1 INTRODUCTION

The Swiss Metropolis

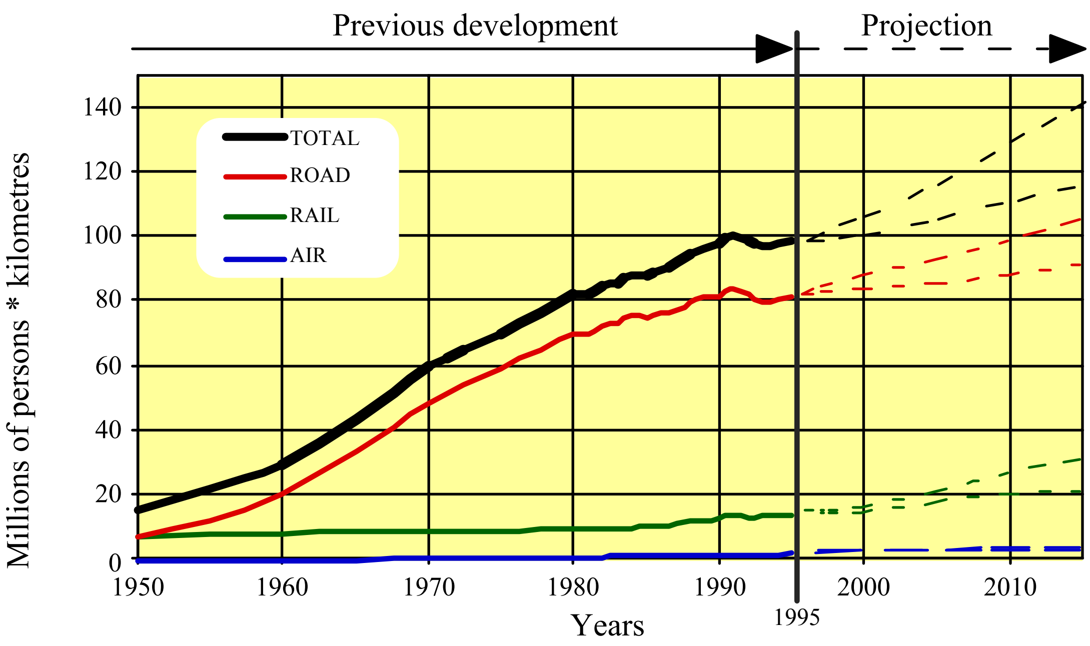
The major towns of a country, being the focal points of information, activities and services, create the structure of an industrialised country. The daily accessibility of these poles of attraction therefore constitutes ever more an essential condition of economic and social development. The creation of wealth depends not only on the ability of the country to structure itself as a metropolis, with the cities of national and international importance connected by a high-speed means of transport, but also on the ease of access to outlying regions by regional public transport. In Europe, it also depends on efficient connections with the major cities of the neighbouring countries.

The transport system of the 3rd millennium

Swissmetro, a high-speed and high-frequency passenger transport system independent of built-up areas and surface obstructions such as topography, working as a super underground railway, meets the new needs that are arising at the dawn of the third millennium. It fits in with existing or projected railway networks, provides a credible response to the foreseeable increase in mobility and, thanks to its attractiveness, contributes actively to the transfer of private/road traffic to public/rail traffic.

Statistical evolution of passenger transport

Swiss transport statistics highlight the spectacular side of the development of passenger transport in Switzerland since 1950, and the marked contrast between the evolution of road and rail transport.



Sources : OFS, Swiss Statistics Yearbook 98, Tab.11.6 et SET 2/95 (adapted to OFS 98 figures)

Figure 1 : Mobility evolution and prospects

Even though the increase in passenger traffic did fall off during the years of economic recession (1990-1996), it will increase in the future whatever the scenari envisaged by the study entitled “Prospects for traffic evolution in Switzerland” (SET 2/95, SGZZ).

Road-rail transfer

These different scenari show that there will not be a sufficient transfer from road to rail despite all the efforts made to improve the current network. Swissmetro, however, would help correct this tendency, for the attractiveness of this new public transport system will win over a part of the passenger traffic that currently travels by car and aeroplane over average distances.

A brief background

The project was first mooted in the ‘70s by Rodolphe Nieth and was supported by the scientists at the Swiss Federal Institute of Technology in Lausanne (EPFL) and by political circles. A preliminary study, financed by the Confederation and private enterprise, and finished in March 1993, showed it to be technically and economically feasible. The Swissmetro Company SA, founded in 1992, collected the funding necessary for the main study, the results of which this report presents.

Future developments

The main study should now lead to an industrial development phase on the electro-mechanical and mechanical systems, before any work can begin on the construction of a pilot line. As soon as possible, a line of about 15 kilometres will be fitted out for testing and approval purposes.

In parallel with the start of the industrial development, various studies are being conducted: HISTAR, trials on waterproof tunnel linings, the completion of the PNR 41 studies, studies of the Geneva-Lyons, and possibly also the St.Gallen-Munich links. Specific supplementary reports will be issued in due course.

Schedule

Under the condition of a rapidly obtaining funding and political approval, the optimum schedule will look like this:

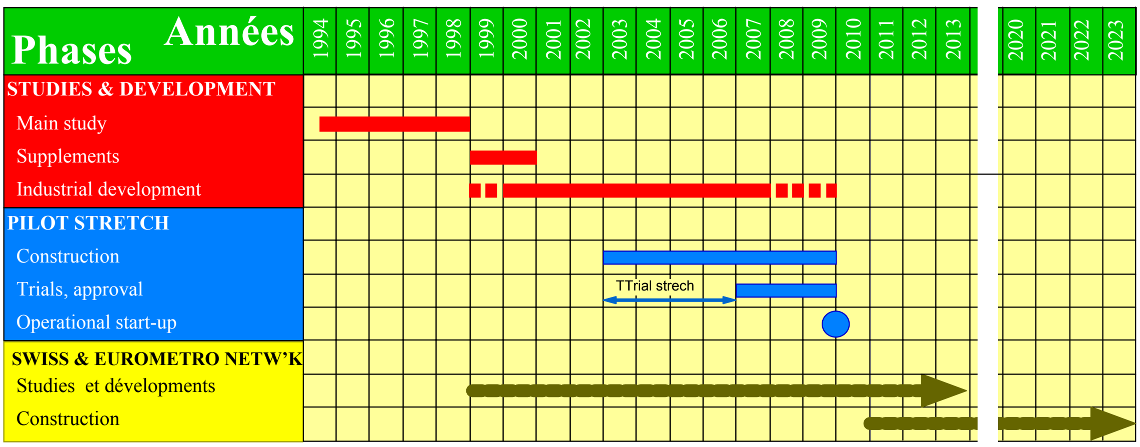


Figure 2 : Study, development and construction schedule

2 DESCRIPTION OF THE SYSTEM

2.1 Technology

Four complementary Technologies

The Swissmetro system is based on the use of four complementary technologies:

- an entirely underground infrastructure, comprising two tunnels of 5 m interior diameter, for the most part, for the pilot line, driven through the bedrock at a depth varying between 60 and 300 m according to the topography, as well as stations in the center of towns connected to the public urban and regional surface transport networks,
- a reduction of the pressure in the tunnels (partial vacuum corresponding to the pressure at about 18,000 m, the altitude at which the Concorde flies) in order to save the energy necessary for the propulsion of the pressurised vehicles,
- a propulsion system of the vehicle made of linear electric motors (two possible variants), allowing speeds in the order of 500 kph,
- a magnetic levitation and guidance system.

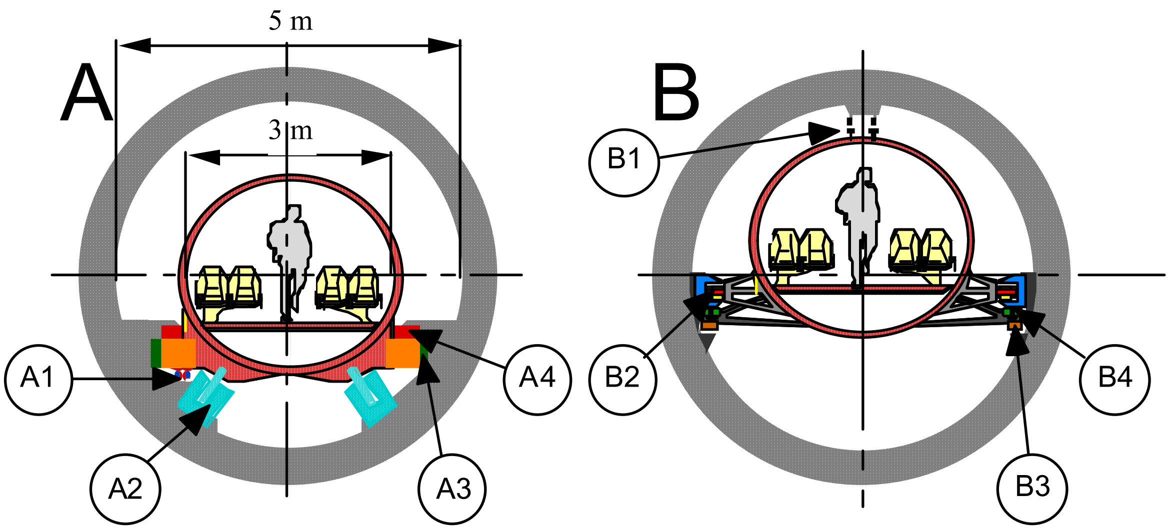


Figure 3 : Schematic cross-sections of the two variants of the tunnel with vehicles

Variant A (motor in the tunnel)		Variant B (motor on-board)	
A1 =	Energy transmission by induction	B1 =	Energy transmission by induction
A2 =	Fixed linear motors in the tunnel	B2 =	Linear motors on-board
A3 =	Guidance inductor	B3 =	Guidance inductor
A4 =	Levitation inductor	B4 =	Levitation inductor

2.2 Civil engineering and equipment

Stations

The underground stations are situated in immediate proximity to the mainline stations. They comprise an upper level (reception and check-in zone) and a lower level (embarkation and disembarkation zone) linked by large-capacity lifts. The lower level also has slots to park reserve or service vehicles, which are moved into place by a rotary system (barrel).

Tunnels

The two one-way tunnels, with an air and waterproof lining, are set at about 25 m centers apart. They are linked by transverse galleries, directly under the intermediate shafts.

Intermediate shafts

(operational stations)

The intermediate shafts or galleries, which served for the construction of the tunnels, are used to feed in electrical power supply for operating the system. The pumps for creating and maintaining the partial vacuum are also housed there.

Passenger airlocks

In the stations, there are airlocks by which passengers can easily enter and leave the vehicles, which remain in the depressurised zone, from the embarkation platforms.

Barrel

Each station is equipped with a rotary transfer system called the "barrel, by means of which vehicles can pass from one tunnel to another.

Maintenance workshop

Maintenance workshops are planned for certain stations. Maintenance will be programmed as with planes, the overhaul of exchanged parts being carried out in the suppliers' workshops.

Power supply

The Swissmetro facilities will, in principle, be connected to the existing electric power network:

- The high-voltage grid will power the electro-magnetic system. In the case of breakdown, a relief system will maintain levitation and magnetic guidance as well as the vital functions of the vehicle,
- The medium-voltage local grids will power the stations and their installations (lifts, etc.) In cases of breakdown, an emergency system will keep important equipment running.

Vehicles

The pressurised vehicles, 80 m in length and of external diameter 3.2 m, can seat 200 persons. At the stations, automatic doors and galleries make for an easy transfer of passengers.

2.3 Mode of operation

Operation

The choice of a method of transport for a journey depends principally on two elements: the duration of the trip and its cost. The former explains the success of the car in comparison to public transport that is penalised by the time that it takes for the traveller to go from the starting point to the departure railway station, the waiting time and the time necessary to go from the destination railway station to the final destination. It is therefore important to take not only speed, but also the frequency of convoys, the location of stations and close co-ordination with other means of transport into account, in order to increase the overall attractiveness of the system.

Swissmetro meets these concerns, with a synchronised schedule, by offering a travel time of twelve minutes between stations, a frequency of six minutes at rush-hours, a station design keeping traveller waiting times limited to a minimum as well as by operating the system in close co-operation with the State Railways and urban transport companies.

To facilitate boarding and leaving the trains rapidly, passengers will be attended and led by a “steward”.

With a vehicle carrying 200 persons every 6 minutes at rush-hours, Swissmetro consequently has a transport capacity of 2’000 seated travellers an hour in each direction. If necessary, this capacity can be increased to 3’000 with a 4-minute frequency. If need be, the train can be extended by adding additional elements between the ends providing a capacity of 6’000 seated travellers per hour and per direction. This capacity can even further be increased at the cost of diminished comfort.

3 MAIN STUDY

3.1 Objectives

Principal objectives

The objectives of the main study are the following:

- the choice of a pilot line and the filing of a licence application,
- the choice of technical, economic and political options for the system.

Technical objectives

The technical objectives of the main study are to define and design the Swissmetro system in the form of a set of coherent solutions.

The criteria for the choice included investment costs, operational costs, safety and environmental impacts.

Economic objectives

The economic objectives are the following:

- the credible estimate of the potential transport capacity, investment costs, operational costs and profitability rate for the pilot line and the network,
- the choice of a financing model and an economic feasibility study,
- the study of the socio-economic impacts.

Political objectives

The political objectives are the following:

- obtaining a licence for a pilot line,
- producing a system that respects the environment and principles of town and country planning, taking account of existing transport systems or those currently being built,
- the promotion of the Swissmetro transport system with a view to expanding across Europe (Eurometro).

3.2 Organisation

Prime Contractor

Swissmetro SA is the company responsible for the main study.

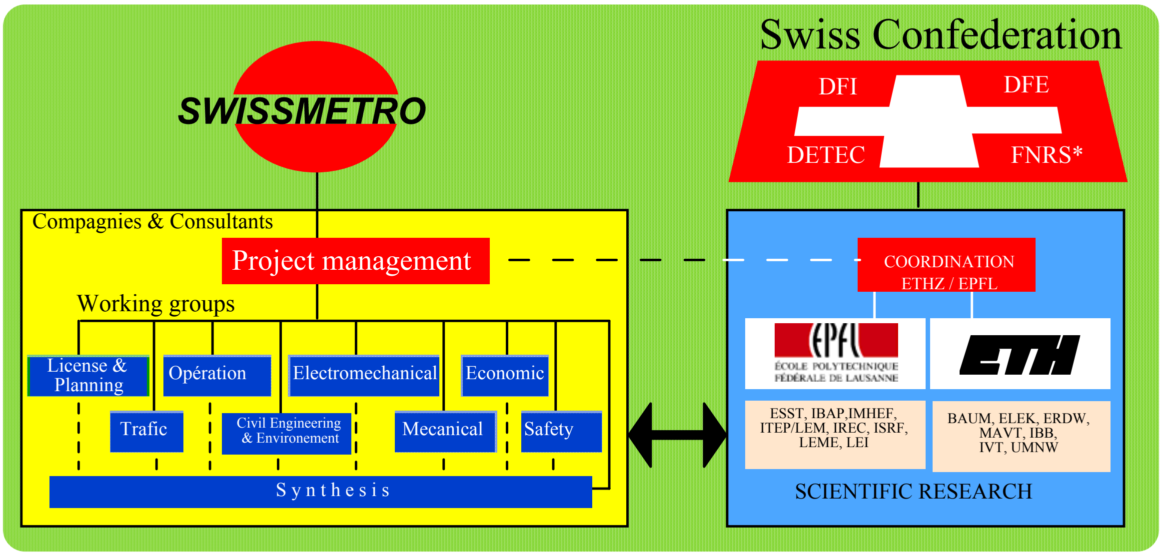
Project Management

Project management, budget auditing, involvement of industrial associates and co-ordination between the Swiss Federal Institutes of Technology and industry have been delegated to Electrowatt Engineering AG (EWE), representing Swissmetro SA. The co-ordination of activities between the two Swiss Federal Institute of Technology has been handled by the EPFL (Lausanne).

Organisation

The main study has been conducted by working groups concerned with specific areas as shown in the flowchart below.

The Synthesis Group stepped in at regular intervals to seek technical and economic compromises between the sometimes-contradictory requirements of the other working groups. In particular, in June 96, it determined the reference values to be taken into consideration by all parties involved in the study in order to ensure its coherence.



* FNRS has also funded research other than that EPF : private consultants, HES.

Figure 4 : Flow chart

To the greatest extent possible, the working groups included representatives of the Polytechnics and private industry. This public/private partnership offered undeniable advantages to both parties. In fact, although the scientific and research aspect obviously remained essentially the preserve of the Polytechnics, the industrialists wanted to obtain economically exploitable results over the medium term. These divergent strategies were sometimes the cause of tension, forcing the partners to engage a fruitful and creative dialogue, generally leading to innovative solutions.

