

Operating Concept and System Design of a Transrapid Maglev Line and a High-Speed Railway in the pan-European Corridor IV

A. Stephan & E. Fritz

IFB Institut für Bahntechnik GmbH, Niederlassung Dresden, Germany

IFB is a founder member of the Centre of Excellence for High Performance Railways and Maglev Systems at TU Dresden

ABSTRACT: By order of the federal state of Saxony a feasibility study regarding high speed urban passenger transport in the so called pan-European Corridor IV from Berlin (Germany) to Budapest (Hungary) via Dresden – Prague – Brno – Vienna – Bratislava was realized in the past two years. The paper describes the methods and results of the operating planning and the system design of both Maglev and Railway system taking into account the number and location of intermediate stops, the track alignment, the traffic prognosis and the technical system parameters. The determination of traveling times using verified simulation tools is explained as well as the setting up of operating programs consisting of time tables and specific train cycles for different variants of this high speed link overall line length of approximately 900 km. The varying system characteristics of Maglev and Railway require different operating programs and technical layout of both systems. Based on the specific operating concepts a preliminary system design is fixed for all variants to determine the total investment and the annual operating costs as well as the expected benefits. Finally the study shall evaluate the feasibility and economic efficiency of high speed urban passenger transport in the pan-European Corridor IV. Supplementary a recommendation concerning the preferred technology is expected.

1 INTRODUCTION

1.1 Project Background

By order of the Federal State of Saxony a feasibility study regarding high-speed urban passenger transport in the so called pan-European Corridor IV from Berlin (Germany) to Budapest (Hungary) via Dresden – Prague – Brno – Vienna – Bratislava was realized in the past two years. This future high-speed line with an overall length of approximately 900 km could connect the capitals of five countries including three further regional centres (see Figure 1.1). The line is located in a traditional economic area of central Europe with round about 60 millions inhabitants.

In the result of this international feasibility study carried out also by the Centre of Intelligence for High Performance Railways and Maglev Systems of Technische Universität Dresden a recommendation concerning the efficiency and profitability of the line as well as the preferred high-speed technology was expected by the customer. Some more details concerning the general work procedure and the final results of the study are presented in the MAGLEV2006 paper of Prof. Wolfgang Fengler.

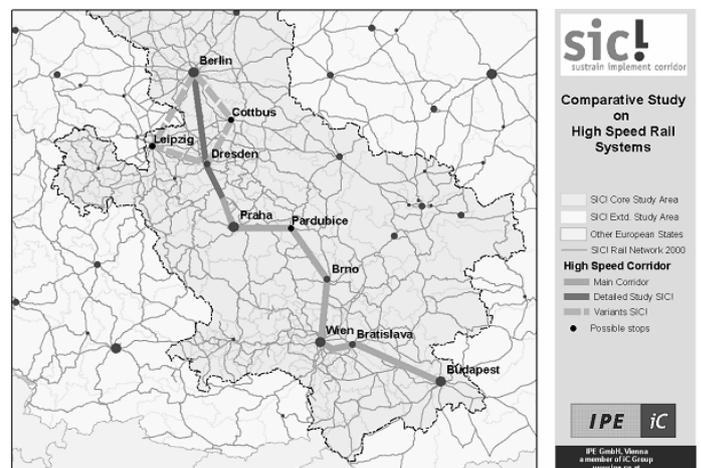


Figure 1.1 High-speed connection in the pan-European corridor IV

1.2 Contents of the presented works

One main item of the study was the operating planning and the system design as a basis for the subsequent cost and benefit determination. In the following the methods and results of the operating planning and the technical system design of both Maglev and railway systems taking into account the number and location of intermediate stops, the track alignment, the traffic prognosis and the technical

system parameters are described. Based on the specific operating concepts a preliminary system design was fixed for all variants to determine the total investment and the annual operating costs as well as the expected benefits.

Therefore the determination of travelling times using verified simulation tools was required as well as the setting up of operating programs consisting of time tables and specific train cycles for different line variants. The varying system characteristics concerning speed and capability of Maglev and high-speed railway required different operating programs and technical layouts of both systems.

The special part of the study regarding the operating concept and the system design was carried out with the following main steps:

1. Runtime calculation based on the route alignment data

contents: runtime simulation between all stations, determination of individual stopping and reserve times

2. Traffic prognosis for all line variants

contents: prognosis of the yearly passenger volume for all line sections based on the station's location, the line routing and the scheduled travel times

3. Determination of operating headway and vehicle capacity

for all line sections in each case regarding maximum and average traffic volume, target: use of a basic headway and a unified train configuration for the whole line

4. Preliminary system design

contents: design of track layout, power supply and propulsion system, operation control system, operating and maintenance facilities

5. Planning of vehicle circulation (round trips)

contents: line concept and use of vehicles, start and end of daily operation, adaptation to peak and low traffic volume periods, requirements on the track layout

6. Verification by operating simulation

using the commercial railway operation simulator OpenTrack and considering the preliminary design of all technical subsystems

2 OPERATING CONCEPT

2.1 Basic data and preconditions

2.1.1 Stations, line routing and track alignment

The basic line routing from Berlin to Budapest with intermediate stops in Dresden, Prague (Praha), Pardubice, Brno, Vienna (Wien) and Bratislava was fixed before by the customer. Additionally two further line variants in Germany between Berlin and Dresden via Leipzig and Cottbus were part of the investigation.

The distances between the main stations of the line are in a range of 90 ... 180 km, which is typically for successful international high-speed railway lines. Only in the so called TwinCity region between Vienna and Bratislava there are shorter stops planned to connect both capitals with each other and with the Vienna International Airport Schwechat.

The Maglev line variants have shorter total lengths of 6 ... 7 % compared with the high-speed railway because of their improved adaptability to difficult terrains and the non-existing integration to the common networks in the city regions.

