending machine. Posted instructions inform the passenger on when to proceed. (See the description in Section 4.6).

3. On the arrival and proper positioning of the next vehicle or train outside the station doors, both sets of biparting doors open simultaneously providing a passenger-opening of sufficient size (170 cm) to permit wheelchair patrons to enter the vehicle from the station platform. The vehicle is berthed and clamped to the station to eliminate sway and its floor level automatically adjusts to approximately the station floor level--an excellent

FIGURE 5-12. INTERIOR OF H-BAHN STATION

feature for elderly and handicapped passengers. Dwell time is set by operations control, and the doors then close automatically. If the vehicle is overloaded this fact will not interfere with operation, but control will be notified to add one or more vehicles to service.

4. After a jerk-limited start, the vehicle will proceed at the guideway determined speed past a sensor outside the next station, and it will stop if the station is occupied by another vehicle. No more than one vehicle or train may be berthed in any one station at a time.

5. During the trip, ride quality seems good, (as far as could be determined from the vehicles on the test track at Erlangen). The interior noise level, because of the rubber-tired support and guide wheels and the electric power, is supposed to be low, about 65 DBA, the equivalent of a normal office environment (as measured at the test track).

6. The vehicle can sway up to 8.5° from the vertical, providing its own superelevation. An only moderate remaining maximum lateral acceleration of 1.0 m/s^2 is permitted.

7. The vehicle in its present form is not air conditioned, although it could be so outfitted with little trouble.

<u>Operation with Trouble or Failure</u>: The above scenario described a vehicle operating normally. The following scenario will describe what happens when trouble occurs; for detail see Sections 4.7.4 and 5.2.1.

1. If the vehicle is disabled due to an overheated motor or another type of failure not requiring immediate evacuation, the passengers in the vehicle would have to wait for either a rescue vehicle to arrive and a catwalk to be extended to the disabled car so the passengers can be transferred, or another vehicle to push the disabled one to an upcoming station.

2. A fire in the vehicle is prevented by the use of non-flammable materials. If there is a fire in the vehicle it is reported to central control. The vehicle stops at the next station where the passengers vacate. Outside of the station passengers in the vehicle cannot open the doors from the inside. (This is required in safe operation of suspended vehicles during normal operation.) If rescuing between stations is necessary, e.g., if the next station is unusually far or unlikely double-failure occurs, the passengers would escape through the hatch in the floor and slide through the escape tube. Elderly or handicapped patrons, though, could possibly bcome trapped.

5.3.3 Subsystem Level

5.3.3.1 Vehicle - When assessing the vehicle design from a human factors viewpoint, two areas of consideration are important. One is the interface between the user or passenger of the system and the vehicle, which addresses issues such as safety, security, comfort and convenience. The other is the interface between the operating authority of the system and the vehicle, which involves those operator/vehicle interactions associated with its maintenance. Although some of these issues are mentioned briefly in other areas of the report, they are summarized here for completeness in the human factors area.

Passenger/Vehicle Interface

Features of the design which affect the interface between the passenger and the vehicle are as follows:

a. Common safety features found on the H-Bahn vehicle include safety glass windows, door-sensitive edges for recycling, non-skid floor material, and onboard emergency lighting.

b. A safety-enhancing feature of the H-Bahn suspended vehicle is the inherent physical separation of the passenger cabin from both the heat-generating (propulsion, tires, etc.) and heat susceptible (hydraulic, etc.) equipment in the truck (bogie). One exception to this is the brake resistor grid located on the cabin roof. This presents no safety problem, however, since the leads, resistor material and insulators are designed to handle the high heat loads. This location for the brake resistor grid is conventional on most German streetcars, on the ET-420 suburban rail car and on the ET-403 long-distance rail car used by the Federal German Railways, for example. Flammability of the structure and the enclosed seats has been considered in the design of the vehicles through choice of proper materials. Also fire alarms are included in each vehicle cabin which notify Central Control of a problem. Once Central Control is notified of a potential fire problem, the vehicle is forwarded immediately to the next station. When there isn't enough time to reach the next station safely because of an unlikely fire, egress from the vehicle is through the escape tube which may be a limited means for quick evacuation, see Section 5.2.1.

c. Vandalism and access to intruders should be reduced because the H-Bahn vehicle is suspended from the guideway. With vehicle access only at stations and TV surveillance of the station areas available to Central Control, passenger communication system with Central Control onboard each vehicle is also a positive factor.

d. In regard to comfort and convenience, one very evident positive feature of the H-Bahn vehicle is the wide door opening (170 cm) available for entering and exiting the vehicle. A waist-high vertical stanchion in the middle of the door allows for two lines of passenter flow with simultaneous entering and exiting, if desirable.

e. Both the vertical and horizontal gap between the vehicle floor and the station platform seemed small with the vertical gap being controlled to within ±10 mm by the air/rubberspring suspension system. In addition, this gap is compensated for by the tilting step at the station platforms. If a passenger overload is sensed by the air/rubberspring suspension system at a given station, a signal is sent to Central Control to send more vehicles to that station.

f. The number and location of stanchions for passenger gripping seemed reasonable and did not seem to interfere with passenger spacings or movement inside the vehicle.

g. Though no air conditioning is currently provided on the vehicles, space has been made available to add it at a latter time. A ventilation system with ambient air does exist and is also used on the interior of the windows to prevent fogging.

h. For the elderly and handicapped (E&H), accessibility of wheel chairs should be no problem, considering the door opening size and gap situation above. (Figure 5-13.) Although, no restraining system for a wheelchair inside the vehicle exists at this time, a simple retaining device could be installed if warranted since wheelchairs already have their own backing brakes.

i. Auditory signals for door closing and for station arrivals, etc. were not evident at the test site at Erlangen, but are planned by the time of operational service.

Operator/Vehicle Interface

Considering the automated features of the system, the prime interface between the operating authority and the vehicle is the area of maintenance. Comments on the maintainability of the vehicle design are given below:

a. As noted in Section 5.2.2 the maintainability features of the H-Bahn vehicle are exellent and apparently well-thought out. Access to vehicle hardware seemed to have been a prime consideration in configuring the vehicle and the maintenance center.

b. Beyond the hardware accessibility features of the design, the interior of the passenger cabin is made of smooth,

FIGURE 5-13. ACCESS FOR ELDERLY AND HANDICAPPED PROVIDED BY H-BAHN

non-absorbent, washable material which is free of crevices and recesses, thus making it easy to clean and maintain.

c. Some maintenance manuals exist for the vehicle and other subsystems in terms of maintenance intervals and tests. Because of vehicle complexity, there is a need for complete maintenance-manual-type documentation prior to revenue service deployment.

5.3.3.2 Guideway - In assessing the H-Bahn guideway system, human factor statements have been grouped into several categories as follows:

- Guideway Aesthetics
- Ride Quality
- Safety
- Urban Integration

Guideway Aesthetics -- The H-Bahn guideway consists of slender columns and a very sleek, narrow track beam and is attractive in appearance. At the Erlangen test track different paint schemes, colors and finishes have been tried to determine which are more acceptable. Painting of the track beam solid green made it appear to be bigger than when painted white with a thin colored stripe running along each side of the beam. Also, CorTen steel was tried but with unfavorable results. The test section is unevenly colored and drippings from the beam have stained the pavement below. Another finish offered for the track beam is the use of steel cover plates which gives the beam a sleeker, smoother look but also adds considerably to the cost of the beam. This alternative has the advantage of hiding the steel ribbing which some find bothersome to the eye and also provides additional space for equipment mounting and running of cables and lines.

Columns constructed of concrete can either be left natural or painted in various ways. At the test track, light and dark colors were used to paint columns of both materials where it was found that a greyish-white finish made columns more attractive. For concrete columns, a natural finish is more practical since it requires no maintenance, but the greyish-white finish looked better than the natural concrete, especially when wet.

The shape of the steel columns is more tapered and unobtrusive than similar concrete columns. The steel columns are uniform in size, and when additional strength is required the columns can retain the same outside cross section by increasing the gage of steel used. Concrete columns, however, are very massive and for special loading or configurations the column diameter would need to be increased considerably.

Ride Quality -- Guideway design and construction can affect ride quality when beam deflection is excessive and when construction joints are encountered. The H-Bahn beam was initially designed with an allowable deflection for ride quality of 15 mm per 30m span. It was later found that bending caused by the weight of the supports themselves could be eliminated by providing an extra upward curve when manufactured. The bending caused by the maximum vehicle load is approximately 20 mm for 30 m span, resulting in an acceptable "ride comfort" value. In curves, the banking of vehicles allows for greater lateral accelerations than normal (2.5 m/s^2) because the 8.5° deflection reduces the effect of acceleration to 1.0 m/s^2.

To eliminate the thumping which might be experienced as the bogie (truck) crosses the track beam joints, a sliding belt arrangement is used on the running rail to ensure a smooth surface.

Safety -- The track beam houses the power rail, bogie and associated equipment thus removing potential hazards from passenger areas. Emergency evacuation from guideways is a safety problem which was addressed in the technological assessment (Sect. 5.2.1).

Urban Integration -- The appearance and size of the H-Bahn system lends itself to relatively easy integration of a system into an urban setting. Disruption of neighborhood and business centers during construction is minimized because of the high amount of prefabrication used in guideway construction. On-site work is limited to excavation, pouring of footings, and erection of columns and track beams. Operation of H-Bahn systems results in little noise, and vibrational effects are unnoticeable only 2 m from the base of columns.

Collision avoidance with other traffic is not a significant problem for normal trucks and vehicles which are under 4.7 m in height. For areas where larger vehicles are frequently encountered or where guideway columns are shorter than the normal height (9.3 m), warning signs, gates, or other appropriate measures might be necessary. Oversized vehicles are required to have special permits and operators are informed of low-clearance locations.

5.3.3.3 Stations - Stations of the H-Bahn system were evaluated relative to the various features which impact or are impacted by system patrons. Assessment comments are based on evaluation of the test track stations and plans for the Erlangen application and are broken down into the following categories:

- Interior Design
- Accessibility to Elderly and Handicapped
- Fare Collection
- Safety & Security

Interior Design -- The H-Bahn stations (except at-grade) provide both stairways and elevators for passenger entrance-exit and an open station lobby, glass-enclosed with station doors keyed to vehicle arrival. Ventilation and, where needed, air conditioning provide patron comfort by reducing the temperature resulting from solar heating through the untinted windows. To reduce the need for air conditioning, tinted windows could be provided. Except for extreme cases, no heating is provided; it is felt that in cold months patrons enter stations with outdoor apparel and will not require heat because wait times are short. Non-skid materials are used on station floors to prevent patrons from slipping and glass is used extensively throughout to provide an open, secure - -atmosphere.

Accessibility to Elderly and Handicapped -- Stations are provided with elevators to facilitate access by elderly and handicapped patrons. Elevators are large enough to allow easy turning of wheelchairs. Elevator controls, ticketing and fare collection machines are located within easy reach of handicapped patrons.

Vehicles are equipped with a load sensor which is required for the air suspension of vehicles for ride comfort reasons and also connects station-vehicle floor heights. The station-vehicle door interface is designed to permit zero horizontal and only a ±10 mm vertical gap. This height differential is compensated for, however, by the tilting step at the station platform.

Station and vehicle doors are keyed by infrared sensors which allow for some door misalignment, but, as a minimum, ensures a 170 cm opening which allows convenient access for wheelchairs.

Safety & Security -- Stations are unmanned. As in other automatic people mover systems, this may induce an insecure, uneasy feeling among passengers, especially during off-peak hours when demand is low and few people are in stations. Television surveillance is used to monitor station activities from central control, but vandalism and crime cannot be protected against--only deterred by the presence of cameras. Lighting is sufficient and stations are designed to minimize dark corners or areas where someone might hide. Also, station platforms are visible from adjacent areas. Public acceptance of unmanned stations is a major road-block which all AGT systems must overcome.

Ionization smoke detectors are provided in stations as well as fire extinguishers which are within reach of patrons. Emergency exits are marked and are within a 30 m radius of any point within the station. Elevators are hydraulic, and if a malfunction occurred, they would automatically return to ground level where passengers could get out. Central control is the focal point for alarms, and in theory, aid can be summoned to any line station in a 10-minute period.

