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FÉDÉRALE DE LAUSANNE

SWISSMETRO

SYNTHESE DER VORSTUDIE

SWISSMETRO

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THE FEASIBILITY OF SWISSMETRO

1 THE CONCEPTION OF SWISSMETRO

1.1 GENERAL LAYOUT

The objective of Swissmetro is to strengthen the complementary of the principal urban centres of Switzerland by means of an ultra-efficient transport system from a point of view of travel time, frequency, cost and safety, whilst taking the demands of environmental protection and energy conservation into account.

If we consider the Swiss central plateau as a region with a very high density of population, spread over a distance of approximately 300 kilometres, with city centres (Geneva, Lausanne, Berne, Lucerne, Zurich, St. Gall) each situated between 40 and 80 kilometres apart, cultivated and exploited by all manner of activities, then the problem of developing a new transport network to be superimposed on the existing ones has to be seen in terms of distinct and multiple constraints. The solution calls for a high-capacity, high-speed line that is virtually independent of the already severely overburdened surface: the idea of constructing a supermetro system seems highly logical.

The above-mentioned east-west line also logically gives rise to the question of a second network running from north to south, crossing the barriers imposed by the Jura range and the Alps, to link Basle and the plain of Alsace with Ticino, via Lucerne or Zurich (Fig. 1.1), with the possibility of connections to the European high-speed rail network, and other subsequent developments.

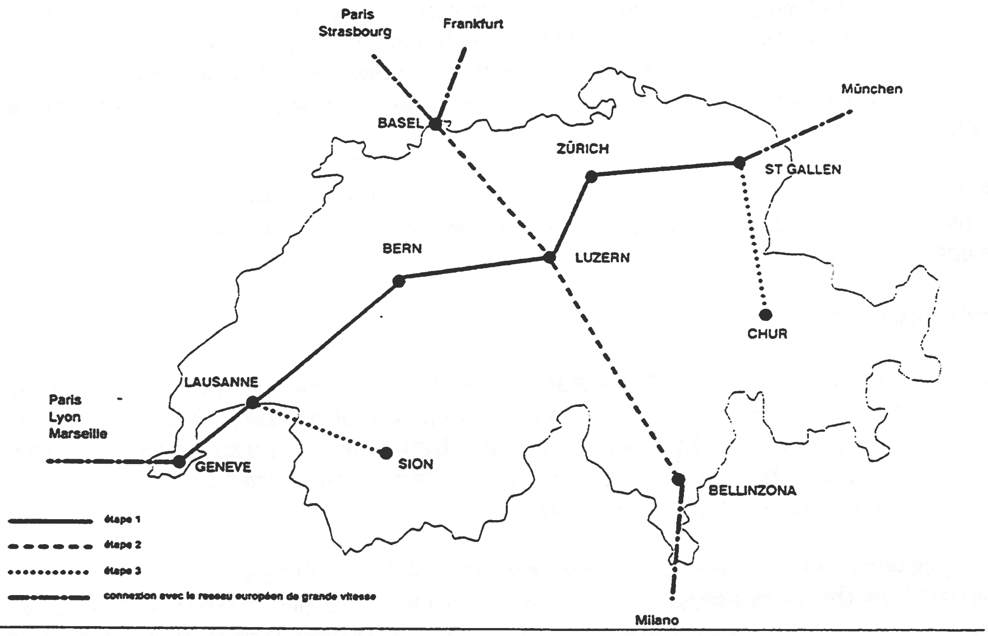


Figure 1.1
The projected Swissmetro network: the two transversals, potential extensions, and connections with the European high-speed rail network.

1.2 TECHNOLOGIES INVOLVED

The Swissmetro project is based on the application of four complementary technologies:

- an entirely subterranean infrastructure in the form of two tunnels of narrow diameter (approximately 5 metres), with stations connected to the existing public transport networks;
- a partial vacuum maintained in the tunnels, to reduce the energy requirements for propelling the pressurised vehicles, and based on the airframe principle;
- a propulsion system using linear electric motors interdependent of the tunnels themselves;
- a magnetic levitation and guidance system allowing high velocities of around 400 kph between the urban centres linked by the underground network.

