Forschung Stadtverkehr

Special Issue

Issue 25 1979

Communications on research aimed at improving transport conditions in cities, towns and other built-up areas

Summary report (entire project):

Study of the operation of new short-distance transport systems and of improved high-speed railways by simulation, including the establishment of bases for planning and decision-making

Published by the Federal Minister of Transport,
Transport Policy Department, Bonn-Bad Godesberg

Kirschbaum Verlag, Bonn-Bad Godesberg

Table of Contents

About this study

The Federal Government supports the development and use of new transport systems for short-distance public transport. To be able to assess the use of track-bound, automatic systems, instrumentalities had to be created which make it possible to investigate these systems in complex networks for real areas and to assist in decision-making.

The core of the instrumentalities created is the simulation of the operation of new short-distance transport systems. This simulation is preceded by the calculation of the level of the demand for travel and by a preliminary dimensioning of the transport services provided. The simulation proper informs about the operating behaviour and the level of service achieved, so that the short-distance transport system can then be dimensioned. Scheduled service of automatic high-speed railways, on the one hand, and demand-actuated service of small cabins, on the other, are dealt with in separate models. The evaluation is carried out by means of a cost-effectiveness analysis which is supplemented by a procedure designed to assist in decision-making. The instrumentalities as a whole are structured as a system of mutually coordinated EDP programs.

Various kinds of short-distance public transport systems are investigated by means of this program system; their concepts are among the factors determining the choice of the area of application for each system. The study covers area-type transport development by a feeder mode, axial transport development by a high-speed mode, and the development of a town's transport by means of a single-mode transport system.

Finally, alternative operational designs of the individual short-distance transport systems are evaluated on a comparative basis. This study is not intended to provide a comparison of different short-distance transport systems and it could not do so, because of the initial situation which varies from case to case.

In submitting this report, we want to express our gratitude to all those who have contributed to the study, i. e.

- — the ,,Committee supervising and attending to the project": gentlemen of the Federal Ministries of Transport, of Regional Planning, Building and Urban Development, and of Research and Technology;
- — the advisors: Mr. Brand, Dr. Frederich, Prof. Dr. Girnau, Messrs. Hußmann and Jähnichen, Prof. Dr. Leonhard, Messrs. Marten, Mies, Scheucken, Schmidt and Schuler, Prof. Dr. Schweizer, Messrs. Waibel, Weigelt and Westphal;
- — for data and pictures made available to us: Prof. Schaechterle, the firms DEMAG, DÜWAG, Hamburg-Consult GVV, KRUPP, MBB, SEL and SIEMENS, the municipal administrations and transport undertakings of the cities of Bielefeld, Hamburg, Karlsruhe, Köln, Krefeld as well as the Battelle and Prognos Institutes;
- — for team support: the Arbeitsgemeinschaft Harloff/Hensel, the firms Berliner Verkehrs Consult, Hamburg Consult GVV, Infosystem, Ing. gruppe Verkehrsplanung Berlin, MBB, Systemtechnik and VFW as well as Messrs. Grabowski, Neufeldt and Dr. Sahling.

The SNV staff who worked on this study were: Apking, Dr. Bents, Bohling, Brüggmann, Dr. Droste, Dübbers, Fürböter, Gerland, Haferstroh, Hahn, Heckelmann, Heine, Heinke, Heinz, Helbing, Henzgen, Hilgenfeld, Dr. Horsmann, Hubschneider, Ilgmann, Kahl, Kaufhold, Koch, Kölln, Kossak, Ludwig, Mannweiler, Marnitz, Dr. Meetz, Müller, Dr. Naumann, Nötzold, Dr. Nuppnau, Pfeiffer, Rothermel, Sauerbrunn, Scharpf, Schmidt-Holzmann, Singethan, Sprenger, Staub, Waschin, Weyerstall and Dr. Zemlin.

As far as the summary of this report is concerned the project manager was Mr. Dübbers.

Important explanations

Short-distance public transport system is the totality of all facilities used for the provision of public transport service in a region. Where just one part of it, consisting of one mode only, is concerned, the term is preceded by "single-mode".

Lines of a short-distance public transport system as used here are designated separately according to direction and opposite direction. Entire round trips are therefore given two numbers.

Traffic periods and their significant hour are

peak	7.00— 8.00 hours
off-peak	13.00—14.00 hours
late evening	21.00—22.00 hours.

Daily values are related to the **average workday** (Monday—Friday; year/310) or, normally, to the **average weekday** (workday, Saturday, Sunday; year/365).

Carryings (boarders) are broken down, according to their access, into **directly boarding** passengers and passengers **interchanging** from feeder systems. **Transferring** passengers are those who change the line within the short-distance public transport system under consideration.

Transport (distance, time, speed) relates to the time spent on the short-distance public transport system from boarding till alighting, including any transfer times.

Journey time = transport time + waiting time.

Departure, arrival and travel times according to timetable are related to the operation and generally do not correspond to the published timetable.

Time reserve is generally determined as 5 % of the minimum travel time.

Quality of transport (QT) /19/ is the ratio of the seats provided to vehicle occupancy. In operation, minimum standards must be maintained which are set for the significant cross-section in terms of average values over 10 minute periods.

Costs have been uniformly established at the level of 1977. The interest rate has been assumed as 6 %. The determination of quantities is based on route layouts at the scale of 1: 10 000 or 1:5 000.

Basic concept is the original design for the operation of a public short-distance transport system from which all **variants** have been directly derived.

Synthetic short-distance public transport systems indicate that a manufacturer's concept does not exist for the basic concept in question or that the basic concept may be different from the manufacturer's concept.

VÖV = Verband öffentlicher Verkehrsbetriebe — Association of Public Transport Undertakings.

B. Application of the instrumentalities to the study of automatic single-mode short-distance public transport systems

3. Transport development of an urban quarter including a high-speed railway link (Hamburg-Nord)

3.0 Hamburg planning region

The study area is located north of the Hamburg city centre (Hmb Mitte) (cf. Fig. 3.0-1); it is bounded in the north by the border of the land (Federal State), in the east by Fuhlsbüttel Airport, in the south by the U1, U2 and U3 metropolitan railway lines, and in the west by the Hamburg-Flensburg motorway.

The airport, the Niendorfer Gehege forest and the northern by-pass freight railway line divide the study area into a southern region, which is a mixed type of development and belongs to the city centre and a northern region, which has the character of a residential neighbourhood and, correspondingly, a more widely dispersed development.

At the time of the investigation no data pertaining to the study area were available, as they are needed for the transport forecast program. Therefore, a separate transport forecast calculation had to be prepared on the basis of structural data for the entire Hamburg area, using information supplied by the Statistisches Landesamt (Hamburg Statistical Office).

Fig. 3.0-1: Hamburg and the study area

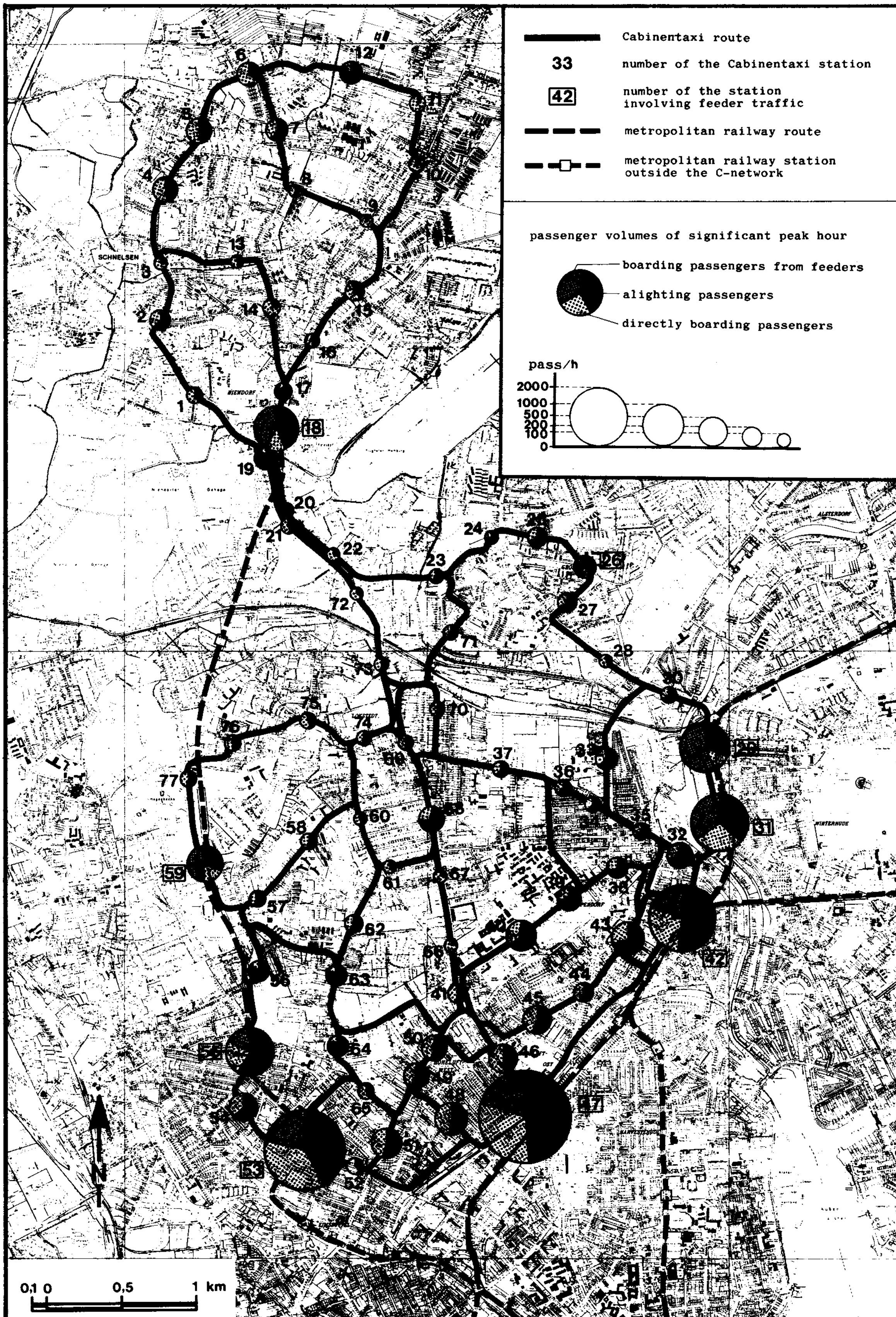


Fig. 3.1.1-1: Network and passenger volume during the significant peak hour

	Hamburg administrative area	Study area
inhabitants in 000's	1620 = 100 %	135 = 8.3 %
workplaces in 000's	917 = 100 %	63 = 6.9 %
capacity for pupils, students and trainees in 000's	173 = 100 %	27 = 15.6 %
person trips+/day in 000's	3460 = 100 %	406 = 11.7 %

Table 3.0-1: Forecast data for 1990

+ public and private transport

In keeping with the anticipated long-term trend [11], this calculation assumes a slightly decreasing population by 1990.

A comparison of the structural data and transport data for the administrative area of Hamburg and for the study area is contained in Table 3.0-1.

The unusually high volume of traffic in the study area is due to the higher trip frequency resulting from the proximity of the city centre and to the feeder transport by rapid transit systems and buses.

Following the general guidelines for urban transport in Hamburg, an approach was chosen here, too, in which the road network is dimensioned for commercial traffic and is consequently not developed in favour of the private motorist. Thus, a potential traffic increase during the peak hours of journeys to and from work primarily affects public transport.

3.1 Small cabin Cabinentaxi KK 3

3.1.1 Network and transport planning

The network of the cabin system is designed to provide area-type coverage for the study area and to link it to the high-speed railways system. The characteristics of the network formation and the operation of the Cabinentaxi must both be taken into account [7].

The high station density and the short walks to and from stations resulting for a large majority of the passengers bring out clearly the taxi-like character of the system. The network shown in Fig. 3.1.1-1 has a fine meshed section in the predominant southern region. The northern route network at Niendorf and Schnelsen has a larger mesh size and is linked with the southern part of the network by a corridor-type multi-lane central part at the narrow passage between airport and forest. A number of relief routes in the southern region make it possible to offer an acceptable service even at the interchange stations to and from metropolitan railways.

Transfer to the high-speed railway is provided at eight stations to distribute the passenger volume. Fig. 3.1.1-1 also shows the traffic volume at the stations during the significant peak hour.

The passenger volume is made up as follows:

- Station volumes are greatest at the cabin system stations adjoining the metropolitan railway stations Hoheluftbrücke (47, about 5500 boarding and alighting passengers), Emilienstraße (53, about 4300) and Kellinghusenstraße (42, about 3100).
- During the significant peak hour the cabin system stations at the eight high-speed railway stations have to cope with about 60 % of the boarding passengers and 50 % of the alighting passengers in the cabin system, i. e. about 12,000 passengers boarding and about 10,000 alighting.
- The percentages defined as "passengers boarding from feeders" (about 31 % during the peak hour, about 24 % on average throughout the day) arrive in batches depending on the headways of high-speed railway trains and buses.
- While the planning case is designed as a feeder to the high-speed railway system, it still carries a large part of the local traffic.

Table 3.1.1-1 contains important characteristic numbers for network and planning area.