3.3 Financing

Sources of finance

The main study was financed by:

- capital in the company subscribed by private interests,
- study services provided by technical consultants, companies and private industry on the promise that these services would be convertible into Swissmetro SA shares, but only if the project came to fruition,
- public loans provided by the Confederation (**DFI**: CEPF, ETHZ, EPFL ; **DETEC** : SET, OFEN ; **DFE** : CTI ; **FNRS** : PNR41

Sources of financing	Amount (CHF)	Percent (%)
Swissmetro SA (cash expenditure as at 31.12.98)	5'064'200	35
Services provided by technical consultants and private industry	4'001'415	27
Swiss Confederation services	5'463'000	38
Total	**14'528'615**	**100**

Table 1 : Financing of the main study as of 31.12.98

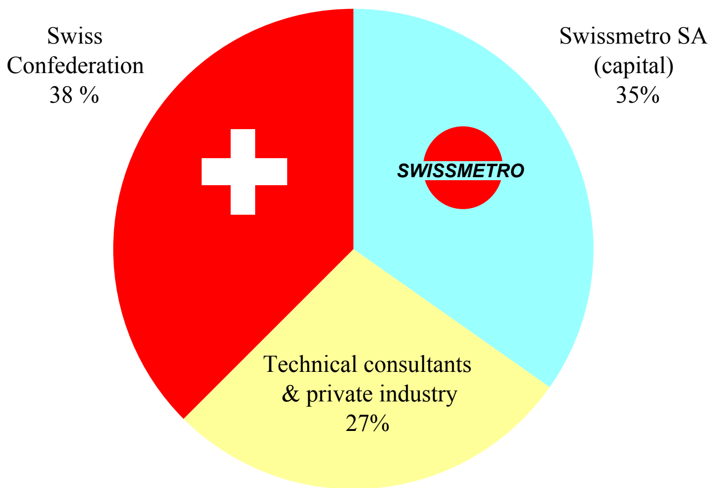


Figure 5 : Distribution of financing

The total budget of the main study, including the further phase 1999-2000 (CTI *et al.*, budget: CHF 3.5 million), is in the order of CHF 18 million.

The capital of Swissmetro SA was used to cover the project-management and promotion commissions, some special services remunerated in cash as well as the participation of the Company in the conducting of bench tests.

Capital distribution	Amount (CHF)	Percent (%)
Administration	1'269'600	25%
Promotion	1'115'800	22%
Management and administration of the project	2'551'100	50%
Studies and trials	127'700	3%
Total	**5'064'200**	**100%**

Table 2 : Distribution of Swissmetro SA expenditure committed to the main study as at 31.12.98

4 LICENCE APPLICATION, GENEVA-LAUSANNE PILOT LINE

Choice of pilot line

The choice of the pilot line was made on the basis of a study involving several criteria and taking account of internal profitability, total investment, political acceptance, environmental acceptability, acceptance by the Federal State Railways, attractiveness, investment ratios and compatibility with the final network. The following 5 potential lines were considered: Geneva-Lausanne, Fribourg-Bern, Bern-Zurich, Lucerne-Zurich and Basel-Zurich.

After consulting the federal political authorities, the choice finally fell on a line between Geneva and Lausanne.

Licence application file

The licence application was filed with the Federal Transport Office on 27.11.97 in the form of a file comprising:

Level A

- The licence application as such, as required by Law, with the required basic plans.

= Level A of the licence application, in French and German

Level B

- Sections 1 to 9 summarising the Methodology adopted and the results obtained by the studies conducted in the various specific domains, i.e. Civil Engineering, Electro-mechanical, Mechanical, Operational, Traffic, Town and Country Planning, Environmental Impact report and the Safety and Economic aspects. Sections 10 and 11 provide further information (reference values, Articles of Association of Swissmetro SA). A file of plans supplement these documents, including a geological study, a route map, tunnels, Geneva station and Lausanne station.

= Level B of the licence application, in French or German (confidential)

Level C

- Swissmetro SA has the other documents and specific reports, classified confidential and used as a basis for preparing the above documents on record, but they are archived with their authors. They are available on request.

= Level C of the licence application, in French or German or English (confidential)

Information on the licence application is available in the quoted documents and is not included in the present report. So the work on the pilot line is not, therefore, mentioned other than where it concerns general options applicable to the entire network or significant examples.

Concrete and interdisciplinary procedure

It should, nevertheless, here be mentioned how beneficial the preparation of the licence application proved to be for the main study in its entirety. It was, in fact, a concrete and interdisciplinary procedure, involving technical and safety aspects as well as ecological, economic and political components. The solutions chosen had, necessarily, to have been studied in a global context and not only from the viewpoint of the individual domain considered. This interdisciplinary approach certainly was very profitable to the development of the project.

5 RESULTS OF MAIN STUDY, FURTHER DEVELOPMENTS

Network variants

Numerous network variants were studied by the working groups, but the present report refers to only the following two:

- Variant A, basic network of the preliminary study
- Variant B, with intersection in Zurich

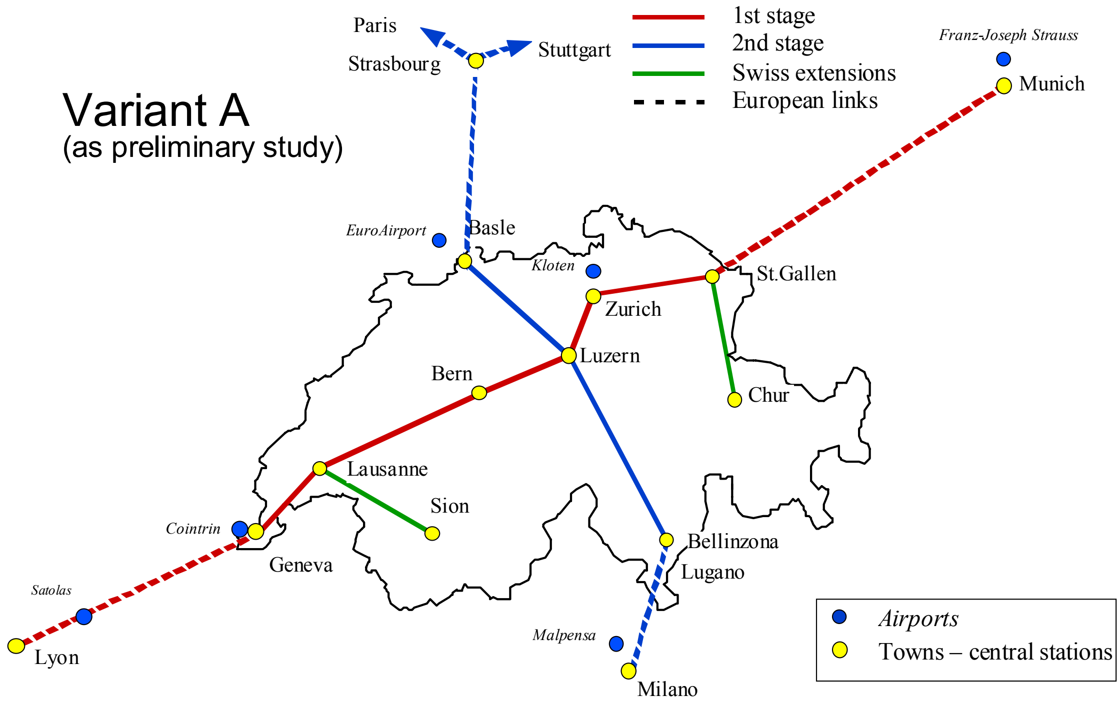


Figure 6 : Variant A, basic network (preliminary study)

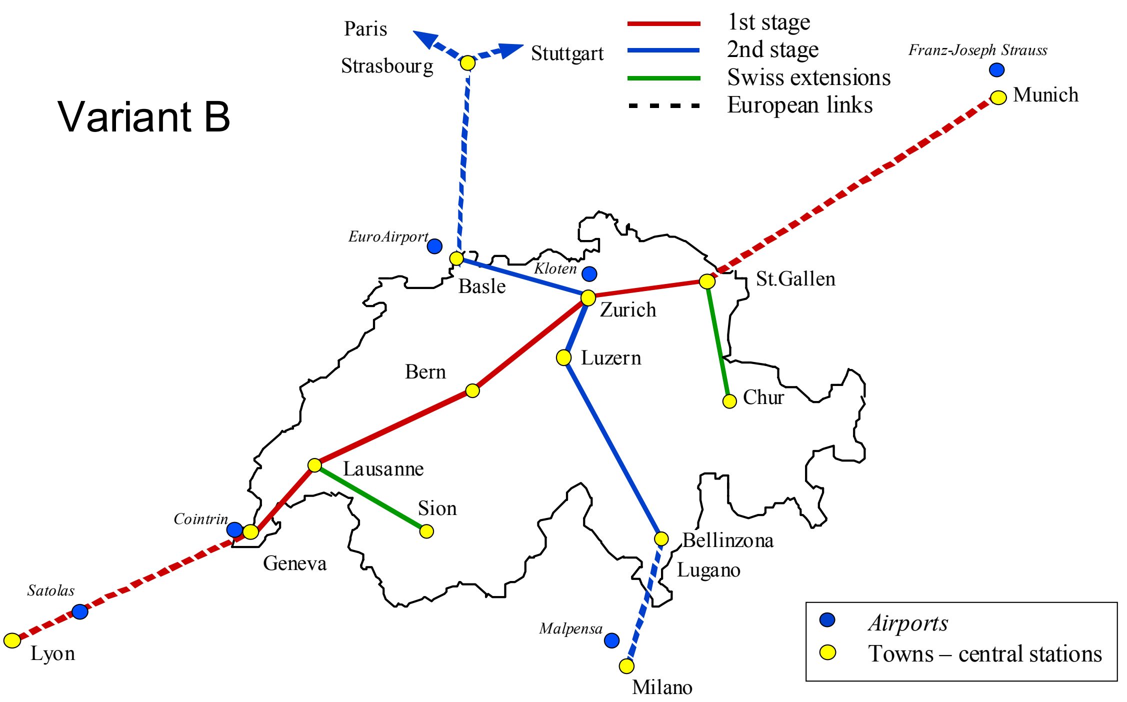


Figure 7 : Network variant B

5.1 Town and country planning aspect

Preliminary remark

The study of the on town and country planning includes in the broad outline the contents of the report drawn up for the request for concession. Indeed, the analysis made for this one examined the compatibility of the pilot line and the Swissmetro network with the plans of development on the levels communal, cantonal, federal and European.

We have of this fact given up the drafting of a book B Regional planning.

5.1.1 Terms of reference of the working group

- to study the consequences of the realisation of the Swissmetro transport system on the town and country planning,
- to study the compatibility of the Swissmetro project with federal, cantonal and municipal town and country planning policies,
- to identify supplementary measures necessary to guarantee this compatibility.

5.1.2 Methodology

Generalities

The work method chosen is similar to that for a study of the impact a town and country development will have on the environment. For an impact analysis, specialists in the different areas refer to norms, recommendations and existing data. We used the planning documents prepared at municipal, cantonal and federal levels (reference data: 1997).

Iterative procedure

There is no recognised procedure for safeguarding public interests. Furthermore, Swissmetro is a new project that does not fit into any traditional line of thought. That is why an iterative procedure has been applied in co-operation with the federal administrations concerned in order to define a common approach, using Railway Law as a guide.

Compatibility of the project

The compatibility of the Swissmetro project with the infrastructural measures taken at municipal, cantonal, federal and, where necessary, European levels was examined.

Finally, the supplementary measures to guarantee this compatibility were identified.

Basic documents

The study is based on the following documents:

- at domestic level, on «The general guidelines for Swiss Town and Country Planning adopted by the Federal Council» (BRP/OFAT 1996),
- at European level, on the «Guideline Document on Co-operation in European Town and Country Planning» (Europe 2000 + European Commission, 1994).

Swiss and European guidelines have many points in common with regard to the identification of current problems and means for solving them, in particular:

- the durable-development model,
- trans-border co-operation,
- the city network,
- the balance between the regions.

5.1.3 Results

Generalities

The debate on town and country planning and the transport policy in Switzerland is permanent and the basic questions asked are awaiting responses, independent of the Swissmetro project.

Nevertheless, Swissmetro provides a new element for reflection that broadens the national and European debate and offers Switzerland a high added value solution.

National cohesion factor

Today, there is a great disparity in the accessibility of various regions of Switzerland, the outlying districts being clearly at a disadvantage.

With Swissmetro, the accessibility conditions change completely and permit almost all inhabitants to move throughout the country in 90 minutes, from one cantonal capital to another.

Network of Swiss towns

Swissmetro would provide an optimum connection between the big cities of the Plateau in the form of a polycentric network, equivalent, in terms of its human and socio-economic population of 4 million, to a European town of average dimensions.

The Swissmetro network will bring about changes on the labour market, resulting in its concentration in the principal cities, and therefore a reduction in the agglomeration phenomenon. Commuting between city centers and their suburbs could diminish in favour of exchanges between the cities themselves. This will have positive effects provided that regional and transport planning manage to balance relations between the cities and the outlying areas. It is therefore necessary - indeed imperative - to strike a balance between the current systems of public transport and Swissmetro.

The relative marginalisation of certain parts of the country means that these regions will have to define specific development strategies, in which the advantages of their marginal nature are exploited (tourism, outstanding landscape, culture, etc.)

In short, it is a question of:

- making the operation of means of public transport, in particular the State Railways and the Swissmetro system complementary (market segmentation),
- including Swissmetro in town and country planning and transport plans at federal, cantonal and municipal level.

Integration into a European Area

The European development of the Swissmetro network will help maintain the central role of Switzerland in European passenger transport thus avoiding its being circumnavigated by Union projects. The interest of the Lyons-Munich Swissmetro link, that will tie in with the North-South European transport lines, is therefore considerable and of priority for Switzerland.

The complete Swissmetro network with, in particular, the links with Lyons, Munich, Milan and Strasbourg is in keeping with the Swiss objective of integrating into the European Area.

The conditions for integration are as follows:

- to give the Swissmetro network a "European" role, with top priority on the Geneva-St.Gallen East-West axis and, as second priority, the BaselBasel-Bellinzona North-South axis,
- to include Swissmetro in the transborder regional plans,
- to take account of the development policies of the European countries.

Synthesis

In general, Swissmetro fits coherently into the general regional planning policies at the various levels studied.

The possibility of asserting the role of Switzerland and of its network of cities within Europe by means of a transport system compatible with the environment is certainly of major interest to the future development of the country.

The realisation of Swissmetro will change the current transport system and will really have to fit in with the defined development objectives and be accompanied by important ancillary measures while, at the same time, avoiding detracting from the financial profitability of the system.

The following measures could reinforce the positive effects of Swissmetro :

- reduce the attractiveness of private transport (no 3rd motorway lane, no new lines of A roads, true costs, etc.),
- attempts to find synergies with the current transport systems (market-sharing with the Federal State Railways, working together with the regional express railways (RERs) and other private companies, etc.),
- implement local town and country planning measures.

The Swiss cities network system is based on the principle of concentrated decentralisation. Swissmetro provides an ideal link between the main cities on this network and thus caters to the concerns of the abovementioned report by the Federal Counsel which states:

« Reinforce the international advantages of Switzerland »

«The system of cities linked into a network is also the federal response to the challenges generated by the increased economic competition between the urban regions of Europe. The three major Swiss cities, Zurich, Basel and Geneva, cannot in size match up to the major European cities. By opting for a system of efficient cities that will allow a decentralisation of various functions throughout Switzerland, our country will be better equipped to preserve its competitiveness than by a concentrating in a single center.» (Report, page 43-French version «The General Guidelines for Swiss Town and Country Planning adopted by the Federal Council»

(BRP/OFAT 1996).

The study confirms Swissmetro as an element of integration on a European scale, the corollary of which will be the reorganisation of conventional networks.

With co-ordination measures between Swissmetro and existing networks, one can speak of a modernisation - indeed of a pan-European updating - of concentrated decentralisation.

5.1.4 Further Developments

Optimisation of the network

The network must be optimised according to the following criteria:

- territorial compatibility (town and country planning and environment),
- scope of accompanying measures,
- political feasibility.

The first results of the Polydrome programme show that, on the basis of economic considerations, the intersecting N/S-E/W station can be located either in Lucerne or in Zurich. The political aspects will, however, have to be taken up in a broad public debate.

New elements

The further studies will have to take account of a number of new elements such as : the confirmed realisation of "Alptransit" and of the "Rail 2000" scheme, the opening of the European Milan-Malpensa hub, the sectorial aviation plan (PSIA, under discussion) and the European high-speed railway network.

Accessibility

A more thorough and systematic study of accessibility, with and without Swissmetro, to all Swiss regions must be undertaken, for example, on the basis of a grid of inter-regional relations.

Internationalisation of the network

Swissmetro is a transport system of European dimensions and contacts are currently in hand with the border regions with a view to developing a Eurometro.

5.2 Traffic aspect

5.2.1 Terms of reference of the working group

- to develop a traffic evaluation software from the railway and motorway networks,
- to evaluate the current volume of traffic and its evolution for all lines and all network variants,
- to evaluate traffic on the pilot line alone and when integrated into the network,
- to evaluate the transfer of traffic from road and rail to Swissmetro according to the attractiveness of the system,
- to define the best location of stations according to traffic.

5.2.2 Methodology

Pilot line

Traffic on the Geneva-Lausanne pilot line was evaluated on the following bases:

- for motorway traffic, according to the 1990 federal population census as well as various traffic surveys specifying, in particular, travel motives and vehicle occupation rates,
- for railway traffic, according to various surveys conducted by the State Railways, based on passenger interrogation on the type of ticket used as well as on their point of departure and their destination,

while taking into consideration:

– different modal hypotheses (motorway, railway and Swissmetro),

– a Swissmetro fare corresponding to that applied by the State Railways, the price thus remaining a neutral factor with no influence on the user’s choice of mode of transport,

– the time-saving effects and frequency of Swissmetro convoys,

– a cautious guess at the increase in traffic of 10% every 10 years over the 30 next years (motorway traffic and railway traffic).

Four scenari were considered :

	Motorway 2-lane	Motorway 3-lane	Rail 2-track	Rail offer unchanged	Rail offer changed ICs abolished
Scenario 1 (1995)	✓		✓	✓	
Scenario 2	✓		✓	✓	
Scenario 3		✓	✓	✓	
Scenario 4	✓		✓		✓

Table 3 : Traffic scenari

Network

Swissmetro SA developed the Polydrome program, which had initially been foreseen for rail traffic only, for studying traffic on the complete national network in such a way as to obtain a general model for road and rail traffic. The decisive criteria used by this software are trip cost and cost per passenger/hour.

Passenger traffic within Switzerland was thus modelled while placing particular emphasis on long-distance traffic, which is decisive in defining Swissmetro traffic.