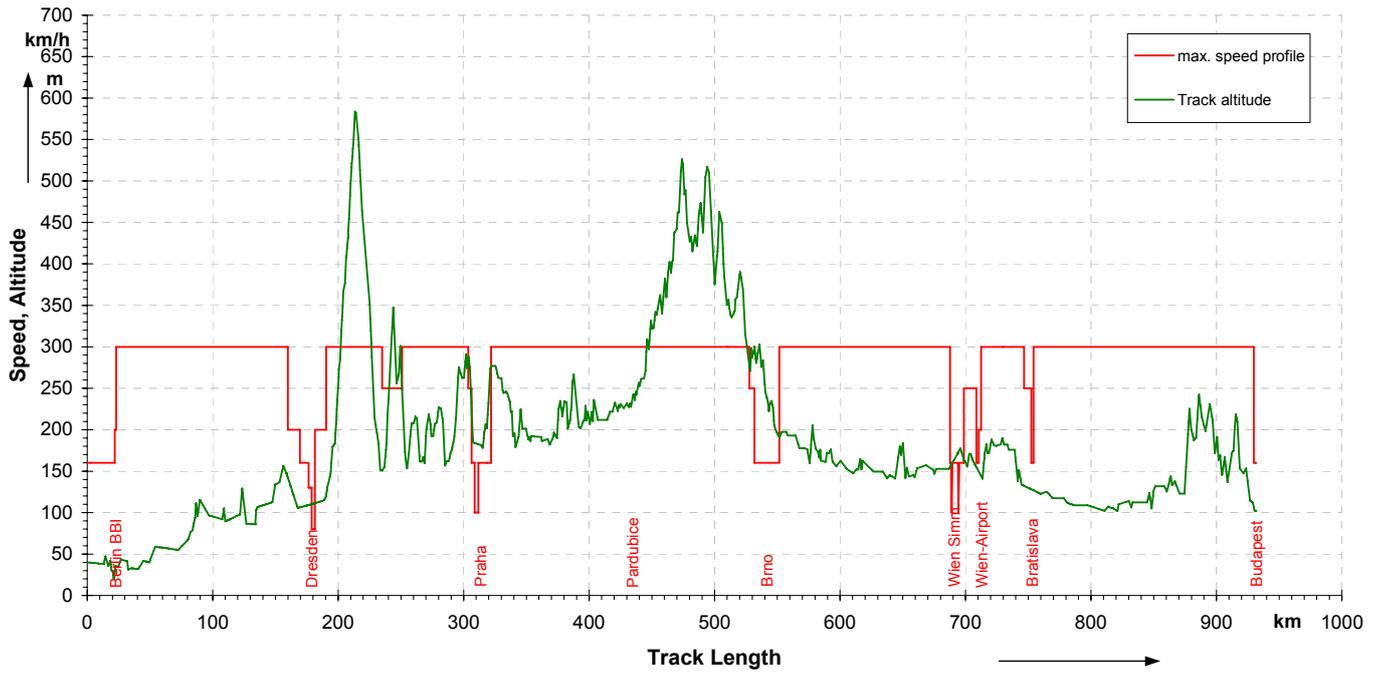


Figure 2.1 Maximum speed profile and track altitude of the high-speed railway line

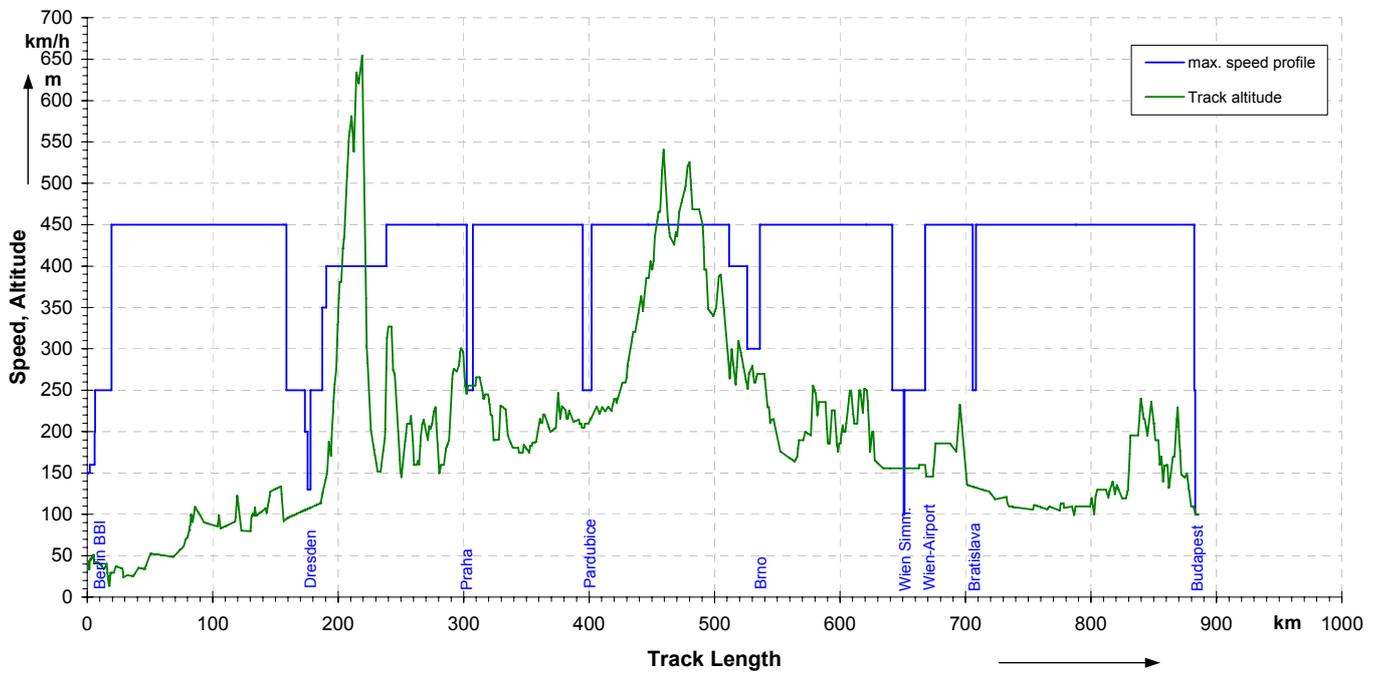


Figure 2.2 Maximum speed profile and track altitude of the Maglev line

The permissible speed profiles as well as the gradient course of both basic variants RST 1 (Railway) und MSB 1 (Maglev) are shown in Figure 2.1 and Figure 2.2. The maximum gradient of the railway system was estimated with 35 ‰ considering the TSI regulations, the maximum gradient of the Maglev amounts to 100 ‰ (for further details see also the paper of Prof. Fengler).

2.1.2 Considered high-speed systems

Corresponding to the customers terms of reference for the railway system the German ICE-3-technology and for the Maglev the German Transrapid system each in the current development state were included (see Table 2.1). While the configuration of one ICE 3 train set is fixed with 8 single cars, for the Maglev system the train configuration was determined as a result of the operating planning.

Table 2.1 Train data of the high-speed railway system and Maglev Transrapid

Parameter	ICE 3M (8-car train)	Transrapid (4 car sections)
Total vehicle length	200,2 m	100,1 m
Vehicle width outside	3,0 m	3,7 m
Vehicle width inside	2,7 m	3,4 m
Vehicle height inside	2,5 m	2,1 m
Vehicle cross section area inside	6,8 m ²	7,3 m ²
Auxiliary power per single car	17,5 kW	18,8 kW
Levitation power (Maglev only)	-	1,7 kW / t
Number of single cars / sections per train	8	4
Vehicle mass (unoccupied)	409,0 t	225,4 t
Number of seats	458	360
Vehicle mass (all seats occupied)	445,6 t	254,2 t
Maximum operating speed	300 km/h	450 km/h
Maximum mechanical traction power	8,0 MW	ca. 2 x 10 MW
Maximum acceleration	0,6 m/s ²	1,0 m/s ²
Regular braking deceleration	0,5 m/s ²	0,8 m/s ²

2.1.3 Runtime simulation and travel time determination

The scheduled travel times of the trains as a fundamental basis for the operating concept were determined in the following steps:

1. Runtime simulation

based on the route alignment data, permitted speed profiles and vehicle data respectively propulsion characteristics

2. Determination of stopping times

standard value: 2 min per station, in stations with extensive passenger change: 4 min, in stations with changes of train configuration: 6 / 4 min

3. System-specific runtime surcharge

Railway: 7 ‰ + 3 ‰ = 10 ‰

Maglev: 3,5 ‰ + 3 ‰ = 6,5 ‰

4. General runtime surcharge for further modifications of line planning

10 ‰ for both systems

5. Rounding up to whole minutes for showing of timetable times

Regarding the achievable speed profiles and running times both systems differ in a substantial way. Figure 2.3 shows the differing speed curves which reflect the noticeable higher performance of the Maglev system.