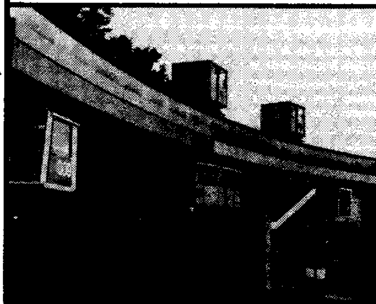
Table 3.1.1-1: Characteristic numbers for network and traffic volume

net building land km^2	15.6			
stations	77	Station density	stations/km^2	4.94
route kilometres	48.86	route density	route kilometres/km^2	3.13
line kilometres	not applicable	average station spacing	route kilometres/station	0.63

passengers boarding	total	directly	from feeders	passengers transferring within the system
per average workday	144,000	109,800	34,200	not applicable
during significant peak hour	19,550	13,530	6,020	not applicable
off-peak hour	10,100	8,470	1,630	not applicable
late evening hour	1,880	1,740	140	not applicable

transport performance	10^6 carryings/year	44.61
	10^6 passenger kilometres/year	194.28
average transport distance	passenger kilometres/carrying	4.36
traffic carried by routes	passenger kilometres/day, route kilometre, direction	6.425
modal split (in original plan)	%	35

Cabinentaxi KK 3



Track

- Characteristics:
Elevated trackway accommodating two lanes, segregated from road traffic and without level crossings

- Construction:
Closed hollow steel box for outside running chassis of supported and suspended vehicles; external equipment for lateral guidance; transmission of power, energy and data; weather and noise protection by means of side screens; passive switches for on-board preselection of direction; supports arranged at the side (cantilevers with normal and long projection, T- and portal supports, special designs)

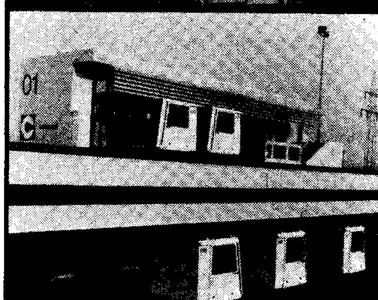
- Data:
Spans on straight sections 40 - 50 m, in curves 30 - 40 m and even more when guyed supports are used; minimum radius 30 m, in exceptional cases 20 m

Vehicle

- Characteristics:
Cabin providing three seats; chassis with external guidance; propulsion by contact-free linear motors; continuous adjustment of voltage and frequency; on-board switch control; automatic running control, automatic and supervised headway maintenance as well as automatic running to destination; automatic or semi-automatic door opening; forced ventilation; communication facilities

- Construction
Lightweight aluminium cabin; chassis made of hollow steel sections; solid tyres for support and guidance; linear and wheel brakes; predominantly identical components for supported and suspended vehicles

- Data:
Cabin l=2.18, w=1.7, h=1.65 m; weight of unladen vehicle 975 kg; maximum speed 14 m/s = 50.4 km/h; maximum acceleration and deceleration in regular service 2.5 m/s^2; climbing ability 15 %



Station

- Characteristics:
Off-line arrangement; two roofed-over split-level platforms on top of each other; at least 2 berths and 1 starting position per level; self-processing of passengers without staff; television monitoring

- Construction and equipment:
Prefabricated steel and/or reinforced concrete construction; single-pillar or double-pillar supporting structure; staircase, lift; automatic equipment for destination to which the ticket is bought and to which cabin is requested, alternatively destination input by means of push-buttons; information and communication facilities, station computer

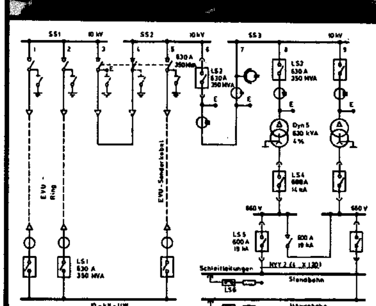
- Data:
Length of boarding dock = number of berths x 2.8 m, effective platform width 3.1 - 4.2 m (4.2 m for central platform), station spacing 400 - 800 m

Operation and automation

- Characteristics of operation:
Passenger-controlled demand-actuated transport; encouragement to form travel parties; travel direct to destination without stops or transfers; vehicles are available at stops (slack hours) or made available according to passenger volume (peak hours)

- Characteristics of automation:
Three largely uncoupled data levels for
- headway control and merging at switches (vehicle automation)
- operation at stations (station computer)
- optimization of traffic flow and deployment of empty cabins (network master computer)

Additional functions of control centre:
- remote control of power supply
- discovery of faults and disruptions and initiation of remedial measures
- communication with passengers at stations and in vehicle.



Supporting services

- Energy supply:
Propulsion by 380 volts three-phase current, separate feed for supported and suspended vehicle system, self-contained medium voltage network.

- Depots:
Storage area for vehicles providing for the direction in which they are moving; depot selection and distribution in network according to vehicle requirements and passenger waiting times.

- Vehicle cleaning and maintenance:
For mechanised and partly automated processes even at short intervals (e.g. check out); buildings adjacent to a depot.

- Salvage and emergency facilities:
Vehicles for inspection of trackway, emergency vehicles in system for en-route repairs, for towing vehicles and for rescuing passengers; road vehicles; footpaths alongside trackway possible on some sections.

Fig. 3.1.2-1: Single-mode short-distance public transport system — Cabinentaxi KK 3

Table 3.1.1-2: Characteristic numbers for route layout

	maximum vehicle speed in m/s		
	10	12	14
curved trackways %	23.3	23.9	25.8
number of curves	164	164	164
number of these requiring reduced speed	14	72	89
low-speed sections %	1.3	7.3	9.9
100 % = 48.86 km route length of the network (exclusive of off-line, siding and maintenance tracks)			

The routing is governed, inter alia, by the consideration that routes and stations should fit easily into the existing townscape. An effort was made to choose radii and upstream clothoids large enough to accommodate vehicles running at their maximum speed. As far as the higher speeds of 12 and 14 m/s are concerned, this routing is possible only with certain qualifications, so that the number and length of low-speed sections go up considerably, as shown by Table 3.1.1-2. A radius of 30 m within which vehicles can travel at a speed of 10 m/s is indispensable at many places, if the track is to fit into the urban area under investigation.

3.1.2 Single-mode short-distance public transport system Cabinentaxi KK 3

The Cabinentaxi KK 3 system falls into the category of "automatic small cabin" systems. The characteristic features of this type are those of demand-actuated, origin-destination operation with small vehicles providing a maximum of four seats without driver, using off-line stations. Essential details of the system are shown by Fig. 3.1.2-1.

Seats only are provided for the passengers. This not only enhances comfort, it also facilitates routing. Owing to high admissible lateral acceleration within the vehicle, radii even down to 30 m can be negotiated at a vehicle speed of 10 m/s = 36 km/h. It corresponds to the proved design speed of the developed system.

In this study, it is assumed that an increase of the speed to 14 m/s = 50.4 km/h is possible. This affects all sub-systems. As far as the vehicle is concerned, this speed was already proved in experiments on the Hagen test track. It is further assumed that switches also permit operation at this speed.

3.1.3 Basic concept

The specific main objectives of this study and for this application are

— to investigate the operation resulting from the mostly stochastic traffic volume,

— to determine the capacity of network junctions and stations,

— to demonstrate the practical limitations of the system.

Before designing the system in detail, a check was made to see whether deviating from the manufacturer's concept for operation — i. e. also from the system configuration described in Fig. 3.1.2-1 — holds out advantages for the Hamburg-Nord application. The studies showed that the following possible concept alternatives must be discarded.

— Running in a loosely composed train (rendezvoustechnique) was discarded owing to the impossibility of obtaining a licence on the grounds of permanent violation of an essential safety criterion.

— Use of a uniform vehicle type (e.g. supported system) and installation of two carrying structures on top of each other instead of just one beam providing two lanes was discarded owing to lack of viability and also on the grounds of visual intrusion into the townscape.

— Use of bigger express vehicles and single-track routes in lightly trafficked outlying areas was discarded because the investigation was restricted to the origin-destination small-cabin type service, taking due consideration of the advantages of the double-track configuration with regard to transport and operation.

— Increasing the capacity of converging switches by making it possible to transfer from one running level to another was discarded because such a measure was unnecessary.

Operating the system according to the manufacturer's concept is, therefore, made the point of departure of the system studies and is designated the basic concept. Even in this case, there remain a number of variants worth examining.

3.1.3.1 Design

The definition of headways is one of the key elements of any design in which automatic vehicles operate at short headways. Apart from small cabins, the medium-sized cabins of the SGK-A also operate in this way. The vehicles must maintain the absolute stopping distance between each other and meet certain requirements, for example, with regard to queue stability [2]. Unlike signal-controlled merging points in road traffic, the converging switches of the Cabinentaxi do not constitute any additional capacity bottlenecks restricting the route downstream of the merging point, because converging is controlled continuously.

When simulating vehicle occupancy, the model used here — unlike previous studies, for example [7] — proceeds from the following assumptions (cf. Fig. 3.1.3-1):

— integral numbers for trip requests TR per O-D relation and time unit;

— integral numbers for corresponding vehicle trips V;

— design value TR/V = η according to Fig. 3.1.3-1.

The design value — unless otherwise indicated — amounts to η = 1.3 trip requests per trip, corresponding to 1.3 persons per occupied vehicle (similar to taxis).

In this model, the higher the number of trip requests is per time unit, the higher the number of travel parties formed to undertake trips together. When the volume is very low — on Fig. 3.1.3.-1 between 1 and 4 trip requests per 10 minutes — it is assumed that single trips only are being made.

By varying the design value η from 1.0 to about 2.0, this approach makes it possible to investigate the results of operating with high or low vehicle numbers in the network and thus contributes to the ascertainment of any capacity thresholds for the study case.

Station organisation is characterized by the arrangement of berths on the off-line spur. All berths are equipped both for boarding

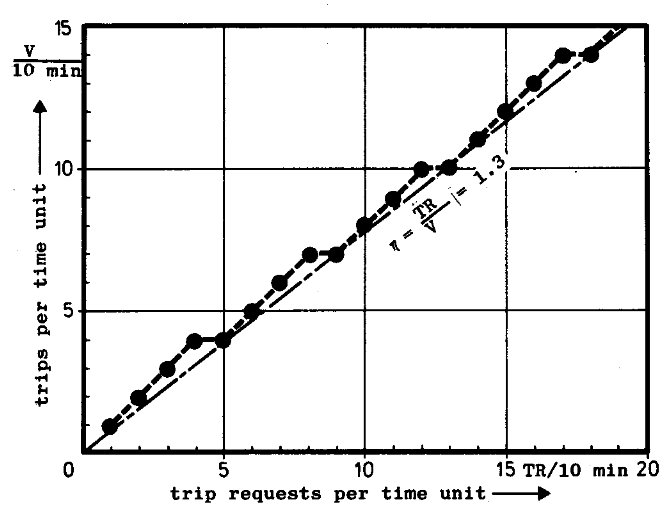


Fig. 3.1.3-1: Approximation of integers to the design value η = 1.3

and alighting. At normally trafficked stations handling up to about 300 vehicles per hour at each operating level, a 2-berth or 4-berth arrangement can be used to cope with the traffic volume, even including a surge of up to 1.5 times the regular volume.

To ensure the necessary capacity even at the most heavily trafficked stations, the following measures are required:

- increase in the number of berths per level up to 16;
- double off-line arrangement for the three heavily trafficked stations 31, 47 and 53 with 14 berths per spur and level;
- arrangement of buffer spaces on the off-line spur immediately upstream of the station for storing individual vehicles for a short time without affecting the main line.

The station times include all vehicle-oriented functions

- for alighting: door opening, alighting, having door closed;
- for boarding: vehicle destination coding and ticket cancelling by means of automatic equipment at berth, door opening, boarding, having door closed, waiting for automatic start;
- for a combination of alighting and boarding at the same berth and from and into the same vehicle. In this case the door is opened and closed only once.

Station times vary within certain lower and upper limits according to a Poisson-type distribution.

The average values — unless otherwise indicated — amount to:

- 11.3 seconds for boarding and
- 5.7 seconds for alighting.

When selecting vehicle storages (depots), particularly in a network containing many vehicles, the following points must be taken into account:

- Central position in the network making possible a quick release of vehicles to and absorption of vehicles from the network, in order to meet an increase in the demand for travel by supplying a corresponding number of vehicles and in order to remove surplus vehicles from the network in case of decreasing demand; this avoids unnecessary empty trips.
- Assignment to the routes in such a way that the outbound or departure lines of depots run into routes carrying the lowest possible volume of traffic.

In this case, secondary importance was attached to the aspect of the depot site suitability with regard to land use considerations.

When nothing to the contrary is mentioned, it will always be assumed in the following that, of all locations under examination, the route sections between stations 17 and 18 and between stations 57 and 58 are best suited for receiving depot departure lines.

According to the manufacturer's concept [3], the deployment of empty cabins (cf. 2.3.5) is geared to passengers' waiting times, the aim being to keep these down to 3 minutes for 95 % of the passengers, i.e. both for the network as a whole and for each individual station. According to this concept, very short mean waiting times (about 10 to 1 seconds) result during the off-peak and late evening hours. This concept is taken as a basis, unless otherwise indicated.

The driving cycle may be seen from Section 2.4.3.

Following these explanations, the examined range of functions to be performed by the basic concept and variants is contained in Table 3.1.3-1.

3.1.3.2 Results

The simulations of the operation yield the following important findings:

- The traffic volume can be coped with at all times, even allowing for fluctuations in the number of passengers.
- Generally, the load on the route network is sufficiently far below the theoretical capacity, of, in this case. about 2 700 vehicles per hour and direction, cf. Fig. 3.1.3-2. However, along certain feeder lines to heavily trafficked stations, e.g. 29 and 31, about 2 500 vehicles per hour and direction are counted. Some grouped lines at merge points also approach the theoretical capacity. This is true, for instance, for the routes between 49 and 50, between 42 and 43 and between 31 and 35.
- During the peak hour the speed drops to about 1.5 m/s for a certain time on some sections of the branches upstream of these routes, because of merging vehicles. Therefore, the average transport speed decreases from about 32.5 km/h during the off-peak period to approximately 28 km/h during the peak period.