Traffic forecasts are based on the 1995 statistics (global traffic, rail and road) : State Railway counts and point-of-departure/destination matrices for State Railway traffic, and counts alone for road traffic.

The Polydrome program takes as its basis the volume of traffic in the year 2010 with the following assumptions:

- the first stage of Rail 2000 has been completed,
- the NLFA (New Alpine Railway Line) network has been completed according to the construction schedule,
- the national highway network is completed according to the 4th construction programme,
- the capacity of the highway network in the Alpine regions is not increased,
- the Swissmetro network, with its speed characteristics and frequency, is completely operational in 2010 (network variants A and B),
- the Intercity (IC) trains are abolished where State Railway and Swissmetro run in parallel.

5.2.3 Results

The Polydrome traffic model gives the following traffic values for Swissmetro in 2010 (average daily traffic, total of the two directions) :

SWISSMETRO Line	Variant A	Variant B
Geneva - Lausanne	27’240	27'360
Lausanne - Bern	24’480	24'840
Bern - Lucerne	58’560	-
Lucerne - Zurich	95’400	53’520
Zurich - St-Gall	30’000	-
Basel - Lucerne	25'680	-
Lucerne - Bellinzona	18'492	17’448
Bern - Zurich	-	57’360
Zurich - St-Gall	-	31'080
Basel - Zurich	-	35’760
St-Gall - Chur	14’400	14’626
Lausanne - Sion	6’012	6’042

Table 4 : Swissmetro traffic in 2010 (ADT) over various lines

The results obtained do not allow for a final choice between variants A and B, given the minimal differences in traffic obtained.

Divergence

For the Geneva-Lausanne pilot line, the traffic values obtained by the method used for the licence application (29’400) and by the Polydrome model are not identical. The divergence noted results from the fact that the Polydrome model gives the traffic in 2010 instead of 2015 and does not take account of the saturation of the motorways that influences the modal transfer in favour of Swissmetro.

5.2.4 Further developments

The Polydrome model, at the current stage of development, is well suited to comparing the loads on various lines for different network configurations. Conversely, for calculating absolute traffic values, it is not credible unless the reliability and the detail of the basic data can be improved. Research must be undertaken to achieve this.

5.3 Operational aspect

5.3.1 Terms of reference of the working group

- to define the operational aspect of the system from traffic data and the adopted frequency and waiting times in stations,
- to investigate the optimum sizing of stations and vehicles according to the operational system plan,
- to study the maintenance plan,
- to study synchronous and asynchronous operational variants,
- to estimate personnel needs and operational costs.

5.3.2 Methodology

Speed and frequency

Two criteria make the Swissmetro transport system attractive:

- high speed,
- high frequency,

which help reduce total travel time.

High frequency, moreover, offers greater operational flexibility in comparison with conventional systems for it permits optimum adaptation to demand and a better distribution of peak traffic.

Traffic

The station, however, is the key element where all the parameters of the operation are concentrated. By working with traffic data and the adopted frequency and travel and waiting times, the study produces an operating system plan and an ideal sizing of stations.

By taking the target vehicle departure timetable, the various parameters were organised in such a manner as to meet the following special objectives:

- to ensure the comfort of passengers, as in an airport, but with a throughflow allowing an operational frequency close to that of an urban underground railway,
- to rationalise the movements of the various elements of the system in order to reduce to a minimum the impact of the equipment, investments costs and the operational expenses.

5.3.3 Results

Target timetable

The target timetable is a basic hypothesis that provisionally and *a priori* determines the sequence of operations performed by all the vehicles in service with a gap of 6 minutes between vehicles at rush hour.

Description of the vehicle

The size of the vehicle was evolved from the estimates of daily traffic, timetable constraints and operational comfort. The Swissmetro vehicle is symmetrical in cross-section and can move in both directions. It comprises 2 compartments of 104 seats each with a lateral entry and exit door at each end. Sacrificing some comfort, for example by having travellers stand can further increase the capacity. Once the East-West axis or the network is completed, it is envisaged to couple two vehicles.

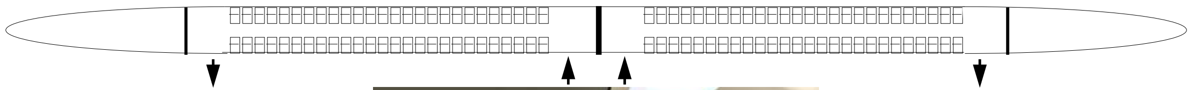


Figure 8 : Plan view of the vehicle

The embarkation and disembarkation of passengers in a station must not exceed 100 seconds. That is made possible by organising passenger movements in such a way that those entering the vehicle do not encounter those leaving the vehicle by having them accompanied by a steward. The asymmetrical layout of the station makes it possible to have airlock doors on just one side of the vehicle, offering the advantage of cost and safety.

Vehicle characteristics

The characteristics of the vehicle are as follows:

- Number of seats: 208
- Total length: 80 m
- Inner diameter: 3 m
- Number of doors: 4
- Dimensions of doors: 1.9 x 1.2 m
- Weight: 50 tons

Model station

The typical Swissmetro station is integrated into the State Railway stations in order to enhance synergy with the urban and regional surface public transport systems. It comprises two underground operational levels:

- the passenger reception hall connected to the surface transport facilities,
- the embarkation and disembarkation zone in an area englobing all the other functions of the station (embarkation zone and disembarkation zone).

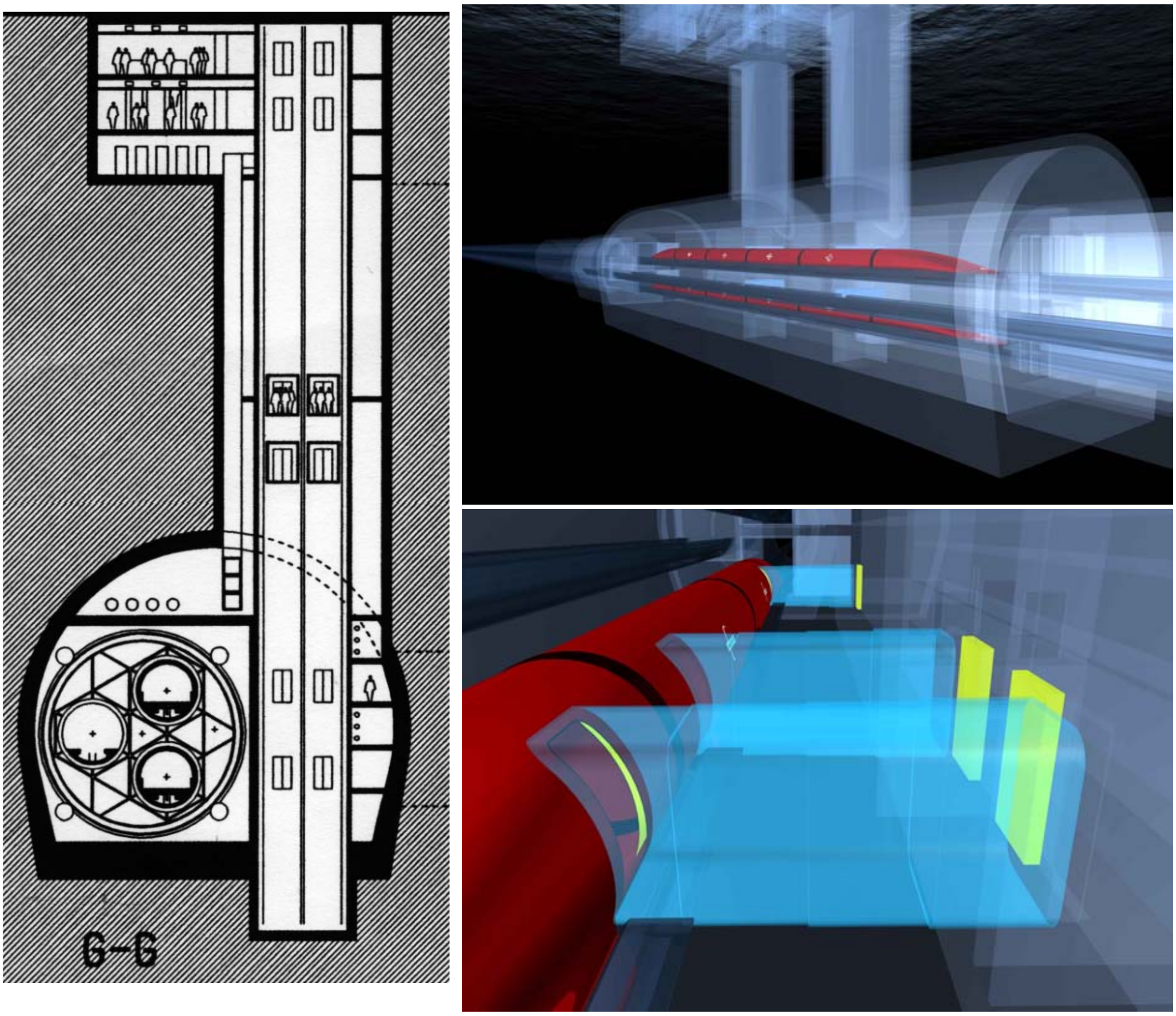


Figure 9 : Model station

In the station, the tunnels are superposed. The vehicles are accessed on two levels depending on where the passengers are coming from or their destination. The reception hall and the embarkation and disembarkation zone are linked by a series of double-bridge lifts. The tunnels remain in a partial vacuum and airlocks are applied to each vehicle door enabling the passengers to board and leave the train at atmospheric pressure. In each station, a barrel system makes it possible, if necessary, to move a vehicle from one tunnel to the other by rotation.

The length of the model station is that of a vehicle. To take account of the foreseeable increase in traffic, this will have to be doubled to be able to take two coupled vehicles. The civil engineering work on extending the excavation will be conducted during the first stage of construction. The equipment (barrels, lifts, etc.) will, however, be installed only as the needs arise.

Mode of operation

The distances between stations vary across the network between 48 and 130 kilometres. Two types of operation are envisaged:

Synchronous operation

- synchronous operation, that is to say a constant travel time between stations regardless of distance, for example, 12 minutes. This solution has the disadvantage of requiring very high speeds on the long lines, the consequences being higher energy consumption and a greater electro-mechanical infrastructure. Conversely, however, this is commercially more advantageous.

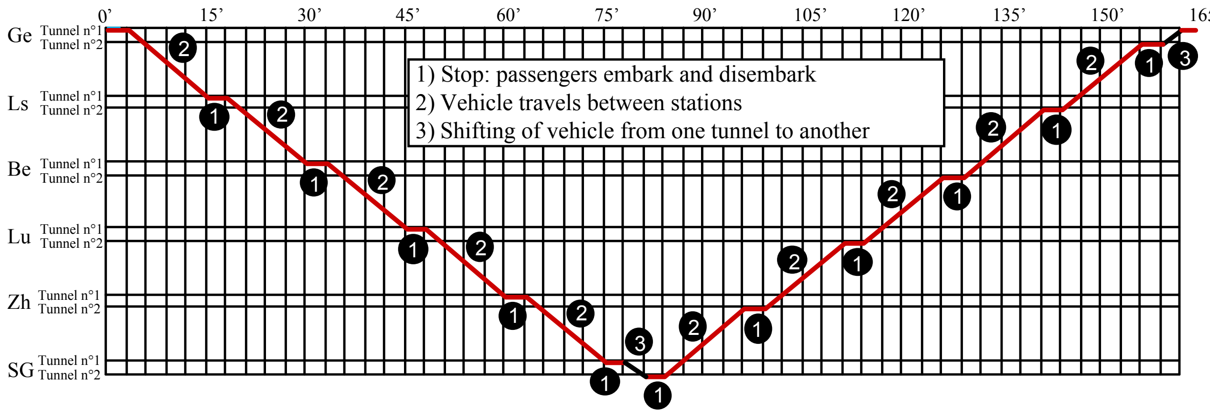


Figure 10 : Target timetable for synchronous operation on the Geneva- St Gallen line

Asynchronous operation

- asynchronous operation, this is to say a variable travel time between stations at adapted speeds. The chosen operational plan can perfectly well adapt to asynchronous operation provided the following rules are respected:
  - a vehicle every 6 minutes and a 3 minute stop in the station. To respect this rule, the travel time between stations must absolutely be in multiples of 3 minutes,
  - the simultaneous stopping of vehicles in stations. This condition is necessary to maintain the choice of double-bridge lifts and a compact reception station.

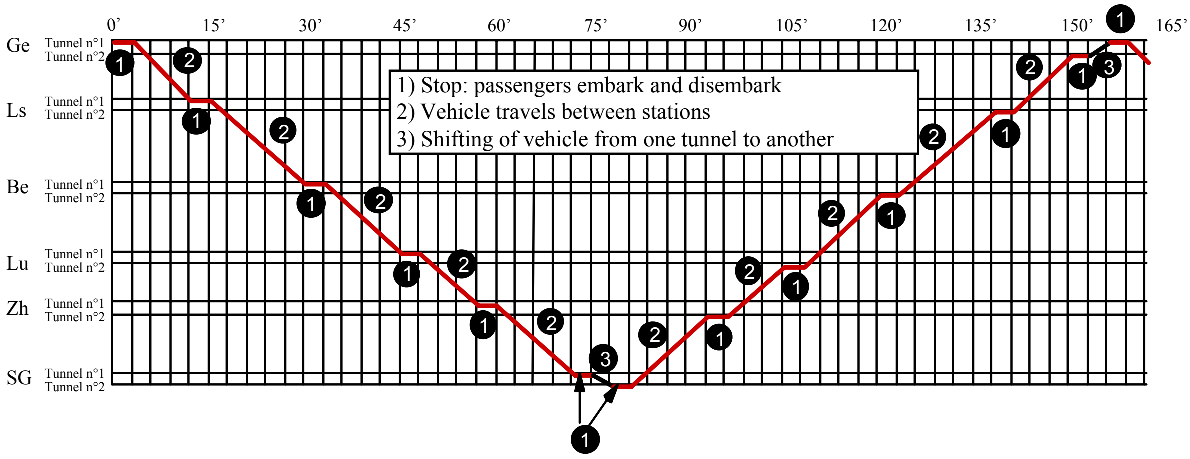


Figure 11 : Target timetable for asynchronous operation on the Geneva- St Gallen line

The choice as to which solution will be adopted remains open for the purposes of the principal study.

Safety plan

Because of the frequency of vehicles, Swissmetro is rather more like an urban underground railway than an aeroplane. That is why the entire system must be supervised essentially by security personnel.
In order to attain a level of safety superior to that of an ordinary underground, the safety plan is as follows:

- passenger identification when reserving seats. This operation can be conducted using digitised photos or automated devices that identify fingerprints, provided that the data protection and commercial aspects are respected,
- permanent supervision of the stations by safety personnel from a central command and surveillance post, and by rapid intervention teams,
- Presence in the vehicles of a “steward” who accompanies passengers and is responsible, in particular, for spotting suspicious objects. The steward will also be responsible for informing and guiding passengers during normal or reduced operation.

All these security techniques and measurements are already being applied today in many areas. These will have to be further developed in order to cope with growing insecurity subject to the use of the data collected remaining subject to a court decision.

Conclusions

With two one-way tracks, the frequency of vehicles can be easily adapted and consequently the transport capacity of the Swissmetro system.

The compact organisation of the station reduces the time spent moving around and offers the possibility of having shorter intervals between trains and fewer passengers per vehicle, while maintaining high transport capacity. This flexibility thus increases the commercial attractiveness of the system, reduces civil engineering investment costs, distributes passengers inside and outside the system and increases the use of all the equipment.

The choice to move small groups of about one hundred passengers at frequent intervals rather than moving a crowd at longer intervals, offers Swissmetro passengers a reduced average waiting time (by a factor of 1:5 as compared to a 30’ frequency) and a comfortable and convivial travelling atmosphere while, at the same time, respecting the high speed performances. This choice also has favourable consequences for the transfer of Swissmetro passengers to urban and regional means of transport.

Operating costs

The operating costs include the cost of personnel, energy, maintenance of the infrastructure, vehicle and mechanical and electro-mechanical installation servicing as well as general expenses.

Estimated costs

Line	Variant		Length [km]	Annual operating costs (Million of CHF)
Geneva - Lausanne	A	B	58.5	51.0
Lausanne - Bern	A	B	81.0	51.3
Bern - Lucerne	A	-	69.2	43.7
Lucerne - Zurich	A	B	48.2	31.6
Zurich - St Gall	A	B	69.6	40.0
Basel - Lucerne	A	-	80.0	55.6
Lucerne - Bellinzona	A	B	127.6	74.1
Bern - Zurich	-	B	104.3	70.3
Basel - Zurich	-	B	75.0	61.7
Total network variant A (stages 1 and 2)			**534.1**	**347.3**
Total network variant B (stages 1 and 2)			**564.2**	**380.0**

Table 5 : Annual operating costs in 1997 CHF

5.3.4 Further developments

The following areas need some further study:

Global plan

- the global plan of operation of the Swissmetro system with the State Railway, inter-regional and urban surface transport systems,

Timetables

- verification and possibly adaptation of the target timetable according to technical developments, in particular of the airlock and "barrel,"
- final choice of the synchronous or asynchronous timetable,
- development of the reduced service timetable,

Passenger flows

- verification of the transfer times of passengers between the station and the vehicle, together with the civil engineering and the vehicle designers,

Vehicles

- development of the interior layout with an eye to security, safety and operation,
- participation in the development of the vehicle,

Stations

- choice of final sizes of the generic station, according to technical developments,
- final organisation of security and choice of equipment,
- organisation of ticket sales, reservation system and choice of equipment,
- development of station equipment: heating, ventilation, electricity, sanitary, etc.,
- thorough study of the organisation of the operational personnel and the skills necessary for the various work posts.