Resulting from the greater propulsion performance the Maglev systems offers not only a higher travel speed but also a higher acceleration and deceleration level. As shown in Figure 2.4 the pure running time difference of both systems regarding a line length of approximately 300 km from Berlin to Prague amounts of 29 minutes (50 ‰ more).

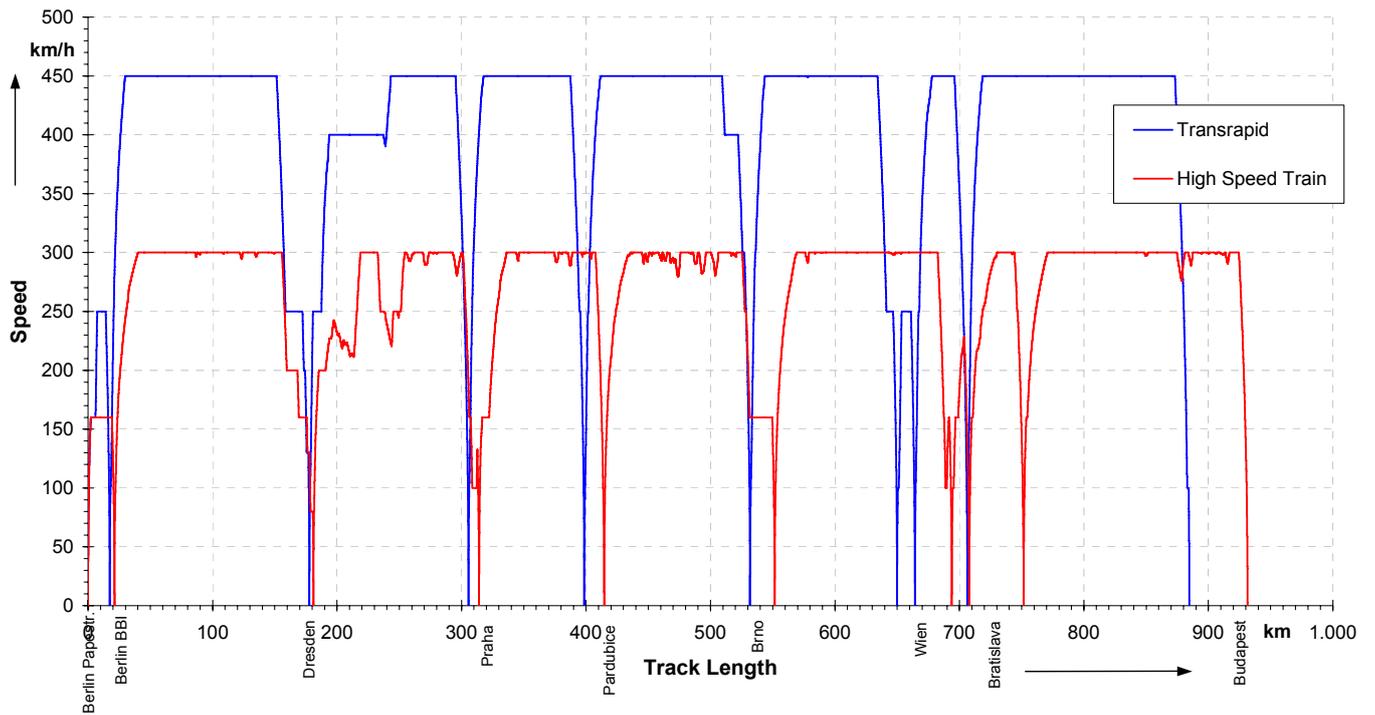


Figure 2.3 Achievable speed profiles versus track length of both high-speed systems

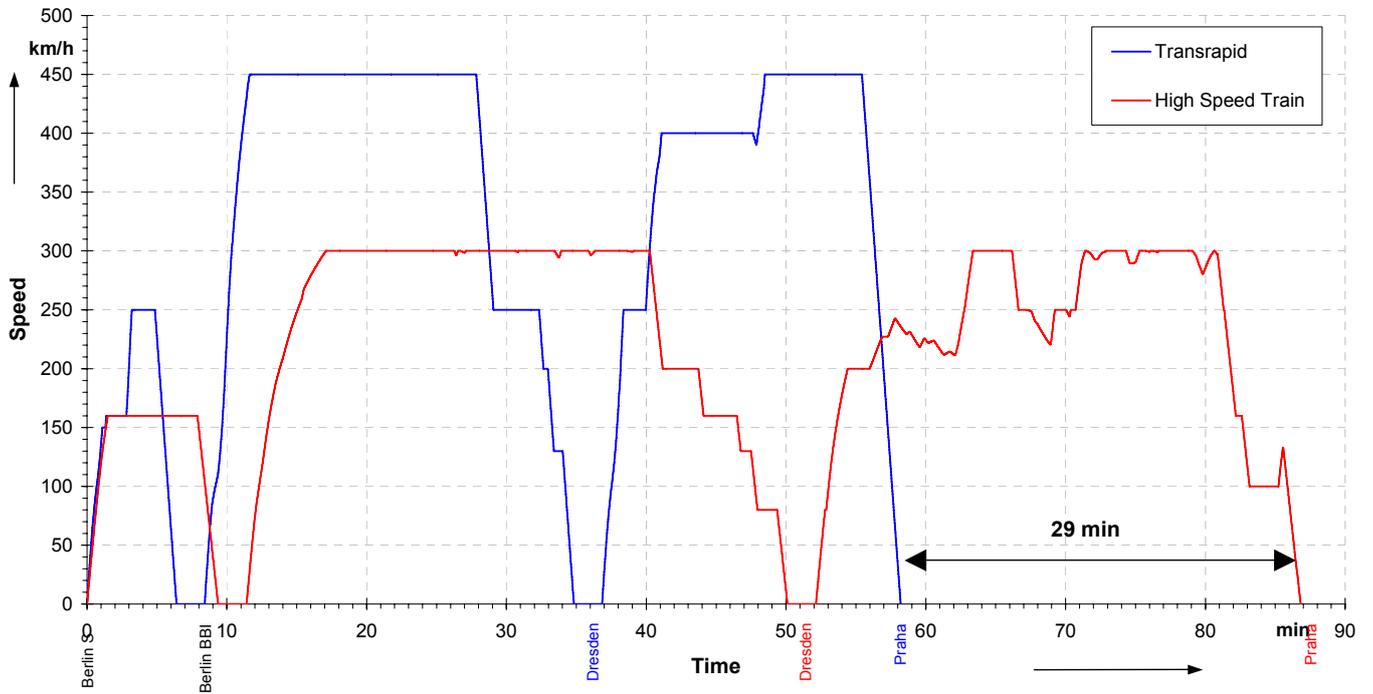


Figure 2.4 Speed profile versus time of both high-speed systems (Berlin – Prague section)

The runtime calculations were carried out using verified simulation programs for both systems. The applied software solutions allow the timetable-controlled driving simulation including the electrical propulsion and power supply network calculation. All programs were verified by on-site measurements on different German and international high-speed lines.