Table 3.1.3-1: Range of functions

Variant under study	Subject under study	Maximum vehicle speed (m/s)	Vehicle occupancy design value (pass./occupied vehicle)	Station times boarding/ alighting (s)	Number of depots	Deployment of empty cabins
basic concept	operation under original conditions	10	1.3	11.3 5.7	2	waiting time target maximum 3 minutes for 95 % of all passengers
series of variants 1	variation of maximum vehicle speed	8 12 14	1.3	11.3 5.7	2	waiting time 3 minutes/95 %
series of variants 2	variation of vehicle occupancy, ascertainment of any capacity limitations	10	1.0, 1.2, 1.4, 1.5, 1.8	11.3 5.7	2	waiting time 3 minutes/95 %
variant 3	influence of handling times	10	1.3	7.3 3.7	2	waiting time 3 minutes/95 %
series of variants 4	influence of number of depots and deployment of empty cabins	10	1.3	11.3 5.7	1	waiting time 3 minutes/95 %
					2	reduction in operating expense

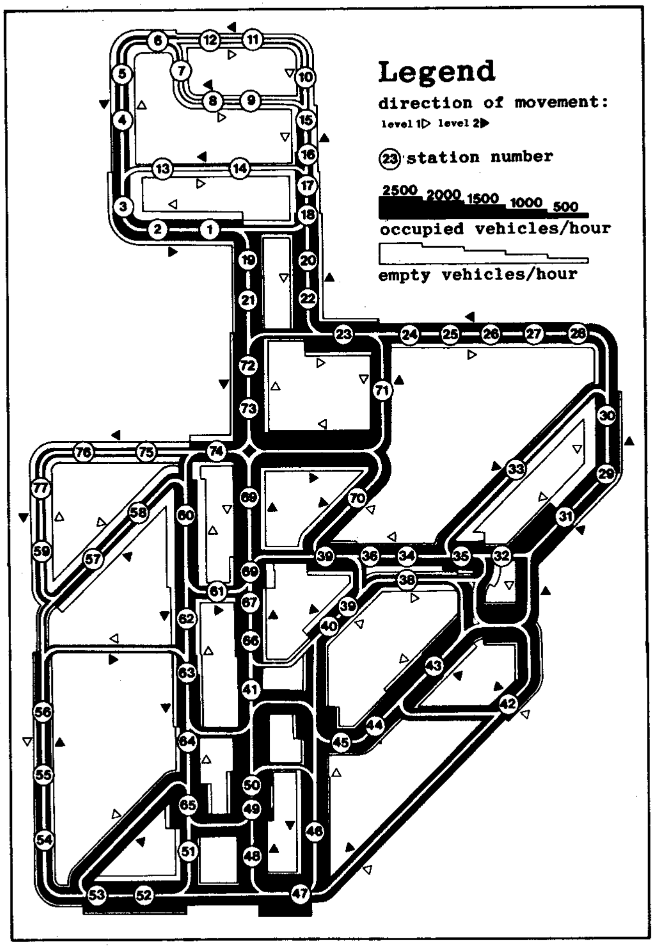


Fig. 3.1.3-2: Traffic load on routes during the significant peak hour

- The high level of service, which is nonetheless achieved, is indicated by the length of the waiting times as well as by the transport speed. Throughout the network, 90% of all passengers have to wait for 2.2 minutes at the most, the average waiting time being only 0.7 minutes, even during the peak hour. At 70% of all platforms, the maximum waiting time for all passengers amounts to only 1 minute. Even at the three heavily trafficked stations providing interchange to the metropolitan railway, 95% of the passengers do not have to wait longer than the given limit of 3 minutes, except on one platform where about 3.5 minutes are required during the peak hour.
- Station capacity has been sufficiently dimensioned by choosing the required number of berths. Apart from the stations adjacent to the metropolitan railway, normal platforms providing 2 or 4 berths are sufficient. In many instances, standardization has produced capacity reserves which are available even during the peak hour. This is also seen in Fig. 3.1.3-3. On the left side one sees the average hourly throughput during the peak hour for each platform of the 77 stations. On the right side, the fluctuations are shown as an average for the six 10-minute intervals of the peak hour for two station platforms handling a major volume of traffic and exposed to the greatest fluctuations.

Additional simulation results concerning transport and operation for the three significant hours of an average workday are contained in Table 3.1.3-2.

Table 3.1.3-3 summarizes required capital investment and cost broken down according to various specifications. Table 3.1.3-4 contains a survey of levels of effectiveness and their composition.

The structure of capital and running cost may be seen from Fig. 3.1.3-4.

Table 3.1.3-2: Selected simulation results

Characteristic value		Period		
		the significant		
designation	dimension	HVZ	NVZ	SVZ
weighted averages				
- transport distance	km	4.34	4.39	4.15
- journey speed	km/h	25.49	31.80	32.86
- journey time	min	9.98	7.93	7.52
of which waiting time	min	0.70	0.12	0.01
maximum waiting time for 90 % of passengers	min	2.20	0.94	0.90
vehicles in motion	units	5100	3022	987
passenger kilometres	10^3 pass.km	86.24	45.64	8.40
of which seated	%	100	100	100
distance travelled including empty running	10^3 veh.km	119.9	77.70	18.70
of which empty running	%	33.7	44.0	55.4
load factor including empty running	%	24.0	19.6	15.0
average vehicle occupancy	pass./occupied vehicle	1.08	1.04	1.00

HVZ = peak hour; NVZ = off-peak hour; SVZ = late evening hour

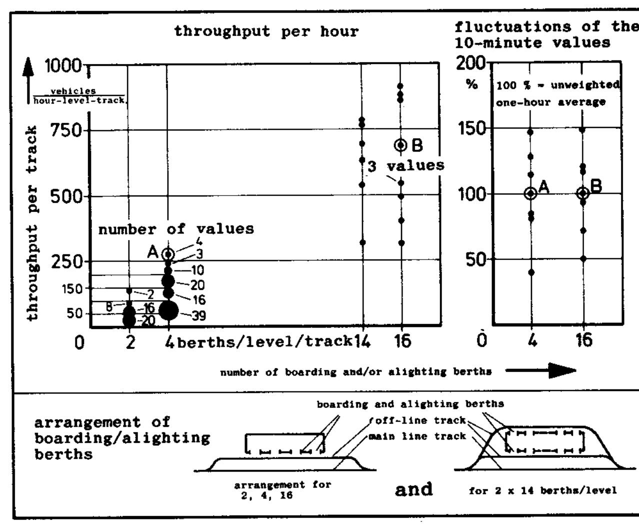


Fig. 3.1.3-3: Vehicle throughput and its fluctuations at the stations

Table 3.1.3-3: Need for capital investment and cost

designation	dimension	value
need for capital investment	mio DM	774.49
of which on vehicles	mio DM	170.64
specific investment need	mio DM/route km	15.84
total cost	mio DM/year	101.06
	DM/carrying	2.27
	DM/passenger km	0.520
capital cost	mio DM/year	61.57
	DM/carrying	1.38
	DM/passenger km	0.32
running cost	mio DM/year	39.49
	DM/carrying	0.89
	DM/passenger km	0.20

Table 3.1.3-4: Composition of the effectiveness elements

Levels of effectiveness		
designation	weight	value
effectiveness	1.000	6.359
user	0.526	3.609
time required	0.178	1.253
accessibility	0.156	0.753
comfort of travel	0.072	0.403
comfort of service	0.120	1.200
operator	0.263	1.553
flexibility	0.086	0.536
reliability	0.138	0.744
safety	0.039	0.273
general public	0.211	1.197
environmental pollution	0.117	0.562
requirements	0.094	0.635

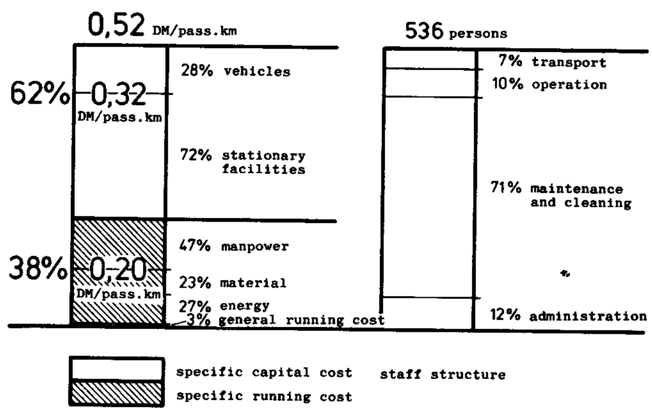


Fig. 3.1.3-4: Structure of capital and running cost

3.1.4 Changes in the maximum speed

This series of variants is intended to further the investigation of the influence of maximum vehicle speed on operation, cost and effectiveness. A vehicle running at a higher speed takes the passenger more quickly to his destination. Operational advantages might occur as a result of the smaller number of vehicles involved, owing to the higher turn-round rates. However, one must not overlook either the increase in energy consumption or those effects, particularly on the route network, which tend to raise cost. These include longer off-line spurs at the stations, a higher percentage of curved sections owing to bigger clothoid radii and greater accuracy in the lateral guidance provided by the trackway. In the present case, additional low-speed sections (cf. 3.1.1) and the heavy traffic load on individual route sections during the significant peak hour must also be taken into account.

These incompatible tendencies make it impossible at the outset to identify an optimum speed. Therefore, speeds of 12 and 14 m/s (= 50.4 km/h), which were higher than those envisaged for the basic concept, viz. 10 m/s = 36 km/h, were investigated, together with one lower speed (8 m/s = 28.8 km/h).

Important results of the study are brought out in Fig. 3.1.4-1. At higher speeds the number of vehicles goes down, albeit by only around 6%. An increase from 12 to 14 m/s hardly affects the number of vehicles at all. The result is similar as far as transport time is concerned, the decrease here being less than proportionate, when the speed is increased from 12 to 14 m/s. However, when decreased to 8 m/s, it goes up by 16%, as measured against the basic concept.

The distance travelled by the individual vehicle goes up roughly proportionally. This is caused by a reduced number of vehicles producing the same amount of passenger kilometres and by a higher overall distance travelled by all vehicles taken together resulting from the improved supply of empty cabins. The overproportional increase in energy requirements stems from, inter alia, the higher air resistance encountered and the increased need for acceleration.

The various trends result particularly from the operation during the peak hour. As shown in Fig. 3.1.4-2, the average journey speed goes up by a maximum of only 15% during this time, but during the off-peak hour increases markedly by as much as 30 %, when measured against the basic concept. Apart from the system-related decrease in the average waiting times of between 0.7 to 1.0 minutes during the peak hour to between 0.1 to 0.2 minutes during the off-peak hour, the above mentioned values reflect the more harmonious driving cycles of the vehicles during the off-peak hour. During the off-peak hour, when the traffic volume is one half of the peak-hour volume, it is only on the low-speed sections and at a few coverging switches that decelerations and accelerations occur which consume travel time and energy. Further improvement during the late evening hour is only slight.

The trends, which are often incompatible, have been worked into the needs for capital expenditure and cost as well as into the levels of effectiveness, cf. Table 3.1.4-1. The required capital expenditure is lowest for the basic concept. Savings on vehicles are more than offset by the additional expenditure on stationary installations, so that about 2% more capital is required for v = 14 m/s. The additional capital required for v = 12 and 8 m/s is around 0.5%. Total costs are at a minimum for the basic concept and for v = 8 m/s. With capital costs hardly changing, the running costs determine the increasing trend at higher speeds. Energy cost is the main controlling parameter.

The levels of effectiveness reach their maximum for design v = 12 m/s. The disadvantages accruing to the "general public", primarily as a result of increasing energy requirements, are more than compensated for — as far as the users are concerned — by the advantages arising from time savings and — as far as the operator is concerned — by the higher operational flexibility arising from the reduced number of vehicles in the network. In this planning case, the influence of the last mentioned factor is only discernable

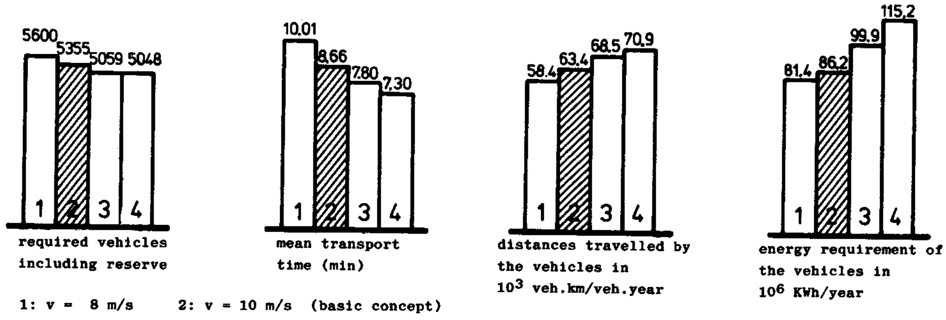


Fig. 3.1.4-1: Results of the study (annual values)

Table 3.1.4-1: Results of the ascertainment of cost and effectiveness

	Results of the cost and effectiveness calculation					
			variant			
	designation	dimension	v = 8 m/s	v = 10 m/s	v = 12 m/s	v = 14 m/s
Investment and cost	need for cap.investment	mio DM	778,20	774,49	776,03	789,36
	of which on vehicles	mio DM	178,28	170,64	161,40	161,06
	spec. investment need	mio DM/ route km	15,91	15,84	15,87	16,14
	total cost	mio DM/year	100,64	101,06	102,55	105,06
		DM/carrying	2,26	2,27	2,30	2,36
		DM/pass.km	0,526	0,520	0,527	0,542
	capital cost	mio DM/year	62,10	61,57	61,25	62,11
		DM/carrying	1,39	1,38	1,37	1,39
		DM/pass.km	0,32	0,32	0,32	0,32
	running cost	mio DM/year	38.53	39,49	41,30	43,40
		DM/carrying	0,86	0,89	0,93	0,97
		DM/pass.km	0,20	0,20	0,21	0,22
Effectiveness levels	designation	weight		basic concept		
	effectiveness	1,000	6,198	6,359	6.428	6.376
	user	0,526	3,423	3,609	3,744	3,840
	time required	0,178	1,067	1,253	1,388	1,484
	accessibility	0,156	0,753	0,753	0,753	0,753
	riding comfort	0,072	0,403	0.403	0,403	0,403
	operating comfort	0,120	1,200	1,200	1,200	1,200
	operator	0,263	1,511	1.553	1,692	1,691
	flexibility	0,086	0,501	0,536	0,670	0,665
	reliability	0,138	0,737	0,744	0,749	0,753
	safety	0,039	0,273	0,273	0.273	0,273
	general public	0,211	1,264	1.197	0,992	0,845
	environmental pollution	0,117	0,572	0.562	0,551	0.538
	requirements	0,094	0,692	0.635	0,441	0,307

down to v = 12 m/s, since there is practically no further decrease in the vehicle requirement for v = 14 m/s.

The "best" system design cannot yet be ascertained from the juxtaposition of cost and effectiveness. The only design that one can exclude is v = 8 m/s, since this involves slightly higher cost accompanied by somewhat decreasing effectiveness. Only the juxtaposition of the "standardized benefits" in Table 3.1.4-2 reveals that the basic concept based on v = 10 m/s and design v = 12 m/s are practically equal in quality.

Depending on whether the emphasis is on cost or on effectiveness, one or the other design would have to be selected for the present planning case.

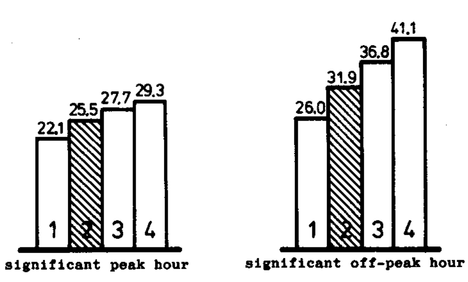


Fig. 3.1.4-2: Journey speeds during the significant hours

Table 3.1.4-2: Standardized benefits

Variant in m/s	Point rating for standardized benefits
8	3,46
10	3,58
12	3,59
14	3,49
maximum value:	3,59

3.1.5. Changes in the occupancy rate

This series of variants is intended to determine the influence of vehicle occupancy on operation and on the cost-effectiveness relationship. In addition, this should provide some help in assessing this factor in relation to other studies.