5.4 Civil Engineering aspect

5.4.1 Terms of reference of the working group

- to prepare the preliminary geological and hydro-geological model,
- to choose the alignment and location of civil engineering works,
- to design the tunnels, stations, galleries, shafts and ancillary works,
- to investigate the air and water-permeability, qualities and the resistance of the linings: concrete technologies, sealing membranes, possibly other solutions,
- permeability design of the works,
- to select construction methods,
- to evaluate excavated materials,
- to estimate construction deadlines and costs.

5.4.2 Methodology

Basic data

The physical data and other information relating to surface conditions (topography, surveying, waterways, access paths, etc.) were collected from existing documents. The subsoil conditions were also determined on the basis of existing information (drillings, seismic profiles, publications, etc.) The collected data were supplemented by site reconnaissance and inquiries with authorities, administrative services or other sources.

Location of civil engineering works

Generally speaking, the civil engineering works were located, taking into account all the identified constraints and, in the case of the pilot line, with the agreement of the authorities concerned. The choices made derive from the comparison of several variants, some of which, although currently eliminated, could be reconsidered depressing on how the situation develops, particularly with regard to the stations.

5.4.3 Results

Tunnels

From the beginning of the main study, a comparative survey was conducted of various layouts for the tunnels to make the two tracks for the Swissmetro vehicles. The various types examined included a design with two separate tubes, as finally adopted in the main study, as well as a series of profiles combining the two tracks in a single tube, of varying dimensions and forms.
Figure 12 shows a variant involving twin two-way tunnels laid out either side by side or one upon the other. Nevertheless, the few advantages offered by the single-tunnel variant, particularly with regard to safety, were judged insufficient to offset the additional cost which, in the best of cases, is in the order of 30% as compared to the two-tube solution. The uses of part of these tunnels for other purposes (telecommunication, electricity lines, goods transport, etc.) could, nevertheless, revive interest in these solutions.

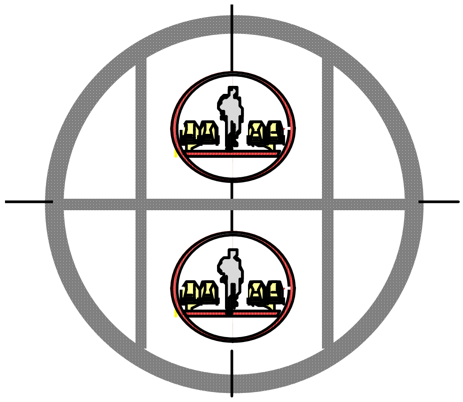


Figure 12 : Variant of the single tunnel

Tunnel linings

The tunnel linings were also examined in detail in relation to the geological conditions and the operational criteria (air and water-permeability, mechanical, thermal and chemical stresses, etc.).

Given that an exterior ring of concrete segments will be systematically placed in advance, during excavation, four interior types of lining meeting the imposed requirements have been identified:

- waterproof- concrete solution,
- sandwich-membrane variant (synthetics, steel or other),
- internal mortar-lining variant (concrete, synthetics or other),
- internal steel-lining variant (armour plating, steel concrete segments, mixed concrete segments).

The comparative studies have shown that in the current state of the art, a sandwich-type lining, comprising a waterproof membrane between two concrete rings (external concrete segments and internal ring) best satisfies the criteria defined.

The cross-section of the tunnels, determined on the basis of the above considerations and reference values (interior diameter 5.0 m, distance between the tunnel axes 25 m), can be seen in figure 9. The liner thickness will have to be adapted to local geological conditions.

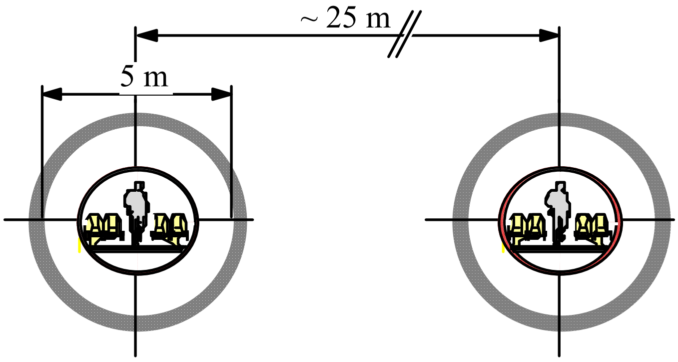


Figure 13 : The two-separate- tunnel variant (selected variant)

The behaviour of the tunnel construction materials is currently (1998) being tested by the Technical Research and Consultancy Office of the Swiss Cement Industry (TFB) in Wildegg together with the Reinforced and Prestressed Concrete Institute (IBAP) of the EPFL, with the help of a CTI research grant.

To start with, these tests concern the concrete subjected to the stresses and strains generated by the operating conditions, in particular the effects relating to the partial vacuum. The first test phase, on concrete samples, will be finished in 1999.

Stations

The Operational Group studied the design of the model Swissmetro station. It was adapted, case by case, to the local conditions.

Operational posts (intermediate shafts)

The operational posts are located in the shafts and excavations used for digging the tunnels. They will house the electrical and mechanical equipment necessary for operation (electrical sub-stations, vacuum pumps, repressurisation device, etc.).

Other studies

The Civil Engineering Group participated in the work of the other groups, especially on the safety and aerodynamic aspects (studies of galleries, tunnels, chambers, etc.) and in the finalisation of various construction details.

Lines studied

The following lines were specifically studied with regard to the geological conditions and the civil engineering work (alignment study, location of works, execution conditions, etc.).

Estimates

Line	**Variant**		**Length [km]**	Civil Engineering costs (Million of CHF)
Geneva - Lausanne	A	B	58.5	2564
Lausanne - Bern	A	B	81.0	3248
Bern - Lucerne	A	-	69.2	2837
Lucerne - Zurich	A	B	48.2	2494
Zurich - St Gall	A	B	69.6	2824
Basel - Lucerne	A	-	80.0	3672
Lucerne - Bellinzona	A	B	127.6	6066
Bern - Zurich	-	B	104.3	4456
Basel - Zurich	-	B	75.0	4080
Total network variant A (stages 1 and 2)			**534.1**	**23705**
Total network variant B (stages 1 and 2)			**564.2**	**25858**

Table 6 : Lines studied and Civil Engineering costs in 1997 CHF

5.4.4 Further Developments

Generalities

The results of the main study are based on information available to date. Adaptations and additional studies will be necessary as the final project develops.

Geological surveys

To gain a better knowledge of geological conditions, in particular high-pressure waterbeds, on-site surveys are necessary. The reconnaissance program mentioned in the geological study of the Geneva-Lausanne pilot line gives an indication of the work expected in a first phase. As each of the lines will have its own characteristics, a specific program will have to be prepared in each case. It must be remembered that the amounts invested in reconnaissance work result in considerable economies when underground work is carried out.

Construction method

The construction of an underground network of the size of Swissmetro is a major challenge for the building industry. Solutions can be expected, which will reduce construction costs, thanks to the high degree of rationalisation of the drilling and earth extraction equipment. The proposed construction methods will, nevertheless, have to take into account, on certain lines, of the presence of high-pressure underground water.

Materials

Research into the behaviour of concrete and the membrane to make the tunnels airtight will have to be conducted in the following three phases :

- tests on samples,
- tests on construction elements,
- 1:1 scale tests to be conducted on a test site or on a trial stretch of a first Swissmetro tunnel.

5.5 Environmental protection aspect

Preliminary remark

Studying the environmental protection aspect takes the form of an impact study which forms part of a licence application. This was done for the Geneva-Lausanne pilot line and it will be repeated at the time of the licence application for each line of the network. Hence the considerations that follow concern only the pilot line, of which the impact study will be used as a model for the other lines. That is why we have refrained from preparing not prepared a Volume B - Study of environmental impacts

5.5.1 Terms of reference of the working group

Geneva-Lausanne pilot line (licence application)

- to conduct a preliminary investigation into the impact on the environment and to draft the impact report specifications,
- to study potential sites for sinking the access shafts, according to a comparison method based on technical and environmental criteria,
- to prepare the scenario and site study for the management and/or re-utilisation of the excavation rubble,
- to prepare Phase I of the environmental impact study, necessary for the licence application,
- to prepare information for cantonal and municipal authorities concerned by the various surface-visible work on the pilot line,
- to draft the specifications for the Phase II impact study, necessary for the plan approval phase.

5.5.2 Methodology

Decisive elements

The decisive elements for the project were identified, with a distinction being made between the operational phase (impact of the reception stations and surface operation posts) and the work-site phase (transport and management of excavation rubble).

Management of excavation rubble

The various solutions and the possible sites for ritualising or depositing the excavation rubble have been inventoried and analysed.

Environmental impacts

The environmental impacts of the operational and work-site phases have been analysed, i.e. town and country planning, sites contaminated, air hygiene, vibrations and ground noises, earth, forests, traffic and modal transfer, energy consumption, natural parks and landscapes, surface water, underground water, traffic and sound nuisances caused, risk and safety.

Location of civil engineering works

The most favourable sites for the operational shafts have been analysed and defined according to the possible routes to be followed. For each sector, a multiple-criterion analysis was done. This is based on the application of both technical and environmental criteria for exclusion and comparison in order, for each surface installation, to determine the location and solutions most favourable to the evacuation and management of excavation rubble.

Impact phase II - study specifications

According to the analysis of the impacts and unknowns of the project, a set of specifications has been prepared for the phase II impact study.

5.5.3 Results

The results are strongly influenced by the specific aspects of Swissmetro, that is to say an underground track and a concentration of working activities at number of surface points that can be specifically chosen. So we can distinguish:

Operational phase

- The operational phase, during which the impacts of Swissmetro are essentially limited to the town and country planning and modal traffic/transfer aspects. The other aspects are generally insignificant or non-existent, or even positive as they offer the possibility of renouncing any extension of surface paths of communication. The positive impacts, especially on decreasing atmospheric pollution, will already appear at the pilot stretch stage alone.

Construction phase

- The construction phase, for which the analysis of the sites and the evacuation possibilities have shown that the surfaces concerned by the work-sites will not be very numerous or very extensive. In each case there are favourable sites and solutions, making the exercise feasible and strongly limiting the potentially negative impacts. The evacuation of rubble is the decisive element at this phase. The study has shown that there are solutions for the reutilisation and deposit of excavation rubble throughout the country.

5.5.4 Further developments

Once the position of the Federal Council and the various offices concerned with the licence application is known, the Phase I and Phase II impact study schemes will be supplemented as necessary.

5.6 Electromechanical aspect

5.6.1 Terms of reference of the working group

- to define the following components and electro-mechanical functions: magnetic lifting and guidance, propulsion by linear electric motors fixed to the tunnel, transformers, energy transfer by induction,
- to develop a variant linear electric motor to be fixed to the vehicle,
- to define the electrical power supply and its contactless transfer to the vehicle,
- to study, with Dornier System Consult, whether Transrapid technology can be adapted to Swissmetro conditions,
- to prepare an energy balance report,
- to study the behaviour of the electro-mechanical components under Swissmetro conditions,
- to construct models (lifting and guidance, propulsion, energy transfer),
- to prepare estimates.

5.6.2 Methodology

Studies, parametric analyses and practical references have been conducted on the various electro-mechanical components and functions.

The Swissmetro electro-mechanical systems do not allow for the confirmation of theoretical analyses by 1:1 scale tests because of the investment costs and practical constraints. Only reduced-scale prototypes, or in certain cases specific 1:1 components, were made and tested. These highlighted the criteria for the technical choices proposed and confirmed scientific developments.

The companies involved in the electro-mechanical group participated directly in this work by pre-dimensioning studies, energy-distribution network analyses, economic evaluations and by their contributions to making up the prototypes.

The Swiss Federal Institutes of Technology were involved in the studies through semester projects, diplomas and doctorate theses as well as through the research work of their scientific staff. Certain Specialised Institutes of Advanced Studies contributed by developing specific electro-mechanical elements.

5.6.3 Results

Propulsion

Two types of linear motors can be considered for propulsion:

Transrapid System

 the classical synchronous linear motor, with a long stator fixed to the tunnel, this being the Transrapid solution which allows for the combination of magnetic propulsion, levitation and contactless energy transfer,

Swissmetro System

 the synchronous homopolar linear motor, with a short stator, this being the Swissmetro solution. Two propulsion variants (see figure 3) were selected:

Variant A : propulsion by short synchronous homopolar linear motors: the stators of which are stationary and secured to the tunnel and the rotor poles are carried on the vehicle. This variant implies a distribution of the stators solely in the acceleration, re-acceleration and braking zones of the line in question,

Variant B : propulsion by short synchronous homopolar linear motor with the stator carried on the vehicle and the fixed rotor poles secured to the tunnel.

Braking

Three braking types were considered:

- normal braking and emergency braking by the linear motors,
- emergency braking by an inductive braking system,
- emergency braking (low speed) and the lowering of the vehicle onto the skids.

Magnetic levitation

The use of magnetic levitation and guidance techniques is very advantageous in terms of mechanical constraints and of operational costs at speeds in excess of 300 kph.

Swissmetro gave its preference to electro-magnetic levitation primarily for reasons of compactness and cost. A feedback control system guarantees that the nominal gap is kept constant because the system is intrinsically unstable.

Safety and reliability are the keys elements of levitation. Reliability is guaranteed by batteries being able to take over operation in the case of a vehicle power supply failure. Furthermore, if one levitation element fails, it can be compensated for by the adjacent element taking over its function. If several inductors fail, contact with the reaction rail or the ground will be avoided by skids.

Magnetic guidance

The guidance system is similar to the levitation system, the only difference residing in the layout of the pairs of inductors which are placed back to back.

Transfer of energy to the vehicle

In the case of variant A, the functions to be powered on the vehicle itself are essentially the lifting, guidance, lighting, heating, ventilation and air-conditioning systems, the associated controls and the other functions. The energy consumption of the different functions of the vehicle is in the order of 500 kW.

In the case of the variant B, the energy necessary for the propulsion must be transferred to the vehicle. Here, the active power is 7 MW.

Modelling

Models of the magnetic levitation and guidance systems, and measurements of the magnetic drag and linear motors have been made and checked.

Energy requirements

Energy requirements have been determined for different vehicle occupation rates. The direct energy consumption is low as compared to total Swiss consumption: the Geneva-St.Gallen line, working at full capacity, would use between 0.18 and 0.24% of the total (1995) energy consumption in Switzerland. Swissmetro consumption does not, therefore, have any marked effect on the national supply strategy. Besides, the energy requirement per passenger, at comparable speeds, shows that Swissmetro is competitive with other transport systems.

Dornier System Consult study

In 1998, Dornier System Consult was commissioned to study the adaptability of all or part of the Transrapid system to the conditions of Swissmetro. The conclusions of this study are as follows:

- the Transrapid system can be adapted to Swissmetro conditions after significant additional developments,
- two options are envisaged:
  - either an adaptation of the whole Transrapid concept
  - or an adaptation of specific components of Transrapid
- the propulsion systems chosen by Transrapid and Swissmetro have different characteristics, each with their advantages and disadvantages,
- the Transrapid vehicle must be adapted to the reduced-pressure conditions according to the standards in the aviation industry, especially with regard to the renewal of ambient air,
- the safety and rescue concept of Transrapid is transferable to Swissmetro. The safety concept of Swissmetro is simpler, for it presents less risks of collision, meteorological influence and sabotage,
- the cost of the industrial development of Swissmetro is estimated at between DM 480 and 650 million if Transrapid components are adapted,
- industrial development can be ensured by a consortium of specialised European companies.

Estimates

Line	**Variant**		**Length**	Electro-mech. costs (Million of CHF)
Geneva - Lausanne	A	B	58.5	700
Lausanne - Bern	A	B	81.0	1100
Bern - Lucerne	A	-	69.2	847
Lucerne - Zurich	A	B	48.2	539
Zurich - St Gall	A	B	69.6	760
Basel - Lucerne	A	-	80.0	822
Lucerne - Bellinzona	A	B	127.6	1547
Bern - Zurich	-	B	104.3	1202
Basel - Zurich	-	B	75.0	1004
Total network variant A (stages 1 and 2)			**534.1**	**6315**
Total network variant B (stages 1 and 2)			**564.2**	**6852**

Table 7 : Electro-mechanical costs in 1997 CHF

5.6.4 Further developments

The following further studies must be undertaken:

- study of local heating of the electro-mechanical components and of possible forced cooling,
- tests and study of the behaviour under vacuum of the high and medium-tension coils and cables,
- spatial integration of the power-supply elements (tunnel, station), the motors (vehicle and tunnel) and the transformers,
- study of electrical connections between the various components,
- study of maintenance,
- study of the feasibility of energy transfer by mechanical contact.

5.7 Mechanical aspect

5.7.1 Terms of reference of the working group

- Study of the aerodynamic aspects: blockage ratio, partial vacuum level, aerodynamic drag, etc.,
- development of aerodynamic test facilities,
- development of the vehicle and of its equipment,
- development of the system for creating the partial vacuum and for the repressurisation of the tunnel,
- estimate of temperature changes inside the tunnel,
- development of the barrel and of the passenger airlocks,
- preparation of the cost estimates.

5.7.2 Methodology

Aerodynamics

With respect to the aerodynamics, a numerical code has been developed whereby the aerodynamic behaviour of the vehicle/tunnel system can be modelled and, for given configurations, a drag force can be deduced. These numerical data will again have to be verified by experimentation.

Partial vacuum

The possibilities have been studied of creating a partial vacuum using technologies currently available on the market.

Thermal behaviour

The heat build-up in the tunnel over the short term (vehicle and motors) and the long term (account being taken of the thermal inertia of the surrounding rock) has been examined.

Vehicle

State-of-the-art aeronautical techniques have been used to design and size the structure of the vehicle and its equipment.