5.3.3.4 Command, Control and Communications (CCC) System - The CCC system affects all aspects of H-Bahn, but its direct effects on the passenger are not visual or sensory; rather it assures the patron of an adequate supply of vehicles, well-timed and announced; and in the event of failure provides for the rapid location and diagnosis of the trouble and expedites restoration of service. The means by which the CCC system provides passengers information on system status, and ensures their safety and security; and the manner by which it assists the operators in failure management are termed herein the "human factors" aspects of the CCC system. They include the passenger-system interfaces concerned with operation; and the interfaces between maintenance and operating personnel and the system hardware. They include any signage of an active nature; vehicle positioning (station stopping); passenger-central voice communications; biparting door control in stations; and all human interfaces of failure management, such as failure sensor operation, definitions of failures; operating consoles and their layout; mimic boards and system status displays; and the maintainability of all the CCC equipment in terms of its accessibility, ease of repair, and ease of failure detection, location, and diagnosis.

Signage -- In stations, active signs are planned and are positioned above the station doors at the test track. They will inform waiting passengers of the next trains expected, presumably activated by the command and control system. The ones installed at the test track are similar to the active signs often used in airports for arrival and departure schedules, and are very readable.

Vehicle Positioning -- In station stopping, it appears that even the worst mismatch between vehicle and station door would allow a door opening of about 170 cm for passenger entrance and exit. If this can be maintained in practice, even wheelchairs should have no trouble passing between the station and vehicle. The positioning is a function of both the control system and the local infrared positioning sensors.

Passenger-Central Voice Communications -- Passenger security and comfort in the system is enhanced by the existence of a channel of voice communication between each vehicle and central control. This is for use in case of emergencies; it probably would never be used by most passengers, but similar links exist in most other AGT systems, and good practice has dictated its inclusion. It uses the same communication channel as the data communications system.

Biparting Door Control -- Station and vehicle door control appears to depend entirely on the proper operation of the station computers, and failure of the latter causes the vehicle to totally bypass the affected station. The effect of station computer failures on public acceptance of the system, therefore, may be much more pronounced than the effect of some other failures.

The same comment applies to other failures that affect door operation of berthed vehicles or of corresponding station doors. If the station computer finds one set of vehicle doors inoperative it tries another set. If it cannot open either, it sends the vehicle to the next station, assuming a better outcome there. This action would seem to have the potential for creating severe passenger dissatisfaction if it happened very often. Door problems are usually fairly frequent in new AGT systems.

Failure Sensor Operation -- Each vehicle has a fire sensor; supervisory control is alerted, and the affected vehicle is driven to the next station where passengers are evacuated. The vehicle also has several other failure sensors, and upon receiving a signal from any one sensor, supervisory control directs the vehicle to perform an emergency stop, proceed to the next station, or after stopping there, to proceed to maintenance. The passengers are, therefore, well protected by the CCC system against failures of various kinds.

Operating Consoles -- These consoles must be tailored to each H-Bahn installation because all of the system parameters are likely to change from system to system. It is impossible to assess how well the job of matching the operators to the system console is likely to be done in the future; the small console at the test track seems to be adequate for the purpose, and much will be learned about its weaknesses, if any, after the automatic operation of the six vehicles has been going on for awhile.

Mimic Boards -- These are related closely to the consoles, and the same comments apply. Mimic boards are planned for the power distribution system, and CRT displays for the guideway under the control of each station computer.

Maintainability -- This has already been discussed at length in Section 4.7.3. The design at this stage in its maturity seems very good from this point of view. The URTL is self-checking and pinpoints trouble; vehicle control is accessible from outside the cabin; control components in the guideway are less accessible; station electronics can be reached easily. Diagnostic routines have not yet been done; preventive maintenance routines are being formulated.

6. COST OF H-BAHN URBAN TRANSIT SYSTEM

6.1 BASES FOR COST CALCULATION

In general, a high value is placed on system economy for new urban transit systems. For this reason, detailed cost estimates have been prepared on H-Bahn within the framework of feasibility and case studies as well as theoretical studies. The goals of these cost analyses can be summarized as follows:

- Cost Determination and Cost Comparison: These were aimed at providing information on the approximate cost of H-Bahn.

- Cost Structure Analysis: This was intended to examine the relationships between the individual cost components at a given cost level.

- Analysis of Specific Costs: This involved analyses of performance-related costs; in other words, those costs which are dependent upon passenger kilometers, available-space kilometers, and specific transit applications.

- Cost Comparison of Alternative Design Variations: The cost effects of changes in the individual components of H-Bahn were determined and analyzed.

- Cost Trend Analyses: The purpose of these was to determine what effects future price increases would have on cost level and cost structure.

- Cost Comparison for Alternative Interest Rate Structures: Determination and comparison of overall system costs and the cost structure for alternative interest rates.

- Cost Comparison for Alternative Transit Modes: Determination and comparison of overall system costs and cost structure for alternative modes of public transit for investments to be made in urban transit.

The goal of this section is to present the individual factors which were taken into account to determine investment and operating costs and to comment upon them, as well as to discuss the results of earlier cost calculations. We proceeded on the basis of the following assumptions:

All costs are based on the German market, and do not include value-added tax. Costs for foreign markets may differ from German prices. Additional shipping costs must be calculated for system components being exported from Germany. In the case of foreign manufacturers, differences in production conditions may result in variations from the German prices.

The starting point for the cost calculation is the information received from the manufacturer based on 1976 prices. These data are partially based upon bids from subcontractors and was checked and supplemented, in part, within the framework of a feasibility study. Thus, for example, the guideway investment cost was based by the manufacturing firms on two bids from outside contractors. The vehicle prices as well as the prices of the power supply facilities can be compared with the aid of special parameters using systems that are already in operation. In the case of Erlangen, about 82 percent of the total investment (without tunnel, elevated sections, additional construction costs) accounts for the three items above. Other items, such as auxiliary construction costs, cost of elevated sections and the like have been supplemented by an engineering firm and the city of Erlangen.

In determining plausibility, work has been done on as much data as possible culled from actual operating experience, available from construction projects in other areas. The costs have also been checked in detail in the operating area as well. This is illustrated in Section 6.2.2, for example, for calculating personnel requirements. Practical experience of other transit systems can be involved especially for this purpose.

The cost determinations were given particular emphasis within the framework of the planning application studies. In addition, the most important cost-influencing parameters could be studied in great detail within the framework of variant calculations. Further refinement of the cost figures which follow is not possible on the basis of estimated cost calculations. This must wait until actual cost calculations are available after the pilot installations have been built and operated.

The base year for the original price figures is 1976. In order to be able to give current prices for the present study, the prices for costs in Section 6.2 have been adjusted to the new reference year of 1980. The calculated system costs in Section 6.3 refer to the corresponding base years of the individual planning studies.

6.2 COSTS

Construction of an H-Bahn requires capital investment (for guideways, stations, vehicles, etc.). Continuous operation requires the use of personnel, materials, and energy. The basic data for these costs have been developed separately for investment and operation. Investment includes all costs for building an H-Bahn ab initio and for replacement costs. Operating costs include all costs of continuous operation, maintenance, and management.

6.2.1 Costs of Investment

The cost tables for investment contain the prices of the system components per unit volume. The prices depend on the total size of the network, since volume discounts can be expected for larger networks. According to the manufacturer, volume discounts will be based upon ordering larger amounts of material, and not on savings in manufacture. Thus, for example, comparing guideway supports in a network with 50 route kilometers with a network with 30 route kilometers, we can anticipate a price reduction of about 2.5 percent. The prices given below essentially relate to a network of average size (approxiamtely 25-35 route kilometers with 100-250 vehicles and approximately one to two stops per route kilometer).

The systems are considered to be of a standard design, built under normal construction conditions. Additional costs resulting from construction problems, such as difficult foundation material or relocation of utilities, have not been included.

The investment cost tables contain the prices of the system components per unit volume. These purchase costs are based upon the facilities in which the investment is made being used for many years. To convert the purchase costs into annual costs, the annuity method may be used.

Calculating the investment costs on an annuity basis means distributing the necessary acquisition cost for building the installation uniformly over the useful life of the facilities, with compound interest. Any residual sales value and cost of scrapping after the end of the useful service life must also be taken into account. The annuity formula for calculating costs on the basis of acquisition cost is as follows:

$$A = \left(a_0 + \frac{D - R}{(1+i)^n}\right) \cdot w,$$

where:

A	= annuity		
a_0	= acquisition cost		
D	= scrapping cost	}	after the end of the economic useful life
R	= residual sales value	}	
i	= interest rate		
n	= planned useful life		
w	= redemption factor	=	$\frac{i\,(1+i)^n}{(1+i)^n - 1}$

Table 6-1 lists the redemption factors for alternative interest rates and useful lifetimes.

TABLE 6-1. REDEMPTION FACTORS FOR DETERMINING ANNUAL INVESTMENT COSTS

Useful Life n	Interest Rates	
	i = 3%	i = 6%
10	0.11723	0.13586
15	0.08377	0.10296
20	0.06722	0.08718
25	0.05743	0.07822
30	0.05102	0.07264
40	0.04326	0.06646
50	0.03887	0.06344
60	0.03613	0.06187
70	0.03434	0.06103
80	0.03311	0.06057
90	0.03226	0.06031

Guideway

The prices for the most important guideway components for H-Bahn are shown in Table 6-2.

The prices for the supports will be understood to include the foundation for normal soil conditions, without any necessary displacement of utilities. For example, in Table 6-2, prices are listed for the normal support height of 9.5 m and a special height of 14.5 m. The manufacturer also offers supports with additional special heights. The base prices for the supports are based upon bids from the manufacturer's subcontractors. In the case of the steel supports, the cost of the steel stock (including fabrication) amounts, on the average, to about 50 percent of the total price. The balance is for the foundation, shipping, assembly, and auxiliary work.

In the case of the guideway supports, the prices are given for one direction (track kilometers). The materials' costs, in this instance, are about 65 to 75 percent. Here again, appropriate offers have been obtained for the base prices.

There is one point which requires special attention in connection with prices offered for switches: In normal cases, the total length of the section is used as the basis for calculating the cost of the guideway beams. If the total price were to be calculated once again for the switches, the length of the switch areas would be calculated twice. In order to avoid this double calculation, the price for the structural component "switches" has been reduced, depending on the lengths of the switch areas, by the price of the corresponding guideway support length (straight and curved). This leaves the difference between the nòrmal length and the structural component "switch", which is broken out in Table 6-2 under the heading "switch core" and amounts to approximately 15 to 20 percent of the total price of a switch.

TABLE 6-2. APPROXIMATE PRICES FOR H-BAHN GUIDEWAY COMPONENTS (PRICE BASE 1980)

Component		Unit	Price per unit in thousands of DM (in Dollars)
1. Concrete supports[1]	(Spun concrete)		
L-supports	9.5 m high	each	33 (18.36)
L-supports	14.5 m high	each	36 (20.03)
T-supports	9.5 m high	each	41 (22.81)
T-supports	14.5 m high	each	45 (25.03)
Portal supports	9.5 m high	each	59 (32.82)
Portal supports	14.5 m high	each	6 (35.60)
2. Steel Supports[1]			
L-supports	9.5 m high	each	37 (20.58)
L-supports	14.5 m high	each	43 (23.92)
T-supports	9.5 m high	each	44 (24.48)
T-supports	14.5 m high	each	52 (28.93)
Portal supports	9.5 m high	each	67 (37.27)
Portal supports	14.5 m hihg	each	76 (42.28)
3. Guideway supports[2]			
Straight		track km	3,600 (2002.68)
Curved, $R \leq 250$ m		track km	5,100 (2837.13)
Curved, $R \geq 250$ m		track km	4,400 (2447.72)
4. Switches			
Switch core		each	44 (24.48)

1) Supports including foundation

2) Guideway beams ready for operation

Stations

Table 6-3 lists the prices of station components separately for the different types of stations, using the example of the Type 2/2 vehicle. The cost of outside amenities is not included. Depending on the size of the station and the local conditions, these outside amenities can be estimated to cost between 10,000 and 20,000 DM per station.

The number of loading positions given in Table 6-3 is for a Type 2/2 vehicle (see Table 6-6) with two doors per side. Type 1/1 vehicles are equipped with one door per side. Therefore, two loading positions for a Type 1/1 vehicle correspond to one loading position for a Type 2/2. The Type 3/3 vehicle has three doors per side, so that two loading positions for a Type 3/3 correspond to approximately three loading positions for a Type 2/2. In addition to the types of stations listed, the manufacturer also offers additional station units whose dimensions and provisions for platform extension are a function of the length of the trains operated.

In the case of stations with side platforms, two station units have been assumed in the calculations, one in each direction; while in the case of island-platform stations, only one unit is required for both directions.

The prices for station structures have been estimated by architects and engineers on the basis of experience in similar projects.

The items under "equipment" include the prices for the following:

- Lighting
- Station doors
- Elevators.