For the runtime simulation the following preconditions were assumed:

- vehicle load 100 % (all seats occupied)
- wind surcharge of 15 km/h constantly in the aerodynamic driving resistance (except in tunnels)
- double feeding method of the Transrapid propulsion sections
- simulation of time minimized way of driving.

The results in Figure 2.5 and Figure 2.6 show the scheduled travel times of all line sections for both systems. Under consideration of the reserve and surcharge times mentioned above the high-speed railway system offers a total travel time of 5 h 16 min (variant RST 1). Relating to the total line length an average travel speed level of 178 ... 182 km/h is realized. These are solid values for the high-speed railway traffic, taking into account, that in the city regions the existing networks with sensitive speed restrictions are passed. In some line sections the average travel speed reaches a level up to 225 km/h (section Bratislava – Budapest).

The Maglev system offers a travel time of 3 h 20 min (variant MSB 1) for the Berlin – Budapest connection. The average travel speed is in the range of 265 ... 270 km/h. Thus its level is approximately 100 km/h higher compared to high-speed railway. In particular line sections the average travel speed reaches a level up to 334 km/h (Bratislava – Budapest).

2.1.4 Traffic prognosis

Based on the station's location in the cities, the scheduled travel times of the regarded high-speed systems and the macro-economic data representing population distribution, economic situation and mobility a detailed traffic prognosis was carried out by an external specialist. To perform this important step of the investigation a basic operating program for both systems had to be assumed. This procedure contains a contradiction because the operating program normally is just the result of the traffic prognosis. But without a basic timetable concept a prognosis is impossible. Thus an iterative procedure for this aspect is required.

The results of the traffic prognosis are shown in Figure 2.7 and Figure 2.8. Considering only the direct-related traffic currents of the line corridor both

systems achieve nearly the same traffic volume. Taking into account also traffic routes which use only parts of the new high-speed network the traffic volume of the railway is higher compared with the Maglev system, although Maglev is approximately 50 % faster. This seems unexpected at first regarding the shorter travel times of the Maglev system. But, in this very special case the numerous existing railway lines can participate from the new high-speed railway corridor, so that trains of other (crossing) directions will run on it only in particular sections. Another aspect to explain this surprising result is the assumed fare level, which is 25 % higher for the Maglev system. A third argument is the location of some Maglev stations outside of the city centers, so that the total travel times from city to city will increase to the level of the railway system.

On the other hand the passenger volume data show an unequal distribution regarding the different line sections. While the traffic volume in the central section of the line is acceptable for high-speed systems, especially in the German section the passenger volume is only small.