Repressurisation

The phenomena relating to the rapid repressurisation of the tunnel via the ventilation shafts (air velocity, pressure and temperature) have been studied. Priority was placed on analysing the physiological problems in cases of accidental de-pressurisation of the passenger compartment (2.5 minutes for partial repressurisation).

Safety

The safety aspects were already taken into account at the design phase of the vehicle, the passenger airlocks and other items of equipment.

5.7.3 Results

Partial vacuum

In proposing the vacuum level and the tunnel diameter, an effort was made to strike a compromise between investment costs (small diameter / pressure level as close as possible to atmospheric pressure) and operating costs (minimum energy consumption) while at the same time accounting for precise safety, heat accumulation, construction aspects and other criteria.

Repressurisation

Emergency tunnel repressurisation, in 2.5 minutes, via the ventilation shafts involves high air speeds which would be difficult to control. This is why a system of continuous and uniform repressurisation along the whole length of the tunnel (pressurised tubes) is proposed in order to very quickly reach a pressure of about 60’000 Pa. The final, slower, repressurisation would then be conducted via the ventilation shafts.

Aerodynamics

The high-performance calculation tools that were developed make it possible to analyse in detail the aerodynamic problems associated with very specific flow fields (flow around the rear of the vehicle, around the electro-mechanical elements, etc.) A complete experimental facility was set up comprising a shock tube 120 m long (STARLET- Shock Tube for Aerodynamic Research on Long and Enhanced Tunnels). A test rig (HISTAR- High-speed Train Aerodynamic Rig) was designed and a CTI financial application was filed. This installation, which will be operational by the beginning of the year 2000, will make it possible to confirm the theoretical results.

Thermal behaviour

During the motion of a vehicle (short term), it generates a non-stationary aero-thermal environment, a knowledge of which makes it possible to quantify convection heat exchanges and thus to dimension any necessary cooling systems. The long-term study has highlighted the high thermal inertia of the rock surrounding the tunnel and its capacity to absorb an important quantity of heat.

A temperature in the order of 30 to 35°C is expected in the tunnel after 48 years of operation. A tunnel cooling system does not, therefore, seem necessary during that period. Nevertheless, the local thermal state of the rock and/or an increase in operational frequency could generate thermal problems and make it necessary to introduce a tunnel cooling system.

Vehicle

The presence of a partial vacuum implies the choice of a pressurised vehicle and airlocks through which passengers can enter and leave it in the stations.

Special attention was paid to the development of the vehicle inter-coach articulation system, on the basis of a new system currently being developed, as well as the integration of electro-mechanical elements on the vehicle.

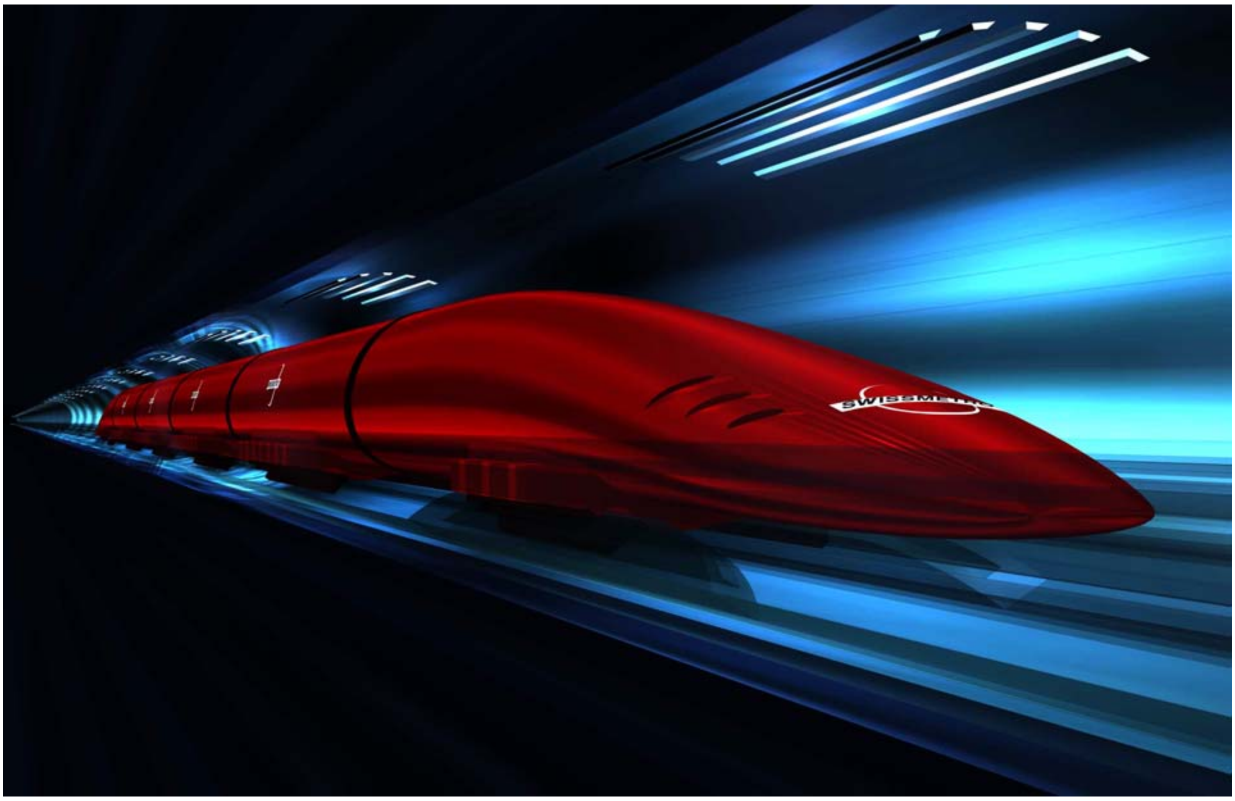


Figure 14 : Front view of the vehicle

Renewal of ambient air

To guarantee the level of air quality in terms of comfort and safety, the vehicle will have to be equipped with an air renewal system. There are three possible solutions for the elimination of pollution - dilution of the air in the passenger compartment with clean air, sorption (chemical or physical) that consists in fixing the pollutants in a liquid or a solid, and separation of the pollutants in gaseous phase by membranes (filtration). This last solution seems the most promising for Swissmetro for it is the most advantageous from the viewpoint of on-board weight. It must, however, be admitted that the current separation membranes do not yet attain the desired coefficients of filtration. But this aspect is fast evolving and Swissmetro will certainly be able to benefit from the current research in this field.

Other mechanical equipment

Equipment existing on the market, such as vacuum pumps, did not necessitate specific studies, their dimensions and costs have been estimated. The design of the airlocks and the barrel, however, were considered.

Estimate

Line	Variant		Length [km]	Mechanical costs (Million of CHF)
Geneva - Lausanne	A	B	58.5	210
Lausanne - Bern	A	B	81.0	197
Bern - Lucerne	A	-	69.2	185
Lucerne - Zurich	A	B	48.2	154
Zurich - St Gall	A	B	69.6	176
Basel - Lucerne	A	-	80.0	223
Lucerne - Bellinzona	A	B	127.6	265
Bern - Zurich	-	B	104.3	221
Basel - Zurich	-	B	75.0	233
Total network variant A (stages 1 and 2)			**534.1**	**1410**
Total network variant B (stages 1 and 2)			**564.2**	**1456**

Table 8 : Cost of mechanical equipment and vehicles en 1997 CHF

5.7.4 Further developments

The following areas need further study:

Aerodynamics

- optimisation of the interconnecting ducts between the two tubes in order to reduce the aerodynamic drag,
- quantification of aeroelastic phenomena which could be the source of vibrations and instabilities,

Thermics

- prediction of the temperature and humidity in the tunnel and around the vehicle during normal, reduced (maintenance) operation and in case of stoppages between stations,
- study of the cooling variants of the guidance and levitation inductors as well as on-board motors,
- dimensioning, if necessary, of a tunnel-cooling system,

Vehicle

- development of the vehicle inter-coach articulation system,
- analysis of the integration of electro-mechanical components on the structure of the vehicle,
- development of the air-conditioning and air renewal systems of vehicle,

Vacuum

- more accurate quantification of leaks (permeability of the tunnel, sealing devices, airlock),
- more thorough investigation of phenomena relating to the emergency repressurisation of the tunnel (aerodynamic and thermal phenomena),
- optimisation of the emergency tunnel repressurisation system.

5.8 Safety aspect

Preliminary remarks

The Safety working group dealt exclusively with the technical safety of Swissmetro during its operational phase and the implications of this on the work of the other working groups.

The passenger security was handled by the Operational-working group. Safety during the construction and manufacturing phase is covered by ordinary legal provisions.

For a new transport system such as Swissmetro, safety, whether the objective safety level or the subjective feeling of safety, is a sensitive subject that conditions the acceptability and the profitability of the system.

As compared to similar systems (trains, undergrounds) Swissmetro offers safety advantages inherent in its design (intrinsic safety). As in classical forms of transport, there are nonetheless hazard sources, which can threaten the physical integrity of passengers. Swissmetro combines, in a special environment, known technologies from aviation, high-speed railways, underground and magnetic trains (at the current stage of development).

5.8.1 Terms of reference of the working group

- to define the safety objectives of the Swissmetro transport system,
- to identify and analyse the risks inherent in the system,
- to propose solutions to achieve a higher safety level than that of other public transport systems at reasonable cost,
- to issue guidelines to take systematic account of safety aspects in the design of the system and of its components.

5.8.2 Methodology

Methodology

A safety plan has been derived from an analysis of system risks (fault tree and consequences).

Guidelines

Safety guidelines were established for the attention of the other working groups responsible for the development of the system. They were designed in such a way as to be able constantly to integrate new knowledge into the development of the system.

Master plan

A safety master plan was prepared with the following objectives:

- high level of safety,
- intrinsic safety level of the system,
- co-ordination of safety measures in all areas,
- account to be taken of safety from the very design phase,
- safety measures with a reasonable cost/effect ratio,
- systematic consideration of the human factor,
- continuous dialogue with the relevant authorities and the public.

5.8.3 Results

Identified risks

Among the risks identified, some are similar to those of existing transport systems and others are different:

- the Swissmetro vehicle travels as an aeroplane in a significantly low-pressure atmosphere. Any damage to the structure of the vehicle would, as with an aeroplane, result in a decrease of the pressure in the passenger compartment,
- the Swissmetro vehicle travels at very high speeds on its own track. The probability of derailment or of a collision is very low,
- the entire system is highly protected from external influences, such as atmospheric conditions and sabotage,
- it does not transport freight, thus eliminating the risks associated with potentially dangerous goods,
- the Swissmetro vehicle travels as an underground railway in a network of tunnels with a highly automated operating system.
- the stations are far apart. The number of passengers per convoy is less than in classical underground or surface trains.

Scenari studied

Risk results from two elements, i.e. the likelihood of some damaging event occurring and the seriousness of the consequences resulting therefrom. Five characteristic scenari were studied and placed in order according to their degree of probability and their consequences:

- The vehicle is brought to a standstill on the line for technical reasons. There is no danger for the passengers, but the vehicle must be moved to a station,

- Following a technical problem, the passenger compartment of the vehicle progressively loses pressure. In this case, the danger is not immediate. The plan here involves reaching the nearest station where passengers can be evacuated quickly and in the best of conditions. If the pressure inside the vehicle descends below the admissible threshold, it is planned to use oxygen masks,
- The vehicle collides with an element of the tunnel, the structure is badly damaged and the passenger compartment rapidly loses pressure. In this case, the health of passengers is seriously threatened. Here, the plan provides for the quick repressurisation of the tunnel and the evacuation of passengers,
- A fire breaks out in the passenger compartment of the vehicle. This is an event particularly dreaded by underground transport systems operators. The plan provides for fighting the fire and transferring the passengers to another compartment while the convoy quickly heads for the nearest station. If necessary, the tunnel can be rapidly repressurised and the passengers evacuated.
- An explosion occurs in the Swissmetro vehicle itself and partly destroys it. As in other transport systems, this extreme scenario cannot be excluded. The plan provides for the quick repressurisation of the tunnel and the intervention of rescue teams.

During the development of the system, special attention has been given to implementing preventive measures aimed at limiting the probability of an event occurring or reducing its consequences.

Evacuation plan

In concrete terms, the analysis of the risks made it possible to develop a passenger evacuation plan based on the following principles:

- as long as the mobility of the vehicle is not affected, it would proceed, either under its own steam or with the help of another vehicle, to the next station where passengers could be evacuated in the most favourable of conditions, (access, lighting, ventilation, proximity of means of urban rescue, etc.),
- If the vehicle cannot be moved, the rescue teams reach the accident site by means of a rescue vehicle and evacuate the passengers. If need be, the pressure can quickly be raised in the tunnel to allow the passengers to escape by their own means.

The rescue plan therefore combines self-rescue and external assistance.

5.8.4 Further developments

- Broad analysis of accident scenari with the help of event trees,
- quantification of the probability of events occurring and of their consequences,
- quantification of an appropriate safety level for individual and collective risks,
- participation in the development of the vehicle, civil engineering and equipment,

- definition of the availability of the system (servicing, maintenance, personnel safety, security, accesses checks, etc.).

5.9 Economic aspect

5.9.1 Terms of reference of the working group

- to systematically study various (public, private and mixed) financing models with their advantages and disadvantages,
- to consolidate the investment cost estimates and the operational costs provided by the various working groups and compare them with those of work actually done,
- to examine the economic and financial feasibility of the project,
- to propose an adequate financing system.

5.9.2 Methodology

General considerations

The economic study conducted with the assistance of financial experts, takes two furthers aspects into consideration**:**

– the economic feasibility of the project, that is to say its global internal and long-term profitability (direct profitability) with some thought for on the savings and the other beneficial effects for the community (indirect profitability);
– the financial feasibility of the project that takes account of returns on invested funds.

Assumptions

The economic study is based on the following assumptions**:**

- Swiss network completely constructed by 2010 (variant A or B),
- estimated average daily traffic in 2010
- useful life of electro-mechanical equipment and vehicles: 20 years,
- useful life of the infrastructure: 100 years,
- Swissmetro fare per kilometre in 2010: 0.276 CHF/km,
- estimated investment costs in 1997 CHF
- estimated operational costs in 1997 CHF
- estimated of operational income in 1997 CHF.

In order to allow an objective comparison of the different lines of networks A and B, it was generally assumed that the entire network would be in operation by 2010. This simplifying assumption avoids the complexity that would result from the vagaries of a progressive construction of the network.

Industrial development costs

The cost of the industrial development of the system was estimated at CHF 500 million, divided between the different lines *pro rata* to their length. An estimate by Dornier System Consult gives an amount of DM 480 to 640 million including the vehicle certification costs, assuming that all or some of the Transrapid technology is used.

5.9.3 Results

The following table gives the investment costs for the various lines as well as the annual operating costs and income.

The investment costs include the costs of the Civil Engineering (tunnels, stations, operational posts), the electro-mechanical and mechanical equipment, the vehicles as well as the cost of industrial development.

Line	Variant		Length [km]	Investment costs [million CHF]	Operational costs [million CHF]	Operational income [million CHF]	
						(Variant A)	(Variant B)
Geneva - Lausanne	A	B	58.5	3’524	51.0	148	149
Lausanne - Bern	A	B	81.0	4’614	51.3	184	186
Bern - Lucerne	A		69.2	3’930	43.7	383	-
Lucerne - Zurich	A	B	48.2	3’225	31.6	357	201
Zurich - Saint Gall	A		69.6	3’814	40.0	197	-
Basel - Lucerne	A		80.0	4’776	55.6	192	-
Lucerne - Bellinzona	A	B	127.6	7’984	74.1	220	208
Bern - Zurich		B	104.3	5’965	70.3	-	509
Zurich - Saint Gall		B	69.6	3’940	40.0	-	204
Basel - Zurich		B	75.0	5’383	61.7	-	251
Total network variant A (stages 1 and 2)			**534.1**	**31’868**	**347.7**	**1681**	**-**
Total network variant B (stages 1 and 2)			**564.2**	**34’635**	**380.0**	**-**	**1708**

Table 9: Recapitulation of investment costs, operational costs and income in 2010, in 1997 CHF

Economic feasibility: direct profitability (IPR)

Internal, global and long-term profitability

The IPR, internal profitability rate expresses the internal profitability of the project over a given period.