Methodologically, the framework of the study is established by presetting the value η, as defined in Section 3.1.3 (cf. also Fig. 3.1.3-1), within the limits of 1.0 to 1.8 persons per occupied vehicle. At the same time, the lower threshold serves as a means for ascertaining possible limitations of the network capacity for the planning case, since in this instance an individual vehicle has to be

Table 3.1.5-1: Average vehicle occupancies

		Pre-set values for occupancy η (passengers/occupied vehicle)				
		1.2	1.3	1.4	1.5	1.8
Average vehicle occupancy (passengers/ occupied vehicle)	peak	1,05	1.08	1.13	1.22	1.30
	off-peak	1.03	1.04	1.08	1.15	1.19
	late evening	1.00	1.00	1.00	1.00	1.01

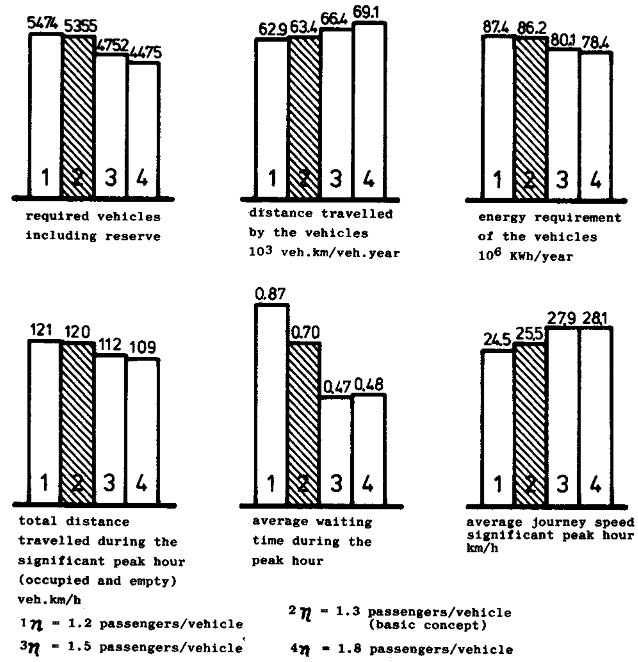


Fig. 3.1.5-1: Study results

provided for each passenger. All other preset values correspond to the basic concept. Table 3.1.5-1 gives the average vehicle occupancies during the significant hours of the three traffic periods. The average value drops from the peak hour to the off-peak hour owing to the substantially decreasing O-D relations between the individual stations and owing to the model used here. Within the bandwidth the average value of 1.30 for the peak hour attains approximately the order of magnitude given in [7].

As far as cost effectiveness aspects are concerned, the results of the study exhibit basically parellel trends in terms of an improvement as the occupancy rate increases. This is made clear by Fig. 3.1.5-1. With an increase in the average vehicle occupancy, the number of vehicles goes down to as much as 84% of the basic concept. The average distance travelled by the vehicles increases slightly. This is attributable to the slightly better supply of empty cabins, made

Table 3.1.5-2: Results of the cost and effectiveness calculation

	designation	dimension	variant η = 1.2	η = 1.3	η = 1.5	η = 1.8
Investment and cost	need for cap.investment	mio DM	779.36	774.49	748.32	736.46
	of which on vehicles	mio DM	174.35	170.64	151.82	143.18
	spec. investment need	mio DM/ route km	15.94	15.84	15.30	15.06
	total cost	mio DM/year	101.92	101.06	96.41	94.61
		DM/carrying	2.28	2.27	2.16	2.12
		DM/pass.km	0.526	0.520	0.494	0.482
	capital cost	mio DM/year	62.03	61.57	59.06	57.95
		DM/carrying	1.39	1.38	1.32	1.30
		DM/pass.km	0.32	0.32	0.30	0.30
	running cost	mio DM/year	39.89	39.49	37.35	36.66
		DM/carrying	0.89	0.89	0.84	0.82
		DM/pass.km	0.21	0.20	0.19	0.19
Effectiveness levels	designation	weight		basic concept		
	effectiveness	1.000	6.309	6.359	6.559	6.599
	user	0.526	3.584	3.609	3.689	3.685
	time required	0.178	1.228	1.253	1.333	1.329
	accessibility	0.156	0.753	0.753	0.753	0.753
	riding comfort	0.072	0.403	0.403	0.403	0.403
	operating comfort	0.120	1.200	1.200	1.200	1.200
	operator	0.263	1.552	1.553	1.559	1.564
	flexibility	0.086	0.534	0.536	0.545	0.550
	reliability	0.138	0.745	0.744	0.741	0.741
	safety	0.039	0.273	0.273	0.273	0.273
	general public	0.211	1.173	1.197	1.311	1.350
	environmental pollution	0.117	0.562	0.562	0.562	0.562
	requirements	0.094	0.611	0.635	0.749	0.788

possible as the number of vehicles in the network decreases. The distance travelled by all vehicles in the network decreases as the occupancy rate increases, but does so less than proportionally in relation to the average of the latter. Similarly, for the same reason, the vehicles' energy requirements decrease less than proportionally. Nonetheless, savings by up to 10 % are possible.

The peak hour values of the lower series of graphs illustrate operation during a traffic period when filling the network has a significant effect. Vehicle kilometres go down by 9%, which is less than anticipated, since distances travelled by empty vehicles go up, i.e. from 3.7% of the total distance travelled under the basic concept to 37.4% for $\eta = 1.8$. The average waiting time drops substantially, thanks to the better supply of empty vehicles, which is only possible when the number of vehicles in the network is smaller. In addition, it should be mentioned that the waiting times for 90% of the passengers drop from 2.7 minutes for $\eta = 1.2$ to 1.7 minutes for $\eta = 1.8$.

Average journey speeds go up rather considerably with a decrease in the number of vehicles and reflect the smoother operation resulting from fewer deceleration manoeuvres at some converging switches. The speed increase during the peak hour includes almost the whole bandwidth of the variation in speed as set out in Fig. 3.1.4-2, since vehicles can move increasingly unhampered throughout the network owing to decongestion.

It was not possible to carry out a simulation of the operation for case $\eta = 1.0$ persons per occupied vehicle, since the capacity of certain corridor lines was exceeded.

Consequently, the operationally oriented result is as follows: the lower one can keep the number of vehicles in the network, the more successful one will be in removing the operation from the critical range and thus ensuring a smooth operation.

In this context, apart from a change in the number of vehicles, the operational effects during the off-peak hour and the late evening hour are negligible.

The requirements for capital expenditure — cf. upper part of Table 3.1.5-2 are characterized by continuously decreasing amounts. The savings in capital required for vehicles cover a bandwidth of well over DM 30 million, the savings in the total capital requirement cover a bandwidth amounting to about DM 43 million, which is about 5.5% of the capital expenditure required for the basic concept. As far as stationary installations are concerned, the size of storage and maintenance facilities as well as some stations can be reduced. Total cost likewise goes down continuously with increasing vehicle occupancy. The savings achieved are related to both capital and running costs. As far as the latter are concerned, staff and energy costs mainly determine the trend.

Effectiveness goes up continuously with increasing vehicle occupancy. This is mainly due to the benefits arising to the user from the saving in time and to the general public from the saving in energy.

As was to be expected the increase in effectiveness accompanies the decrease in costs. Therefore a network operation involving high vehicle occupancy appears desirable.

While this basic finding as such is not surprising, this result becomes significant, when we consider the entire spectrum of other variants of influencing the operation. The level of quality can be modified, and particularly raised, by means of a change in the vehicle occupancy, more than by any other variation.

Table 3.1.5-3 gives the standardized benefits. According to the study of speeds, the basic concept, which is geared to $\eta = 1.3$, is among the variants attaining the highest level in that study.

3.1.6 Changes in the passenger turnover times

This investigation is intended to come up with an answer to the question of how a change in the boarding and alighting times of the passengers at the stations affects operations.

Table 3.1.5-3: Standardized benefit

Variant 12 (pass./veh.)	Point rating for standardized benefit
1.2	3.52
1.3	3.58
1.5	3.81
1.8	3.89
maximum value:	3.89

The average boarding and alighting time of 11.3 and 5.7 seconds, respectively, for individuals and small groups are comparatively long and they suggest that some saving in the number of vehicles could be made, if the times could be reduced appreciably.

This was simulated by changing the average of the random distribution for the passenger turnover times. The distribution was shifted towards the range of shorter times, while its pattern was maintained. The new averages are 7.4 and 3.7 seconds, respectively.

The simulated operation shows no effects on the quantitative conditions within the system, particularly on the number of vehicles used. This result is not surprising, when one considers that the reduction of the passenger turnover time occurs only once in the case of origin-destination traffic, and not serveral times during a passenger trip as in stop-and-go operation, and that taking up 6 seconds it accounts for only about 1% of the transport time of approximately 9 minutes.

The passenger enjoys minor advantages:
The average waiting time during the significant peak hour drops from 0.7 to 0.6 minutes, the waiting time for 90% of all passengers from 2.2 to 1.9 minutes. By and large, quicker boarding and alighting benefits the passenger himself. However, as far as the operation itself is concerned, the influence of passenger turnover times in the order of magnitude discussed here is practically insignificant.

In order to achieve the same waiting times as those in the basic concept, some vehicles could presumably be taken out of the system, and this wóuld slightly reduce cost. This detailed investigation was not, however, carried out because it was only of minor importance. A discussion of cost and effectiveness can be dispensed with because, in this respect, it tallies with the basic concept with only a few small random deviations.

3.1.7 Changing the depot site and empty cabin deployment

The aim of this series of variants is to investigate the empty cabin supply within the network. The controlling parameters examined were:

— concentration of the depots in one central depot,
— changing the algorithm of empty cabin equalization,

the aim being to check the manufacturer's concept. This concept has been designed to meet rush-hour requirements and it copes with the traffic volume at the peak hour and at the off-peak hour without any falling off in the level of service quality provided. During the late evening hour, operating expenditure and level of service are too high.

The central depot is planned to discharge between stations 57 and 58. This arrangement is considerably less flexible than the basic concept vis-à-vis the requirements during the peak hour. Since departure from the depot becomes increasingly difficult with the growing network load and since the average distance between depot and station goes up, the majority of vehicles must be brought into the network a good half hour before the peak hour begins, in order to meet the basic need of the demand for transport during the first ten minutes. It is also more difficult to satisfy additional needs which are

Table 3.1.7-1: Waiting times

	Basic concept b.c.	1 Depot	Modified empty cabin deployment: entire operating time	Modified empty cabin deployment: late evening hour
average waiting time in minutes				
peak	0.70	0.95	1.71	same as b.c.
off-peak	0.12	0.27	0.33	same as b.c.
late evening	0.01	< 0.01	0.06	0.06
maximum waiting time for 90 % of all passengers!				
peak	2.20	2.66	5.06	same as b.c.
off-peak	0.94	0.98	1.00	same as b.c.
late evening	0.90	0.90	0.91	0.90

due to stochastic variations at the stations. The increasing waiting times are shown in Table 3.1.7-1.

The fact that empty vehicles have to be supplied well in advance of the actual peak hour, in order to make do with only one depot, precludes the operational application of this variant. Therefore cost and effectiveness are not given any further attention.

Result: At least two depots must be provided for networks having the same structure and carrying the same traffic volume during the peak hour as the one under study here. Their discharge points should be situated on lightly trafficked routes, so that they can cope with the additional load.

The result of the change in empty cabin deployment is that during the peak hour the number of vehicles made available drops to a point where the volume of traffic can no longer be coped with. Consequently, the operational advantages (the number of vehicles was reduced to 92%, and, correspondingly, the percentage of empty trips and the consumption of energy went down) are only apparent.

On the negative side, they are in fact offset by substantially longer waiting times for the users, cf. Table 3.1.7-1. It must be added that the maximum waiting time of 3 minutes for 95% of all passengers, which is desirable if a high level of service is to be provided, is entirely unattainable during the peak hour. At 31 of the 154 passenger platforms, including four platforms of the tree most heavily trafficked stations adjoining the metropolitan railway, it is in some instances exceeded considerably. Under the basic concept only eight platforms fail by a small margin to stay within this target time. While the target time for the network as a whole is attained during the off-peak hour, passengers at eleven platforms must wait longer. This is true for only three platforms under the basic concept.

The algorithm referred to above can so far only be applied with considerable qualifications. It has only been tested on the present planning case and only for the late evening hour has it supplied satisfactory results. Operation during the peak hour and the off-peak hour could only be simulated by resorting to outside measures. Despite the fact that, viewed objectively, the service was unsatisfactory, usable figures for the follow-up studies were obtained.

Table 3.1.7-2: Cost and effectiveness of alternative empty cabin supply

Results of the cost and effectiveness calculation

	designation	dimension	basic concept	modified empty cabin deployment: all operating times +)	modified empty cabin deployment: late evening hour only +)
Investment and cost	need for capital investment	mio DM	774.49	755.08	774.41
	of which on vehicles	mio DM	170.64	156.81	170.64
	specific investment need	mio DM/route km	15.84	15.44	15.84
	total cost	mio DM/year	101.06	97.02	100.36
		DM/carrying	2.27	2.17	2.25
		DM/passenger km	0.520	0.502	0.516
	capital cost	mio DM/year	61.57	59.71	61.56
		DM/carrying	1.38	1.34	1.38
		DM/passenger km	0.32	0.31	0.32
	running cost	mio DM/year	39.49	37.31	38.80
		DM carrying	0.89	0.84	0.87
		DM/passenger km	0.20	0.19	0.20
Effectiveness levels	designation	weight	basic concept	+) see page 148	+) see page 148
	effectiveness	1.000	6.359	6.164	6.394
	user	0.526	3.609	3.126	3.608
	time required	0.178	1.253	1.091	1.252
	accessibility	0.156	0.753	0.753	0.753
	riding comfort	0.072	0.403	0.403	0.403
	operating comfort	0.120	1.200	0.879	1.200
	operator	0.263	1.553	1.739	1.549
	flexibility	0.086	0.536	0.728	0.536
	reliability	0.138	0.744	0.738	0.740
	safety	0.039	0.273	0.273	0.273
	general public	0.211	1.197	1.299	1.237
	environmental pollution	0.117	0.562	0.562	0.562
	requirements	0.094	0.635	0.737	0.675

Table 3.1.7-3: Standardized benefits

Variant	Point rating for standardized benefits
basic concept	3.58
modified deployment scheme	
- all operating times	3.55
- late evening hour	3.62
maximum value:	3.62

Owing to the fact that the results accruing to the user differ so markedly from those accruing to the operator, the study is suitable for a cost-effectiveness analysis. As an additional variant, a combination of the different methods of empty cabin deployment is also calculated, which provides operation during the peak hour and the off-peak hour according to the basic concept and during the late evening hour according to the system of modified control.