Larger station installations can also be provided with escalators. The cost of these in Germany is between 90,000 ($50,067) and 160,000 DM ($89,008). These prices depend in each case primarily upon the length, inclination, and useful width.

TABLE 6-3. PRICE FOR STATION COMPONENTS OF H-BAHN, WITH A NETWORK OF AVERAGE SIZE (1980 PRICE BASE)

Type of Station and Component		Price per Station in Thousands of DM (in dollars)
1.	Stations with one platform edge (side platform)	
1.1	Stations with 1 loading position[1] (2 platform doors)	
	Structure	240 (133.51)
	Equipment	150 (83.45)
	Control and passenger handling	270 (150.20)
	Safety engineering	110 (61.19)
1.2	Stations with 2 loading positions[1] (4 platform doors)	
	Structure	330 (183.58)
	Equipment	180 (100.13)
	Control and passenger handling	300 (166.89)
	Safety engineering	110 (61.19)
1.3	Stations with 3 loading positions[1] (6 platform doors)	
	Structure	370 (205.83)
	Equipment	220 (122.39)
	Control and passenger handling	360 (200.27)
	Safety engineering	110 (61.19)
2.	Stations with two platform edges (island platform)	
2.1	Stations with 2 x 1 loading position[1] (2 doors on each side of platform)	
	Structure	370 (205.83)
	Equipment	190 (105.70)
	Control and passenger handling	500 (278.15)
	Safety engineering	220 (122.39)
2.2	Stations with 2 x 2 loading positions[2] (4 doors on each side of platform)	
	Structure	490 (272.59)
	Equipment	260 (144.64)
	Control and passenger handling	550 (305.97)
	Safety engineering	220 (122.39)
2.3	Stations with 2 x 3 loading positions[1] (6 doors on each side of platform)	
	Structure	550 (305.97)
	Equipment	330 (183.58)
	Control and passenger handling	670 (372.72)
	Safety engineering	220 (122.39)

1) Loading positions for Type 2/2 vehicles

The following components come under the heading "station control and passenger handling facilities":

- Computers
- Passenger handling facilities
- Automatic ticket-selling machines.

Power Supply

The price of the power supply system is largely dependent upon the individual case. According to the detail plans covered by the feasibility study for Erlangen, however, using the 1980 price base, we can use 155 DM ($86.23) per track meter as a starting value. This assumes a separate 20 kV cable network for H-Bahn, with remote-controlled substations and connecting points. The cost of the materials is about 85 percent of the total price.

The price of power buses is included in the costs for the guideway supports (see Table 6-2).

Central Control

Automatic control equipment is required for the largely unmanned operation of H-Bahn. If these control devices are located on the line, at the stops, or in the vehicles, the manufacturing costs of these items are covered by the corresponding component prices (see Tables 6-2, 6-3, and 6-6). However, to this must also be added the equipment for the control and monitoring center, as well as the preparation of software. It is very difficult to come up with generally valid price estimates because these values are largely dependent upon a given situation. Moreover, the high fixed-cost components of central control systems must also be taken into account.

Using the experience gained with earlier feasibility studies as a basis, tentative values are given in Table 6-4 for equipping the central control and monitoring center. The number of stations in the network was selected as a reference parameter.

TABLE 6-4. PRICES FOR CENTRAL CONTROL COMPONENTS (1980 PRICE BASE)

Component	Reference Parameter	Cost of Manufacture in Thousands of DM (in Dollars)
1. Central computer	per station	20-40 (11.13 to 22.25)
2. Central passenger-handling facility	per station	5-40 (2.78 to 5.56)
3. Air-conditioning system	central	100-150 (55.63 to 83.45)
4. Electrical installation and interruption-free power supply	central	50-60 (27.82 to 33.38)

Structural components are not taken into account in Table 6-4, because the central building, in which the general administration is also housed, can be used for the purpose (see "operation support").

The control of the automatic people-mover system requires the use of process computers and associated software. Cost estimates can be based upon the necessary personnel for software preparation. Hence, in the case of an implemented H-Bahn system in Germany, the available basic software must be adapted to the specific case, and the preparation of the supplementary software for each specific case must also be considered. In the case of an average-size network, an expenditure of approximately three man-years can be considered adequate for this work, so that value calculations are at the order of about 450,000 ($250,335) to 500,000 DM ($278,150).

Operation Support

The area "operation support" includes the following facilities:

- Storage facilities and turnaround facilities
- Shops
- Cleaning facilities
- Administration buildings.

The structural dimensioning and equipping of these facilities are governed, among other things, by the size of the network and the number of vehicles. In addition, the size of the office building is influenced by the number of system employees. The manufacturing costs for operation support facilities are also dependent upon local conditions in each individual planning case. Thus, for example, vehicle depots and turnaround facilities can only be built where space permits.

On the basis of these factors, it is impossible to come up with any generally valid price figures for operation support facilities. For this reason, Table 6-5 provides examples of selected price figures from the feasibility study on Erlangen, raised to the 1980 price base. For greater ease in interpretation, the cost values have been expressed as a ratio of the number of vehicles. However, no linear relationship between the number of vehicles and their manufacturing costs should be assumed. Rather, the high fixed cost components of the operating support facility should be taken into account. The figures in Tables 6-5 relate to the network in the Erlangen planning case with 115 cars.

TABLE 6-5. PRICES FOR EQUIPMENT FOR OPERATION SUPPORT IN THE ERLANGEN PLANNING CASE RAISED TO THE 1980 PRICE BASE

Component	Reference value	Manufacturing cost in thousands of DM (in Dollars)
1. Storage facilities and turnaround facilities	per vehicle[1]	115 (63.97)
2. Shops		
2.1 Structures	per vehicle[1]	70 (38.94)
2.2 Equipment, including machinery	per vehicle[1]	26 (14.46)
3. Cleaning facilities	per vehicle[1]	5 (2.78)
4. Administration buildings[2]	planning case	1,800 (1001.34)

1) Vehicle Type 2/2

2) Structures and equipment for offices

The manufacturing cost for the storage facility and turnaround facilities includes the prices of:

- Guideway supports
- Switches
- Supports.

The storage facilities must be dimensioned to suit the number of vehicles. The space requirements for each vehicle can be determined from the vehicle length and the distance between two vehicles when parked. The values in Table 6-5 relate to Type 2/2 vehicles. It is calculated here that each vehicle requires approximately 11 m when parked. To this must be added the switches and the tracks leading to and from them. The length of these stretches is a function of the arrangements of the storage facilities in the network.

The manufacturing costs of the storage facility and turnaround facilities also include track connections along the line. It was found that, for operating reasons, at every fifth to sixth station, track connections between the parallel operating tracks should be provided. These track connections should be combined with storage facilities for at least one vehicle in order, for example, to be able to set out malfunctioning vehicles for a short period of time.

The specific manufacturing costs for shop buildings include the maintenance building, the maintenance stands, and the employee and auxiliary rooms.

The item "equipment in shops" includes the transfer tables and cranes as well as the measurement and checkout equipment, together with the machinery in the shops.

The cost of the cleaning facilities is composed of the costs of the equipment and the washing machines.

The amount for the administration building assumes an average space requirement for management personnel of about 50 m^3 of enclosed space per person. A percentage is included for auxiliary and employee areas in the administration buildings.

The prices for structures were estimated by architects and engineers employed by a subcontractor for the manufacturer in accordance with the practical values determined from comparable construction projects.

TABLE 6-6. PRICES FOR VEHICLES IN A MEDIUM-SIZED NETWORK (1980 PRICE BASE)

Vehicle Type	Cost per vehicle in thousands of DM (in Dollars)
1. Passenger car Type 2/2, 41 passengers	610 (339.34)
2. Passenger car Type 3/3, 69 passengers	660 (367.16)
3. Work vehicle, tracked	440 (244.77)
4. Measuring car, unpowered	170 (94.57)

6.2.2 Operating Costs

Operating costs include all costs for running operations, maintenance, and administration. The requirements and costs involved for the following:

- Personnel
- Supplies
- Power
- Other expenses,

are expressed directly in amounts per year, so that there is no need to convert to annual values for operating costs.

The cost figures in the operations area were determined analytically. As much as possible, the practical values determined from operation on other urban transit systems were selected as a basis for the calculations.

Personnel

The H-Bahn operating design provides for automatic operation, with intervention being required only if some unusual event or problem develops. Therefore, the personnel requirements for H-Bahn are markedly different from those for conventional systems.

The values given below are based upon operating designs and personnel cost estimates developed within the framework of planning studies.

The required personnel and the associated annual personnel costs are given separately for the following areas:

- Operating and service personnel
- Maintenance and repair personnel
- Cleaning personnel
- Management.

Operating and Service Personnel are required for monitoring and telephone communications as well as for central operations monitoring and local station monitoring. To calculate the personnel costs associated with these functions the following general approach was adopted:

1. Establishment of tasks and job descriptions,
2. Determination of the number of hours the individual workplaces must be manned each day,
3. Adaptation of working times in the work schedule, taking into account absences for vacations, training, sickness, etc.
4. Calculating the salaries to be paid.

For example, in the task area "operations maintenance," if one workplace must be manned 24 hours a day (i.e., 7 days a week), 3 shifts of 8 hours each must be set up accordingly. In addition, absences for holidays, training, sickness, and the like must be taken into account. Estimation of corresponding additional factors must be carried out on the basis of available experience on transit systems. If the average weekly work time is 31 hours, for example, three shifts of 5.4 salaries each will have to be paid. The annual figure for one position will be established as a function of its necessary qualifications. The salary costs associated with transit operation will therefore be calculated from the annual gross figure for employees plus employer contributions, which in the Federal Republic of Germany can amount to approximately 80 percent of the gross salary. Average surcharge factors for employer contributions of 27 to 30 percent have been included in the following figures.

Sometimes there are considerable differences in salaries and wages between individual areas in the Federal Republic of Germany. Thus, for example, salary levels in large urban areas are generally higher than those paid in small cities and areas with a more agricultural environment. An average to medium-salary level can earn an employee approximately 20,000 DM ($11,126) for simple jobs and about 45,000 DM ($25,033.5) for skilled jobs (plus employer contributions in all cases). Since there may be considerable differences in salary level and wage structure by comparison with foreign countries, an international comparison should be made, especially as regards personnel requirements.

Planning studies carried out thus far have yeilded specific personnel requirements of 0.68 persons per station to 1.47 persons per station; this amounts to about 1.2 to 2.3 persons per route kilometer relative to the route length. The considerable differences show how much the requirements for operating and service personnel depend upon the layout of the system in each individual case. A personnel requirement of about 0.9 to 1.0 persons per station can be used as an average. The average personnel cost for operating and service personnel, increased to the 1980 level, amounts to 42,000 DM ($23,364.6) to 45,000 DM (25,033.5).

The requirements for Maintenance and Repair Personnel are determined for the individual H-Bahn system components as a function of the average work to be expected. The specific costs for this area are summarized in Table 6-7.

These values were derived as much as possible from actual experience in other areas. A few explanations are in order for the entries under "maintenance and repair of the vehicles." These tasks occur partially on a periodic basis at certain time intervals and partially as a function of the operating performance of the vehicles themselves. Thus, provision is made for one inspection and operating check per week. The time required for this amounts to an average of 33.5 hours per vehicle per year and is relatively low because automatic diagnostic techniques may be used.

TABLE 6-7. ESTIMATED UNIT COSTS FOR MAINTENANCE AND REPAIR (1980 PRICE BASE)

Maintenance and Repair Personnel for:	Unit	Average time per year	Cost per hour in DM[1] (in Dollars)
Concrete supports	hrs./support	1.33	21.20 (11.79)
Steel supports	hrs./support	2.66	21.20 (11.79)
Guideway supports	hrs./track km	32.50	28.25 (15.72)
Switches	hrs./switch	12.00	21.50 (11.96)
Buildings	hrs./million DM capital expenditure[2]	160.00	22.20 (12.35)
Station equipment	hrs./platform edge	7.50	28.25 (15.72)
Power supply	hrs./track km	39.50	28.25 (15.72)
Central computer	hrs./track km	0.01	30.00 (16.69)
Machine tools	hrs./million DM capital investment[2]	400.00	28.25 (15.72)
Vehicles	hrs./vehicle Type 2/2[3]	141.50	24.65 (13.71)

1) For 1,600 working hours per year

2) Based on 1980 price levels

3) Assuming 100,000 km operation per vehicle per year (with vehicle equipped\with dc motor drive).