The result of the calculations made is shown in the following figures:

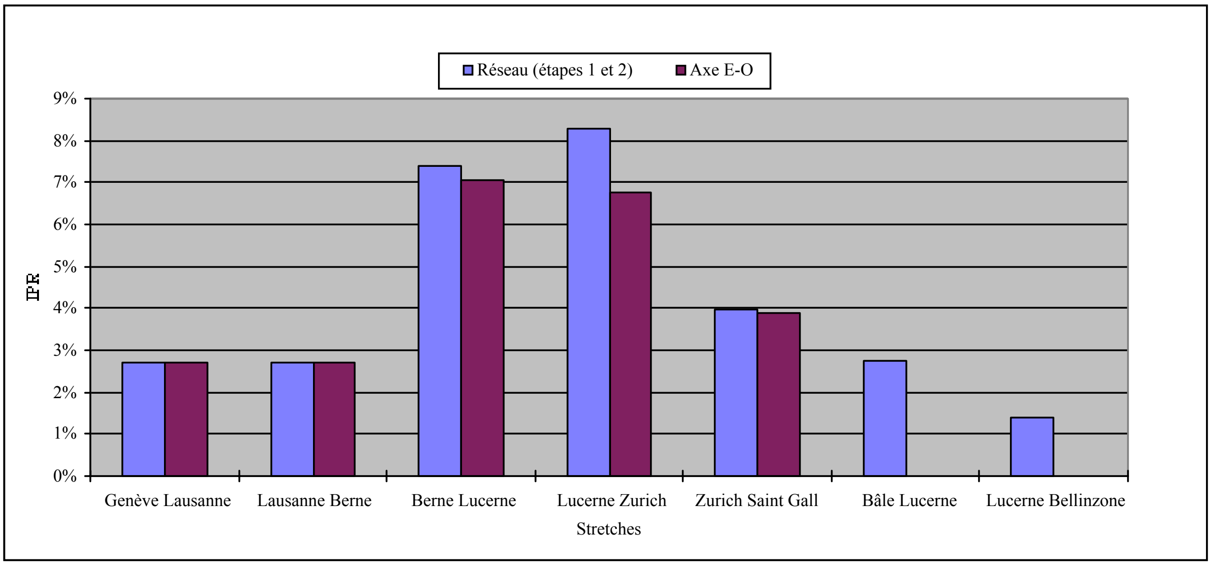


Figure 15 : Economic profitability, IPR of variant A lines

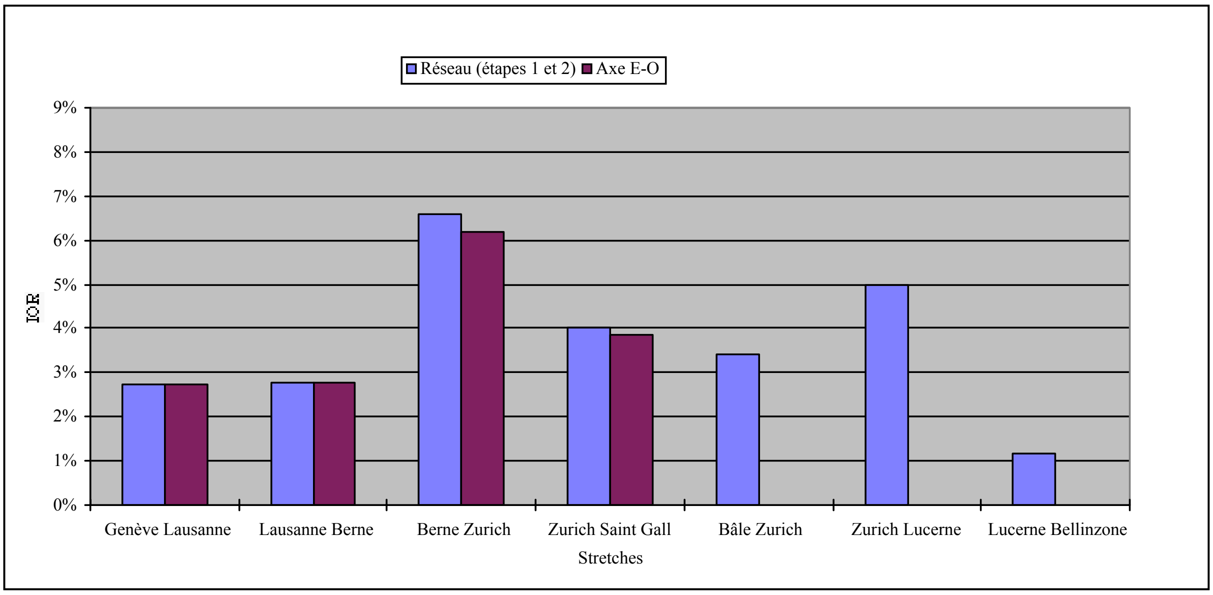


Figure 16 : Economic profitability, IPR of variant B lines

The internal profitability rates, calculated over the 10 years of construction (2000-2009) and 40 years of operation (2010- 2059) for the two variants A and B (network and E/W line) range between 1 and 8% for the various lines.

The peripheral lines obviously return the lowest rates, which is what necessitated the extension abroad (Eurometro) to improve the profitability of the Swiss network.

Network IPR

The average IPR values for the network (stages 1 and 2) are in fact 4.7% for the variant A network and 4.3% for the variant B network.

Economic feasibility: indirect profitability

Induced and extended indirect profitability

Indirect profitability considers the induce and extended advantages for the public of realising the network.

Induced savings

The evaluation first takes account of the savings induced by the project according to the following recapitulation:

Elements	Savings (million CHF)	
	Investments	Annual
Compared to road and motorway investments	4’500	
Motorway maintenance savings		90
Compared to railway investments	2’250	
Savings on railway operation costs		110
Total	**6’750**	**200**

Table 10 : Savings induced by the Swissmetro network

The accumulated savings over 35 years amount to CHF 13.75 billion

Extended savings

The evaluation next takes account of the economic and social advantages generated by the project, as recapitulated below:

Elements	Savings (million CHF)	
	Overall	Annual
Time saved		400
Jobs and tax income	360+1’000	9
Town and country planning		17
Environment		30
Total	**1’360**	**456**

Table 11 : Extended savings effected for the East-West line

The accumulated savings over 35 years amount to CHF 17.32 billions

Macro-economic advantages

In short, the macro-economic advantages of Swissmetro are the following**:**

- time-saving for users
- cost reduction due to fewer accidents
- lower social costs inherent in energy and fuel consumption
- lowers social costs inherent in air pollution
- job creation during the construction and operational phases.

Financial feasibility

Financing models studied

Several financing models - public, private and mixed - were studied. The mixed model was finally adopted in order to ensure suitable returns on private funds.

To simplify matters, the financing model accepted in the licence application for the pilot line was adopted for the network, even though the amounts at issue, the construction schedule and the differences in yield between the lines made the results obtained rather uncertain.

Financing model chosen

The financing model for the Berlin-Hamburg TRANSRAPID project which involved the German Federal Government, the Deutsche Bahn and the Thyssen AG, Siemens AG, and ADtranz GmbH companies was adopted and adapted by Swissmetro SA, with the three following companies:

- **SOFINF,** an infrastructural company in hands of public entities, will finance the system infrastructure and will entrust the maintenance to SOGEST, an operating company. No interest will be paid on the funds invested by SOFINF; it will, nevertheless, receive a one-third cut of the operating profits realised by SOGEST. The risk run by SOFINF resides in the construction estimate being exceeded but this risk can be reduced by farming out the work for a fixed sum to main contractors.
- **SOTRANS,** a private transport company, will finance the purchase of the vehicles and the bulk of the equipment and will entrusts their operation to SOGEST in return for a one-third cut of the operating profits. The financial risk assumed by SOTRANS resides in the estimate for the supply and replacement of equipment, the payment of interest and the reimbursement of foreign funds being exceeded as well as in the return on its own equity.
- **SOGEST,** a private operating company (State Railways alone, associated with private interests, or a third-party company) will operate the system (management, marketing, sales, propulsion, safety and passenger ushering) and maintain it. It will cede two-thirds of the operating profits to SOFINF and SOTRANS. The financial risk assumed by SOGEST, which does not participate in the financing, resides in the development of traffic which can be influenced by dynamic marketing, quality service and good co-ordination with all the means of surface public transport.

Financial profitability of SOTRANS

The following figures illustrate the average profitability (ROE, Return On Equity) of SOTRANS equity for each line of variants A and B (network and East-West axis) for the first 30 years' operation.

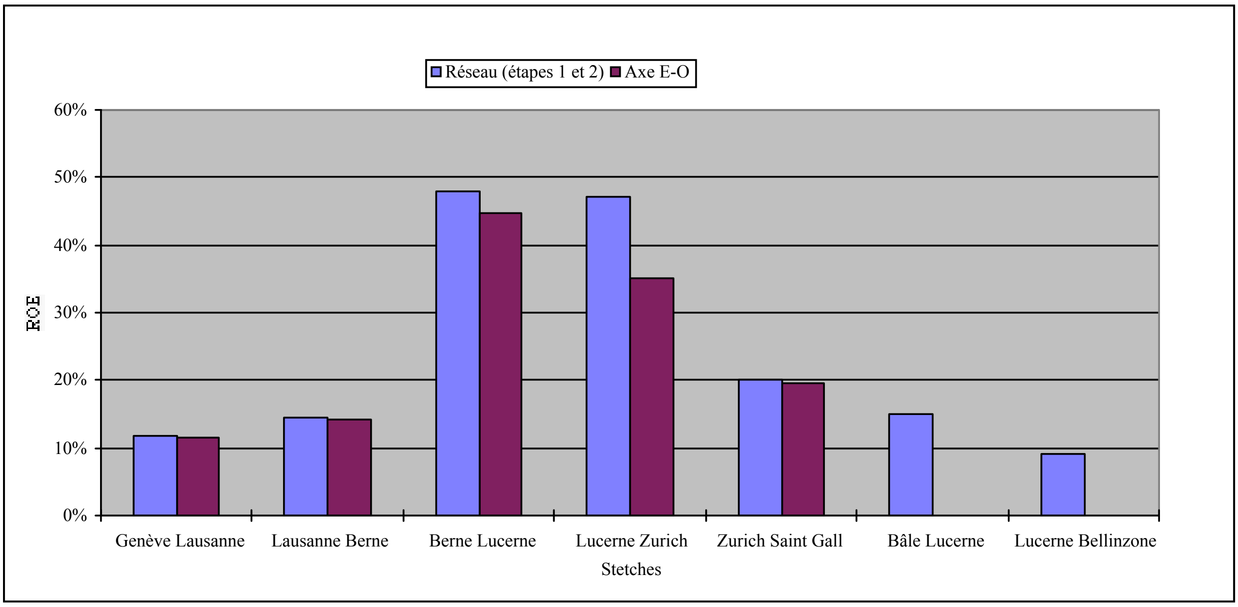


Figure 17 : Mean returns on equity of SOTRANS, network variant A (stage 1 and 2)

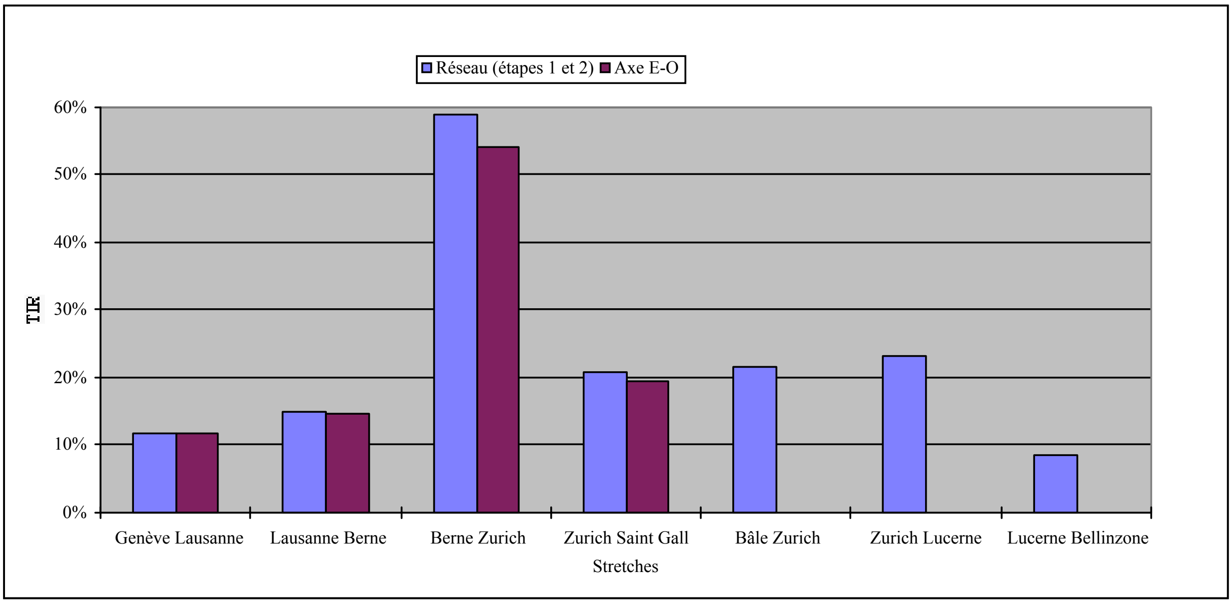


Figure 18 : Mean returns on equity of SOTRANS, network variant B (stage 1 and 2)

Network ROE

The average ROE for the network (stages 1 and 2) is 4.0% for the variant A and of 3.7% for the variant B.

Reimbursement of public capital

The capital invested in SOFINF by public entities will be progressively reimbursed by the collection of the third of SOGEST profits, as shown in the following figure for the Geneva-St.Gallen line of network variant A.

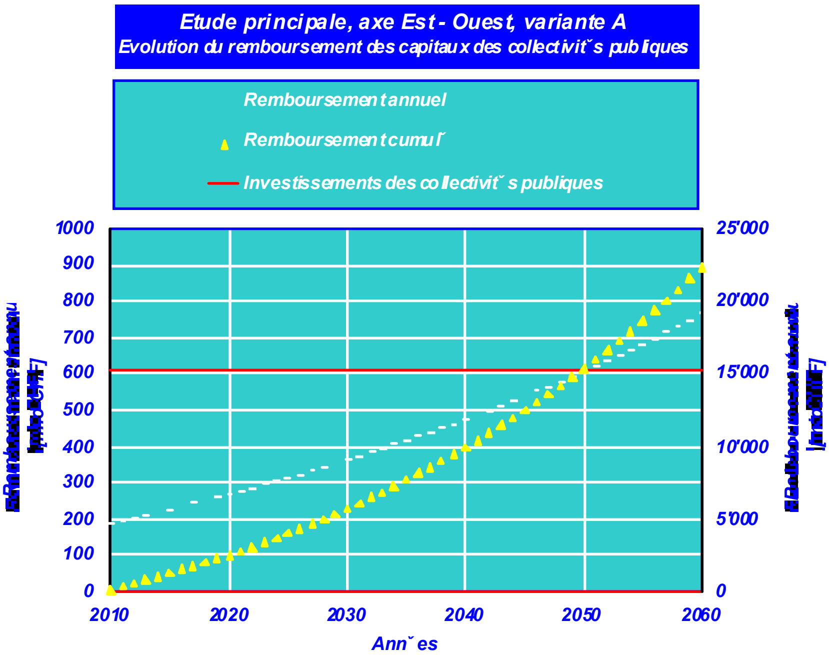


Figure 19: Annual and cumulated SOFINF reimbursement curves for variant A of the Geneva -St Gallen line

It will be seen that after 40 years of operation this reimbursement reaches close to CHF 15 billion, which covers the investments made by SOFINF, without any account being taken of the induced savings and socio-economic advantages generated by the system.

Sensitivity analysis

A sensitivity analysis was carried out for the pilot line, the purpose of which was to show the effect of the number of passenger (earnings), investments, and operating costs on**:**

- internal profitability (IPR)
- return on equity (ROE)
- the public fund reimbursement period

The sensitivity analysis shows that the earnings and, to a lesser degree, investments have a preponderant effect on profitability. While the effects of operating costs is of little significance. It is therefore important for SOGEST to ensure an increase in earnings by a dynamic promotion and of marketing policy. SOTRANS, for its part, will have to ensure respect for the investment budgets when planning and realising the project..

Conclusions

The economic study shows that**:**

- the average internal profitability rate varies, according to the lines, between 4 and 5% on average for the two network variants on the basis of the assumptions adopted,
- private financing alone can not be envisaged,
- the chosen financing model proposes an equitable distribution of the risks between public entities and private companies,

- private investors will, from the very first year of operation, benefit from a suitable return on their equity so that they can meet their commitments,
- the State Railways can be associated with the realisation and the operation of a high-performance and attractive transport system that will, moreover, improve the profitability of their surface network,
- the funds advanced by public entities are offset by investment savings on other transport systems. They do not have to make these investments without security as an amortisation is envisaged right from the first years of operation and full amortisation will ensue after 40 years (variant A, E/W axis),
- the IPR analysis shows that the East-West lines and the Basel-Zurich-Lucerne lines offer acceptable profitability with mixed financing. This is not the case with the Lucerne-Bellinzona and peripheral lines,
- the extension of the Swissmetro network beyond the borders (Eurometro) would help somewhat improve profitability.

5.9.4 Further developments

The economic study of the pilot line is based on relatively precise estimates of the investment costs and operating income and expenditure.

This is not the case for the two network variants for which these values were extrapolated. Further studies are therefore necessary to calculate these values more precisely**.**

Moreover, other financing models can be developed according to the wishes of the licensing authority and the private and public investors.

6 RESULTS OF RESEARCH WORK UNDER THE PNR 41

Objective of the PNR 41

The PNR41 National Research Program «Transport and Environment: Swiss-European interactions» aims to provide information useful for formulating an efficient transport policy that respects the environment.

Six modules

The 52 projects are grouped into the following modules**:**

- A Mobility: socio-institutional aspects (11 projects)
- B Mobility: socio-economic aspects (9 projects)
- C Environment: methods and models for analysing environmental effects (8 projects)
- D Political and economic strategies and framework-conditions (13 projects)
- E Transport system management: potential and effects (5 projects)
- F Technology: potential and effects (6 projects)

The Swissmetro main study benefits directly from 5 of these projects and indirectly from 24 others. The final results of these studies are not yet known

Reference

All these projects are described in the PNR 41 portrait and bulletins as well as on the Web (http://ww.snf.ch/NFP41/HOME.HTM). The 5 projects directly concerning Swissmetro will be presented at a symposium at the EPFL on 23.6.99**.**

The publication of reports is planned for 1999 and 2000, and they will be obtainable from the OCFIM (EDMZ) 3000 Bern. The summaries, in French, English and German, will be directly accessible on the Web.

6.1 Projects directly concerning Swissmetro

6.1.1 Evaluation of the demand for Swissmetro (Project F1)

The problems

It is very difficult to evaluate traffic flows induce by fundamentally new technologies and systems.

The objectives

The project aims to further develop the stated preferences method and to compare it with other methods while, at the same time, producing concrete results on the demand for Swissmetro.

The methodology

By means of questionnaires, this project has sounded out the preferences of the potential customers (stated preferences), by taking Swissmetro as an example.