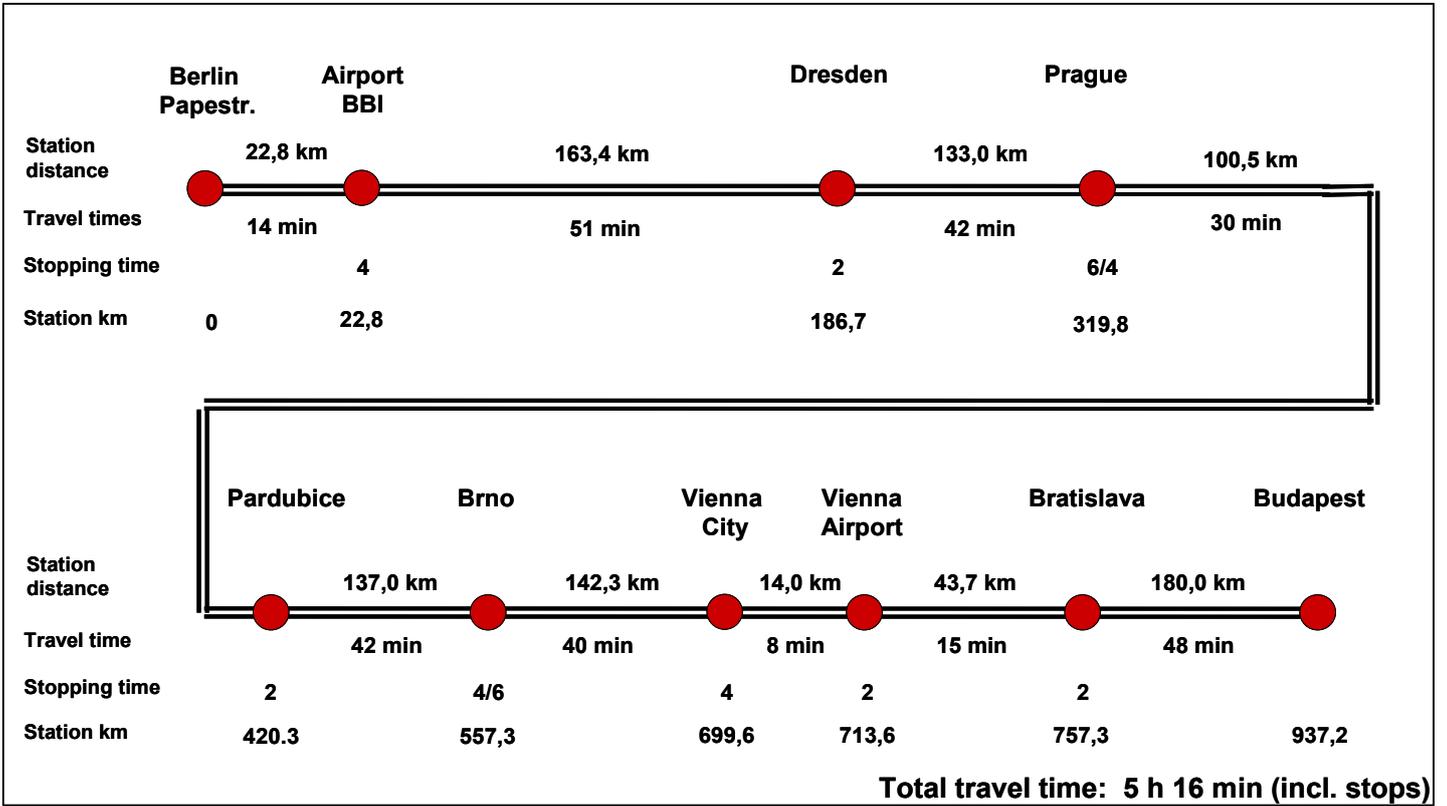


Figure 2.5 Distances and scheduled running times of the high-speed railway line

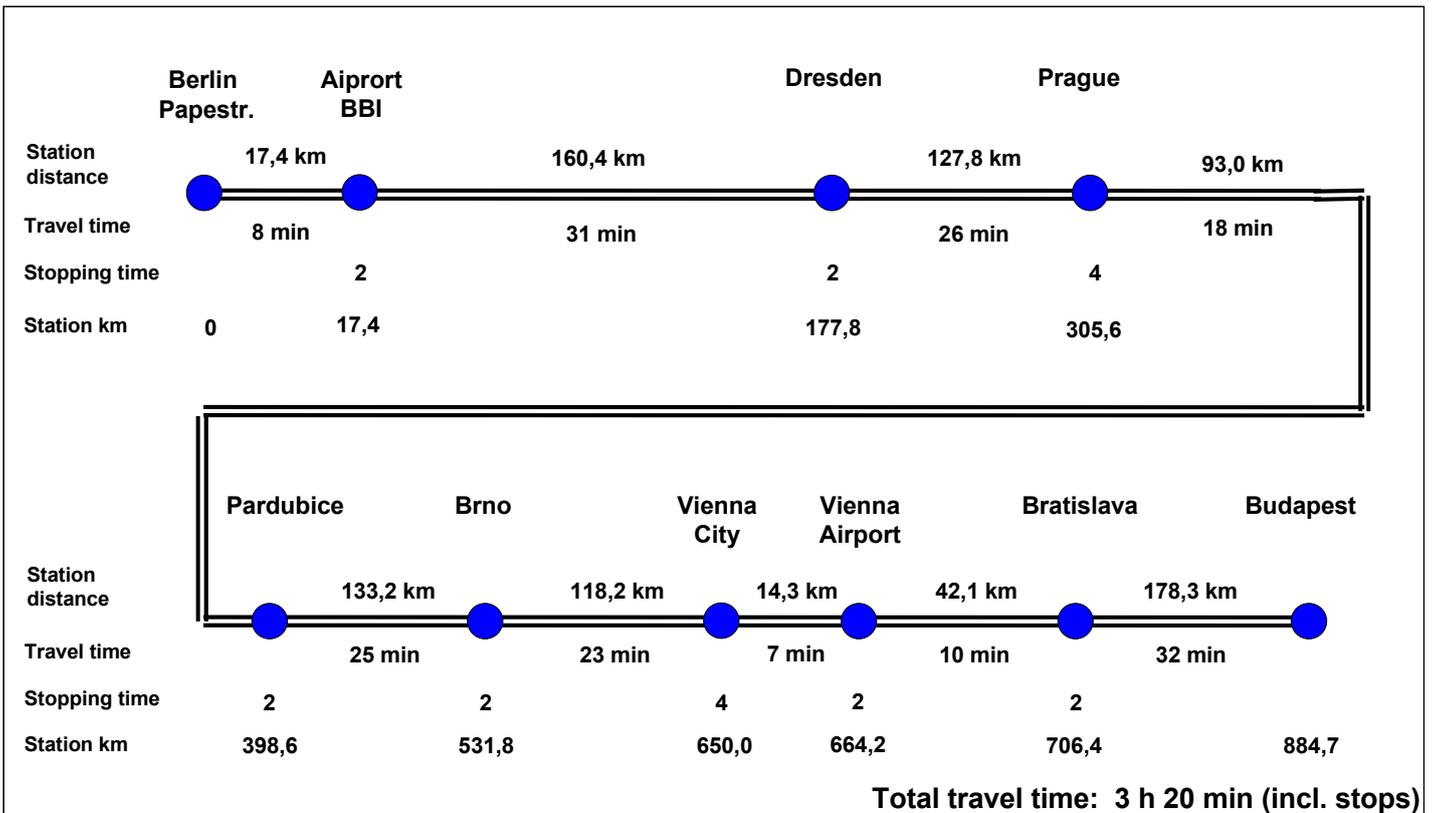


Figure 2.6 Distances and scheduled running times of the high-speed Maglev line

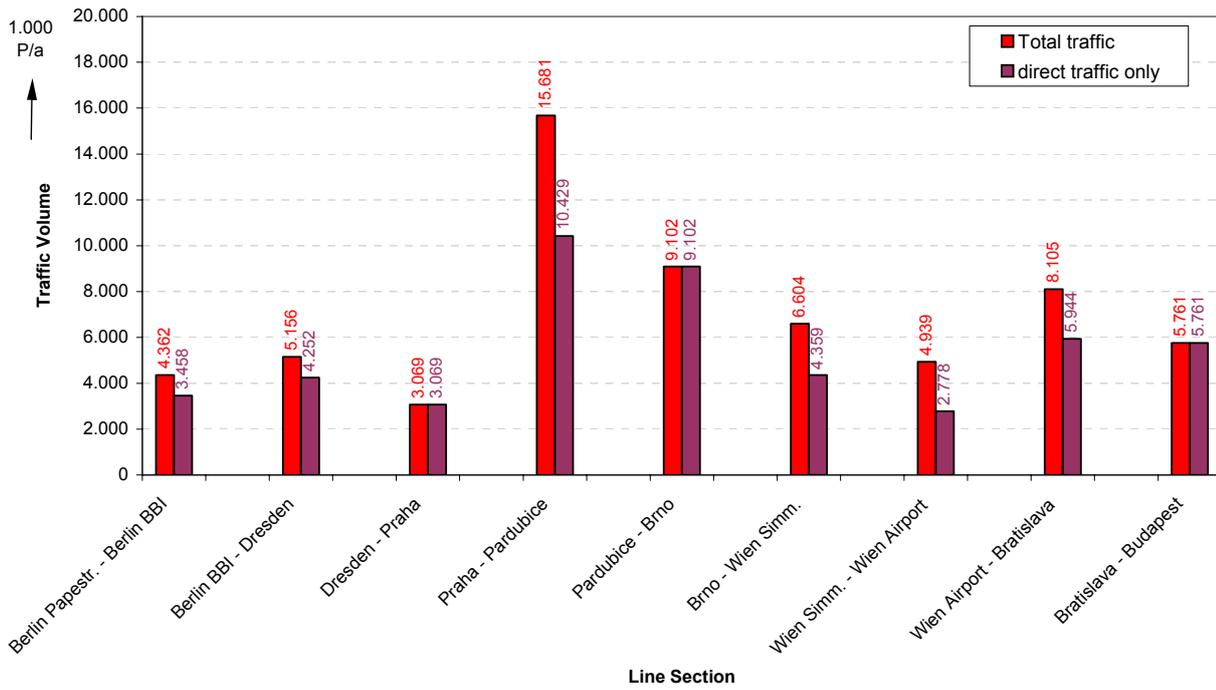


Figure 2.7 Traffic prognosis for a high-speed railway line Berlin – Budapest

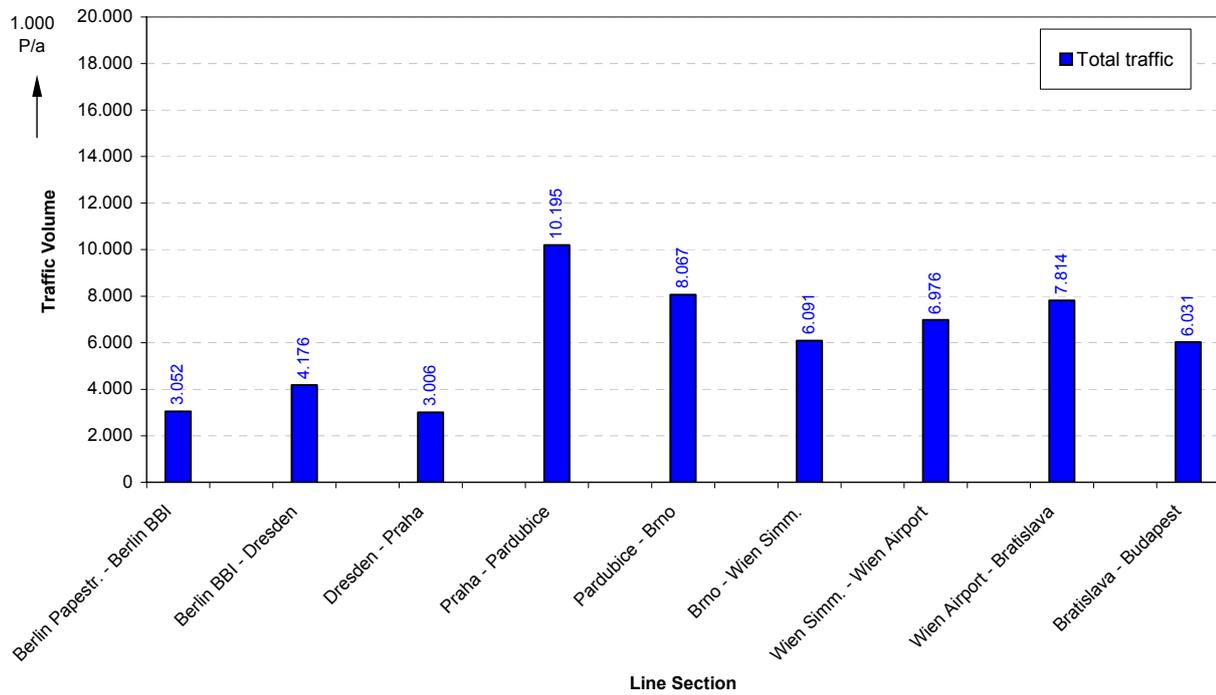


Figure 2.8 Traffic prognosis for a Maglev line Berlin – Budapest

2.1.5 Design of the operating concept

Based on the scheduled travel times, the passenger volumes and the operating processes on the line ends detailed operating programs for both systems were established.

Resulting from the passenger volume data per day and direction a daily distribution was assumed as follows:

Daily operation period: 18 hours 05 ... 23 h

Peak operation period: 6 hours 07 ... 10 h
16 ... 19 h

Normal operation period: 12 hours 05 ... 07 h
10 ... 16 h
19 ... 23 h

Passenger volume in peak operation period per day:

50 % of the total daily passenger volume
10 % of the total daily passenger volume within one peak hour

Passenger volume in normal operation period per day:

50 % of the total daily passenger volume
passenger volume equally distributed over 12 hours of normal operation.

The differences of the passenger volume level alongside the line lead to divergent requirements concerning the operating headway and the vehicle capacity. Basically it was the aim to offer a constant train frequency over the total line length, which is (locally) increased by additional train sets during peak load times.

Based on the chosen train frequencies in the line sections practical train courses (round trips) were set up and the number of vehicles required was determined. Furthermore the requirements on the track layout (number of platform tracks, junctions, switches, holding and siding tracks) resulting from the operating program were defined.

2.1.5.1 Railway operating program

Because of the fixed configuration of the ICE 3 trains the only degrees of freedom for the timetable planning were the choice of the operating frequency (headway) and the use of single and double train sets in sections. The resulting operating program is characterized by the following values:

Normal operation period:

