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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

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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;
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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).

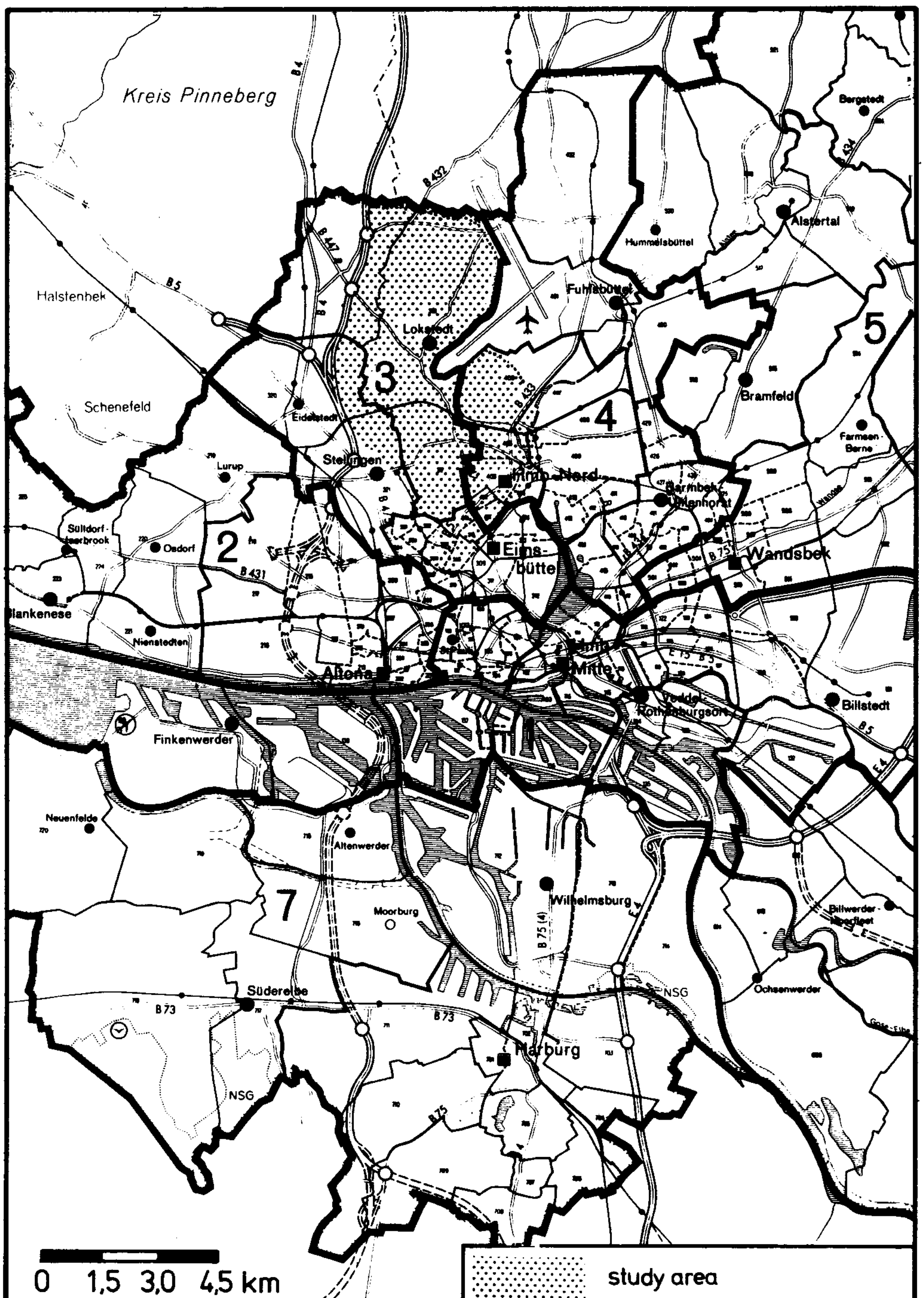


Fig. 3.0-1: Hamburg and the study area

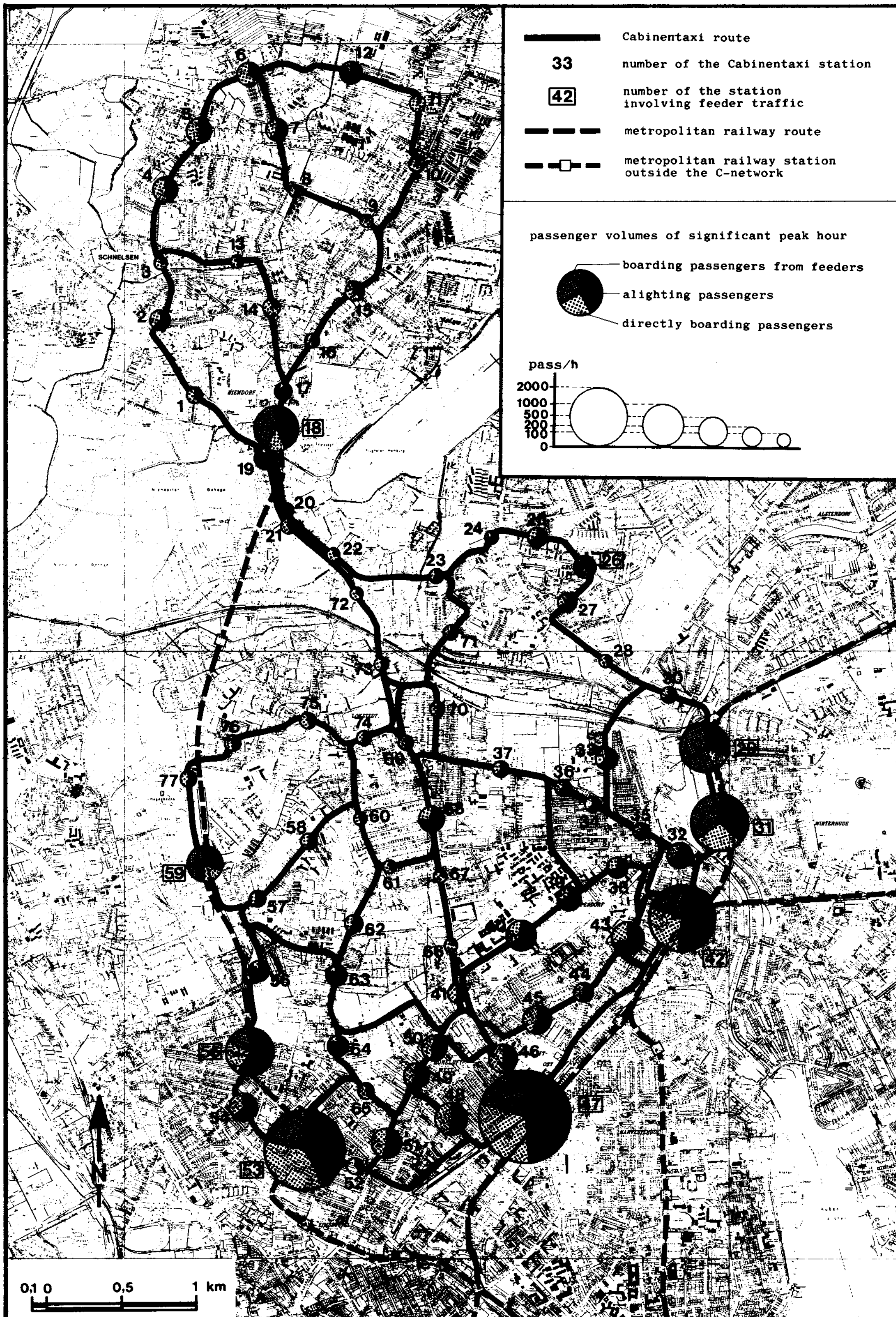


Fig. 3.1.1-1: Network and passenger volume during the significant peak hour

Table 3.0-1: Forecast data for 1990

	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 %

+ 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.

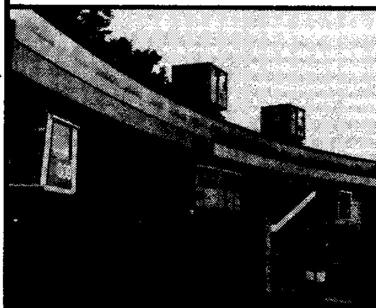
Table 3.1.1-1: Characteristic numbers for network and traffic volume

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	
off-peak hour	10,100	8,470	1,630	
late evening hour	1,880	1,740	140	

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

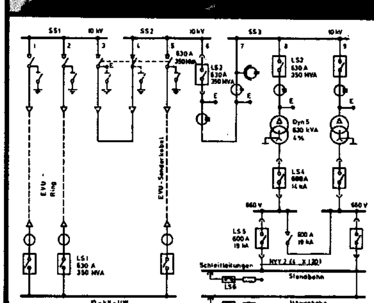
- Data:
Length of boarding dock = number of berths x 2.8 m, effective platform width 3.1 - 4.2 m (4.2 m for central platform), station spacing 400 - 800 m

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 $= \eta$ 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