Maintenance and repair work which depend upon operating performance are classified into various stages (T1 to T4):

T1: Visual checks and operating tests are performed every 12,500 km;

T2: Visual checks and operating tests as well as wear-control of mechanical parts are carried out every 25,000 km;

T3: An intermediate check is carried out every 250,000 km with T1 and T2 checks as well as replacement of worn parts;

T4: A major overhaul is performed every 500,000 km.

To this, we must add work time for extraordinary repair work. On the whole, plans call for time to be invested in maintenance and repair work which depends upon operating performance of 1.08 hours per 1,000 vehicle km. At 100,000 vehicles km per year, an annual figure of 108 hours is accumulated.

The total of the periodic and operating performance-dependent maintenance work is 141.5 hours per vehicle for an annual vehicle operating distance of 100,000; with operation of 70,000 km, the work required drops to about 109 hours per vehicle, while at 130,000 km, we have about 174 hours per vehicle.

The figures used to determine the number of Cleaning Personnel are given in Table 6-8. These values are composed of the daily routine cleanings and the thorough cleaning operations that are carried out at longer intervals. For example, it is estimated that about 31 hours per year are required for thorough cleaning of the vehicles, and about 84 hours for routine cleaning.

TABLE 6-8. UNIT COSTS FOR CLEANING H-BAHN FACILITIES

Cleaning personnel for:	Unit	Average time per year	Cost per hour, DM[1] (in Dollars)
Stations	hrs./station	120.00	19.50 (10.85)
Buildings	hrs./m^3 of enclosed space	0.04	19.50 (10.85)
Vehicles	hrs./vehicle Type 2/2	115.00	19.50 (10.85)

1) With 1,600 productive hours per year.

Management Personnel are generally included in planning calculations as a percentage of a total number of employees. Thus, for example, on the basis of existing experience from the Federal Republic of Germany, we find 12 to 20 percent additional management personnel for every 200 to 300 employees. In making our cost calculations, we must keep in mind that the average salaries of these personnel are generally higher than the salaries and wages paid to the other personnel. For example, as an average cost about 50,000 ($27,815) to 60,000 DM ($33,378) per man year (1980 price base) must be added.

Materials

To calculate material costs, material factors were estimated which reflect annual material consumption as a function of the acquisition costs of the system components. Table 6-9 lists the material factors used in previous feasibility studies (1979 level). To the extent it was possible, these estimates were based upon actual experience from operations on conventional transit systems. In particular, this was used as a basis for developing figures on uprights, buildings, automatic ticket-selling machines, and machine tools in Table 6-9.

TABLE 6-9. FACTORS FOR DETERMINING MATERIAL COSTS

System components	Material factor (in % of acquisition cost)
Supports	0.004
Guideway supports	0.230
Switches	1.100
Catenary	0.350
Buildings	0.300
Station controls	0.800
Safety engineering	0.700
Communications and monitoring	1.700
Automatic ticket-selling machines	0.800
Power supply	0.680
Machine tools	3.500
Central computer	1.000
Vehicles (Type 2/2)	1.830

For components in which it was not possible to refer to material consumption figures for conventional systems, the material factor was estimated in conjunction with the specific time requirement for maintenance and repair work. Thus, for example, the maintenance schedule for vehicles given above yielded an estimated material factor of 1.7 percent of the acquisition cost for an annual operation of the vehicles over 80,000 km. According to the manufacturer's information, about 70 percent of this figure is time-dependent and the remainder (30 percent) is based upon operating performance. If we convert these values, we will obtain material factors for Type 2/2 passenger vehicles as follows:

1.83 percent for 100,000 km annual operation and
2.02 percent for 130,000 km annual operation.

Power

Power consumption by vehicles depends upon the following factors, among others:

- Type of motor
- Operating data
- Service conditions
- Efficiency.

The calculations made in previous planning studies have yielded an average power consumption of approximately 1.0 kWh per vehicle km for the Type 2/2 vehicle fitted with a dc motor. This corresponds to a specific energy consumption per passenger km of 0.024 kWh. This value was determined on the basis of the special operating situation in Erlangen. It also included such things as the distance between stops, the average vehicle weight as a function of loading, the efficiency of the dc motor, and the guideway resistance and air resistance factors measured at the test facility.

The power consumption figures for fixed installations were estimated on the basis of the connected loads. The power consumption figures for the stations, listed in Table 6-10 are based upon an average daily operating time of 20 to 21 hours.

TABLE 6-10. ANNUAL POWER CONSUMPTION BY STATIONS (WITHOUT ESCALATORS)

Station Type	Annual Power Consumption per Station, in MWh
1. Stations with 1 platform edge (side platforms)	
2 platform doors	40.0
3 platform doors	42.5
4 platform doors	45.0
6 platform doors	50.0
2. Stations with 2 platform edges (island platform)	
2 x 2 platform doors	75.6
2 x 3 platform doors	80.0
2 x 4 platform doors	84.4
2 x 6 platform doors	93.2

These values include the cost of running the elevators. On the other hand, power consumption by escalators is not included. The connected load (escalator) to overcome a height differential of about 5 m amounts to about 22 kW. Assuming a load factor of about 25 percent on a daily operating time of 10 hours, we come up with an estimated power consumption of 20 MWh per year. Thus, for a station with two escalators, a figure of about 40 MWh would be used.

TABLE 6-11. SPECIFIC ANNUAL POWER CONSUMPTION FOR CENTRAL FACILITIES

Central Facilities	Annual Power Consumption
Depot	0.625 MWh/vehicle
Shop	4.900 MWh/person
Central control	7.500 MWh/person
Administration	3.300 MWh/person
Building heating	9.400 GCal/person

The energy costs are obtained by multiplying the power consumption by the price per energy unit. It should be kept in mind, in this connection, that transit operations in many instances agree upon a graduated rate with the power supply companies. The cost of traction power is generally below the prices charged to other companies, while a higher price is charged for power at the stations. The average energy cost at the present time in the Federal Republic of Germany is about 0.15 DM/kWh ($.08). As individual prices 0.11 DM/kWh ($.06) to 0.12 DM/kWh ($.07) could be quoted for traction power and 0.20 DM/kWh ($.11) to 0.22 DM/kWh ($.12) for station power.

Other Consumers

Under this heading, general operating costs (insurance contributions, taxes, etc.) have been summarized. Figures are available from conventional urban transit systems, but they differ considerably from one system to another. As a starting point for average loading with general operating costs, the present feasibility studies have been made using 1.7 to 2.1 pfennigs/ride.

6.3 SYSTEM COSTS

6.3.1 Cost Level

The most important service and operating data and the results of cost calculations from the planning cases of Erlangen, Karlsruhe and Berlin are summarized in Table 6-12. In order to interpret these data, the reader is referred to Sections 4.12 and 4.13 which contain information from the planning cases. Section 6.1 discusses the plausibility and basis for the cost figures employed. It should also be kept in mind that the values for the individual cases studied are based upon different price levels. The corresponding base year for the cost calculation is given at the top of the chart in Table 6-12.

One point that is immediately apparent from Table 6-12 is the difference in specific capital expenditure per route kilometer. At the two test areas in Berlin, we calculated 12.6 ($6.28) to 12.3 million DM ($6.13) per route kilometer (1978 price base); in the case of Erlangen, this figure is 14.2 million DM ($5.64) (1976 price base), and for Karlsruhe, 21.0 million DM ($9.05) (1977 price base). These differences are due primarily to the specific nature of the routing. Thus, for example in Erlangen, about 0.7 km of the 30.4 route kilometers in Table 6-12 are in tunnel, while the tunnel in Karlsruhe is 5.2 km long. On the other hand, in the cases investigated for Berlin, only above-ground routes were planned.

The annual capital costs were calculated using the annuity method (see Section 6.1). The interest rate used for these calculations was 6 percent. It was assumed that there would be complete outside financing of the original investment and all further reinvestments. In addition, costs were estimated assuming alternative public transit for original and subsequent investments. The significance of the type of financing supplied affected the level of the investment costs. In the case of Karlsruhe, for example, the total costs in the case with public funding were only about 48 percent of the total costs of the case without public funding. Therefore, public funds in this particular case resulted in the reduction of the costs to less than half the total.

Likewise, the cost calculations were performed with alternative interest rates. Table 6-13 shows the results.

TABLE 6-12. OPERATING AND TRAFFIC DATA, AND COST CALCULATIONS FOR H-BAHN STUDIES IN DM (IN DOLLARS)

Item	Dimension	Erlangen (1976)	Karlsruhe (1977)	Berlin UG1* (1978)	Berlin UG2** (1978)
1. Line length	line km	30.4 (12.08)	45.2 (19.47)	22.4 (11.17)	27.3 (13.61)
2. Stops	number	50 (19.87)	67 (28.86)	27 (13.46	40 (19.95)
3. Vehicles	number	115 (45.70)	334 (143.89)	73 (36.41)	76 (37.90)
4. Operating capacity	million of vehicle km/ year	9.4 (3.74)	39.8 (17.15)	8.9 (4.44)	9.3 (4.64)
5. Carrying capacity	million of person km/ year	85.0 (33.78)	319.7 (137.73)	95.1 (47.43)	65.0 (32.42)
6. Rides	million/yr	26.0 (10.33)	61.3 (26.41)	20.2 (10.07)	25.1 (12.52)
7. Capital requirements	millions DM	430.5 (171.08)	948.2 (408.48)	282.4 (140.83)	336.0 (167.56)
8. Consisting of the following:					
9. Guideway	millions DM	272.5 (108.29)	513.9 (221.39)	177.8 (88.67)	216.0 (107.72)
stops	millions DM	61.3 (24.36)	144.3 (62.16)	41.0 (20.45)	55.2 (27.53)
10. Vehicles	millions DM	65.8 (26.15)	216.8 (93.40)	43.1 (21.49)	44.7 (22.29)
11. Specific capital requirement	millions DM/ km of line	14.2 (5.64)	21.0 (9.05)	12.6 (6.28)	12.3 (6.13)
12. Capital costs (6% interest)	1000 DM/yr (397.4)	29570 (11751.12)	66824 (28787.78)	19559 (9754.07)	23322 (11630.68)
13. Specific capital costs	DM/ride	1.13 (.45)	1.09 (.47)	0.97 (.48)	0.94 (.47)
14. Specific capital costs	DM/person km	0.35 (.14)	0.21 (.09)	0.21 (.10)	0.36 (.18)
15. Operating costs	1000 DM/yr (397.4)	10804 (4293.51)	27722 (11942.64)	8938 (4457.38)	9892 (4933.14)
16. As follows: Personnel	1000 DM/Yr (397.4)	5106 (2029.12)	9295 (4004.29)	4550 (2269.09)	4936 (2461.58)
17. Material	1000 DM/yr (397.4)	2882 (1145.31)	8286 (3569.61)	2158 (1076.19)	2501 (1247.25)
18. Energy	1000 DM/yr (397.4)	2259 (897.73)	7256 (3125.88)	1806 (900.65)	2080 (1037.30)
19. General operating costs	1000 DM/yr (397.4)	557 (221.35)	2885 (1242.86)	424 (211.45)	423 (210.95)
20. Specific operating costs	DM/ride	0.42 (.17)	0.45 (.19)	0.44 (.22)	0.39 (.19)
21. Specific operating costs	DM/person km	0.13 (.05)	0.09 (.04)	0.09 (.04)	0.15 (.07)
22. Total costs	1000 DM/yr (397.4)	40374 (16044.63)	94547 (40730.85)	28497 (14211.45)	33214 (16563.82)
23. Specific total costs	DM/ride	1.55 (.62)	1.54 (.66)	1.41 (.70)	1.33 (.66)
24. Specific total costs	DM/person	0.48 (.19)	0.30 (.13)	0.30 (.15)	0.51 (.25)

*UG1 = Berlin - application Märkisches Viertel/Wittenau
**UG2 = Berlin - application Spaudau

TABLE 6-13. CAPITAL COSTS FOR VARIOUS INTEREST RATES

Planning Case	Interest Rate Used for Calculation 3.5%		6%	8%	
	Millions DM (in Dollars)	FPRO[1]	Millions DM (in Dollars)	Millions DM (in Dollars)	FPRO[1]
Erlangen	20.4 (8.11)	0.69	29.6 (11.76)	37.4 (14.86)	1.26
Karlsruhe	47.1 (20.29)	0.71	66.8 (28.78)	83.7 (36.06)	1.25
Berlin UG 1	13.6 (6.78)	0.69	19.6 (9.77)	24.7 (12.32)	1.26
Berlin UG 2	16.2 (8.08)	0.70	23.3 (11.62)	29.4 (14.66)	1.26

1) FPRO = Percentage of corresponding capital costs with an interest rate of 6% used for calculation; K (6%) = 1.