This is justifiable because the waiting time target during the late evening hour is attained even under the modified deployment scheme. While no vehicles are saved in this case, the energy requirement of the vehicles goes down by about 3%.

The results of the cost and effectiveness calculation may be seen from Table 3.1.7-2.

The modification of the deployment scheme during the late evening hour does not influence the need for capital expenditure.

The saving in energy costs affects the running costs.

The level of effectiveness is 0.035 higher than the level of effectiveness of the basic concept.

The standardized benefits can be seen from Table 3.1.7-3. The level of quality achieved when the deployment scheme is changed for the late evening hour is clearly superior to the deployment scheme modification for all operating hours and slightly superior to that of the basic concept.

This study makes clear that there is a close interrelationship between the number of vehicles in the system, the waiting times of the passengers, cost and effectiveness.

3.1.8 Interpretation of the results and recommendations for improvements

The values of specific total cost, effectiveness and standardized benefits which are decisive in this case vary within a relatively small margin. Obviously, the extent to which one can improve the investigated system beyond the present state of knowledge and development by means of operational measures alone is limited. This lends weight to the importance of careful planning for any application, since it is here that cost and effectiveness are essentially fixed.

Following is a systematic list of the important results of the study.

— Ranking according to the variation in speed puts the manufacturer's design of 10 m/s, together with variant 12 m/s, among the "best" solutions. Depending on whether more weight is given to total cost or to effectiveness, one or the other design would have to be selected for implementation.

— As far as empty cabin deployment is concerned, a user-oriented strategy which strictly limits waiting times is accorded high priority. However, during slack hours it is permissible to make cuts in waiting times, because of the saving in running cost involved. In the present study, the limits of such measures could not be entirely defined.

— An increase in the vehicle occupancy rates produces the most pronounced results in decreasing costs and increasing effectiveness, since a great many improvements result from this measure. The socio-economic behaviour of the users, which may result in more passengers riding in travel parties, was not simulated in line with the definition of the objective of this study, which was geared to operational considerations. It is, however, to be expected, that a limit for improvements is reached when, in addition to allowing for waiting times for operational reasons, the passenger has to spend a lot of time in making up the travel parties. This would not only tend to make the undertaking less attractive, which in this case would be tantamount, methodologically, to a decrease in effectiveness but care would also have to be taken to see that the operation itself was not impaired, e.g. by passengers reserving vehicles. It becomes clear that in this system incorporating origin-destination operation, vehicle occupancy can be "decreed" by an operational limitation of the supply of seats to a far lesser degree than is the case in collective means of public transport.

Hence, in conclusion, the following recommendations:

— During the slack hours the stations should only be supplied with empty vehicles if the operating cost is minimized by allowing these cabins to travel the lowest possible distance. In view of the extremely short waiting times involved, their increse up to a defined limit is acceptable.

— Considerable incentives should be provided to encourage passengers to form travel parties. The holding of a ticket and the use of the system should be so coordinated that the ticket is valid when used for the small cabin system alone and also when this is combined with travel on other single-mode short-distance transport systems.

3.2 Synthetic large cabin Type A (SGK-A)

A system analysis of large cabins contained in SNV 1 [26] gave rise i. a. to the question concerning suitable vehicle sizes in relation to the areas of use, cf. also 4.2. Subsequent studies regarding use, technology and economics produced types of operation which are characterized by the use of vehicles providing 40 and more seats, by line-haul operation, by the use of fixed headways and by stopping at every station.

Simultaneously the use of medium-sized vehicles and corresponding types of operation were investigated, Studies [6,5] have shown that other system configurations, too, in addition to the above mentioned ones, can be implemented by means of the technology which has already been developed. As far as the technology is concerned, these configurations are based on the small-cabin approach, but as far as the operation itself is concerned, they rely more than small-cabin systems do on the concept of line-haul short-distance public transport of the traditional kind. Judging from the body of knowledge we have acquired to date they are very well suited as feeders to high-speed railways, while also providing a good internal service. No study of their use as a primary system in medium-sized cities has so far come to notice.

Likewise, a systematic investigation has yet to be carried out on how a variation in important design parameters influences the cost and benefit relationship in a defined case of practical application. In [6] the result of a first vehicle speed variation has been given.

Following is a report on such a systematic investigation. The model-type application which has been selected for this purpose is a feeder to a high-speed railway. The study concerns itself particularly with the question as to whether this can meet the demands placed on the concept of synthetic large cabins, i. e. for a high level of attractiveness at reasonable cost. For the purpose of this study, the SGK-A stands for the concept of an automatic cabin railway with the following features:

— medium-sized vehicles, the capacity of which is clearly above 4 and clearly below 40 passengers per vehicle,

— line-haul operation,

— transport speeds which come close to those of high-speed urban railways,

- acceptable waiting times for the passengers even during the late evening hours,
- good transport development for internal travel.

3.2.1 Network and transport planning

The cabin railway network is designed to link the study area with the high-speed railways and to provide area coverage by means of line-haul operation.

The route network has been conceived according to the basic shape of a double ring including certain additional connecting routes [6]. In principle, this concept makes it possible to by-pass any route section which has broken down.

As shown in Fig. 3.2.1-1, the network in its predominant southern part is clearly meshed in accordance with the double ring concept. The northern part of the network at Niendorf and Schnelsen is connected with the southern network by a four-lane, corridor-type intermediate section at the bottleneck between airport and forest. Owing to this structure, the northern part cannot privede the above mentioned by-pass capability at every point. However, a connection by means of switches between stations 7 and 50, which is not necessary for normal operation, prevents the repercussion of any disruptions on the southern network.

The lines are loop-shaped and adjusted to the main flows of traffic. In addition to the predominant radial relations which are oriented in the direction of the city centre, they also constitute, to a certain extent, important tangential relations and thus improve the internal transport development of the study area. All lines are operated both clockwise and counter-clockwise. Owing to the low traffic volumes, lines 5 to 7 are suspended during the late evening hours.

Normally the stations are on-line. Owing to the very short fixed-cycle headway of the heavily trafficked line 5, amounting to about 20 seconds during the significant peak hour, 21 out of 55 stations must be built off-line to allow, for instance, occupied vehicles to pass. In addition, another 8 stations are double on-line, i. e. each platform can be served on either side. This increases capacity while allowing short stopped times for the vehicles, as in the case of the stations adjoining metropolitan railway stations 6, 11, 16 and 38. In addition, this configuration is necessary for operational reasons at stations 26, 36, 41 and 53 because of their function as stations form which the vehicles of certain lines start operating at fixed intervals, cf. Section 3.2.2.

The structure of the passenger volume is as follows:

- The most heavily trafficked cabin railway stations are those ajoining the metropolitan railway stations Kellinghusenstraße (16, about 5,900 boarding and alighting passengers), Hoheluftbrücke (11, about 4,800) and Osterstraße (38, about 4,200).
- The cabin railway stations adjoining the five high-speed railway stations must cope with about 60% of the boarding and 48% of the alighting passengers during the significant peak hour, that is about 9,600 boarding and 7,800 alighting.
- The boarding passengers from feeders account for about 30% during the peak hour and for about 24% on average throughout the day. These passengers arrive in batches according to the fixed headways between the feeder vehicles.
- Thus, in analogy to 3.1, this planning case includes a major portion of internal traffic.

Tabel 3.2.1-1 contains important characteristic numbers for network and planning area.

The routing is governed, inter alia, by the consideration that routes and stations should fit easily into the existing townscape. It is assumed that the track is elevated throughout. A minimum radius of 30 m is sufficient, because the trackway is normally constructed on main roads. This radius is necessary at 28 places of altogether 112 curves in the network having radii smaller than 300 m. Radii of at least 30 m have also been assumed for other routes designed for maximum-speed operation, such as additional station tracks and routes providing access to depot facilities. Thus, for a vehicle speed of 10 m/s, no speed restrictions on account of the routing are necessary.

3.2.2 Single-mode short-distance public transport system SGK-A

This system belongs to the category of automatic cabin railways using medium-sized vehicles. The shortest vehicle headway constitutes the essential technological design criterion. If twelve-seat vehicles are assumed for the purpose of the present planning case, an average vehicle headway of about 7.5 seconds results on the most heavily travelled route. Therefore the shortest technologically ensured vehicle headway which must be required to permit adjustment to short-term and longer-term volume fluctuations, is 4 to 5 seconds.

Table 3.2.1-1: Characteristic numbers for network and traffic volume

net building land	km^2	15.6			
stations		55	station density	stations/km^2	3.53
route kilometres		36.14	route density	route kilometres/km^2	2.32
line kilometres		104.40	average station spacing	route kilometres/station	0.66

passengers boarding	total	directly	from feeders	passengers transferring within the system
per average workday	119,400	90,800	28,600	11,070
during significant				
peak hour	16,200	11,390	4,820	1,560
off-peak hour	8,320	7,030	1,290	810
late evening hour	1,580	1,460	120	150

transport performance	10^6 carryings/year	37.02
	10^6 passenger kilometres/year	160.72
average transport distance	passenger kilometres/carrying	4.34
traffic carried by routes	passenger kilometres/day, route kilometre, direction	7,170
modal split (in original plan)	%	about 30

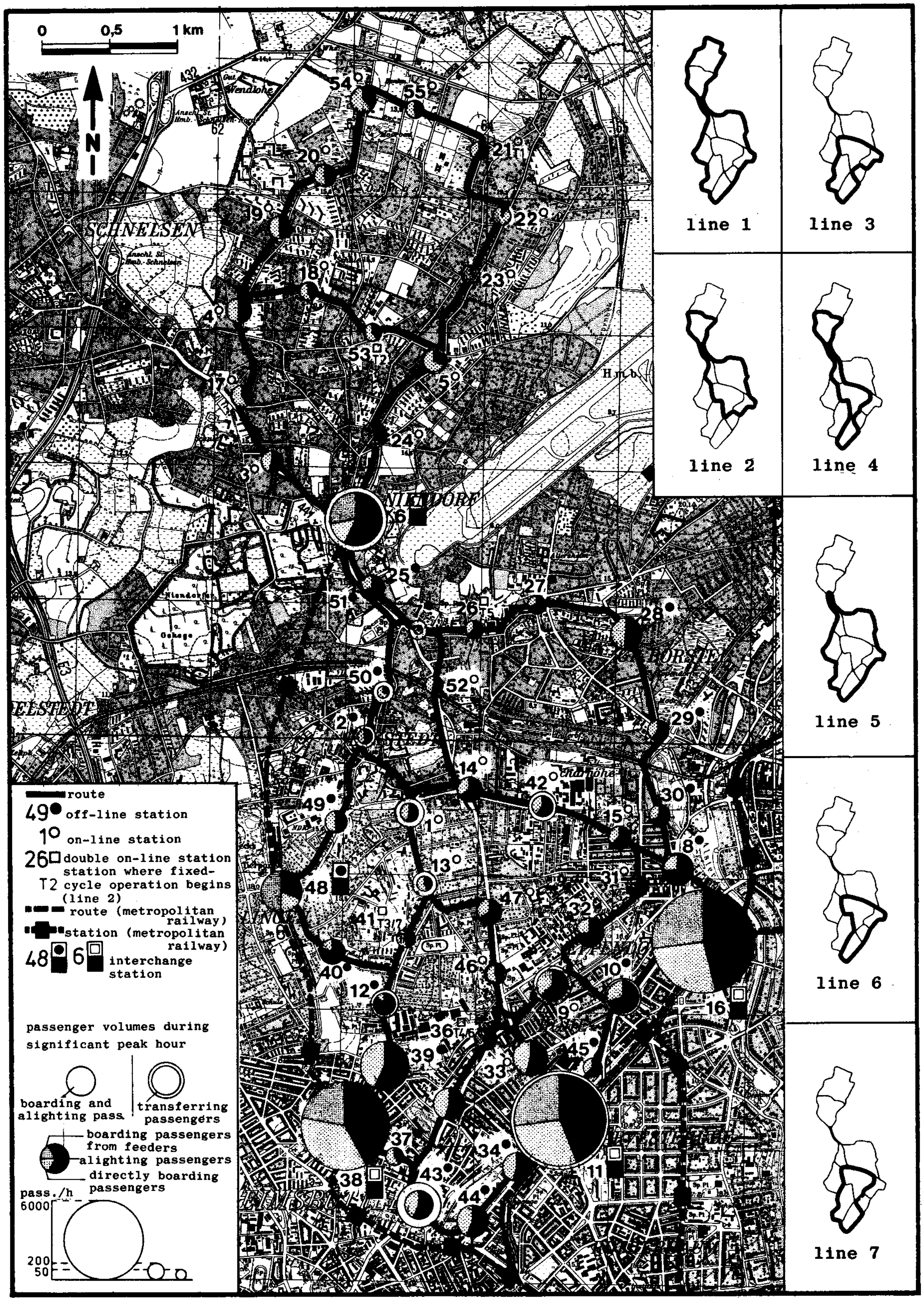


Fig. 3.2.1-1: Network, line-routing and traffic volumes during the significant peak hour

Synthetic large cabin "SGK-A" Type A

medium-sized vehicles designed for line-haul service, stopping on request and medium traffic volume

Track

- Characteristics:
Elevated trackway accommodating two lanes, segregated from road traffic and without level crossings.

- Construction:
Closed hollow steel box for outside running chassis of supported and suspended vehicles; external equipment for lateral guidance; transmission of power, energy and data; weather and noise protection by means of side screens; passive switches for on-board preselection of direction; supports arranged at the side (cantilevers with normal and long projection, T- and portal supports, special designs).

- Data:
Spans on straight sections 40 - 50 m, in curves 30 - 40 m and even more when guyed supports are used; minimum radius 30 m, in exceptional cases 20 m.

Vehicle

- Characteristics:
Cabin providing 12 seats; vehicle made up of single (KK 12) or double motor car (KK 24). Propulsion by contact-free linear motors; continuous adjustment of voltage and frequency; on-board switch control; automatic running control; automatic and supervised headway maintenance as well as automatic direction control alongside the line; on-board equipment for receiving passengers' requests for stops; automatic station display and/or announcement; automatic opening and closing of doors; forced ventilation; communication facilities.