Infrastructure

A relatively detailed preliminary study of the infrastructure has been carried out for the section Lausanne-Berne, from which it has been possible to derive information and figures applicable for the entire line from Geneva to St. Gall. The average depth of the line is several tens of metres below the surface, passing through the sandstone substratum of the Swiss central plateau. The tunnels, with their underground installations and connections to the surface, urban stations and intermediary shafts for construction and operation, represent around three-quarters of the project's total costs. This is of decisive importance: multi-criteria studies concerning the choice of the layout and system options will permit the optimisation of the overall construction and operation.

For the east-west axis, the geological conditions are fairly well known, and are regular and suitable for excavation by tunnelling machines. Experience gained from galleries excavated in the sandstone layer with diameters similar to those required by the project - between 4.5 and 5.0 m - has been the subject of a number of studies such as those carried out for the underground accelerators at CERN, pilot galleries for motor way tunnels, and hydraulic galleries.

The profile of the tunnels (Fig. 1.2) provides for prefabricated support walls installed under the protection of a shield in a process similar to that associated with standard tunnel construction.

Vacuum technology

Travel in a vacuum offers the advantage of considerable energy savings with regard to the propulsion of the vehicles, and thus lower overall operating costs. There is barely another solution for achieving very high velocities in a tunnel with a circumference limited to that of the vehicle itself, in which the piston effect would not otherwise quickly become an obstacle that is incompatible with such speeds.

The air pressure would need to be reduced to 1'000-10'000 Pa (0.01 to 0.1 atm), which corresponds to the atmospheric conditions at approx. 15'000 metres asl. The generation and maintenance of the vacuum can be carried out by means of pumps already available on the market.

Propulsion

Vehicles propelled by linear motors and suspended over their supports by a magnetic force have already been developed in Germany and Japan.

Contrary to the general notion according to which an engine is carried by a vehicle, the Swissmetro system will be propelled by linear motors affixed to the tunnel, with inductors linked in tern to the vehicle. The arrangements of the motors, as well as their capacities, will depend on economic factors and on aspects relating to the comfort of the passengers.

The preliminary study has indicated that for the distances separating the main urban centres of Switzerland, maximum speeds of around 400 to 500 kph will be attainable, with an energy consumption per passenger lower than that of systems such as Intercity trains or the TGV.

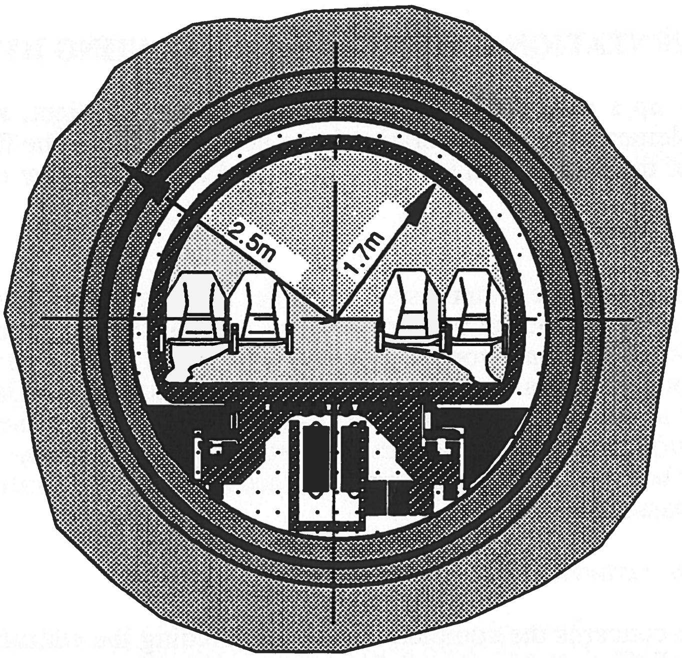


Figure 1.2 Profile of the tunnel and the Swissmetro vehicle.

Magnetic levitation

Only magnetic levitation is capable of ensuring economical guidance at velocities in excess of 300 kph. Furthermore, it eliminates wear and tear, which leads to a significant saving of costs for maintenance and replacement of materials. Audible noise, too, is entirely eliminated.