The relative values listed in the columns headed "FPRO" relative to the capital costs with an interest rate of 6 percent differ in part from one another. This is due to the different structures of the fixed assets in the individual planning cases.

The specific cost values listed in Table 6-12 (Costs per ride and costs per person kilometer) are defined as follows:

$$\frac{\text{total cost}}{\text{traffic volume}}$$

Accordingly, the differences in specific costs can be attributed to two influential parameters:

a) The total cost level, especially on the basis of the differences in routing and the different number of vehicles;

b) The load on the passenger facilities; see also the numbers in Table 6-14.

TABLE 6-14. SYSTEM CHARACTERISTICS OF H-BAHN APPLICATIONS

Planning Case	Parameters: Passenger km / space-availability km	Rides / km of route	Vehicles / km of route
Erlangen	0.16	0.86	3.8
Karlsruhe	0.12	1.36	7.4
Berlin UG 1	0.26	0.90	3.3
Berlin UG 2	0.17	0.92	2.8

Thus for example, the low cost per passenger kilometer in Berlin-application 1 by comparison with application 2 is due primarily to the relatively high utilization of space, 26 percent, by comparison with 17 percent in application 2. On the other hand, the specific costs per ride in application 1 are higher than in application 2 because here, the average travel distance is almost twice as high as in application 2 (see Table 6-15).

TABLE 6-15. AVERAGE TRAVEL DISTANCES

Planning Case	Average Travel Distances
Erlangen	3.2 km
Karlsruhe	5.1 km
Berlin application 1	4.7 km
Berlin application 2	2.6 km

Because of the different average values for the travel distances, the costs given in the table for each ride cannot be compared directly with one another.

In the planning case for Karlsruhe, relatively low average costs per passenger kilometer were obtained, although the vehicle loading here was only about 12 percent (see Table 6-14). Here however, the increase in use in toto relative to the route length was very favorable. The low specific costs are due to the comparatively good capacity utilization of the fixed facilities. This is also documented by the high number of vehicles relative to the route length (see Table 6-14).

6.3.2 Cost Structure

Table 6-16 contains some important parameters in the cost structure. According to the values given in the first line, with an interest rate of 6 percent, it is expected that capital costs will make up about 70 percent of the total costs. In terms of magnitude, this is approximately the same as the percentage of capital costs for conventional rail urban transit systems, while the capital costs for conventional bus systems amount to only about 15 to 25 percent of the total costs.

TABLE 6-16. COST STRUCTURE VALUES

Specific Costs	Planning Case (%)			
	Erlangen	Karlsruhe	Berlin UG 1	Berling UG 2
1. Capital costs / Total costs	73.2	70.7	68.6	70.2
2. Operating costs / Total costs	26.8	29.3	31.4	29.8
3. Personnel costs / Operating costs	47.2	33.5	50.9	49.9
4. Material costs / Operating costs	26.7	29.8	24.1	25.2
5. Energy costs / Operating costs	20.9	26.1	20.2	21.0

A more detailed breakdown of personnel costs by personnel functions is shown in Figure 6-1, using the example of the Karlsruhe and Berlin planning cases.

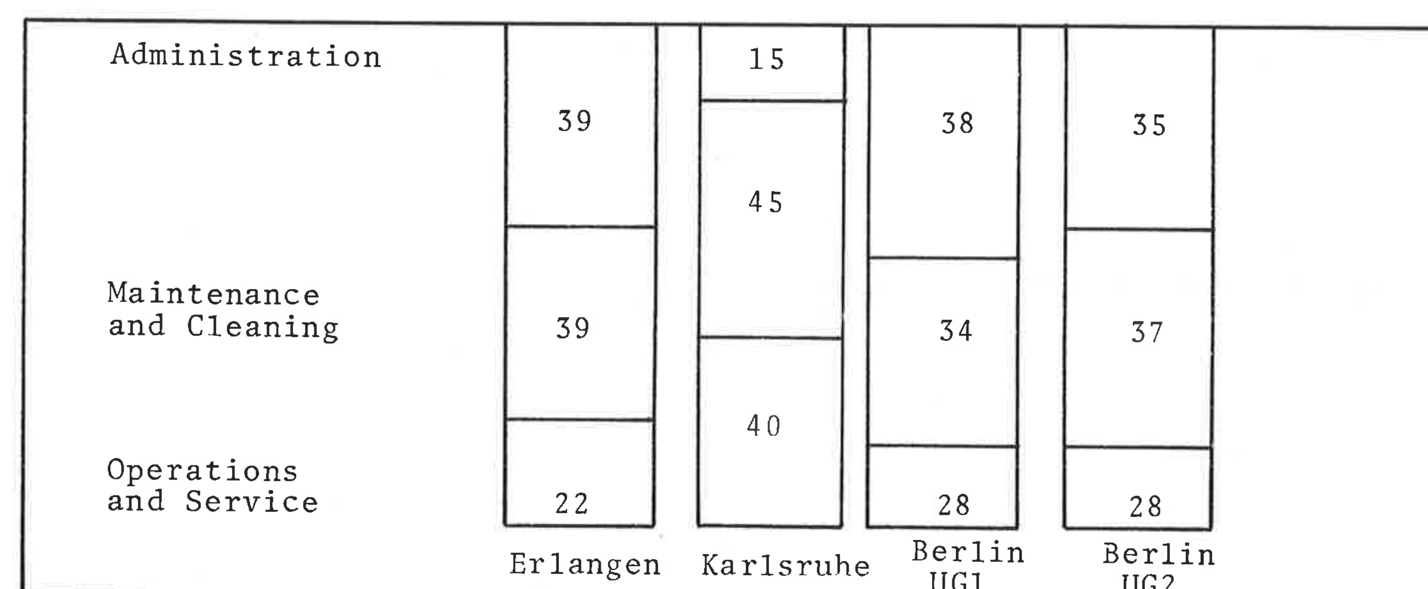


FIGURE 6-1. STRUCTURE OF PERSONNEL COSTS (in PERCENT)

The different percentages of the individual types of personnel are partially due to factors which are specific to each individual planning case. However, it is also apparent that particularly in the case of administrative personnel, there is a high fixed-cost level which is independent of the number of employees.

There is also a certain distortion of the personnel cost structure because in the planning cases of Erlangen and Berlin, services provided by outside contractors must be taken into account; while in the planning case of Karlsruhe, all personnel belonged to the company.

6.3.3 Cost Comparison of Alternative Designs

The cost calculations were carried out with a cost program. In this way, calculations for alternative design variations could be implemented in short-time intervals and the cost effects resulting from detailed differential cost printouts could be interpreted.

Thus, for example, the following variations were studied for the Karlsruhe planning case:

- Basic design: Operational development according to the manufacturer's design;
- Type 1: BQ = 50 percent (BQ is a measure of the ride quality; it is defined as the number of available seats as a percentage of the passenger load with a given vehicle cross section);
- Type 2: BQ = 40 percent;
- Type 3: V = 60 km/h;

- Type 4: V = 40 km/h;
- Type 5: Change in the ratio of seats/space for standees.

Figure 6-2 shows the following for the basic design and the investigated variations:

- Percentage of total cost represented by capital and operating costs,
- Percentage of capital cost for vehicles and fixed facilities,
- Structure of operating costs broken down into personnel, material, power, and general operating costs.

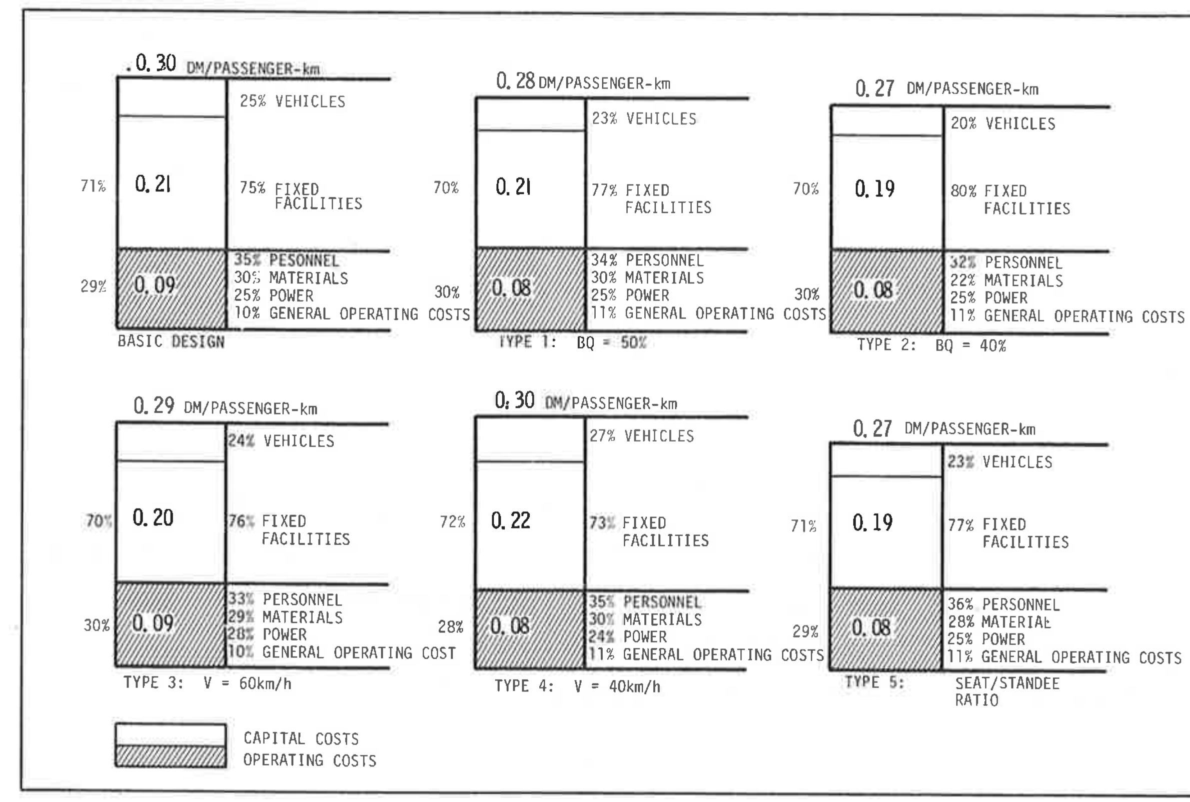


FIGURE 6-2. ALTERNATIVE DESIGN COSTS FOR KARLSRUHE APPLICATION

The capital costs were again determined by calculation, using the annuity method for an interest rate of 6 percent.

A comparison of the operating cost structure of the basic design with the structures of the investigated variations shows that the differences in operating design influence the cost structures only insignificantly. The personnel cost component makes up an average of about 34 percent of the operating costs.

The cost results available here were based upon very detailed cost increases and estimates. Particular emphasis was placed upon an increase in the cost input data within the framework of the planning studies because the accuracy of the input data in the final analysis is critical to the reliability of the cost results. However, one must not overlook the fact that the cost data used, because of certain uncertainty factors, do have some mistakes in them which can be further limited during practical operations only by actual construction and operations planning or by increases.

The most important cost-impacting parameters, however, can be investigated in greater detail on the basis of many different calculations. Without undertaking an exact error-propagation calculation, we can determine that the cost calculations which have been presented here are sufficiently exact. In order to transfer these results to other planning cases, detailed information on the relationships which are specific to the individual planning cases will be required.

7. ACCEPTANCE PROCEDURE

In the Federal Republic of Germany, the construction and operation of public transit systems require official acceptance. According to the Personenbeförderungsgesetz (TRANSIT LAW), the H-Bahn automatic urban transit system is classified as a "railroad of special design." It is considered to be a street railway to the extent that it "serves exclusively or primarily to carry passengers in local or suburban traffic." This means that all laws, decrees, and guidelines used to determine acceptance of street railways, including subways also apply to the implementation of H-Bahn as a form of public urban transit. A survey of the acceptance procedures prescribed in the Personenbeförderungsgesetz has already been given in the Cabinentaxi-Assessment study. Specific points relating to the approval of driverless automatically controlled people-mover systems are discussed. Therefore, we can omit a general description of the procedure here.

At the present time, permission to build driverless automatic urban transit systems for public transit applications in the Federal Republic of Germany is possible only in exceptional cases. Legislators are attempting to alter this situation by updating the law (known by its German initials as Bo-Strab) pertaining to construction and operation of street railways to account for further technological developments in the field of urban transit automation. These revisions will affect the acceptance procedures as well. In particular, the goal is to include in the law regulations covering driverless automatic operation. Draft versions of an updated Bo-Strab are currently in their final phases. In addition, guidelines are being developed which will give concrete form to the generally applicable specifications of Bo-Strab. The "technical standards" project which is being carried out by SNV Studiengesellschaft Nahverkehr mbH for the Federal Ministry of Transportation will make an important contribution in this regard.