- Construction
Lightweight aluminium cabin; chassis made of hollow steel sections; solid tyres for support and guidance; linear and wheel brakes; predominantly identical components for supported and suspended vehicles

- Data:
KK cabin: l = 4.85, w = 1.7, h = 1.65+m; weight of unladen vehicle 2ooo+ kg (+ = data for purpose of energy calculation); KK 24 assumed to be made up for two inseparably coupled KK 12; maximum speed 14 m/s = 50.4 km/h; maximum acceleration and deceleration in regular service 2.5 m/s^2, climbing ability 15 %.

Station

- Characteristics:
On-line or off-line or double online arrangement; two roofed-over split-level platforms on top of each other; at least 2 berths per level (for KK 24 at least 1 berth); self-processing of passengers without staff; television monitoring.

- Construction and equipment:
Prefabricated steel and/or reinforced concrete construction; single-pillar or double-pillar supporting structure; staircase, lift; ticket vending machines; push-button equipment for selecting destination (alternatively conceivable: preselection of lines); station computer; information and communication facilities.

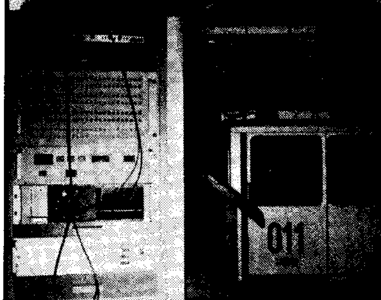
- Data:
Length of boarding dock = number of berths x 5.6 m for KK 12 and x 11.o m for KK 24; effective platform width 3.1 - 4.2 m (4.2 m for central platform), station spacing 300 - 900 m.

Operation and automation

- Characteristics of operation:
Line-haul service, relatively numerous lines to provide service on main O-D relations requiring few transfers; request stops of the vehicles following stop request input by passengers on board the vehicle or at the station; vehicle deployment according to the anticipated passenger volume and defined waiting time limits. No train formation. Possibly reduction of number of lines in the late evening.

- Characteristics of automation:
Three largely uncoupled data levels for
- headway control and merging at switches (vehicle automation)
- operation at stations (station computer)
- monitoring of traffic flow by checking the intervals between the vehicles of a line. If necessary, retention of vehicles at individual stations where fixed-headway operation commences, to avoid platooning. At same station also establishment of mean headway per line.

Additional functions of control centre:
- remote control of power supply
- discovery of faults and disruptions and initiation of remedial measures
- communication with passengers at stations and in vehicles



Supporting services

- Energy supply:
Propulsion by 380 volts three-phase current, separate feed for supported and suspended vehicle system, self-contained medium voltage network.

- Depots:
Storage area for vehicles providing for the direction in which they are moving; preferably central depot, provided that vehicles do not have to travel excessive distances to the points where their actual operation commences.

- Vehicle cleaning and maintenance:
For mechanised and partly automated processes even at short intervals (e.g. check out); buildings adjacent to a depot.

- Salvage and emergency facilities:
Vehicles for inspection of trackway, emergency vehicles in system for en-route repairs, for towing vehicles and for rescuing passengers; road vehicles; footpaths alongside trackway possible on some sections.

Fig. 3.2.2-1: Short-distance transport system SGK-A based on Cabinentaxi technology

Hereinafter the Cabinentaxi technology will be taken as a basis partly because it meets that requirement. To be consistent, all other relevant design parameters of this technology should be taken as a basis for the planning case, since they are, on the one hand, mutually coordinated and since, on the other hand, the system components can be regarded as fully developed. Essential details of the system configuration are shown in Fig. 3.2.2-1.

As in the KK 3 Cabinentaxi, seats only are available in the vehicles of the SGK-A. This not only enhances the passengers' comfort, it also facilitates routing.

The other technological characteristics are likewise in line with those of the small-cabin system. It has been assumed that vehicle speed can be increased to 14 m/s, which is about 50 km/h, and that both switches and on-line stations can be negotiated at this higher speed.

This is necessary because of the operating mode involving line-haul service and request stops. The vehicles do not stop unless requested by passengers either for alighting or for boardng a not yet fully occupied vehicle. Passenger requests are communicated to the system both on board the vehicle as regards alighting and in the station as regards boarding. Before boarding, the passenger only has to find out about the position of his destination station within the network and to preselect the destination or the respective lines. It is taken for granted that an organisational solution to the queuing problems at the boarding station has been found.

Since the vehicle is not scheduled to stop at all stations, the transport speed is rather high in relation to the maximum speed. This ratio, however, can only materialize if the vehicles are not stopped too often in their journey. A frequency of stopping at about 50% of all stations can be assumed as the standard value based on previous studies [6,5]. This calls for a capacity which is not too high, so that the probability of stopping is on the above mentioned scale. Therefore, ascertaining the influence of vehicle size on important operating parameters is one of the interesting tasks of this study.

The SGK-A knows no timetable in the traditional sense but rather only stations within the loop where the vehicles of a line start operating at average intervals. An adjustment to the volume of passengers is not carried out instantaneously as in the origin-destination service of small cabins, but rather on a medium-term basis through the observation of vehicle occupancy and passenger waiting times and by means of vehicle deployment. In this study it has been assumed, that any peaks of passengers arriving in batches have been known in advance in terms of place and time and have therefore been taken into cnsideration in the deployment of vehicles.

3.2.3 Basic concept

Preliminary studies of scheduled fixed-cycle operation which includes stopping at every station have shown that this operating mode is not necessarily suitable for small to medium-sized vehicles possessing a relatively low maximum speed. Fixed-cycle operation including request stops may result in a remarkable transport speed, since the vehicles simply pass through many stations. In addition, the small vehicle size permits vehicle headways which hold out the possibility of an attractive service for the passengers together with a satisfactory load factor even during slack hours. Therefore, the possibilities offered by the operation described in 3.2.2, and which includes request stops, will be examined in detail later on. The study includes views on express service, a modified form of which is already included in the regular operation; it excludes the simultaneous use of vehicles of different capacity under the same operating mode (e. g. KK 12 and KK 24) as well as the simultaneous use of vehicles in one network which require different operating modes and the corresponding specific network shape (KK 3 and KK 12). We rather concentrate here on basic studies of uniform vehicle sizes and uniform operating modes.

3.2.3.1 Design

The definition of headways (cf. Section 3.1.3.1) corresponds to that for the small cabin KK 3, making due allowance for the greater length of the vehicles used here, which slightly increases the shortest vehicle headways by some 10th of a second. According to Section 3.1.3.1, the maintenance of absolute stopping distance and queue stability and the fact that due allowance was made for the intrinsic characteristics of converging switches are part of the technology which has been taken as a basis.

Apart from five heavily trafficked converging switches in the network and twelve such switches at stations, the so-called traffic light switches are mainly used. By means of a red/green signal, they permit the alternate running on the branches upstream of the switch without providing continuous control and their electronic construction is simpler than that of the so-called merging switches with imaging.

Vehicle occupancy as a separate value for each traffic period results form the provision of vehicles and the demand for travel, allowance being made for the choice of line. The waiting time convention is one of the determinants controlling the provision of vehicles. One component of the operating concept is the feature that individual vehicles — provided they are fully occupied — run without stopping until a request for alighting has been registered. While requests for boarding cannot be considered in these cases, the extensions of waiting times for the passengers are minor owing to the short vehicle headways and they are, of course, contained in the indicated waiting times. Such vehicle occupanices occur predominantly during heavily travelled hours. They tend to improve the load factor.

The station organization ensures that passengers entering the station make their desired destination known to the system, that passengers wishing to alight do leave the vehicle, and that vehicles which are not requested to stop or summoned, as well as occupied vehicles, can pass right through the station (even in case of an on-line arrangement). A quick throughput of the vehicles is important, so that passengers remaining seated in the vehicle lose little time and so that following vehicles are not impeded. The standard station has two berths per level to obviate the waiting of vehicles upstream of the station. In this planning case the number of berths is increased to three at stations which have to cope with a high volume of passengers.

Where a further increase in station capacity is required, two tracks per level (double on-line) are provided. In addition, such a configuration is called for where one ore more lines pass a station at which fixed-headway operation starts. Thus, any waiting vehicles do not impede other vehicles. The location of these stations may be seen from Fig. 3.2.1-1.

The station times include all vehicle-oriented functions

- for aligthing: door opening, alighting, having door closed, waiting for automatic start,
- for boarding: door opening, boarding, having door closed, waiting for automatic start,
- for alighting and boarding: door opening, alighting, boarding, having door closed, waiting for automatic start.

The station times are composed of

- a fixed allotment of 4 seconds per stop, largely to allow for door opening and closing,
- a volume-dependent allotment of 1 second per boarding or alighting passenger.

In view of the relatively low number of vehicles expected, one collective vehicle depot is sufficient. Its location between stations 28 and 29 is sufficiently central, inter alia, for quick deployment to the stations at which vehicles start fixed-headway operation.

The driving cycle may be seen from Section 2.4.3. Free passage through many stations obviating a great many energy-consuming acceleration manoeuvres is important for a fuel-conserving mode of operation.

The waiting time targets for the passengers are essential pre-set data for vehicle deployment and level of service. To stay within the range of the existing standard of service, the upper limits contained in Table 3.2.3-1 are defined both for the network as a whole and for each individual station.

Table 3.2.3-1: Upper limits of waiting times

Waiting times in terms of minutes	Peak	Off-peak	Late evening
maximum for 98 % of the passengers	5	5	10
average for all passengers	2	2.5	5

It has proved necessary to define a transfer criterion, because, owing to the high number of lines, many destinations can, it is true, be reached directly, but occassionally they can only be reached via major detours or by using a later cabin. As a result of preliminary investigations, it is agreed that

— every passenger who is able to benefit form journey distance advantages which are at least tantamount to those listed in Table 3.2.3-2 will transfer, even if he has to change to an other operating level.

Table 3.2.3-2: Journey distance advantages

Shortening of	Peak and off-peak	Late evening
- journey distance in terms of km	2	4
- journey time in terms of minutes	about 5	about 9

The average fixed-cycle headways per line, direction and traffic time are the result of an iterative examination process, which coordinates the quality of service in keeping with the upper limits of waiting times and the deployment of vehicles.

3.2.3.2 Results

Operating simulations show that the traffic volumes can be coped with (without operating bottlenecks) at all traffic periods, even when taking into account both stochastic fluctuations of the passenger volume and a 35% increase in the volume of traffic, by an adjustment of the operating program.

The level of service reveals itself in, among other things, the average fixed-cycle vehicle headways, cf. Table 3.2.3-3. These fixed headways are averages, which are maintained at the stations from which vehicles start operating at fixed intervals, to avoid or reduce platoon formation. The average fixed-cycle headways of about 0.5 to 2 minutes during the peak hour, 1 to 5 minutes during the off-peak hour and 2 to 10 minutes during the late evening hour characterize one aspect of the level of the service provided.

Table 3.2.3-3: Average vehicle headways per line

Data in seconds	Peak		Off-peak		Late evening	
	level+1	level+2	level+1	level+2	level+1	level+2
line 1	44	49	98	76	132	147
line 2	111	117	272	174	579	585
line 3	138	112	333	221	443	446
line 4	82	114	199	135	349	343
line 5	32	23	47	48	-	-
line 6	106	116	305	170	-	-
line 7	82	66	107	152	-	-
average	63	63	119	102	247	264

+ = operating level

The other aspect is brought out by the waiting times, cf. Table 3.2.3-4. The values fall short of the pre-set targets in order to limit the longest waiting time to about 10 minutes.

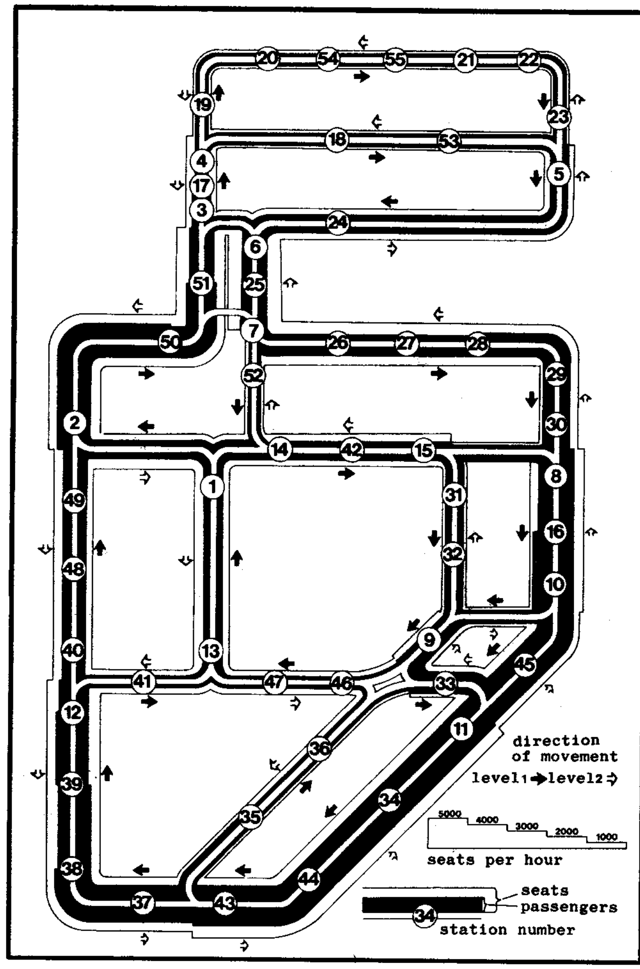


Fig. 3.2.3-1: Traffic load on routes during the significant peak hour

Table 3.2.3-4: Waiting times for the passengers

Data in minutes	Peak	Off-peak	Late evening
average waiting time	0.78	0.99	2.19
maximum for 95 % of the pass.	2.27	2.97	6.11
maximum for 98 % of the pass.	2.90	3.97	7.42
longest waiting time in the network	8.0	10.0	11.0

Table 3.2.3-5: Selected simulation results

Characteristic value designation	dimension	Period the significant HVZ	NVZ	SVZ
weighted averages				
- transport distance	km	4.17	4.24	4.37
- journey speed	km/h	26.35	25.83	22.65
- journey time	min	9.09	9.40	10.66
of which waiting time	min	0.78	0.99	2.19
- transfer time per transferring passenger	min	0.97	1.47	2.71
maximum waiting time for 90 % of passengers	min	1.84	2.36	5.06
vehicles in motion	units	403	216	60
passenger kilometres	10^3 pass.km	69.99	35.83	7.03
of which seated	%	100	100	100
distance travelled	10^3 veh.km	11.99	6.45	1.84
load factor	%	48.7	46.3	31.8
average vehicle occupancy	pass./occupied vehicle	5.84	5.53	3.83

HVZ = peak hour; NVZ = off-peak hour; SVZ = late evening hour

These waiting times presuppose stochastic passenger arrivals, i. e. with the exception of those boarding from feeders, the passengers in this model are not guided by time structures. However, particularly for the slack hours a quasi-timetable will have to be published, which has to be adhered to within narrow limits at the stations downstream of the station at which fixed-cycle interval vehicle operation begins, and, during the further run, within an increasing margin of arrival times, owing to request stops. By and large, this will make it possible for passengers to be guided by this time structure. Seen from this point of view, the indicated waiting times should be considered as upper limits, particularly during the slack hours. For methodological reasons, they will be further considered in subsequent Sections.