If a breakdown were to occur in the propulsion system, this would not affect the levitation system since the power for these systems comes from two different sources. In the worst case, the vehicle would land on its brake shoes and would be slowed down mechanically by means of friction.

Vehicles and stations

The Swissmetro vehicle would display many analogies to an airframe. The envisaged diameter is 3.6 m, and the overall length of the vehicle would probably be around 200 m. The pressurised and comfortable interior would provide seating for some 800 passengers. Airlocks and automatic gates at stations would provide access to and from the Swissmetro. The vehicle would be equipped with safety equipment for use only in exceptional circumstances: this includes shoes for braking and guidance, emergency wheels, plus an autonomous motor to enable the Swissmetro to reach the next station or an emergency exit.

The travel conditions would be similar to those encountered in an aircraft. Since the techniques of airframe construction have now been fully mastered, the production of the actual vehicles should present no additional problem.
The subterranean stations would need to be connected to the existing public transport networks by means of efficient mechanical systems. Their actual locations will obviously depend on the particular conditions at each individual urban centre: beneath main railway stations, if accessibility and parking are sufficient, or beneath outlying stations or on the outskirts if this is not the case, or, in the case of Geneva and Zurich, beneath the airports.

1.3 IMPLEMENTATION SCHEDULE AND OPERATING HYPOTHESES

In order to draw up a realistic budget for the Swissmetro project, a set of hypotheses regarding its implementation and operation have been proposed. The first point is that the overall network of the Swissmetro is to be constructed in two separate phases.

Phase 1: Geneva - St. Gall

The operation of a single line system is very simple. The first phase involves the Geneva to St. Gall axis, which would be put into operation as soon as the construction work has been completed. The Swissmetro network comprises two parallel tubes (one for each direction), linking six stations (Geneva-Lausanne-Berne-Lucerne-Zurich-St. Gall). The system is intended to allow an identical travel time of twelve minutes for each section, regardless of distance, and a stop of three minutes at each station. The operating frequency of four vehicles per hour both ways would be simple to accomplish. The capacity of each vehicle is eight hundred passengers.

Phase 2: Complete network

The second phase concerns the complete network, including the additional sections Basle-Bellinzona, St. Gall-Chur and Lausanne-Sion. Work will commence following completion of phase 1. The same method of operation is foreseen for these new sections. This means that a total of 32 underground vehicles would be required to operate the completed system.

2 DEMAND

2.1 DEVELOPMENT OF PASSENGER TRAFFIC AND ITS MODAL DISTRIBUTION

Swiss transport statistics demonstrate the dramatic nature of the development of passenger traffic in Switzerland since 1950, and the marked contrast between the evolution of road and rail traffic (Fig. 2.1).

The road traffic figures include the total of all services carried out on all roads (national, cantonal and local). In order to estimate the traffic volume on the Swissmetro system, short journeys of only a few kilometres should not be taken into account.

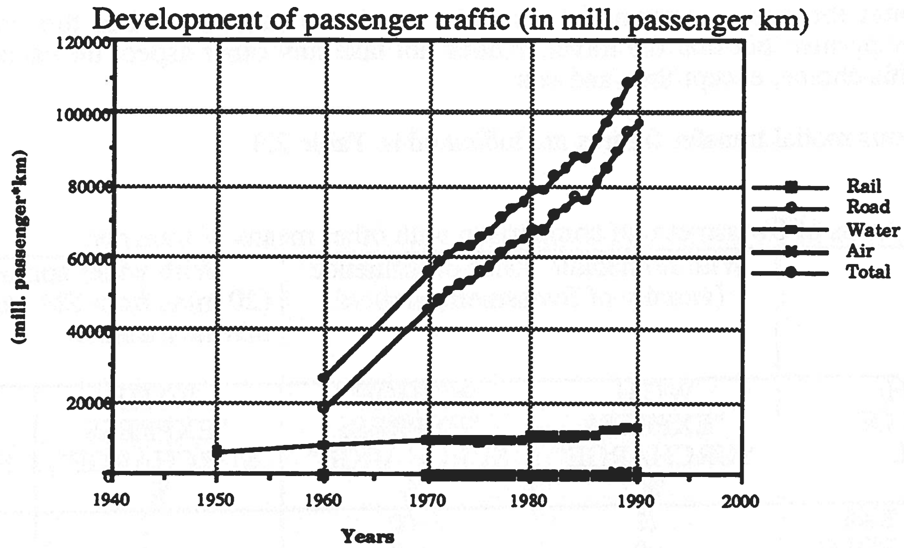


Figure 2.1 Modal development of passenger traffic in Switzerland

Figure 2.2. shows the importance of the two main means of transport, namely road and rail, and the reversal of preponderances since the beginning of the 1950s.