In developing H-Bahn, the manufacturer has always kept in mind the current status of the guidelines, for both the overall system and the individual components.

The H-Bahn system was developed, taking into account existing applicable decrees, guidelines, and recommendations. These included special decrees on street railways which come under transit law, such as Bo-Strab, as well as general technical guidelines like the DIN standards. Thus, for example, the dimensioning of the electrical equipment and facilities in the H-Bahn system is based upon the guidelines of the Society of German Electrical Engineers, referred to as the VDE guidelines. Since the installation is considered to be a railroad, the applicable guidelines for the German Federal Railways have also been included. These include recommendations by the Public Transit Association on the electrical equipment of urban transit systems as well as the guidelines of the German Standards Institute (DIN standards).

Whenever existing orders, guidelines and decrees were insufficient to define the acceptability of one part of the H-Bahn development process, experts at TÜV, TAB, and the Federal German Railways were contacted. This was done to clarify any possible conflict between existing system safety requirements and new state-of-the-art developments.

There were no special guidelines or regulations available for certain system components, such as dimensioning of guideway supports. In such cases, guidelines that were used for comparable installations or components were relied on. For example, in the case of the guideway supports, information on static calculations, construction, and design relied upon the DIN specifications (load capacities of structures) and such guidelines of the German Federal Railways as "Calculation Bases for Steel Railway Bridges" (DV804) and "Guidelines for Welded Railroad Bridges" (DV848). The State Development Office of Nürnberg, the expert on straight guideway supports, found a good agreement in terms of calculated measured values for stresses, vibrations, and oscillations at the Erlangen test facility. On the other hand, the investigated arch support was not fully utilized in terms of permissible stresses. The vibrating effect as determined by measurement was considerably less than the coefficient of vibration provided in the dimensioning guidelines. On the basis of these results, the system manufacturer intends to revise the dimensioning guidelines which were used.

A safety system is a prerequisite for driverless automatic operation, and will be included in the future, revised Bo-Strab. An important component of the H-Bahn safety system is the URTL safety switching system, composed of various components, and based on the fail-safe principle. Within the framework of a future acceptance procedure, it will be necessary to prove that the H-Bahn system can operate safely. The system manufacturer has requested the German Federal Railways (DB) and the Technischen Überwachungsverein Rheinland (TÜV Rheinland) to act as independent advisors for safety engineering testing of URTL components. The Federal German Railways confirmed the fail-safe operation of the URTL components, thus satisfying a prerequisite for future acceptance of the system by the Technischen Aufsichtsbehörde (TAB, Technical Inspecting Authority). The overall system, especially the components for spacing, monitoring the maximum permissible speed, and monitoring switch positions, is currently being tested by TÜV Rheinland.

The safety of the passengers aboard the vehicle, for example in the case of fire, is particularly important. The system manufacturers are trying to make fires as unlikely as possible by using suitable materials for the vehicles. Thus, within the framework of the H-Bahn system development process, studies of fireproofing are also underway. The fiberglass-reinforced plastic which is used in the cabin of the Type 1/1 vehicle has been subjected to a fire test in accordance with DIN standard 4102. The fire tests were performed at the materials testing laboratory of the Behörde für Wirtschaft und Verkehr (Economics and Commerce Authority) in Hamburg. The material used was then classified as Class F30 according to DIN 4102 in terms of its resistance to fire. This corresponds to the fire-resistance time for fiberglass-reinforced plastic of between 30 and 60 minutes.

8. FINDINGS AND CONCLUSIONS

8.1 SYSTEM DEVELOPMENT AND TESTING

- In contrast to extending the state-of-the-art in automated system through innovative concepts and new hardware, the H-Bahn approach has been one of utilizing existing technology with emphasis on simplicity, flexibility, and extensive testing.
- The developers have relied heavily on an extensive test program in order to evolve and mature their system design. With such a high level of dependence on conventional technology, the empahsis has been and is anticipated to continue to be focused on the integration of hardware into applications representative of revenue operation.

8.2 SYSTEMS AND SUBSYSTEMS

- The H-Bahn system concept of providing various sized vehicles suspended from guideways in a scheduled mode of operation appears to be a sound approach.
- Overall safety of the H-Bahn system has been addressed by the system developers through a fail-safe approach to design and through general safety practices and features. Detailed analyses, such as failure mode and effects or fault-tree analyses, have not yet been accomplished to date. At the present time an analysis of the fault types and their effects based on stringent Federal Railroad requirements is being carried out for safety-related components.
- The concepts proposed for passenger rescue appear adequate, but some effort will be required for a specific site to develop an emergency action plan which classifies emergencies and outlines the approach measures which must be taken to remedy a particular situation. Field testing of the rescue concepts for their practicality in revenue systems should be demonstrated.

- Although several good reliability practices and features have been incorporated into the design, a detailed analysis allocating and specifying reliability requirements and goals for each subsystem has not been conducted. The approach of utilizing test track experience to evaluate system reliability will be sufficient if the 600,000 km goal of the testing is achieved.
- Maintainability features of the H-Bahn system are good, especially with respect to the vehicle. Pallets are utilized for the auxilliary and control equipment. The enclosed track beam extends into the maintenance facility, where all bogie equipment can be easily serviced or replaced. The equipment located within the beam is not as easily accessible, but infrequent repairs or maintenance is required for beam hardware.
- The primary cost-saving feature of the H-Bahn system is the guideway design. Its sleek, narrow cross section can be prefabricated, requiring fewer materials than other AGT systems, and only a narrow right-of-way resulting in lower land costs. Operating costs for the track beam are less than those for other concepts, since no snow/ice removal measures are necessary, and life-cycle costs for beam hardware are reduced because of added protection provided from adverse weather conditions.

8.2.1 Vehicle

- Because of the conventional technology and hardware used in the system's design, the H-Bahn vehicle has an inherent level of maturity. The H-Bahn vehicle development program has focused on the interfacing and integration of technology and on new designs and hardware. Extensive testing has especially been conducted on new design parts.

- Linking two or more vehicles together for train operation provides good flexibility for peak hour traffic; once the mechanism for linking the vehicles has been tested and revised, it will make a good marketing feature of the system.
- Physical separation of the vehicle bogie from the passenger cabin is an excellent design feature in that it separates the potential fire-source areas from the passengers. Use of non-flammable materials in the vehicle design also minimizes the possibility of fire.
- Many safety features have been incorporated into the vehicle design such as safety glass, door safety edges, and fire alarms. In addition, fire extinguishers could be added to each vehicle to provide the passenger with some capability to extinguish a small fire.
- The antenna system design used for data communication between the vehicle and the station/central computer needs to be finalized and tested prior to revenue operation.
- The attention given to vehicle maintainability by the developer is significant, particularly in relation to hardware accessibility.
- A significant level of redundancy is incorporated into the vehicle design, enhancing system availability.
- The availability of several vehicle configurations with varying capacities provides flexibility in adapting the H-Bahn system to the travel demands of any local community.
- The option of using linear induction motors for the H-Bahn vehicle offers significant advantages over the dc drive motor relative to grade, noise, wear, and all-weather operations.

- The reversible nature of the vehicle offers added flexibility in designing the guideway at the network ends and also provides increased system capability to react to a disabled vehicle.

8.2.2 Guideway

- The H-Bahn guideway is constructed of proven materials using conventional construction methods.
- Extensive testing at Düsseldorf and Erlangen has produced a mature H-Bahn guideway design.
- The guideway system displayed at Erlangen is similar to the one which would be proposed for operational deployment with a few changes: 1) The mounting bracket for fastening the track beam to the column head would be modified to allow easier, quicker beam erection. 2) The running rails will be eliminated making the bottom web of the beam the new running surface.
- Using a steel box beam with steel ribs allows for the construction of a beam with a strong and stiff cross section; the stiffness can be varied by changing the spacing of the ribs. This feature can result in substantial cost savings.
- The stations and guideways are aesthetically pleasing and therefore, should be easily accepted by the public. The narrow track beams and tapered columns could be easily integrated into an urban environment without detracting from the surroundings.
- The track beam configuration provides maximum protection from the environment (rain, snow, wind, etc.). The protection afforded by the closed track beam has a positive effect on performance parameters such as dependability, availability, and traction for propulsion and braking. This should improve system reliability as well as reduce life-cycle costs of system components mounted within the

beam and operating costs of system in adverse weather.

- Condensation along the top chord of the track beam combining with brush fibers and tire filings often formed a slippery surface on the test track during operations in Erlangen. As a result, Siemens has changed the tire and brush materials to ones which have reduced wear and shed and are developing a device which will be used to keep the running surfaces clear of contaminents.
- For H-Bahn applications in regions with high solar radiation levels, some effort might be required to reduce beam temperatures to ensure proper performance of electrical components and a work environment suitable for maintenance personnel.
- A significant cost-saving feature of H-Bahn is that guideway components can be prefabricated and transported to a site for erection. If transportation is not a major expense, significant cost savings can result. Prefabrication also reduces site and traffic disruption during construction and can provide the tight tolerances necessary for beam positioning and alignment.
- Guideway maintenance is minimized by the closed track beam arrangement and the fact that switch ramps are the only moveable parts. When maintenance is required, access must be gained through small manholes on the beam top or from the beam end at the maintenance shop; however, this might prove difficult for certain infrequent repairs. Siemens has developed a vehicle which can be driven through the inside of the track beam and anticipates completion of an automatic monitoring device design which can be circulated through the beam to detect potential problems.
- Guideway materials govern the amount of maintenance required for beams and columns. Where concrete is used, maintenance is minimized; but where steel or painted

concrete is used, periodic repainting will be needed (repainting will be needed at approximately 10-15 year intervals). Use of Cor-Ten has been curtailed because the self-rusting feature does not slow down after an initial rust coating is formed, but continues to rust at nearly the same rate.

- Deisgn specifications used for guideways are similar to those used for U.S. construction and in some cases, such as for impact resistance, are more stringent resulting in an improved product.

- Switch design has evolved from refinement of earilier designs, and extensive testing helps to increase confidence in seitch reliability and safety. The use of a back-up system comprised of nearly all mechanical components contributes to safe switch operation.

8.2.3 Command and Control

- The command and control subsystem is an adaptation of conventional technology. This should ensure that with adequate testing, the system will be relatively mature when first deployed.

- Data transmission is conventional and due to innovative applications of existing technology, data transmission in normal operation is minimized.

- The hierarchical structure of the subsystem is conventional and reliable.

- The traffic control system requires much equipment and some of its problems have not yet been solved such as the selection of a guideway antenna. At present, a few hundred components are located in each mile of guideway. They are generally simple, and should have long lives, as proven by the performance of the Bero sensors.

- The safety system is indiependent of the other two levels of control, thereby improving its reliability.
- The safety system electronics have been under development for several years and have been certified "fail safe" by the German Federal Railways.
- Little reiliability analysis has been done on the H-Bahn subsystems and components, with the exception of the URTL safety electronics. The developer prefers to perform extensive tests, failure analysis, and redesign of parts when necessary. This is an effective approach when conscientiously followed, and particularly for as complex an assembly of equipment as the command and control subsystem.
- The command and control system incorporates jerk limitation and limits on normal acceleration and deceleration, ensuring a smooth ride for the passengers.
- Automatic reporting of on-line failures to central control will enhance passenger safety and reduce the time needed to restore the system to normal operation.
- Safety of passengers will be enhanced by the anticipated:
  - passenger-central voice communications
  - failure and fire sensors in the vehicles
  - mimic boards and CRTs in central control giving the operator continuous awareness of the vehicle condition.

8.2.4 Dynamic Simulation

- The simulation tests that have been performed thus far have demonstrated that H-Bahn is an efficient system and indicate that it is also effective.
- In planning H-Bahn, dynamic simulation must be carried out in order to be able to properly dimension the stations, vehicle sizes and numbers, operating reserve,

schedules, etc. In addition, the effects of possible malfunctions should be simulated in order to obtain information needed to plan suitable counter measures (network modifications or reactions).

- Dyanmic simulation could also be used for answering the question of whether, in the case of applications involving late-night operations, line-request operation (vheicles running only on demand) makes sense, or whether the vehicle should continue running late at night using the line system, with vehicles arriving at regularly spaced intervals (e.g., one car every 10 minutes).