A selection of simulation results is shown in Table 3.2.3.-5. Journey speed clearly goes down during the late evening hour, largely on account of longer waiting times. The high load factor during the significant peak and off-peak hours is remarkable; this is also clearly brought out by he graphical representation of the ratio of utilized to provided seats on the lines, cf. Fig. 3.2.3-1. The load factor is remarkably high, particularly on the heavily trafficked routes, since in the vicinity of the sites where maximum traffic volumes arise, more vehicles are fully occupied and travel longer distances fully occupied. As a consequence of this, passengers at stations do not immediately get a vehicle of the desired line. This is reflected in the following figures for the so-called "left-behind" passengers (data per significant hour; 100% = all carryings of the hour in question):

peak	55%
off-peak	7%
late evening	3%.

The practical effect is seen in proportion, if the short average fixed-cycle headways according to Table 3.2.3-3 are considered. This "leaving-behind" is already included in the waiting times contained in Tables 3.2.3.-4 and -5. The actual waiting times are known to be shorter than those previously agreed to be admissible.

The high vehicle occupancy level makes an indirect contribution to the high transport speed achieved within the system. The fact that the vehicles are fully occupied is one of the reasons why the wishes of passengers waiting at the stations cannot be satisfied immediately. This, however, proves to be to the advantage of the passengers sitting in the vehicles passing through. The stopping frequency (i. e. the ratio of the average number of stops per time interval to the maximum possible number) established for the relevant central 10 minutes and the average transport speeds are listed in Table 3.2.3-6.

Table 3.2.3-7 summarizes required capital investment and cost broken down according to various specifications. Table 3.2.3-8 contains a survey of the levels of effectiveness and their composition.

The structure of capital and running cost may be seen from Fig. 3.2.3-2.

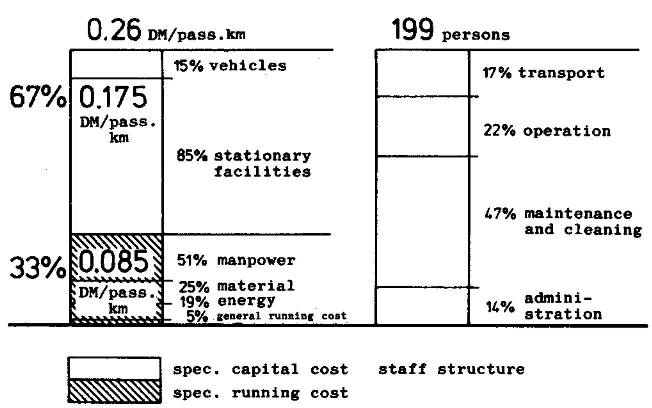


Fig. 3.2.3-2: Cost and staff structure, basic concept

Table 3.2.3-6: Stopping frequency and transport speed

	Peak	Off-peak	Late evening
stopping frequency	0,52	0,52	0,46
transport speed km/h	29,9	30,2	30,8

Table 3.2.3-7: Capital investment and cost

Need for capital investment and cost		
designation	dimension	value
need for capital investment	mio DM	385.32
of which on vehicles	mio DM	41.26
specific investment need	mio DM/route km	10.67
total cost	mio DM/year	42.07
	DM/carrying	1.14
	DM/pass.km	0.262
capital cost	mio DM/year	28.30
	DM/carrying	0.77
	DM/pass.km	0.18
running cost	mio DM/year	13.77
	DM/carrying	0.37
	DM/pass.km	0.08

Table 3.2.3-8: Levels of effectiveness

designation	weight	value
effectiveness	1.000	6.711
user	0.539	3.718
time required	0.197	1.412
accessibility	0.126	0.570
comfort of travel	0.067	0.409
comfort of service	0.149	1.327
operator	0.263	1.818
flexibility	0.089	0.877
reliability	0.135	0.668
safety	0.039	0.273
general public	0.198	1.175
environmental pollution	0.114	0.526
requirements	0.084	0.649

3.2.4 Changes in the maximum speed

This study is intended to further the investigation of the influence of vehicle maximum speed on operation, on the level of service and on the cost effectiveness relationship.

The basic technological parameters should be noted from Section 3.1.4. Unlike the conditions described there, the vehicles in this case do not in fact impede each other, if one disregards system-specific delays of individual vehicles upstream of certain switches and the planned retention of vehicles at the stations where they start operating at fixed intervals. The maximum volume on any line occuring here is still far below the technical capacity limit.

This study is confined to an increase in speed, since no volume-dependent bottlenecks on routes exist and since a loss in attractiveness for the passengers on account of clearly longer travel times because of lower speeds appears unacceptable.

For the variant under study here, i. e. 14 m/s, the routing calls for speed restrictions at 39 points on 112 curves in the network having radii of below 300 m.

Results of the simulation as compared with those for the basic concept are given in Fig. 3.2.4-1. Owing to a faster turn-round, the number of vehicles goes down to 84%. Transport speed clearly goes up. However, the ratio of actual speed to vehicle maximum speed decreases form 83% for the basic concept to 71% for faster vehicle running. The specific distance travelled by each vehicle goes up roughly proportinally owing to the reduced number of vehicles. The energy consumption of the vehicles is up by 19%, since the air drag of the vehicles grows and since acceleration manoeuvres increase in number and duration (speed restrictions, individual stations and switches).

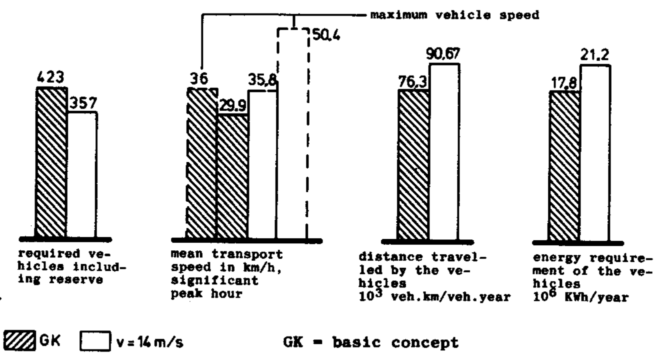


Fig. 3.2.4-1: Results of the simulation (selection) as compared with those of the basic concept

Important passenger-related characteristic numbers are listed in Table 3.2.4-1. The waiting times increase slightly, only their maximum values going up somewhat more markedly. On account of slightly shorter average vehicle headways, the level of service is deemed equal to that offered by the basic concept. The considerable increase in transport speeds is clearly reflected in the journey speeds and times, albeit less pronouncedly owing to the influence of waiting times. The savings in journey times due to the higher vehicle speed are in the range of 1.5 minutes.

The results of the cost and effectiveness calculation are shown in Table 3.2.4.-2 in comparison with those for the basic concept. The required capital investment for the design allowing a higher speed is up by 1 % and thus slightly higher than that for the basic concept. The lower vehicle requirement is slightly overcompensated by the additional expenditure on stationary facilities owing to longer off-line station tracks and a more accurate guidance by the trackways.

Total cost likewise increases slightly by about 1% for the higher speed, solely as a result of the running cost, the additional energy requirement here being the predominant factor. Accounting for about DM 0.4 million per year this is, however, in absolute terms not of major importance.

The levels of effectiveness are very similar, totalling 6.71 and 6.73. The increase in the user-oriented effectiveness from 3.72 for the

Table 3.2.4-2: Results of the cost and effectiveness calculation

	designation	dimension	basic concept	speed
	need for cap.investment	mio DM	385.32	389.61
	of which on vehicles	mio DM	41.26	35.22
	spec.investment need	mio DM/ route km	1o.67	1o.79
Investment and cost	total cost	mio DM/year	42,o7	42.41
		DM/carrying	1,14	1.15
		DM/pass.km	o.262	o.264
	capital cost	mio DM/year	28.3o	28.34
		DM/carrying	o.77	o.77
		DM/pass.km	o.18	o.18
	running cost	mio DM/year	13.77	14.o7
		DM/carrying	o.37	o.38
		DM/pass.km	o.o8	o.o8
	designation	weight	basic concept	v = 14 m/s
	effectiveness	1.000	6.711	6.734
Effectiveness levels	user	o.539	3.718	3.845
	time required	o.197	1.412	1.566
	accessibility	o.126	o.57o	o.57o
	riding comfort	o.o67	o.4o9	o.4o9
	operating comfort	o.149	1.327	1.3oo
	operator	o.263	1.818	1.822
	flexibility	o.o89	o.877	o.875
	reliability	o.135	o.668	o.674
	safety	o.o39	o.273	o.273
	general public	o.198	1.175	1.o67
	environmental pollution	o.114	o.526	o.497
	requirements	o.o84	o.649	o.57o

basic concept to 3.85 for the variant is almost overcompensated by the disadvantages of the variants accruing in the general public sector, mainly as a result of the increase in noise pollution and the energy requirement. The operator criteria remain nearly constant.

Like cost and effectiveness, the standardized benefit of the speed variant, amounting to 5.117, is hardly different from that of the basic concept, amounting to 5.112. Thus for the purpose of the instrumentalities, both solutions are regarded as equally suitable. Depending on whether more weight is attributed to the effectiveness for the users or for the operators or, for instance, to capital or operating cost, one or the other design would have to be selected for the present planning case.

3.2.5. Change in the size of vehicles

Unlike driver-controlled trains where the staff cost of the drivers requires the longest possible headways and the biggest possible vehicles, in driver-less operation a great many partly concurrent and

Table 3.2.4-1: Passenger-related times and speeds as compared with those in the basic concept

		Peak		Off-peak		Late evening	
		basic concept	v = 14 m/s	basic concept	v = 14 m/s	basic concept	v = 14 m/s
Waiting times	average (min)	o,78	o.85	o.99	1.o8	2.19	2.21
	98 % of the veh. (min)	2,9o	3.61	3.97	4.26	7.42	7.11
	maximum (min)	8.oo	11.oo	1o.oo	11.oo	11.oo	13.oo
transport speed (km/h)		29.9	35.8	3o.2	36.8	3o.8	38.9
journey speed (km/h)		26.4	3o.6	25.8	3o,3	22.7	27.o
journey times (min)		9.o9	7.76	9.4o	7.94	1o.66	8.9o

Table 3.2.5-1: Average vehicle headways per traffic period and operating level

Data in seconds	Peak level 1	Peak level 2	Off-peak level 1	Off-peak level 2	Late evening level 1	Late evening level 2
line 1	102	107	148	153	209	210
2	255	203	212	253	347	346
3	230	203	333	275	443	447
4	163	167	292	310	412	414
5	73	53	96	103	-	-
6	221	189	315	311	-	-
line 7	161	144	202	305	-	-
averages	137	121	215	170	305	306
for comparison: basic concept	63	63	119	102	247	264

partly opposing trends influence cost and effectiveness in a way which is not easily perceived.

On the cost side, bigger vehicles tend towards somewhat more favourable capital requirements per seat and towards somewhat lower running cost per seat kilometre. For the passenger, however, losses in attractiveness are foreseeable, inter alia, owing to the tendency towards an increase in vehicle headways if the provision of service is, within certain limits, adjusted to the volume of traffic. In addition, if the operating mode includes request stops, some influence on transport speed should be anticipated.

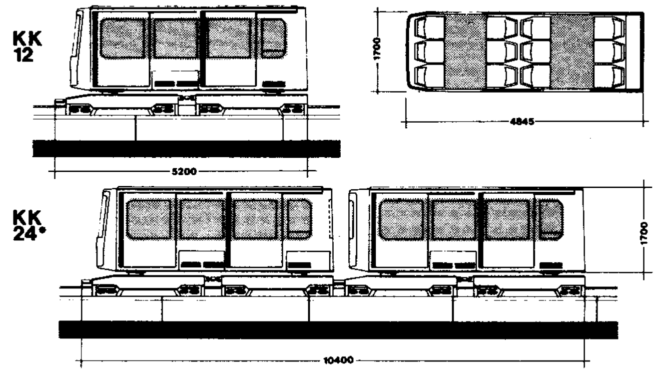
In the following, an increase in vehicle capacity only will be examined, because preliminary studies suggest that this will result in cost savings and since the quantitative change of the operating mode towards scheduled stops at every station is of interest.

The variant studied here is vehicle KK 24 consisting of two inseparably coupled motor cars, cf. Fig. 3.2.5-1. Since the trackway dimensions are to be kept unchanged, each motor car has two bogies. A basic assumption is the safe transmission of control movements and signals between both motor cars for preselecting the running direction at switches and for any other functions. Both motor cars make joint use of an on-board controlling device and a propulsion regulator. Social supervision is provided by a visual connection between both cars.

The operational design is geared to the volume of passengers and the adherence to the conventions on waiting times according to 3.2.3.1. Table 3.2.5-1 contains the mean vehicle headways per line and the average value weighted by the number of vehicles per line. Fig. 3.2.5-2 contains the number of vehicles in operation at certain hours as compared with the number in the basic concept.

Whereas during the peak hour the traffic volume can be transported within the waiting time limits by half as many big vehicles, i.e. by the same number of motor cars in all as are required under the basic concept, during the off-peak and late evening hours fewer vehicles altogether but more motor cars are necessary than is the case under the basic concept.

Fig. 3.2.5-3 clearly shows that the waiting-time targets are achieved and that, the lower the traffic volume, the more the waiting times of the variant and of the basic concept come to resemble each other, owing to an adjustment of the vehicle headways. The maximum waiting times of the variant are 3 minutes longer during the peak hour, amounting to 11 minutes, and 1 minute shorter during the late evening hour, amounting to 10 minutes, than those in the basic concept.



*at present not included in the manufacturer's concept

Fig. 3.2.5-1: Vehicles equipped with 12 and with 24 seats

Table 3.2.5-2 contains the characteristic values which are of interest here, i.e. stopping frequency and transport speed. Owing to the higher seat number and the greater probability of different destination requests in one vehicle, the larger vehicle stops more frequently than the smaller one. Therefore, the transport speed of the variant is consistently lower than that of the basic concept. Owing to the variation in the supply of vehicles, variant and basic concept come close to each other when the traffic volume is low.