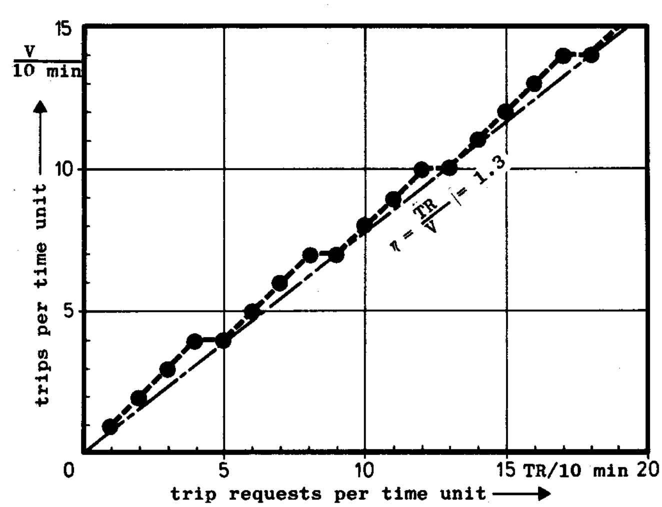


Fig. 3.1.3-1: Approximation of integers to the design value η = 1.3

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

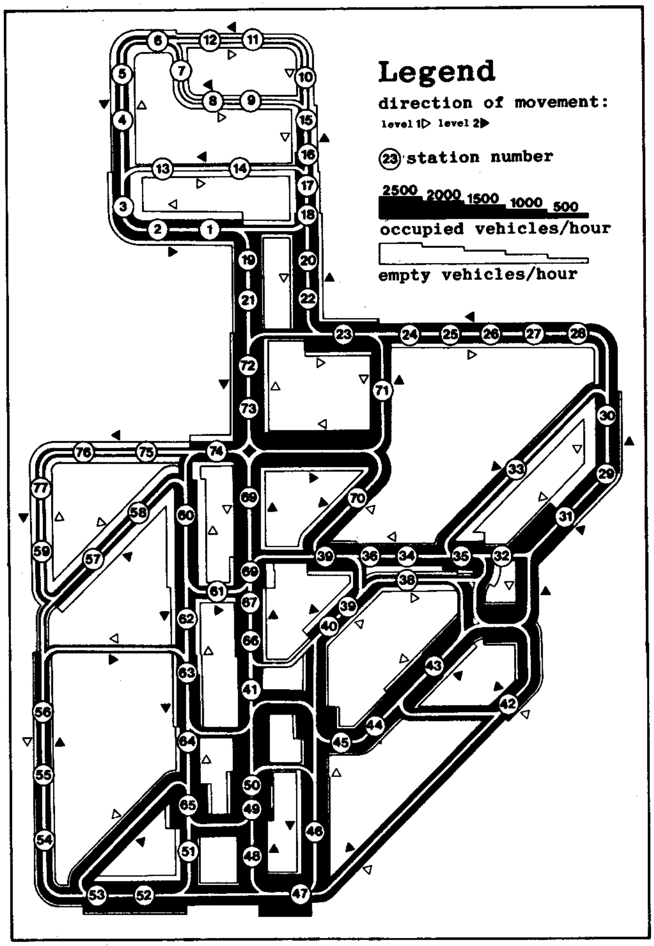


Fig. 3.1.3-2: Traffic load on routes during the significant peak hour

— 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

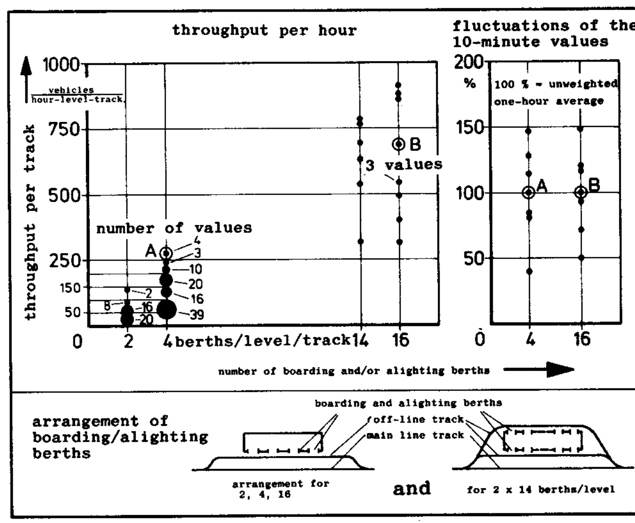


Fig. 3.1.3-3: Vehicle throughput and its fluctuations at the stations

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