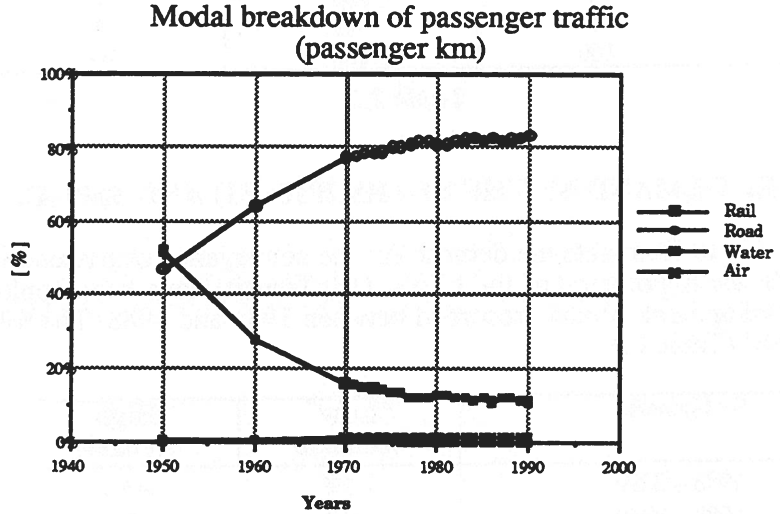


Figure 2.2 Development of the modal distribution of passenger traffic in Switzerland

2.2 INFLUENCE OF SWISSMETRO ON THE MODAL DISTRIBUTION

The introduction of a new public transport network will clearly attract a proportion of the flow of passengers currently using the existing and competing means of transport, i.e. rail, road, air.

In order to provide figures for the probable transfer from existing means of transport to the Swissmetro, a very rudimentary "price/time" model has been used, which nonetheless proved to be very reliable in estimating general traffic figures for the introduction of the French high-speed train service, the TGV.

The model is based on the choice a user will make between a faster and more expensive means of transport, and a slower but cheaper alternative. This choice is made according to the amount the user is prepared to spend in order to save time. For this model, it is expressly pointed out that the traveller does not take any other aspect into account when making his choice, except time and cost.

The various modal transfer figures are indicated in Table 2.3.

Attractiveness of Swissmetro in comparison with other means of transport

		With immediate zones of influence (vicinity of Swissmetro station)		With wider zones of influence (20 mins from SM station by private transport)	
LENGTH/ MEANS OF TRAVEL		WITH "EXPRESS SURCHARGE" %	WITHOUT "EXPRESS SURCHARGE" %	WITH "EXPRESS SURCHARGE" %	WITHOUT "EXPRESS SURCHARGE" %
50 km	RAIL	12	100	2	4
	ROAD	0	0	0	0
100 km	RAIL	33	100	6	10
	ROAD	4	7	0	1
200 km	RAIL	47	100	18	28
	ROAD	13	21	9	14
300 km	RAIL	62	100	28	40
	ROAD	32	49	28	42
	AIR	100	100	100	100

Table 2.3

2.3 TRAVEL DEMAND BY THE YEARS 2010 (E1) AND 2040 (E2)

In order to be able to formulate the demand for the conveyance of passengers for the years 2010 and 2040, the hypotheses of the NLFA (AlpTransit) have been applied, taking into account the developments already recorded between 1984 and 1988. The following figures are thus obtained (Table 2.4):

% Growth	"Low" scenario	"High" scenario
1988 – 2010	+ 2%	+ 5%
1988 – 2040	+ 4%	+ 26%

Table 2.4

The graph in Figure 2.5 represents the number of passengers x km per year conveyed by Swissmetro for the three scenarios and the three estimated levels.