6.1.2 Analysis of risks relating to accidents in tunnels (Project F2)

The problems

Given the rarity of accidents in road and railway tunnels, it is difficult to analyse them statistically**.**

Nevertheless, these accidents can have considerable human, environmental and material consequences.

The objectives

This study aims to improve the knowledge on risks, their causes, their consequences and their probability in tunnels.

The methodology

The project has used different methods, as for example analyses by fault trees. Possible serious accidents have been simulated on the basis of specific tunnel projects.

6.1.3 Evaluation of technological choices: high speed (Project F3)

The problems

The impact of high-speed, long-distance systems involves ecological, technical, social and town-and-country-planning aspects.

The objectives

The study makes a contribution to the method of evaluating technological choices and the concrete bases for evaluating new high-speed systems such as Swissmetro.

The methodology

On the basis of experience such as that gained with the TGV in France, and of known magnetic levitation techniques, an evaluation was made of the technological options (Technology Assessment) for a Swiss high-speed system (Swissmetro example).

6.1.4 Spatial effects of Swissmetro (Project F5)

The problems

While modifying the accessibility of various regions, the development of transport systems does not fail to affect the attractiveness of locations and the regional planning.

The objectives

Taking Swissmetro as an example, this study aims to analyse the consequences of a notable reduction in trip time on spatial organisation.

The methodology

Two research teams approached these questions using different methods**:**

- the Zurich EPF team used an integrated transport and land utilisation model to simulate various scenari,
- the Lausanne EPF team analysed the social aspects, such as the consequences of the transformation of transport systems.

6.1.5 Eurometro (Project F6)

The problems

The "Eurometro" project consists in Swissmetro transposed to the European scale, while providing a system that would offer an alternative to air transport over short distances while, for example, linking Frankfurt to Rome and Madrid to Budapest. An increase in demand and greater distances especially could have a positive influence on the environment and energy consumption.

The objectives

This project aims to go in considerably greater depth into the preparatory work done by various highly specialised schools.

The methodology

Together with the EPFZ, the EPFL and other specialists, environmental and energy reports as well as sustainability for different scenari have been prepared.

6.2 PNR41 projects indirectly concerning Swissmetro

	No.	Applicant	Institute	Short title	Deadline
A	4	Joye Dominique	EPFL, IREC	Attractive combinations of means of transport	9.99
A	5	Meier-Dallach Hans-Peter	culture prospective	Social determining factors and leisure mobility	4.99
A	7	Elsasser Hans	ZH Uni, Geogr. Inst.	New communication media (EVITA I)	3.00
A	8	Probst André	UNIL, HEC	Virtual company communication (EVITA II)	3.00
A	11	Ratti Remigio	IRE Lugano	Mesuring accessibility	6.00
B	6	Marti Peter	Metron	Integrating into European networks: passenger transport	4.99
B	9	Rumley Pierre-Alain	EPFL, IREC	Multiservice logistic platforms	6.00
C	1	Egger Mark	Infraconsult	Cost and utility of protectiing Nature and the countryside	12.98
C	2	Keller Mario	Infras	MODUM (strategic model for environmental mobility)	12.99
C	5	Spillmann Werner	Baselr+Partner	Criteria for durable mobility	publ.
C	6	Spillmann Werner	Baselr+Partner	Evaluation of the durability of projets and strategies	10.99
C	7	Kaufmann-Hayoz Ruth	IKAÖ Uni Bern	“Durable Transport” strategy	4.00
C	8	Marti Peter	Metron	Transport and regional organisation	8.00
D	2	Lundsgaard-Hansen Niklaus	LHGP	Rail-based competition and supply	1.99
D	3	Maibach Markus	Infras	Fair and effective prices	12.98
D	5	Meier Ruedi	Bern	Leisure mobility strategies	6.99
D	7	Rey Michel	C.E.A.T.	Transport policy in border régions	6.99
D	8	Oliva Carl	Büro Oliva	Liberalisation of air traffic	4.99
D	9	Blöchliger Hansjörg	B,S,S.	Institutions and financing	6.99
D	10	Maggi Rico	Uni Lugano	Economic avantages of transport	6.00
D	12	Vatter Adrian	BE Uni	Acceptability: Referenda	8.00
D	13	Widmer Thomas	ZH Uni	Acceptability: Political processes	8.00
E	1	Holzinger Stefan	Aarproject	Information system for public transport users	publ./99
F	4	Brändli Heinrich	IVT ETHZ	Technical development potential of rail	publ.

7 EUROPEAN DEVELOPMENT

From Swissmetro ...

It is understandable that the Swissmetro transport system was designed and developed in Switzerland because the topography and urbanisation of the country and environmental protection do not today permit the building of high-speed railway lines of the TGV type. The application for a licence for the Geneva-Lausanne pilot line was deposited to avoid costly investment in an extra-network test site (the Transrapid concept) and also, by this official act, to give Swissmetro SA the necessary credibility for the development of the system on a broader territory than that of Switzerland alone.

... to Eurometro

In fact, from the very first studies, it quickly appeared that such a transport means of high-speed and high-frequency between the major European cities made it an ideal instrument of socio-economic development, while allowing daily access to the activities and services of the cities of major importance.

Participation of European companies

Foreign industrial companies, such as Daimler-Benz, Alstom, Dornier and Thyssen, demonstrated their understanding of the importance of what was at stake, either by becoming influential shareholders in Swissmetro SA, or by proposing their services in various forms.

The high cost of the industrial development of this new transport system also leads to a broadening of the circle of its promoters on a European, indeed worldwide scale.

Geneva - Lyons link

That is why, since 1998, contact has been made with the authorities of the Rhône-Alpes Region in order to study the socio-economic effects and feasibility of a fast link between Geneva and Lyons using Swissmetro technology. The Rhône-Alpes Region, the Canton of Geneva and Swissmetro SA will finance this study in equal share. An agreement is currently being drawn up and should be signed during the first half of 1999.

St Gallen - Munich link

Contacts of the same nature are being established with the *Land* of Bavaria, for a quick link between St.Gallen and Munich, thus confirming the priority placed on the East-West line between Lyons and Munich by way of Switzerland.

Other links

Other contacts will be made in 1999 for the study of network extensions from Basel to Bellinzona, towards Strasbourg - Stuttgart and to Milan.

Inter-regional loans

Swissmetro SA is also examining the possibility of financing all the studies of the international lines with loans from the Interreg II A programme or even the Interreg III B or C programmes (2000-2006 period).

Conclusion

The firm and resolute support of the federal and cantonal political authorities is an essential condition to the success of these measures.

8 INDUSTRIAL DEVELOPMENT

How the Swissmetro project is followed up is very obviously going to be influenced by the response of the Federal Counsel to the licence application for the Geneva-Lausanne pilot line, expected in early 1999**.**

Nevertheless, the Board of Directors of Swissmetro SA already started thinking about the measures to be taken as soon as the main study was complete.

Achievements of the main study

The achievements by the end of 1998 were:

- a draft infrastructural project which, after some furthers research (geo-technical probes), will make it possible to start planning the investigation and implementation of the Geneva-Lausanne pilot line, or to adapt it to other lines in Switzerland or abroad,
- a coherent set of electro-mechanical and mechanical solutions (aerodynamics, vacuum, heat and vehicle) allowing for the industrial development of the Swissmetro system, possibly with the contribution of Transrapid technologies,
- the first results of current experimental trials on scale models (STARLET).

Industrial development

The Board of Directors decided directly to start the industrial development phase on the vehicles and electro-mechanical and mechanical installations. It is not, in fact, unthinkable to pursue this development along the lines used for the main study, that is to say, the awarding of study and planning commissions followed by a call for tenders for the supply of the elements.

Integration of suppliers

As the industrial development of the system concerns essentially the electro-mechanical and mechanical aspects, the Board of Directors considered it essential that the suppliers immediately start to participate in the development and preparation of the elements that they will be required to supply, on the basis of specifications stipulating the objectives and the performances to be attained in each area. Furthermore, the industrial development phase must be conducted in a professional manner but Swissmetro SA does not have any an operational management that would permit it to assume this task. That is why the system will be developed by the main industrial associates, it being left up to them to choose and to control such associates and sub-contractors of which they may have need.

Hence, on the basis of the above plan, the Board of Directors is currently looking for Swiss and foreign industrial associates in order to be able to begin the industrial development phase as soon as possible.

9 CONCLUSIONS

Objectives attained

It may be considered that the objectives of the main study, viz.

- the choice of a pilot line and the filing of a licence application,
- the choice of technical, economic and political system options

have been attained, as Swissmetro SA is now in a position to enter the industrial development phase, even though some further studies are still necessary.

In comparison to the preliminary study, the results of which were presented in 1993, considerable progress has been made:

Technical feasibility

- The technical feasibility of the system in the main areas has been shown, even though it has, of course yet to be confirmed by 1:1 scale models. In most cases, a single solution will henceforth be proposed instead of variants. Choices still remain open in some areas where it is appropriate to leave the suppliers and builders a certain degree of freedom.

Traffic volume

- There are credible indications of the traffic volume Swissmetro can expect, partly because of the development of the Polydrome program, which permits the estimation of the modal transfer from motorway and railway networks.

Operational plan

- There is a rational operational plan together with the design of specific model infrastructures and equipment to carry it and models of synchronous and asynchronous schedules for running it.

Civil engineering

- The civil engineering aspect has been mastered, the designs being completed in the form of a preliminary draft and their feasibility has been shown, with the exception of the final nature of the sealing of tunnel linings on which tests are still being run.

Electro-mechanical

- There are experimental and numerical models of the propulsion, levitation, magnetic guidance, feedback control, motor energy supply and contactless energy transfer systems. A test bench for levitation at 400 kph has been completed, as well as a reduced-scale test installation for the envisaged motor. Conversely, a variant of an onboard motor is being developed in parallel with a view to effecting considerable investment savings. Finally, a Dornier study offers the possibility of envisaging the adaptation to the Swissmetro system of certain components developed by Transrapid, thus reducing the industrial development cost.

Mechanical

- In the mechanical area, there are solutions for the vehicles and the mechanical equipment which are ready to be developed and tested by specialised companies (airlock, barrel, partial vacuum and emergency repressurisation system, etc.)

Aerodynamics

- Considerable progresses has been made in the area of aerodynamics where there are now reliable mathematical models and test benches up and running or being set up to verify the parameters used and choose the best solution. The thermal aspects of aerodynamics, however, need further investigation in particular in regards to the tunnel and the vehicle.

Town and country planning and environmental protection

- The feasibility of Swissmetro in the town-and-country-planning and environmental-protection areas has been shown and the ancillary measures identified. Specifications have been drawn up for the impact studies, and impact study phase I has been completed for the pilot line and serves as a model for the future.

Safety

- There is a safety plan and set of safety guidelines to ensure that the reliability of the system is at least equal to, if not better than that of existing transport systems.

Economic and financial feasibility

- The economic and financial feasibility have been confirmed and there is an applicable financing model.

In short, Swissmetro:

- is a safe, attractive, high-performance, environmentally respectful public transport system with great operational flexibility,
- is probably, in the opinion of specialists, the transport system that should succeed high-speed trains of the TGV type as, beyond a commercial speed (average speed between departure and destination) of 280 to 300 kph, the operation of a surface train is no longer possible for reasons of cost, energy consumption, environmental nuisance and safety. This new transport system must be developed now, if it is to be operational in 10 or 15 years,
- is the means, on a Swiss and European scale, to create a metropolitan area, while allowing daily access to the activities and services of the cities of major importance and, at the same time, ensuring a good coverage of outlying regions by efficient regional transport systems,
- offers Switzerland and Europe an opportunity to assume a preponderant position among the industrialised countries that have decided to adopt high-performance public transport systems to boost their economic development and to cope with growing mobility,
- offers to the companies and countries that commit to this development the chance of occupying a leading position and of opening up promising markets.

In closing this report, Swissmetro SA wishes to express its deep gratitude to the political authorities and the federal, cantonal and municipal administrations, to the two Polytechnics, to the Swiss National Fund for Scientific Research, to all the representatives and companies in the private sector that made their skills available in the form of services rendered at their own risk, as well as to all the shareholders in the Company, for their technical and financial support throughout the main study. Without this tremendous effort, their confidence in the future and their enthusiasm, the Swissmetro project could not have made the progress that will soon enable it to move on the industrial development phase, both at Swiss and European level.

10 ANNEXES

10.1 List of associates and persons who participated in the main study

10.1.1 Companies and private consultants

Company	Contact person	Address	
Abay&Meier AG	Dr. Georg Abay	Ceresstr. 10	8008 ZURICH
ABB Sécheron SA	Harry Zueger	Case postale 2095	1211 GENEVE 2
AC Atelier Commun SA	Dominique Dériaz	Rue du Simplon 25	1006 LAUSANNE
AGBTS SA	André Grangier.	L'Aiguille-du-Pin	1845 NOVILLE
AGZ Arbeitsgruppe Zentralschweiz, p.a. Bucher + Dillier	Peter Bucher	Industriestrasse 6	6006 LUZERN
Albrecht & Partner	Bruno Albrecht	Murbacherstrasse 19	6003 LUZERN
Alcatel Câble Suisse SA	Alain Rochat	Av. François Borel	2016 CORTAILLOD
Alstom Suisse SA	Peter Schmutz	Case postale 183	5036 OBERENTFELDEN
Amberg IngenieurbüroAG	Felix Amberg	Trockenloostrasse 21	8105 REGENSDORF-WATT
Ambrosetti Holding SA	Richard Ambrosetti	Case postale 6015	1211 GENEVE 6
Amila Video&Film Production	Roberto Luzzani	Via Cantonale 3	6944 CUREGLIA
Amsler & Bombeli SA	Pierre Amsler	31, rue Chêne-Bougeries	1224 CHENE-BOUGERIES
ASS Architectes SA	Christine Delarue	40 av. du Lignon	1219 GENEVE
Bakoplan Elektro Ingenieure AG	Arthur Aepli	Neugutstrasse 88 Postfach	8600 DÜBENDORF
Basler & Hofmann	Felix Jenny	Bachweg 1	8133 ESSLINGEN
Techn. Beratungs- u. Forschungsstelle der Schweiz. Zementindustrie (TFB)	Dr. Fritz Hunkeler	Lindenstrasse 10	5103 WILDEGG
Beric SA	Jean-Robert Lorenzini	2 Bd. des Promenades	1227 CAROUGE
Betelec SA	Dominique Chambettaz	Chemin de Chantemerle 14	1010 LAUSANNE
Bonnard & Gardel	Alan Weatherill	Av. de Cour 61	1001 LAUSANNE
Bourgeois Géomètre	Jean-Jacques Bourgeois	Grand-Rue 9	1337 VALLORBE
Bucher + Dillier AG	Peter Bucher	Industriestr. 6	6003 LUZERN
Büchi + Müller AG	Dr. Michael Stockmayer	Zürcherstrasse 34	8501 FRAUENFELD
Burkhart Bauinformatik AG	Pierre Burkhart	Kuonimatt, Industriestr. 13	6010 KRIENS
Busch AG	Hans Steybe	Waldweg 22	4312 MAGDEN
C. von der Weid SA	Jean-Bernard Demont	11, av. Moléson	1701 FRIBOURG
Cemsuisse + TFB	Georges Spicher	Marktgasse 53	3011 BERN
CETP	Pierre Balegno	Route du Simplon 16	1094 PAUDEX