8.2.5 Power Supply

- The power supply system of H-Bahn, as provided for specific applications, is designed to be redundant in its most important parts. This helps protect against breakdown and ensures a high level of availability for urban transit systems. The emergency power generator must be designed so that even the last section of line can be cleared in a space of time which passengers will tolerate.
- Like the traction power supply, power supply to the stations is made redundant to protect against power outages.
- In accordance with VDE guideline No. 0115, all current-carrying system components, especially guideway supports, vehicles, and station platforms, must be grounded.
- Truck dimensions, feed cables, and power rails for a given train length and predetermined train interval are largely affected by the choice of drive, either linear or dc motor.
- The power rail/current collector system is currently undergoing long-term testing at the H-Bahn test facility, and is being developed further. The protected arrangement of the power rails inside the guideway supports ensures that the traction current will be available even in extreme weather conditions. Even during the

harsh winter of 1978/1979, there were no operating problems at the test facility caused by failures in the power supply.

- Studies of feedback effects into the line, especially when linear motors are used, have not yet been conducted. They will be performed, within the framework of subsequent testing, at the H-Bahn test facility.

8.2.6 Maintenance and Repair

- In order to achieve long maintenance and repair intervals, low-maintenance, high-reliability components are being developed within the framework of long-term testing. Requirements for high reliability of all components and, hence, for low-maintenance costs have been met by extensive use of conventional technology in H-Bahn.
- Theoretical reliability analyses are viewed with skepticism by the H-Bahn manufacturer; instead, it is preferred that further information be obtained through practical testing, analysis of test results, possible modifications, repetition of tests, etc.
- In particular, it is necessary to obtain information on the frequency and scope of necessary maintenance and repair work for the total system. This depends, among other things, upon the number and expected lifetime of components subject to wear, and their reliability determined on the basis of further operating experience.
- Maintenance and repairs must be carried out at the lowest possible cost. This work is expected to take very little time because the vehicle equipment is combined and laid out in an easily accessible fashion, and a rapid fault location system is designed around automatic checkout stands.

- In order to be able to detect brief, transient problems with the vehicles, a fault recognition system has also been developed for H-Bahn.
- Maintenance costs for guideway supports are limited to those incurred primarily from visual checks, especially the monitoring of switch components. The equipment within the track beam is not as accessible as the vehicle components, but operating experience, thus far, indicates that there will be relatively few failures and little wear, since all of the parts are fixed except for the moving switch points.
- It is not certain how often the support interiors will require rust-proofing or how often the equipment itself will have to be removed to allow this maintenance to be carried out. Points to be investigated in this area should include determining the effects of condensation (from fog, for example) inside the guideway supports, and how this could be avoided.
- Efforts must be continued to develop methods for locating failures as well as for maintenance and repair work within the guideway interior.

8.3 PASSENGER-RELATED SYSTEM ASPECTS

8.3.1 Rescue System

- Aid and rescue devices have been designed for H-Bahn and are currently available at the test facility. The nature and scope of the rescue equipment must be determined for each specific application and tested prior to deployment.
- The time required for the operating personnel to arrive, the disconnection of the safety level, the approach of the rescue vehicle to an incapacitated one, coupling up and towing to the next station after the safety system has been reactivated, must be included in an allotted space of time.

- In order to move the disabled vehicle or to rescue passengers, using a special vehicle, it must be possible to reach the defective car. In other words, the approach of the special vehicle must not be blocked by any other vehicles.
- When the passengers are transferred by using an extendible platform, unilateral loading may result in a lateral tilting of the vehicles and, therefore, the platform. The tilted position may have to be limited by using a special device.
- A rescue vehicle especially designed for the system is a combined type of vehicle which in addition to its function of passenger rescue makes the disabled car accessible and is capable of moving it.
- The use of emergency vehicles operating on the ground assumes that the location where the malfunction occurs can be reached by such a vehicle.
- If escape routes must be used when the line is underground in a tunnel, it must be possible for the passengers to open the doors in emergencies. For example, the lock of the rescue tube can be released by a signal from the control center.
- If particularly rapid evacuation is necessary, e.g., in case of a fire, the fire detector in the cabin will indicate this to central control. By using fireproof materials in the vehicle passengers should have sufficient time to reach the next station. When selecting materials the level of toxicity should be considered.
- In the unlikely event that two incidents happen at the same vehicle, the rescue tube lock will be released. However, the height differential between the guideway and the ground may cause problems, if the tube is used to rescue certain classes of passengers such as the elderly, handicapped, and children. In case a dangerous fire

breaks out despite the use of fire-resistant materials, it is questionable whether all the passengers could escape safely. Therefore, further tests on the rescue tube design are necessary, and possible modifications should be tested.

8.3.2 Fare Collection

- Equipment for fare collection and passenger handling, at the stations, is in every application determined by the local specific installation and the operator's requirements. In its basic operating form (line operation according to a fixed schedule), fare collection in Germnay will largely correspond to the current practice used on public transit systems in the Federal Republic of Germany. For applications outside Germany, the particular type of equipment generally found at stations in that location may be used.
- The location of ticket-canceling machines directly in front of car entrances can lead to delays in passenger interchange. Another location for the ticket-canceling machine, for example, in an area near the automatic ticket-selling machines, might be more appropriate.
- If the operator wishes, a demand operation system can be implemented for late-night operation. Vehicle requests by passengers can either be tied in to the ticket-canceling system (protection against abuse) or can be independent of that system (easily integrated into an existing fare system). In both cases, spot checks may be necessary, since even if the tickets must be canceled in order to request a ride, there is nothing to prevent a number of people from riding on only one ticket or to prevent improper use of nontransferable tickets.

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APPENDIX A

THE "BERO" PROXIMITY SWITCH, USED AS BLOCK
SENSOR IN THE H-BAHN BEAM

The following figure is abstracted from the Siemens catalog sheet describing the Bero Proximity Switch, and from a descriptive article entitled "Contactless Proximity Switch (BERO) With Integrated Circuit," from Siemens Zeitschrift, Vol. 49, No. 4, April 1975, by Krimmling and Walker.

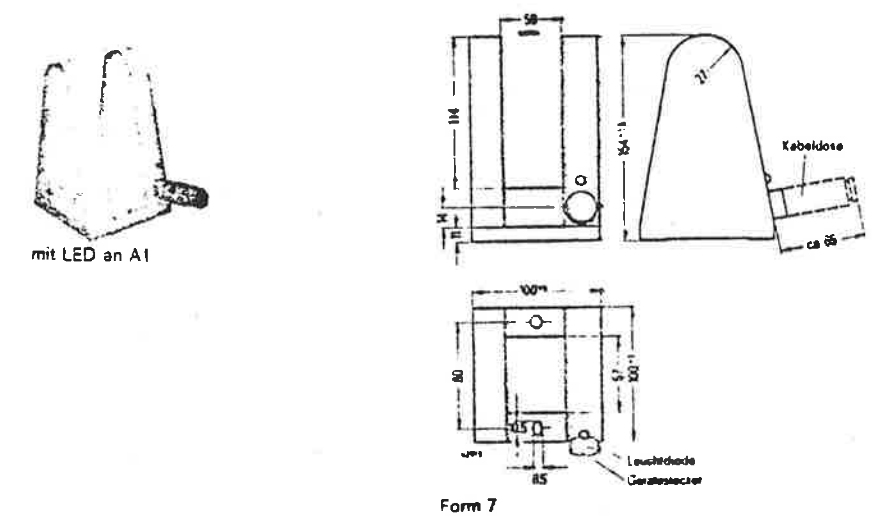


FIGURE A-1. BERO SENSOR (DIMENSIONS SHOWN IN MILLIMETERS)

2. The following figure shows how this sensor works. (The cited article also discusses at length the precautions taken to protect the sensor and its associated integrated circuit against the effects of accidental shorting, electrical noise in its environment, and from other environmental effects that could cause either interference with its operation or destruction of its component parts. An integrated circuit is used with the sensor because of its small

size and compatibility with the mechanical design.)

The following figure explains the operation of an inductive proximity switch.

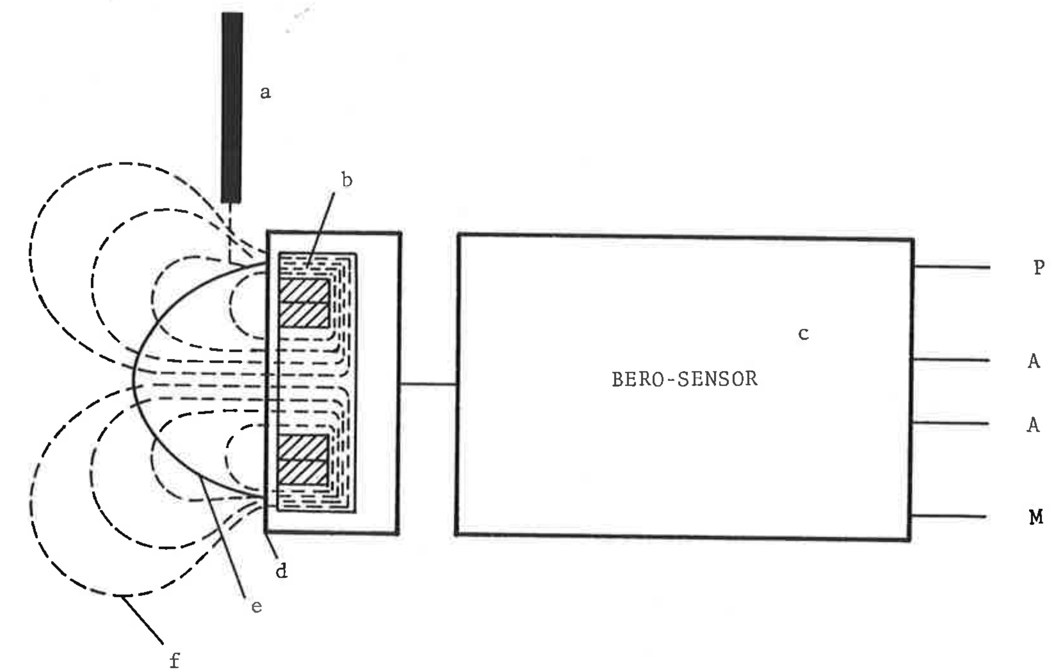


FIGURE A-2. INDUCTIVE PROXIMITY SWITCH

A high-frequency electromagnetic field is emitted by the wound core at the left. The pattern of the lines of force shown in the drawing may be assumed to be theoretically correct. The coil (b) constitutes the inductive part of an oscillator circuit which is driven by the oscillator at a frequency of several hundred kilohertz. If a metallic conducting object (a) comes into the proximity of the field, the resultant eddy currents will draw energy from the oscillator. This will result in a damping of the oscillation amplitude such that the limiting value of a series-connected evaluation circuit will be undershot and a corresponding change in the signal will be produced at the output.

The above-mentioned alternating field is produced in the oscillator. This oscillator is designed as an integrated Meissner oscillator such that it is only necessary to have an inductance for the parallel resonance circuit to produce the sinusoidal oscillations. This oscillator circuit is a part of the integrated circuit shown associated with the BERO-Schaltung sensor (or BERO- circuit) shown in the figure.

APPENDIX B

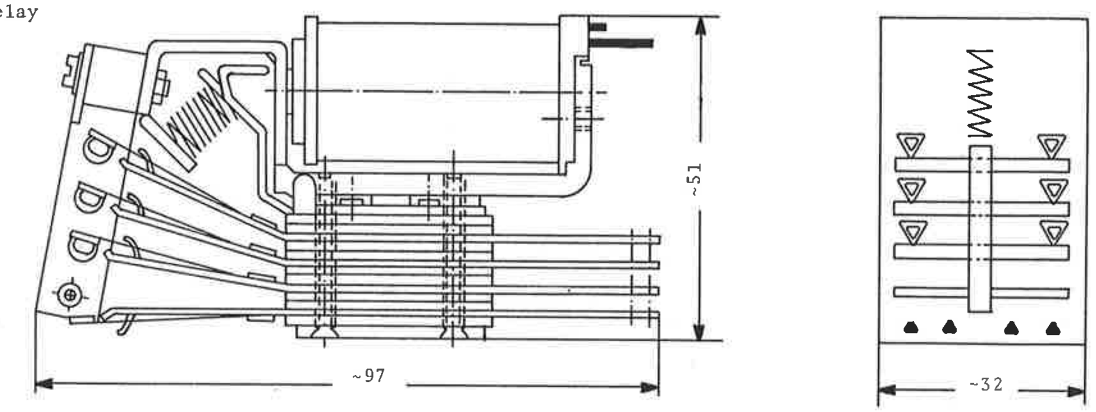
HIGH CURRENT SIGNAL RELAY K50

For switching power in networks of railroad signal systems, the K50 high current signal relay was developed. It can also be used advantageously for control applications in other circuits, especially when high operating safety is required with a high contact load. In addition to having high current contacts, the relay is fitted with contacts of regular design which can be used as auxiliary contacts with low switching power for other circuits. The relays are marked by the following features:

1. High opening safety produced by two contact positions connected in series.
2. Self-cleaning safety contacts (friction contacts) in which the contact point and the separating point are separate from one another.
3. Rigid mechanical coupling of the contact parts moved by the armature.
4. Contact closures which contradict the armature position are ruled out by the design, even in the event of contact parts being welded together.