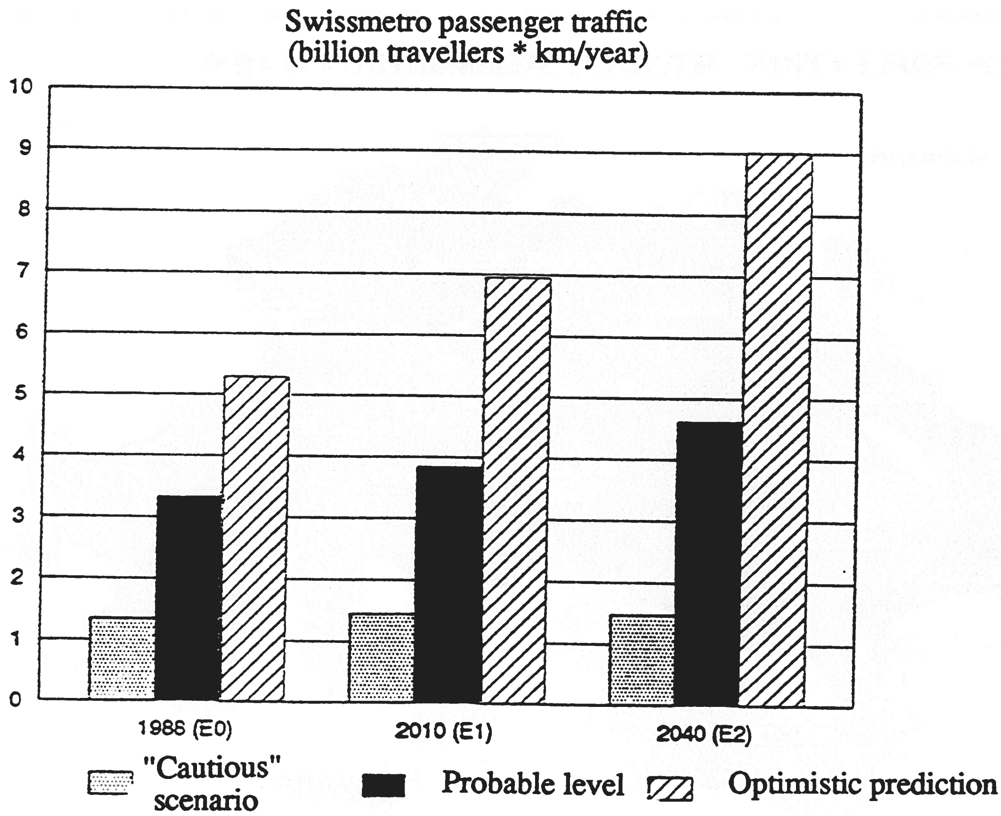


Figure 2.5 Annual Swissmetro passenger traffic

3 POTENTIAL IMPACT ON MOBILITY

The analyses of passenger travel trends since 1950 and of transalpine freight carriage emphasise a constant high growth-rate. Although fluctuations in the economy have caused a number of short-term interruptions of these tendencies on occasion, the growth-rate of the overall travel volume remains steady. The tendencies with regard to modal distribution during the same period indicate a marked predominance of road over rail, both for freight carriage and passenger traffic. Whilst in 1950, the proportion of total passenger kilometres between the urban centres of Switzerland by rail was over 50%, today it is only 18%, with road transport now absorbing over 80%.

How can these negative trends be fundamentally modified, so that travel habits can be reoriented towards the use of public transport, when we are aware of the passivity of consumer habits and behaviour? Two types of solution can be conceived. The first, with the demands of environmental protection as its goal, calls for far-reaching measures such as the recourse to coercive methods of restricting the free use of individualised and motorised means of transport. The second possibility, based on a principle of incentive, is more appealing in a free-market economy, though in fact is often impossible to implement today in view of a lack of available funds or the necessary technology. But Swissmetro could provide an alternative which would help bring about a major change with regard to inter-urban travel trends, thanks to its appeal resulting from the combined pre-defined criteria of fast travel, safety, convenience, standardised transport cost, etc.

The network to be introduced in two stages, and covering Swiss territory in the form of a double transversal - from Geneva to St. Gall, and later Chur, and from Basle to Bellinzona via Lucerne - has to be viewed from a European perspective with respect to links with other means of transport, notably in the direction of the two main "neighbouring" airports.