- basic headway of 60 min on the whole line
- double train sets in the Praha – Brno section
- headway extension onto 30 min in the Wien – Bratislava section (airport shuttle)
- additionally 1 train set per hours in the Praha – Pardubice section (to Ostrava)

Peak operation period:

- basic headway of 30 min on the whole line

- double train sets in the Praha – Brno section
- headway extension onto 15 min in the Wien – Bratislava section (airport shuttle)
- additionally 2 train sets per hour in the Praha – Pardubice section (to Ostrava)
- additionally 1 train set per hour in the Wien – Brno section (to Ostrava)

Operation with train sets of ICE 3M type

- 8 cars each
- train length: 200 m
- 458 seats
- v_{max} 300 km/h.

As starting and ending points of the different train courses the passenger stations Berlin, Praha, Brno (only for double train missions), Vienna and Budapest were determined. In the near of these station the holding and siding tracks as well as the maintenance facilities for the trains are located.

2.1.5.2 Maglev operating program

As a premise for the timetable and roundtrip design was determined, that the train operation on the whole line in the normal operating period as well as in the peak operating period should be realized with a uniform train configuration, i.e. a constant number of car sections per train. This allows an unrestricted use of all trains in every line section at any time. The operating program is characterized by the following values:

Normal operation period:

- basic headway of 60 min on the whole line
- headway extension onto 30 min in the Praha – Budapest section

Peak operation period:

- basic headway of 30 min on the whole line
- headway extension onto 15 min in the Praha – Budapest section

Operation with 4-section trains

- train length: 100 m
- 360 seats
- v_{max} 450 km/h.

Additionally variant of investigation: operation with 6-section trains

- increased headway of 20 / 40 min during peak operation period
- version leads to extra demand of car sections (+ 9 %)

As starting and ending points of the different train courses the passenger stations Berlin, Praha, Vienna and Budapest were determined. In the near of these station the holding and siding tracks as well as the maintenance facilities for the trains are located.