Source: Siemens catalog sheets for K50 high current signal relay.

Size of relay



Mounting of relay, holes in base plate

Screw depth max. 3 mm

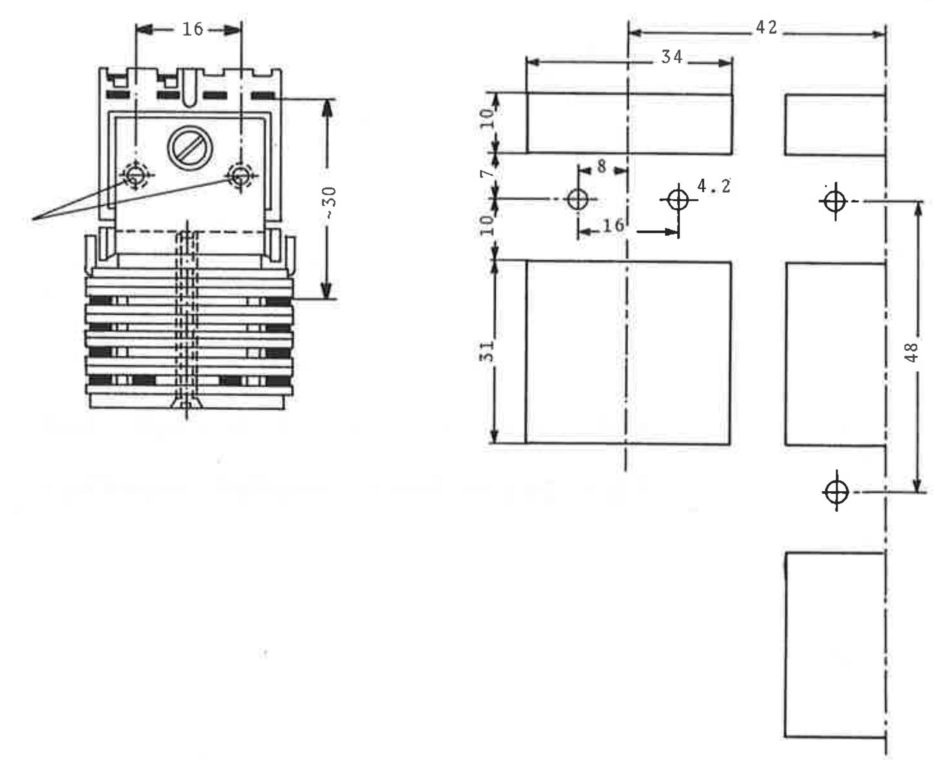


FIGURE B-1. K50 HIGH CURRENT SIGNAL RELAY

APPENDIX C

NOTES FROM SIEMENS ON COMMUNICATIONS

Message Structure:

1. At the test track,16-bit serial messages are used both to and from vehicle.

2. In a deployed system of over seven vehicles, a 32-bit message would be used, with the following structure:

1-----------9	10-------------------31	32
Vehicle Address	Vehicle commands or answers	Parity check (only for the commands)

Commands to Vehicle:

1. Turn drive and brake unit on or off
2. Open emergency exit
3. Stop
4. Speedstep (7 steps: 0.16 to 1.0 max speed)
5. Start
6. Driving direction
7. Couple vehicle
8. Decouple vehicle

(plus a possible addition of 10 more commands)

Vehicle Responses:

1. Stop call by passengers
2. Emergency call
3. Fire on board

4. Failure on vehicle, 3 categories

   I. Breakdown, unable to drive

   II. Main component failure, driving to next station

   III. Secondary failure, check next night

5. Emergency brake open or closed

6. Weight

7. Doors closed

8. Drive on, brake off

9. Driving direction

10. Coupled or decoupled

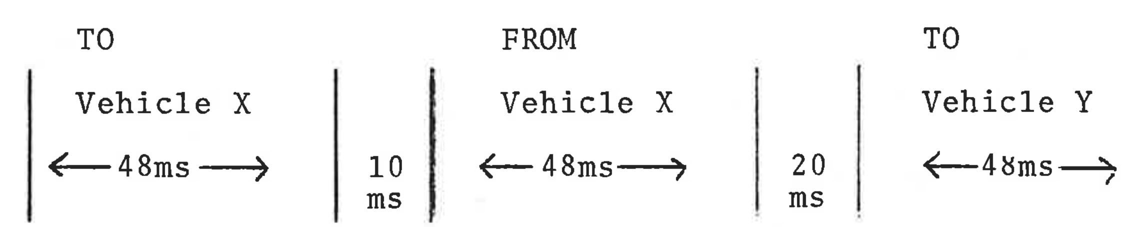
11. Speed

12. Location.

<u>Message Rate</u>:

1. Station computer sends and receives to and from one vehicle at a time.

2. Message time, one direction, is 48 ms/16-bit message.



<u>Parity Check</u>:

If an error is detected by the parity check

1. Vehicle ignores any message with an error.

2. When station computer receives no answer, or one with a parity error, it sends a second message to the vehicle.

Source: Letter from Siemèns Signal Engineer Birnfeld.

APPENDIX D
PROGRESS IN H-BAHN SYSTEM DEVELOPMENT (30 SEPTEMBER 1980)

Since the assessment visit (March 1979) the H-Bahn developers have accomplished additional testing at the Erlangen test facility, and the maturity of the H-Bahn development has advanced rapidly. This appendix outlines the progress made since the assessment visit.

1. SIGNIFICANT EVENTS DURING THE TIME PERIOD FOLLOWING ASSESSMENT VISIT

The time period from April 1979 until September 1980, was essentially characterized by the following events:

- Continuation of long-term tests on the Erlangen experimental system
- System test on the experimental system with interaction of all components
- Basic decision of the Erlangen City Council to construct a larger demonstration system in the city of Erlangen
- Beginning of work on H-Bahn system for Dortmund University

1.1 CONTINUATION OF LONG-TERM TESTS

During the period under report, one remote-control vehicle, and later several of them, ran every work day for 16 hours. Beginning March 1980, the vehicles ran under computer control. These long-term experiments took place outside the normal daily working time since, during this time, work was being done on the line or on the vehicles, and measurements as well as start-ups were being performed. The total running distance of all the vehicles together now amounts to 225,000 kilometers.

1.2 SYSTEM TEST

From 3 March 1980 to 8 March 1980, a five-day continuous test with daily 24-hour operation was performed on the experimental installation in Erlangen, under the control of representatives of the BMFT (Federal Ministry for Research and Technology). Three computer-controlled vehicles were always deployed, of these two with D.C. and one with LIM drive. When a vehicle was subjected to routine checking or if there was a problem with a vehicle, another vehicle was immediately pulled into the program. The test extended to the following system components:

- Vehicles with all mechanical and electrical components and equipment for automatic operational guidance
- Roadway, including equipment for electric power supply, automation, and safety engineering
- Stations with equipment for station- and vehicle-control (doors, docking equipment, passenger dispatch, and monitoring)
- Central control with operating console and monitors for operating and checking the computer-controlled operation
- Maintenance platform for inspecting the vehicles utilized

The vehicles ran in the closet sequence that was allowed in terms of the safety level, so that sometimes vehicles were dispatched at the "Technikum" station at 30-second intervals. (Because of the boundary conditions of the available experimental system, this test naturally took place without passengers.)

With this first system test, availability was about 95 percent. The vehicle and station components, which had already been tested for some time, were nearly trouble-free. The troubles which did occur primarily still lay in the automatic operating technology. These problems were analyzed, and at this time appropriate modifications are being prepared with the objective of substantially increasing availability.

1.3 BASIC DECISION OF THE ERLANGEN CITY COUNCIL

On 24 October 1979, the Erlangen City Council decided to construct an H-Bahn demonstration system in the city of Erlangen. This decision was the logical consequence of the following presuppositions:

- A small financial contribution on the part of the city of Erlangen. (After about 1 year, a modality acceptable by all partners was found.)
- Problem-free and effective line layout (Several variants were discussed. At this time, an alternative has been found which has the greatest chance for a political compromise, while implementing the desired building decision.)

1.4 OPERATIONAL DEMONSTRATION SYSTEM OF DORTMUND UNIVERSITY

On 7 May 1980, the H-Bahn Company Dortmund (mbH) was founded. It has members from the province of North Rhine-Westfalia, the city of Dortmund, Siemens AG, and DÜWAG Wagon Factory Uerdingen AG.

The purpose of the company is to construct and operate an H-Bahn system of about 1.1 km in length, which will connect the two campuses of Dortmund University. The total system will be treated and approved like a project involving public passenger traffic. At this time, the application documents are being set up. According to the laws of the Federal Republic, these documents are required for the construction and operation of a local transport system. The application was submitted in November 1980. Under the presupposition that approval will be granted by June 1981, trial operation could begin in January 1983.

2. ENGINEERING IMPROVEMENTS AND FURTHER DEVELOPMENTS

Long-term and system-level tests gave cause to consider various designs for some components. For this reason, new solutions were investigated which will already be applied in the Dortmund installation.

2.1 IMPROVEMENTS TO EXISTING VEHICLES

To simplify matters and to reduce weight, the pull-up motors of the spring storing brake, which up to now have been fed from the battery through converters, were experimentally replaced by three-phase motors for 380 V fed from the mains.

The rubber wheels have fulfilled the requirements for low sound emission. In view of round trueness, wear behavior, and durability of the rubber tires, extensive investigations were performed on the processes which occur in the rubber during the rolling process. As a consequence, the structure of the tires and the rims were changed. In the meantime, such a wheel has reached a total running distance in excess of 75,000 km. The objective of replacing wheels only once a year will therefore certainly be reached.

2.2 BUILDING A LIGHT-CONSTRUCTION VEHICLE

Changing the details of existing vehicles results in improvements only under certain conditions. Consequently, previous experience in designing a new vehicle is to be taken into account. The design work has begun; the vehicle is to be put in operation in the fall of 1982, on the Dortmund installation.

The vehicle involves a central cabin with a new seating arrangement and two running drive units with ROT drives. Even though the cabin has been enlarged, the total weight of the vehicle will be reduced by 1.5 tons, to 7.0 tons. Proven subassemblies will be taken over into the drive unit; however, it does not contain a switch-changing device, since active switches are used in Dortmund. The frame of the drive unit is a welded construction of standardized steel sections. This makes the individual components more accessible and reduces the weight by about 30 percent. The seating/standing room ratio was improved. The anticipated design has 20 seats and 22 stand-up places.

2.3 DEVELOPMENT OF AN ACTIVE SWITCH

The current design of essentially passive switches has been tested by the appropriate West German agencies. This design entails practically no limitations for the tightest vehicle sequence on a line, but successive switches must have a certain distance from one another. This distance increases as the speed increases. In order to be able to lay out short turns, depot systems, and especially branch points with minimum effort and with a low space requirement, an active switching design was worked out which utilizes the concepts for safety engineering for railroad switches. The functions "switch", "lock", "report final position", "retain final position" are contained in the switching drive. Siemens AG delivers such drives to the German Federal Railroad.

The direction is prescribed by means of the switching points. In the switching area, these represent the guiding tracks for the side wheels. With this new design, the drive unit does not need switch-guiding rollers with bearings, steering, and drive, and the roadway support will not require switch-guiding and interlock rails as well as switching ramps. Compared to previous switches, the effort involved is greater because of the mechanical built-ins and because of the drive. However, a considerable saving is made in terms of movable parts that require maintenance, in the case of installations of line operation, with few switches and many vehicles.

The use of such switches on the small Dortumund installation is not absolutely necessary. However, installing them affords a good opportunity for an operational tryout, both for the switches and for the new vehicles. One switch has already been produced and has been installed separately on the H-Bahn experimental system in Erlangen, so that long-term tests can be performed. Up to now, 225,000 switching processes have been performed with this new switch design.

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