Chuard bureau d'ingénieur	Pierre Chuard	En Budron A2	1052 LE MONT/LAUSANNE
CIGLE Communauté des Ingénieurs	Jean-Jacques Bourgeois	Ch. de Chantemerle 14	1010 LAUSANNE
Colenco Power Engineering AG	Dr. Markus Hugi	Mellingerstrasse 207	5405 BADEN
Condis –Montena SA	Roland Gallay	Zone industrielle	1728 ROSSENS
Credit Suisse Grp	Werner Guyer	Trittligasse 2	8001 ZURICH
CSD - Ingénieurs Conseils SA	Felix Schmidt	Ch. de Maillefer 36	1052 MONT S/LAUSANNE
CVE, p.a. Romande Energie	Bettler Martin	Rue de Lausanne 53 CP	1110 MORGES 1
De Cérenville Géotechnique SA	Hervé Detrey	17, ch. des Champs-Courbes	1024 ECUBLENS
Dionea SA	Pippo Gianoni	Lungolago Motta 8	6000 LOCARNO
Dr. Heinrich Jäckli AG	Dr. Heinrich Jäckli	Limmattalstrasse 289	8049 ZÜRICH
Dr. Vollenweider AG	Kurt Boppart	Neue Jonastrasse 71	8640 RAPPERSWIL
Dr. Von Moos AG	Dr. Matthias Freimoser	Bachofnerstrasse 5	8037 ZÜRICH
Dornier System Consult Gmbh	Willi Mayer	Postfach 1306	D-88003 FRIEDERICHSHAFEN
EEF-Entreprises électriques fribourgeoises	André Sudan	Bd. Pérolles 25, CP 1044	1701 FRIBOURG
Electrowatt Engineering AG	Alberto Turi	Bellerivestrasse 36	8034 ZÜRICH
EZ Associates	Enrico Zuffi	Case postale 9	1226 THONEX
Fédération des Syndicats Patronaux	Dr. Pierre Weiss	Rue de St. Jean 98	1211 GENEVE 11
GEOFORM Geologische Beratungen	Dr. Werner Leu	Anton Graff-Strasse 6	8401 WINTERTHUR
Geol. Büro Dr. Lorenz Wyssling AG	Dr. Paul Felber	Lohzelgstrasse 5	8118 PFAFFHAUSEN
Géotechnique Appliquée Dériaz SA	Michel Odier	10 rue Blavignac	1227 CAROUGE
Geotest AG	Dr. Hans-Rudolf Keusen	Birkenstrasse 15	3052 ZOLLIKOFEN
Gillièron Electronique SA	Claude Gillièron	Chemin Buvelot 2	1110 MORGES
Grundbauberatung AG	Dr. Hans Kapp	Helvetiastrasse 41	9000 ST.GALLEN
Fachhochschulen Bern u. Zentralschweiz	Walter Ernst	Pestalozzistrasse 20	3400 BURGDORF
Huber + Suhner AG	Thomas Cantz	Tumbelenstrasse 20	8330 PFÄFFIKON
IG Zürich, p.a. Schindler + Schindler	Dr. Johannes Schindler	Albistrasse 103	8038 ZÜRICH
ILF Beratende Ingenieure Gmbh	Bernhard Kohl	Lustenauerstrasse 9	A-4020 LINZ
ILF Beratende Ingenieure AG	Günther Strappler	Richard-Wagner-Strasse 6	8027 ZÜRICH
Infraconsult SA	Claude Hilfiker	37, av. du Lignon	1219 LE LIGNON
IST- Institut de la santé au travail	David Vernez	rte du Bugnon 19	1005 LAUSANNE
Jenni + Gottardi AG	Dr. Giovanni Gottardi	Hornhaldenstrasse 9	8802 KILCHBERG/ZÜRICH
Karakas & Français SA	Olivier Français	Bd de Grancy 19A	1006 LAUSANNE
Küng et associés SA	Pierre-Alain Matthey	Av. de Beaulieu 43	1004 LAUSANNE
Lienert & Haering AG	Christoph Haering	Poststrasse 4	9113 DEGERSHEIM
Locher	André Hagmann	Chemin Isaac Anken 8-10	1219 GENEVE-AÏRE
Losinger Holding SA	Philippe Pot	Route du Grenet 14	1074 MOLLIE-MARGOT
M. Kobel + Partner AG	Dr. Max Kobel	Grossfeldstrasse 74	7320 SARGANS
Mantilleri, Bureau d'ingénieurs	Roland Mantilleri	Bd des Promenades 2	1227 CAROUGE
Matousek, Baumann & Niggli AG	Dr. Federico Matousek	Mäderstrasse 8	5401 BADEN
Mengis+Lorenz AG	Dr. Beat Keller	Schlossstr. 3	6005 LUZERN
Mettler Rudolf		Belmontstrasse 1	7006 CHUR
Norbert Géologues Conseil SA	Georg Schaeren	6, rue Enning	1003 LAUSANNE
NTB-Neutechnikum, Buchs	Prof. Roland Rebsamen	Werdenbergstrasse 4	9470 BUCHS
OFEL – Office d'électricité de la Suisse romande	Dr. François Gaille	Case postale 534	1003 LAUSANNE
Otis	Gilbert Monneron	Case postale 1047	1701 FRIBOURG
Passera + Pedretti SA	Mauro Pedretti	Via al Molino 6	6916 GRANCIA
Perret-Gentil, Rey et Associés SA	Jacques Bize	Rue de la Villette 34	1400 YVERDON 3
Perss, Ingénieurs conseils SA	René Crisinel	Rue de l'Industrie 8	1020 RENENS
Pétignat bureau d'ingénieurs	Jean Pétignat	Rue de la Paix 11	1820 MONTREUX
Pilatus Aircraft Ltd	Dr. P. Masefield		6370 STANS

Polysoft Consulting	Jean-Michel Blumenthal	3, rue des Buis	1202 GENEVE
RBA Réalini Bader et Associés SA	Jean-Paul Vuillemin	Av. Bois-de-la-Chapelle 15	1213 ONEX
Rudolf Keller & Partner	Rudolf Keller	Gartenstrasse 15	4132 MUTTENZ
SA Conrad Zschokke	Jules Wilhelm	Chemin Isaac Anken 8-10	1219 GENEVE-AÏRE
SBB Kreis 2	Peter Hünkeler	Schweizerhof G6	6002 LUZERN
Schärlig Alain Prof.		19, chemin du Calabry	1233 BERNEX
Schindler & Schindler	Dr. Johannes Schindler	Albistrasse 103	8038 ZÜRICH
SEL- Service de l'électricité de la Ville de Lausanne	Bernard Krummen	Case postale 836	1000 LAUSANNE 9
SF Schweizer Flugzeuge und Systeme	Dr. Martin Monkewitz	Postfach 301	6032 EMMEN
Sieber Cassina + Partner AG	Dr. Nick Sieber	Langstrasse 149	8004 ZÜRICH
SIG- Services industriels de Genève	Bernard Bugnon	Case postale 2777	1211 GENEVE 2
Steigerpartner	Jürg P. Branschi	Klausstrasse 20	8034 ZURICH
Systems Consult	Casimir de Rham	Les Abeilles 7 Blvd d'Italie	MC-98000 MONACO
Theiler+Kalbermatter Bau AG	Peter Theiler	Obergütschrain 2	6003 LUZERN
Thyssen Transrapid System Gmbh (TTS)	Dr. Lässer	Anzingestrasse 11	D-81671 MUNICH
Transrapid International Gmbh	Manfred Wackers	Pascalstrasse 10	D-10587 BERLIN
Tradoc SA	Jean-Werner Signer	Rue Verdaine 4bis	1095 LUTRY
University of Dundee	Alan E. Vardy	Dunholm 512 Perth Road	GB- DUNDEE DD2 ILW
Urbaplan	Fred Wenger	Montchoisi 21	1006 LAUSANNE
von der Weid SA	Jean-Bernard Demont	11, avenue Moléson	1700 FRIBOURG
Wyss Roland	Dr. Roland Wyss.	Staubeggstrasse 23	8500 FRAUENFELD
ZS Trafitec SA	Michel Savary	2, rue des Grand-Portes	1213 ONEX-GENEVE

10.1.2Research institutes and laboratories

Swiss Federal Institute of Technology Lausanne (EPFL)

Polytech.	Institute or laboratory	Contact person	Address	
EPFL	DE-LEME	Prof. Jufer Marcel	EL-Ecublens	1015 LAUSANNE
EPFL	DE-LEI	Prof. Rufer Alfred	EL-Ecublens	1015 LAUSANNE
EPFL	DGC-ITEP-LEM	Prof. Perret Francis-Luc	GC-Ecublens	1015 LAUSANNE
EPFL	DA-IREC	Prof. Bassand Michel	Av.de l'Eglise Anglaise	1001 LAUSANNE
EPFL	DA-IREC	Prof. Rumeley Pierre-Alain	14, Av.de l'Eglise Anglaise	1001 LAUSANNE
EPFL	ESST	Dr Rossel Pierre	INR 112	1001 LAUSANNE
EPFL	DGC-ISRF	Prof. Descoeudres François	GC- Ecublens	1015 LAUSANNE
EPFL	DGM-IMHEF	Prof. Deville Michel	ME-Ecublens	1015 LAUSANNE
EPFL	DGM-IMHEF	Prof. Monkewitz Peter	ME-Ecublens	1015 LAUSANNE
EPFL	DGC-IBAP	Prof. Badoux Marc	GC-Ecublens	1015 LAUSANNE

Swiss Federal Institute of Technology Zurich (ETHZ)

Polytech.	Institute or laboratory	Contact person	Address	
ETHZ	D-ERDW	Prof. Conrad Schindler	ETH- Hoenggerberg/HIL D21-3	8093 ZURICH
ETHZ	D-ELEK	Prof. Hans Glavitsch	ETH-Zentrum./ETL G29	8092 ZURICH
ETHZ	D-ELEK	Prof. Herbert Stemmler	ETH-Zentrum / ETL H22	8092 ZURICH
ETHZ	D-ERDW, Geologie	Prof. Simon Löw	ETH- Hoenggerberg/HIL D 21.3	8093 ZURICH
ETHZ	D-ARCH	Dr. Alfred Moser	ETH-Zentrum / LOW E2	8092 ZURICH
ETHZ	D-BAUM	Prof. Gerhard Girmscheid	ETH-Hoenggerberg, HIL F 23.3	8093 ZURICH
ETHZ	D-BAUM, IVT	Prof Heinrich Brändli	ETH Hoenggerberg, HIL F 33.3	8093 ZURICH

ETHZ D-UMNW	Prof. Thomas Baumgartner	Haldenbachstr. 44, HAD F 2	8006 ZURICH

10.2 List of publications dealing with Swissmetro

10.2.1Publications

- The 14th International Conference on Magnetically Levitated Systems – Maglev 95, 26-29 November 1995, Bremen, Germany
  - *High Speed Underground Transportation System Propulsion, Levitation and Guiding System*. EPFL, Prof. M. Jufer, Dr A. Cassat, N. Macabrey,
  - *Contactless Induction Energy Transmission System for High Speed Vehicles- Application to Swissmetro*. EPFL, N. Macabrey.
- AIDAA; XIII congresso nazionale, Roma 11-15 September 1995. *Studio aerodinamico di treni ad alta velocita in tunnel.* M. Mossi, V. Bourquin, M. Deville.
- AFTES, Bruxelles, décembre 1996. *Swissmetro - Transport interrégional à grande vitesse*. F. Descoeudres, R. Mantilleri et Y. Trottet.
- AAAF – 33ème colloque d'aérodynamique appliquée: 4.34-4.38, Poitiers, Mars 1997. *Simulation numérique de l'écoulement d'air autour d'un train évoluant à haute vitesse dans un tunnel.* M. Mossi, V. Bourquin, J.B. Vos et M. Deville.
- 9th International Symposium on Aerodynamics and Ventilation of Vehicle Tunnels, Aosta, Italy, 6-8 October 1997. *Simulation of CompressibleFlow Phenomena in the Swissmetro Tunnel Network.* EPFL, Alexander Rudolf.
- World Congress on Railway Research, Florence, November 1997. *The importance of aerodynamics on the design of high-speed transportation systems in tunnels: an illustration with the TGV and the Swissmetro*. V. Bourquin, M. Mossi, R. Grégoire and J.M. Réty.
- Safety in Road and Rail Tunnels, ITC, Nice 9-11 March 1998. *Development of a safety concept for Swissmetro an innovative transport idea for Switzerland*. EPFL,Y. Trottet & ILF, B. Kohl
- The 15th International Conference on Magnetically Levitated Systems and Linaer Drives - Maglev 98, 15-18 April 1998, Mt Fuji, Yamanashi, Japan
  - *Swissmetro project*. EPFL, Prof. M. Jufer
  - *Electromechanical Aspects of the Swissmetro Pilot Track Geneva* – Lausanne,,EPFL, Dr A. Cassat
  - *Power Supply for a High-Power Propulsion System with Short Stator Linear Motors*. ETHZ, M. Rosenmayr, A. Cassat, H. Glavitsch, H. Stemmler

10.2.2Theses completed

- *L'ingénierie économique et financière des grands jets d'infrastructure, modèle appliqué au projet Swissmetro.* Pascal Gentinetta, Universität St. Gallen, 1997, ISBN 3-258-05725-7
- *Etude de réglage en position de la sustentation magnétique par attraction*, Michel Zayadine, (thèse n°1508)EPFL 1996.
- *Simulation of compressible flow in tunnel systems induced by trains traveling at high speed.* Alexander Rudolf (thèse n°1806), EPFL 1998.
- *Alimentation et guidage linéaires sans contact.* Nicolas Macabrey (thèse n°1840), EPFL 1998.

10.2.3Theses under preparation

- *Simulation of benchmark and industrial unsteady compressible turbulent fluid flows*. Michele Mossi, (thèse n°1958), EPFL 1999.

- *Analyse de risque lors de la conception de projets novateurs : application au Swissmetro.* David Vernez, (thèse n°1946), EPFL 1999.
- *Problems of reduced-scale aerodynamic testing of high-speed vehicles intunnels.* Vincent Bourquin, (thèse n°1973), EPFL 1999.
- *SWISSMETRO - Power Supply and Control for Linear Motor.* Marc Rosenmayr, ETHZ 1999.
- SWISSMETRO-Die USM im Raum Lausanne-Genf: Relation zwischen Geologie, Geotechnik und dem mechanisierten Untertagebau. David Estoppey, ETHZ 2000

10.2.4Articles that have appeared in specialised reviews

- Die Volkswirtschaf, Februar 1994- *Swissmetro, eine Chance zur Neubelebung für die Schweitzer Industrie.* Prof. M. Jufer, Prof. F-L. Perret
- La Vie économique, février 1994 – *Swissmetro, une chance de renouveau pour l'industrie suisse.* M. Jufer, Prof. F-L. Perret
- Les cahiers de l'électricité n°27, mars 1995 – *L'étude principale est engagée, l'heure de vérité en 1998*. Prof. M. Jufer
- Tunnel 8/1996 (ISSN0722-6241), *Stand des Swissmetro-Projektes, Level of Progress reached by the Swissmetro Project*
- Rail International, 11.96, SWISSMETRO - *Le défi des transports de la prochaine génération -The transport challenge of the next generation- Der Verkehr der nächsten Generation als Herausforderung.* Prof. M. Jufer
- Schweizer Ingenieur und Architekt 51/52, 18.12.97*, Swissmetro-Untertagebauten und Pilotstrecke Genf-Lausanne.* Marc Badoux et J. Wilhelm
- De Ingenieur N° 21 (ISSN 0020-1146), 10.12.97, *Swissmetro, ondergrondse trein met snelheid van 500 km/h, HSL is een boemeltje.* Prof. F-L. Perret
- Schweizer Baublatt n° 5, 13.1.98, *Konzessionsgesuch für ertse Swissmetro-Strecke eingereicht, Technologie unterirdischer Personenschnellbahn*.
- Vision-Science and Innovation in Switzerland, 1/98, Swissmetro*, Much more than just a tunnel vision*. M. Jufer
- Technique des transports en Suisse, 1998. *Swissmetro : les ouvrages souterrains du tronçon pilote Genève – Lausanne.* Dr. M. Badoux, J. Wilhelm
- Bulletin ASE/UCS 12/1998. *Swissmetro : tronçon pilote Genève-Lausanne, aspects électromécaniques*. A. Cassat, N. Macabrey, M. Jufer
- Bulletin ASE/UCS 12/1998. *Stratégies de réglage pour la sustentation et le guidage magnétique des véhicules de Swissmetro.* S. Colombi, A. Rufer, M. Zayadine, M. Girardin
- Industries et Techniques, nov. 1998 (ISSN01506617). Un train sous vide sous la Suisse. Th. Mahé
- Revue E n°1-2/98 (décembre 1998) (ISSN0770024. *Les trains d'avant-garde vus par les électriciens, Swissmetro le rôle de l'électrotechnique*. Prof. M. Jufer, A.Cassat

10.3 Acronyms

- ADT : Average Daily Traffic
- DETEC : Département fédéral de l'environnement, des transports, de l'énergie et de la communication
  (Federal Department of Transport, Energy and Communications)
- DFI : Département fédéral de l'intérieur *(Swiss Home Office)*
- DFE : Département fédéral de l'economic *(Swiss Ministry of the Economy)*
- FNRS : Fonds national suisse de la recherche scientifique
  (Swiss National Fund for Scientific Research)
- OFEN : Office fédéral de l'énergie *(Swiss Ministry of Energy)*
- PNR41 : Programme national de recherche 41 : Transports et environnement
  (National Research programme 41: Transport and the Environment)
- OFS : Office fédéral de la statistique *(Swiss Federal Statistics Office)*
- OCFIM : Office central fédéral des imprimés et du matériel *(Swiss Government Publishing Office)*
- CTI : Commission pour la Technology et l'innovation *(Technology and Innovation Commission)*
- SET : Service d'étude des transports *(Transport Study Service)*
- SGZZ : St. Galler Zentrum für Zukunftsforschung
  (St. Gallen Centre for Futuristic Research)
- EWE : Electrowatt Engineering
- CEPF : Conseil des écoles polytechniques fédérales *(Board of Federal Polytechnics)*
- HISTAR : High-speed Train Aerodynamic Rig
- STARLET : Shock Tube for the Aerodynamic Research on Long and Enhanced Tunnels
- NTB : Neutechnikum Buchs *(Buchs New Technical College)*

- EPFL : Ecole polytechnique fédérale de Lausanne
  (Swiss Federal Institute of Technology, Lausanne)
  - ESST : European Society of Science & Technology
  - IBAP : Institut de béton armé et précontraint (Reinforced and Prestressed Concrete Insitute)
  - IMHEF : Institut de machines hydrauliques et de mecanique des fluides
    (Institute of Hydraulic Machinery and Fluid Mechanics)
  - ITEP : Institut des transports et de la planification *(Institute of Planning and Transport)*
  - IREC : Institut de recherche sur l'environnement construit
    (Institute of Research into the Man-made Environment)
  - ISRF : Institut des sols, roches et fondations *(The Soil, Rock and Foundations Institute)*
  - LEME : Laboratoire d'électromechanique et de machines électriques
    (The Electro-mechanical and Electrical Machinery Laboratory)
  - LEI : Laboratoire d'électronique industrielle *(The Industrial Electronics Laboratory)*

- ETHZ : Eidgenössische Technische Hochschule Zurich
  (Swiss Federal Institute of Technology,Zurich)
  - BAUM : Bau und Umwelt *(Construction and Environment)*
  - ELEK : Elektrotechnik *(Electro-Technology)*
  - LEM : Leistungselektronik und Messtechnik *(Power Electronics and Metrology)*
  - EEH : Institut für Elektrische Energieübertragung und HochspannungsTechnology

(Institute for Energy-Transfer and High-Voltage Technology)

- ERDW : Department of Earth Sciences
- MAVT : Maschinenbau und Verfahrenstechnik *(Machinery Construction and Process technology)*
- IBB : Institut für Bauplanung und Baubetrieb *(Construcion-Planning and Contracting Institute)*
- IVT : Institut für Verkehrsplanung, Transporttechnik, Strassen- und Eisenbahnbau *(Traffic-Planning, Transport Technology, Highway and Railway Construction Institute)*
- UMNW: Umweltnaturwissenschaften *(Environmental Sciences)*