The numbers of passengers "left behind", which are mainly of statistical interest, are listed in Table 3.2.5-3. These percentage figures go down progressively with increasing vehicle size and decreasing traffic volume.

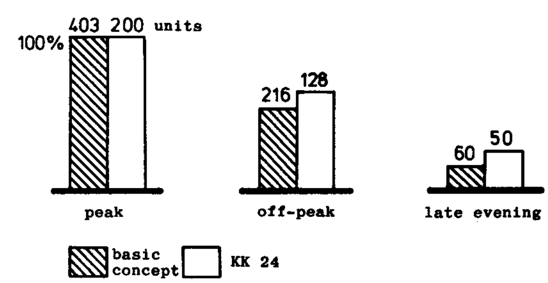


Fig. 3.2.5-2: Vehicles in operation during significant hour

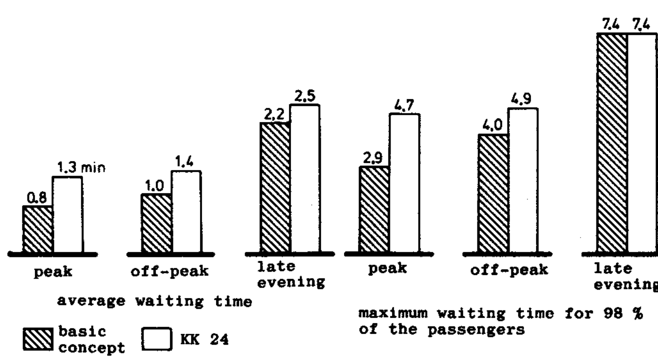


Fig. 3.2.5-3: Waiting times

Table 3.2.5-2: Stopping frequency and transport speed

	Peak basic concept	Peak KK 24	Off-peak basic concept	Off-peak KK 24	Late evening basic concept	Late evening KK 24
stopping frequency	0.52	0.73	0.52	0.69	0.46	0.55
transport speed km/h	29.9	27.7	30.2	28.5	30.8	30.2

Table 3.2.5-3: Percentages of passengers left behind

Data in %	Basic concept	KK 24
significant peak hour	55	51
significant off-peak hour	7	4
significant late evening hour	3	<o.1

100 % = carryings per significant hour of the traffic period concerned

As seen from Fig. 3.2.5-4, the journey speeds, which are influenced, among other things, by transport times and waiting times, differ more widely during the peak hour than at other times. When larger vehicles are used, the increase in journey time is about 1.1 minutes during the peak hour and this decreases via 0.9 minutes during the off-peak hour to about 0.4 minutes during the late evening hour.

As a result of the overlapping of the already mentioned influences, the load factors are as shown in Fig. 3.2.5-5. During off-peak and late evening hours, the utilization of seats is worse in the case of bigger vehicles than in the case of smaller ones. The annual value reveals clear differences which are, however, not serious.

Fig. 3.2.5-6 shows the vehicle energy requirement, which is mainly important for the operator. During the peak hour clearly less energy is consumed than is the case under the basic concept owing to the fact that the bigger vehicle has a rather more favourable specific energy consumption and a somewhat better load factor, but at other times the bigger vehicle clearly requires more energy to maintain the level of service. As far as annual consumption is concerned, the KK 24 achieves a small saving.

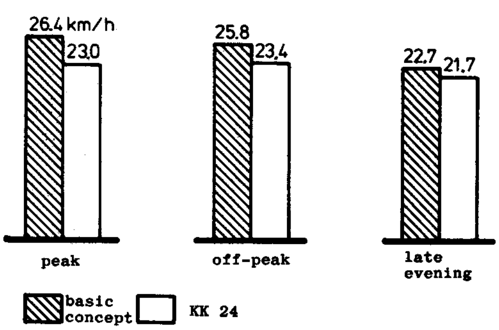


Fig. 3.2.5-4: Average journey speeds

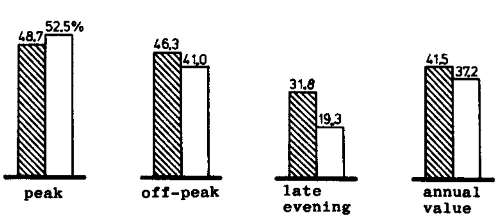


Fig. 3.2.5-5: Load factor

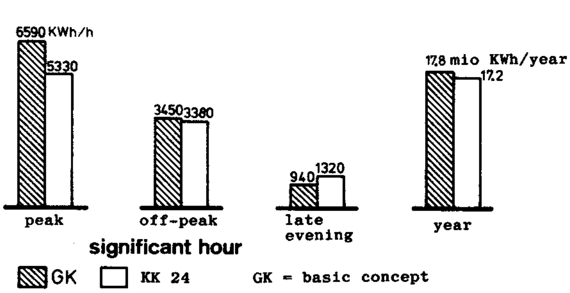


Fig. 3.2.5-6: Vehicle energy requirement

It is apparent that, after this close scrutiny, the argument that a small vehicle makes sense because of its better adjustment to the volume of traffic is not borne out here, when energy is taken into account.

The results of the ascertainment of cost and effectiveness contained in Table 3.2.5-4 indicate a saving in capital investment totalling around DM 18 million for KK 24, this resulting mainly from a lower investment at the stations. Twelve of the 21 off-line stations can become on-line stations, since the mean peak hour vehicle headways practically double. In addition, all stations designed for three berths according to the basic concept can become one-berth stations for KK 24. Thus capital investment decreases. Smaller savings in operating cost are mainly the result of reduced manpower requirements. Altogether, about DM 0.013 per passenger kilometre can be saved.

It is true, however, that effectiveness clearly decreases when the bigger vehicle is used, since disadvantages in the users' sector (increased journey time) outweigh the minor advantages accruing to the operators and the general public.

The "best" system design in this case is clearly obtained by comparing the standardized benefit of 5.11 for the basic concept and 4.86 for vehicle variant KK 24. As far as the decision-making model is concerned the basic concept is clearly preferable.

The study reported on here may make a contribution to our knowledge on the relationship between vehicle size and operating mode, which has applications beyond the confines of the planning case. Line-haul operation plus request stops is still of interest to both users and operators, even for the 24-seat vehicle under consideration here, as opposed to the mode of operation providing for stops at every station, because of the savings in time, energy and vehicles involved.

Table 3.2.5-4: Results of the cost and effectiveness calculation

	designation	dimension	basic concept	vehicle size
Investment and cost	need for cap.investment	mio DM	385,32	367,41
	of which on vehicles	mio DM	41,26	37,94
	spec. investment need	mio DM/ route km	1o,67	1o,18
	total cost	mio DM/year	42,o7	4o,o6
		DM/carrying	1,14	1,o8
		DM/pass.km	o,262	o,249
	capital cost	mio DM/year	28,3o	26,86
		DM/carrying	o,77	o,72
		DM/pass.km	o,18	o,17
	running cost	mio DM/year	13,77	13,2o
		DM/carrying	o,37	o,36
		DM/pass.km	o,o8	o,o8
	designation	weight	basic concept	KK 24
Effectiveness levels	effectiveness	1,000	6,711	6,27o
	user	o,539	3,718	3,221
	time required	o,197	1,412	1,o86
	accessibility	o,126	o,57o	o,568
	riding comfort	o,o67	o,4o9	o,4o9
	operating comfort	o,149	1,327	1,158
	operator	o,263	1,818	1,866
	flexibility	o,o89	o,877	o,887
	reliability	o,135	o,668	o,7o6
	safety	o,o39	o,273	o,273
	general public	o,198	1,175	1,183
	environmental pollution	o,114	o,526	o,52o
	requirements	o,o84	o,649	o,663

3.2.6 Change in the acceleration and deceleration of the vehicles during normal operation

The purpose of this study is to consider the influence of a reduced longitudinal vehicle acceleration and deceleration on the pattern of operation, on the quality of service and on the cost effectiveness relationship of the variant. Smaller acceleration clearly reduces the starting-up currents of the vehicles and permits an energy design which is more economical than that included in the basic concept, since the peak current load is closer to the average load. This reduces the capital investment required for energy supply. Therefore, in this variant the maximum acceleration is fixed at one half of that in the basic concept. The study of a higher acceleration is out of the question, inter alia, for reasons of comfort.

At every off-line station, acceleration lanes become necessary which are longer by 2 times 10 m; this somewhat increases the required capital investment according to the number of such stations. Therefore, the counter effects of energy supply and station design on capital requirements are of some interest.

As far as the practical operation is concerned, this variant is designed to use the same number of vehicles per line as were ascertained for the basic concept, since the slightly reduced overall running speeds do not justify an increase in the number of vehicles. As seen from Table 3.2.6-1, the waiting times increase slightly, but as in the basic concept these stay within the agreed limits. The minor decrease in transport speed is due to the somewhat slower acceleration. As seen from the journey times, which are extended by about 1/4 minute, the overall influence is small.

Table 3.2.6-1: Passenger-related times and speeds as compared with those in the basic concept

		Peak		Off-peak		Late evening	
		basic concept	b*/2	basic concept	b/2	basic concept	b*/2
Waiting times	average (min)	0.78	0.84	0.99	1.03	2.19	2.26
	98 % of veh. (min)	2.90	3.18	3.97	4.15	7.42	7.54
	maximum (min)	8.0	8.0	10.0	10.0	11.0	11.0
transport speed (km/h)		29.9	29.2	30.2	29.6	30.8	30.2
journey speed (km/h)		26.4	25.6	25.8	25.2	22.7	22.2
journey times (min)		9.09	9.35	9.40	9.62	10.66	10.89

* b = acceleration

A number of other operating data likewise change only marginally. Thus, for instance, the load factor increases according to the time of day by 0.3% during the peak hour and by about 1.0% during the off-peak and the late evening hours. Annual energy consumption goes down by approximately 2%, owing to a smaller number of starting-up operations.

As seen from Table 3.2.6-2 the need for capital investment goes up by about 1.5%, owing to the additional expenditure on stationary facilities. In this planning case, the additional requirements for tracks at the off-line stations outweigh the savings in energy supply installations. The total cost of the variant exceeds that of the basic concept by slightly under 1%. Minor savings in running cost are overcompensated by somewhat higher additional capital costs.

As far as effectiveness is concerned, the disadvantages accruing to the users, particularly on account of somewhat longer travel times, outweigh the slight advantages accruing to the general public. Here again, however, the variant and the basic concept are very similar. The small difference is also brought out by the standardized benefits

basic concept	5.11 points
variant	5.04 points.

Thus the variant comes off slightly worse than the basic concept.

This result is largely due to the numerous off-line stations (21 out of the 54 stations in the network). In less heavily trafficked networks the results may well be equal to or even better than the basic concept.

Table 3.2.6-2: Cost and effectiveness of examined variant and of basic concept

Results of the cost and effectiveness calculation				
	designation	dimension	basic concept	acceleration
Investment and cost	need for cap. investment	mio DM	385.32	391.46
	of which on vehicles	mio DM	41.26	41.26
	spec. investment need	mio DM/ route km	10.67	10.84
	total cost	mio DM/year	42.07	42.41
		DM/carrying	1.14	1.15
		DM/pass.km	0.262	0.264
	capital cost	mio DM/year	28.30	28.70
		DM/carrying	0.77	0.78
		DM/pass.km	0.18	0.18
	running cost	mio DM/year	13.77	13.71
		DM/carrying	0.37	0.37
		DM/pass.km	0.08	0.08
	designation	weight	basic concept	$b^* = b_0/2$
Effectiveness levels	effectiveness	1.000	6.711	6.629
	user	0.539	3.718	3.635
	time required	0.197	1.412	1.355
	accessibility	0.126	0.570	0.570
	riding comfort	0.067	0.409	0.409
	operating comfort	0.149	1.327	1.301
	operator	0.263	1.818	1.812
	flexibility	0.089	0.877	0.874
	reliability	0.135	0.668	0.665
	safety	0.039	0.273	0.273
	general public	0.198	1.175	1.182
	environmental pollution	0.114	0.526	0.526
	requirements	0.084	0.649	0.656

* b = acceleration

3.2.7 Summary and recommendations

The cabin railway system considered here which employs medium-sized vehicles is very well suited for performing the transport functions of a feeder system to a high-speed railway and for developing internal transport.

The operating concept of stopping on request even in line-haul service turned out to be advantageous at all operating hours for the vehicle sizes under study here, i.e. capacities of 12 and 24 seats. Long-term increases in traffic volumes can be coped with just as can short-term peaks in passenger arrivals—even when the passengers arrive in batches—provided they are known about in advance.

An increase in maximum vehicle speed from 36 to 50 km/h permits quicker passenger transport, while leaving the overall cost almost unchanged, and thus produces an increase in effectiveness for the users, but this is almost offset by the disadvantages arising in the general public sector. For the purpose of the decision-making model introduced here, this variant and the basic concept are therefore equal.

The investigations into vehicle size reaffirm the advantage of the smaller vehicle type included in the basic concept, despite a slight decrease in overall cost when using twin motor cars.

The discussion of the maximum acceleration during normal operation once again confirms the manufacturer's basic concept, although it is not very different from the variant which received a lower rating. In other planning cases there may well be equality, particularly if in the course of further development additional small cost savings can be achieved.

On the whole, there is a wide spectrum of potential design variations of the cabin railway on the basis of the technology under consideration here. This might be of interest on a long-term basis, if the optimization conditions should change on account of a shift in the relative importance of the individual levels of effectiveness.

Quite apart from that, the following recommendations on the solution of marginal problems can be given today.

- There should be an investigation into whether a quasi-timetable could be published for the periods outside the peak hours indicating the expected arrival time and the margin per station due to request stops. In the case of longer average headways (e.g. 5 minutes and more), this quasi-timetable could enable the regular passenger to adjust himself to the time structure known to him and — as in the case of the fixed timetable — reduce the calculated waiting times in practice.
- It is important to keep the station times assumed here, since they also influence vehicle deployment and station arrangement. Suitable measures on the vehicle itself (e.g. rapid door opening and closing) and at the station (arranging the waiting passengers according to destination or line) can contribute to this end.
- The influence of the unexpected and hence unplanned for arrivals of passengers in batches, particularly during the off-peak and late evening hours, should be examined. The times necessary for summoning any additionally required extra vehicles from the depot should be determined and possibly suitable small vehicle depots should be provided at suitable sites in the network.