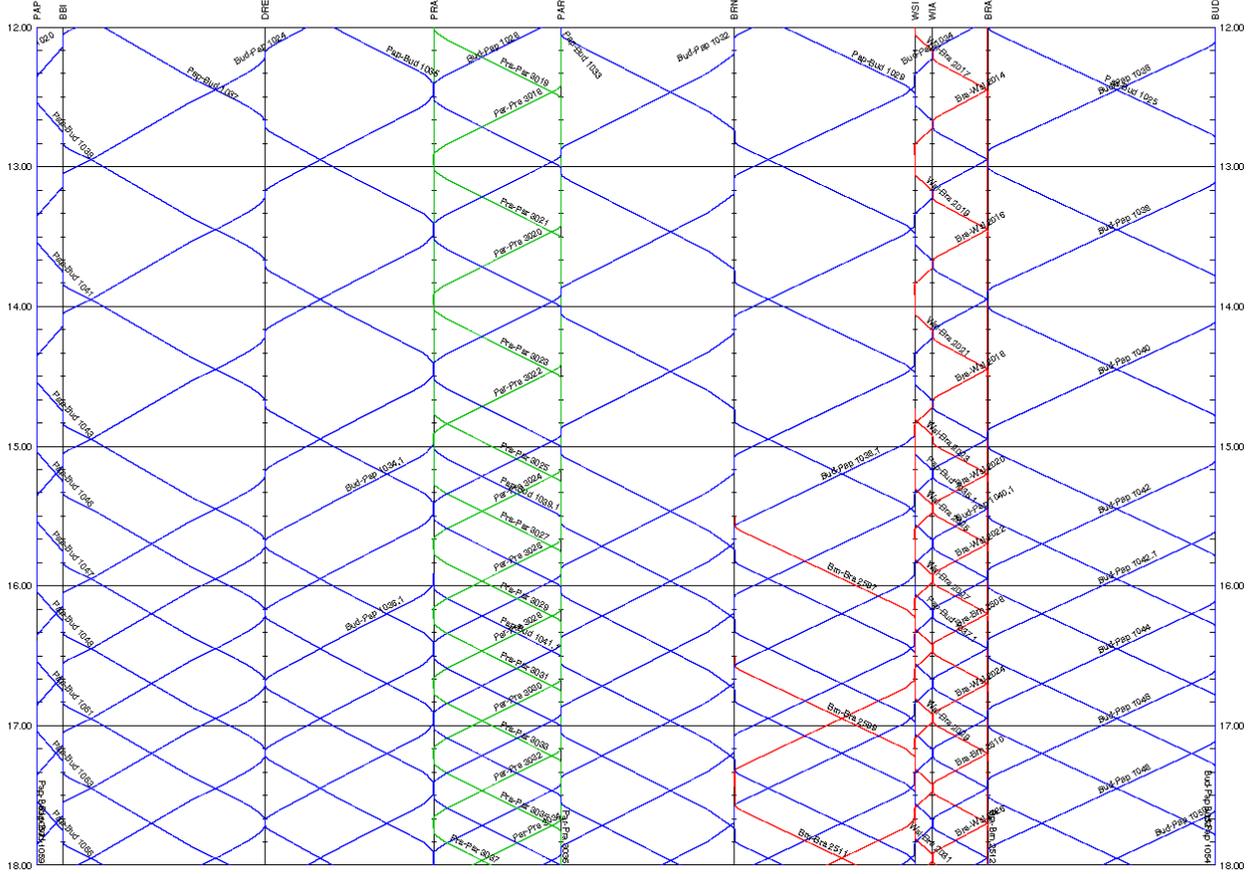


Figure 2.9 Operating simulation results for the railway line (detail)

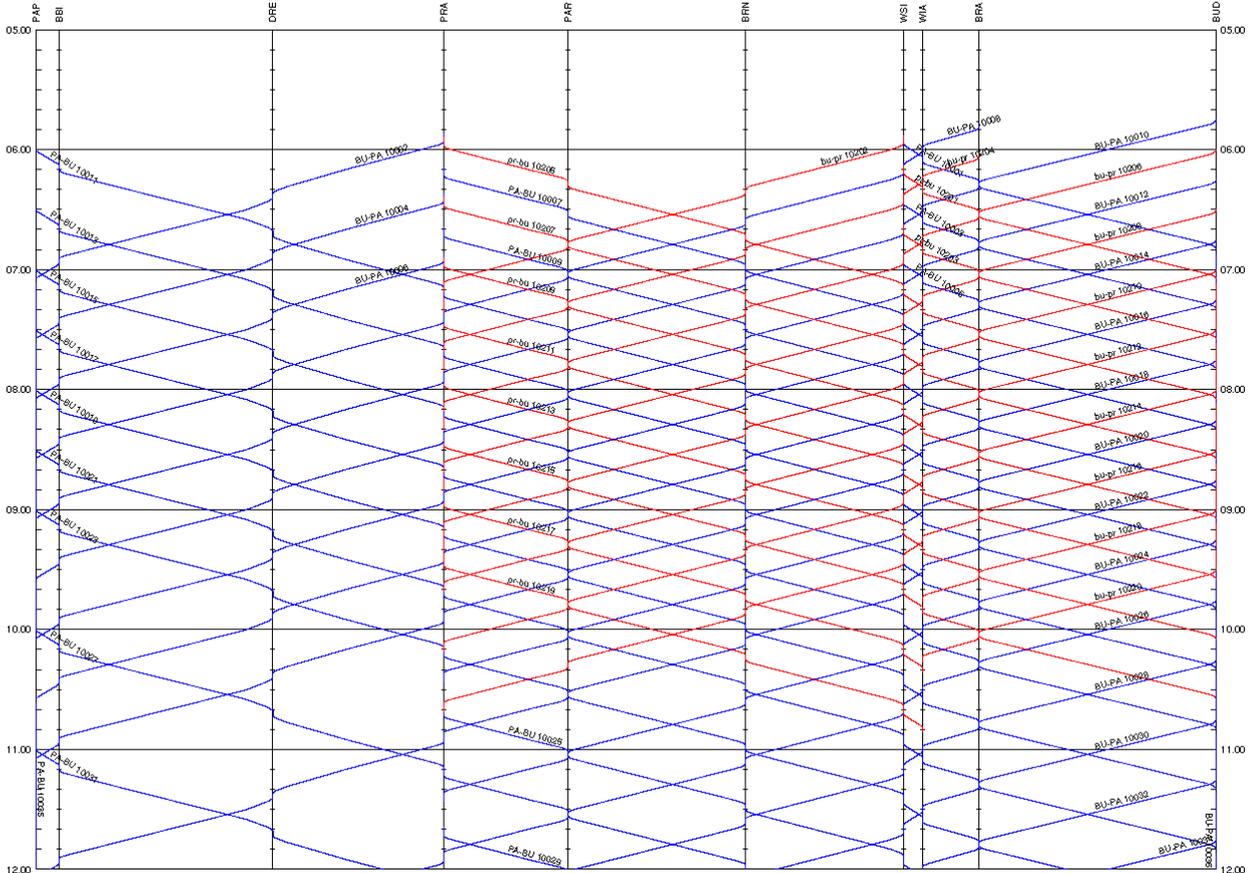


Figure 2.10 Operating simulation results for the Maglev line (detail)

2.1.6 Verification by operating simulation

After the theoretic timetable and roundtrip construction design and the preliminary technical design a verification of the daily train operation program was performed using the commercial railway operation simulator OpenTrack. For that purpose all technical features and characteristics of the systems as well as the operating procedures were simulated with high accuracy. Are there no conflicts detected during the simulation runs it can be assumed, that the operating program is feasible and stable (Figure 2.9 and 2.10).

2.2 Results

Because of the varying passenger volume prognosis values, the different travel times and the vary flexible vehicle configurations in the result also very different operating concepts arise for both systems. One main item is, that the Maglev system needs less vehicles because of the very short roundtrip times of the trains.

In the result the following vehicle numbers and seat capacities were determined.

Table 2.2: Required vehicle number for the high-speed railway line

Use of trains	peak operation period	normal operation period
Basic round trip operation	24	13
Double train sets Praha - Brno	7	4
Shuttle trains Wien - Bratislava	3	2
Increase Praha - Pardubice (- Ostrava)	3	2
Increase Wien – Brno (- Ostrava)	2	0
Sum operation	39	21
Operating reserve	3	3
Maintenance reserve	2	2
Total sum	44	26
Seat capacity	20.152	11.908
Number of single cars	352	208

The railway data include the train numbers of the „crossing” train courses which run on the high speed line only in particular sections.

Table 2.3 Required vehicle number for the Maglev line

Use of trains	peak operation period	normal operation period
Basic round trip operation (4-car trains)	25	13
Operating reserve	2	2
Maintenance reserve	2	2
Total sum	29	17
Seat capacity	10.440	6.120
Number of single cars	116	68

Regarding the longer travel times of the railway trains on the one hand the operating time is longer and on the other hand the nightly usable maintenance window is shorter compared with the Maglev system.

The main data of the operating programs both for the high-speed railway and the Maglev line are summarized in the following table:

Table 2.4 Basic parameters of the operating concepts of both systems

Basic operating parameters	Unit	Railway system	MAGLEV system
Total line length	km	937,2	884,7
Daily Operating period	hours	18	18
Min. headway during peak period	min	30 (15)	15 (30)
Min. headway during normal period	min	60 (30)	30 (60)
Passenger-km per year	Pkm/a	6.575.740.899	5.353.626.506
Train-km per year	Trkm/a	25.990.150	26.713.511
Seat-km per year	Skm/a	11.903.488.631	9.616.863.780
Average train load	%	55,2	55,7
Total number of trains	1	44	29
Total number of single cars	1	352	116
Total number of seats	1	20.152	10.440
km per train and day	km/d	1.618	2.524
Total fare receipts	Bill. EUR/a	1.048	1.268

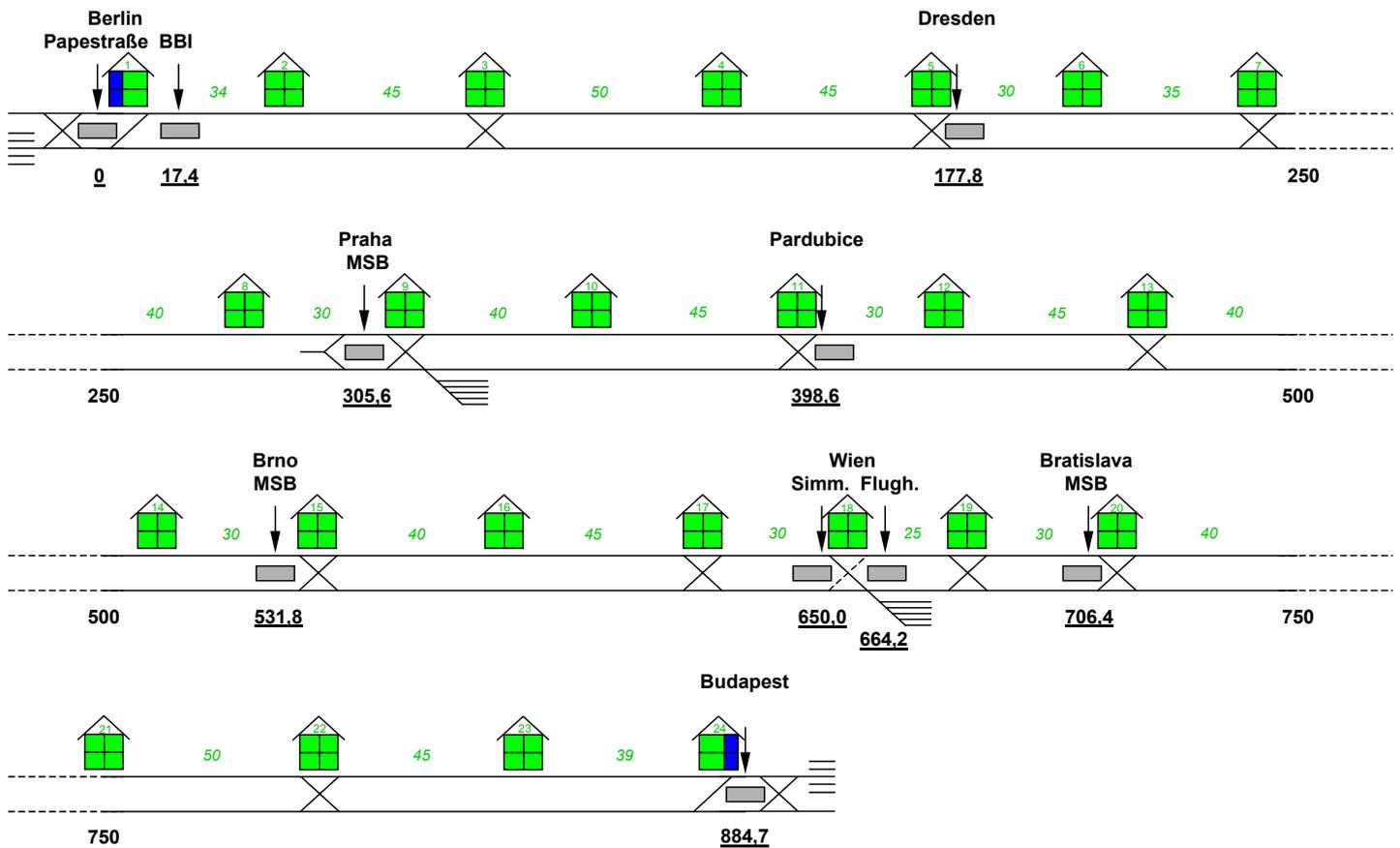


Figure 3.1 Preliminary design of the Maglev propulsion system (substation arrangement)

3 PRELIMINARY SYSTEM DESIGN

3.1 Indication of quantities for investment calculation

Under consideration of the operating concepts a preliminary technical system design was executed. The design work contained the relevant sub-systems of the operating system as

- Permanent way
- Track layout (switches, junctions, siding tracks)
- Vehicle fleet
- Operation Control System
- Power Supply and Propulsion system
- Machinery equipment
- Operating and maintenance facilities.

The technical layout is the basis for the subsequent indication of quantities and the cost calculation for the operating system. The requirements concerning capacity and performance of the railway and Maglev operation were considered completely.

Figure 3.1 shows as an example the substation arrangement of the propulsion system of the Maglev line. The numbers between the substations indicate the propulsion segment lengths depending on the operating program (speed, occupation time and headway).

The investment cost determination comprised the following parts:

- Civil assets (substructure, permanent way, Maglev guideway, Tunnels, bridges)
- Operating infrastructure (power supply, overhead contact line – only for railway, propulsion – only for Maglev, operation control system, machinery, facilities) and
- Vehicles (passenger as well as maintenance vehicles).

The investment costs of the operating system (infrastructure and vehicles) were determined using the detailed indication of quantities resulting from the system design and existing price calculations related to the components.

3.2 Determination of resources for operating cost calculation

The cost determination for the operating phase of the systems included the following main positions:

- Operational staff
- Maintenance
- Energy

- Sales and marketing
- Miscellaneous.

Especially for the dynamic manpower requirement calculation and the energy consumption simulation specific computerized planning tools were used.

Finally all the determined cost data based on the operating concepts and the technical system design were considered in a comprehensive profitability and efficiency analysis. An overview and an evaluation is given in the corresponding paper of Prof. Wolfgang Fengler.