The impact of such a network on the potential mobility of the population can be conveniently illustrated in the form of a map, which shows the number of persons

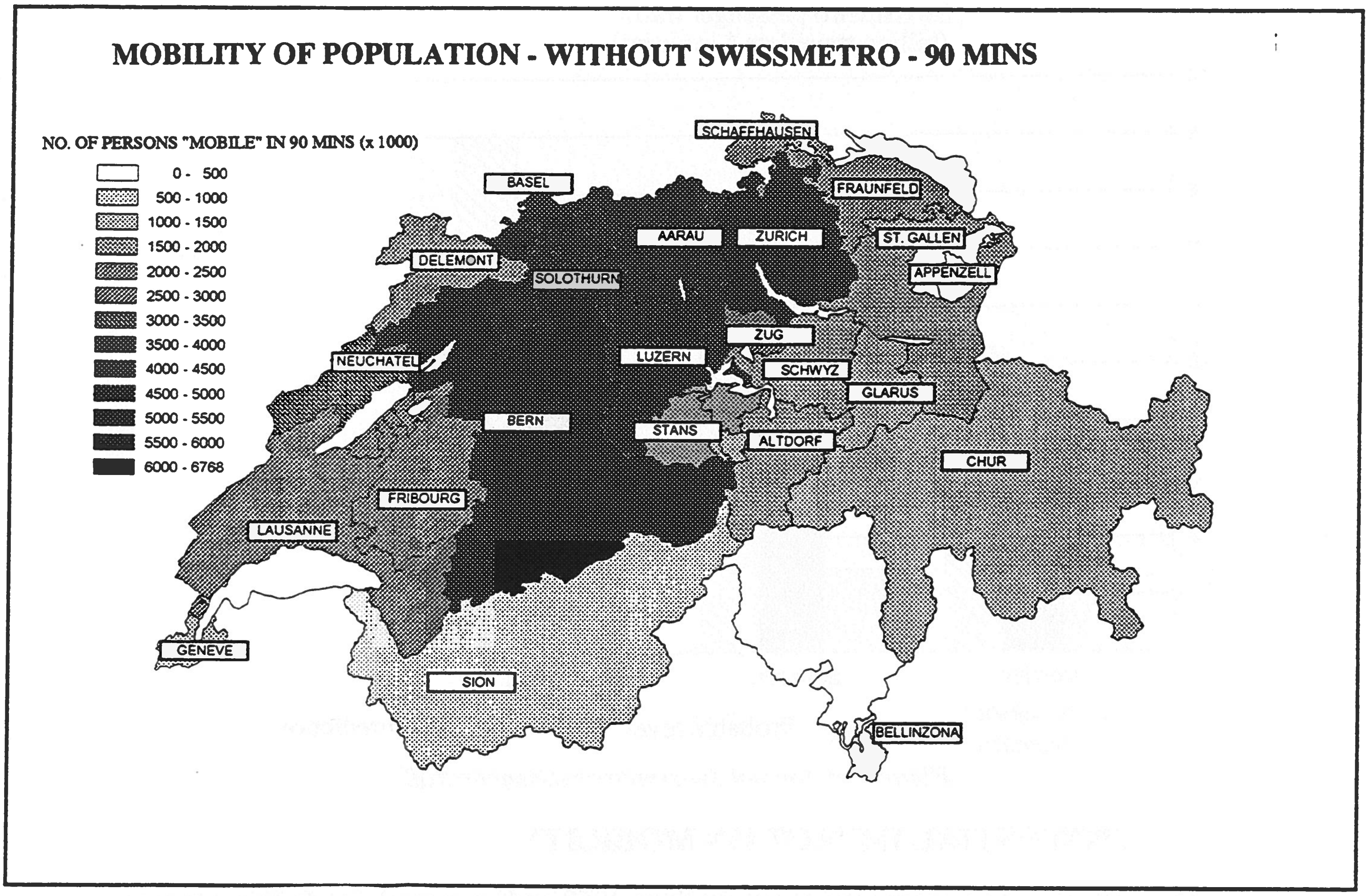
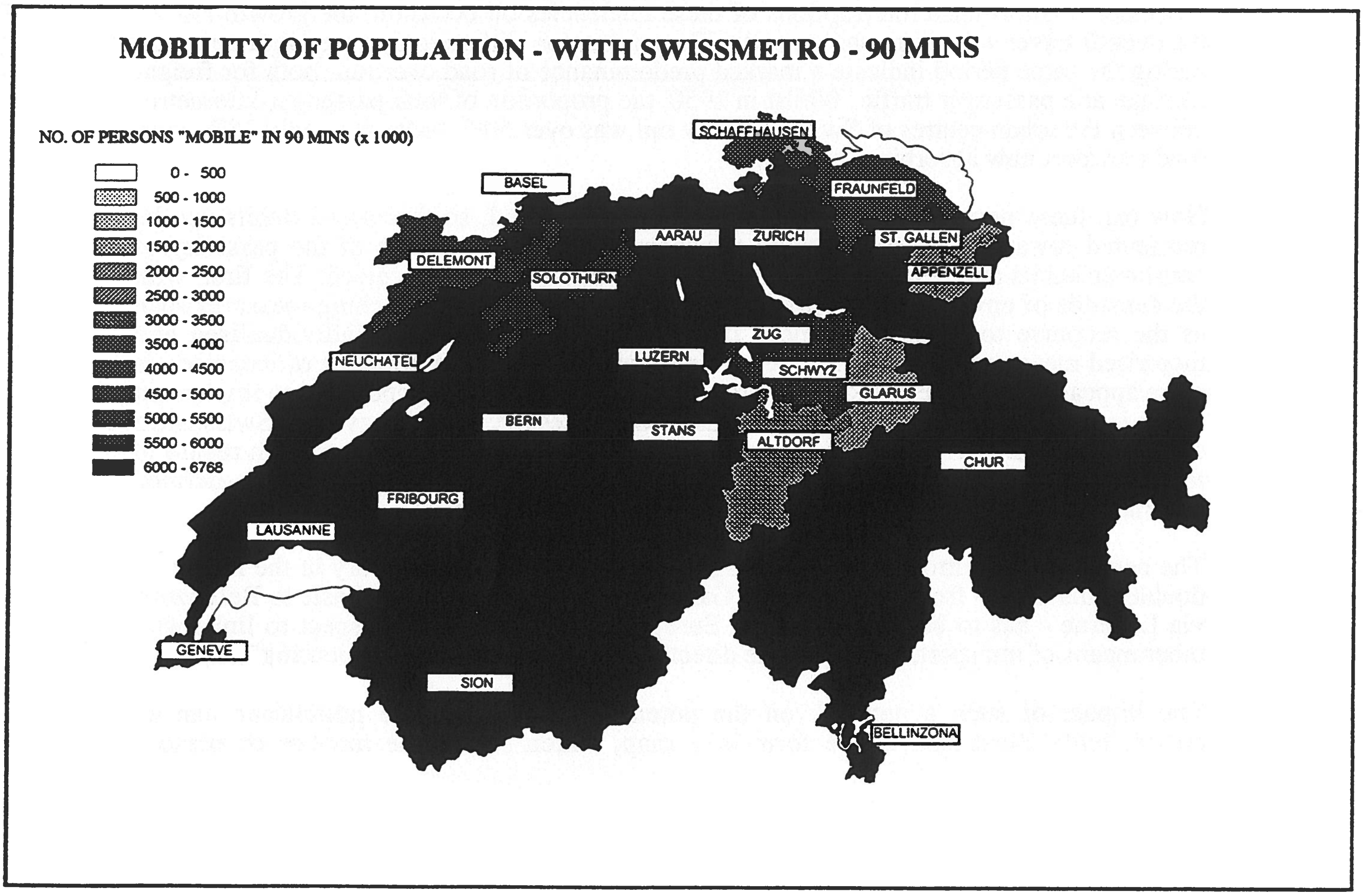


Figure 3.1 ↑ ↓ Figure 3.2



reachable within a period of 90 minutes from the capital of each canton. The cantons of the Swiss central plateau enjoy a considerably greater degree of accessibility than the cantons situated in "peripheral" regions such as Geneva, Valais, Ticino, Grisons, etc.

The availability of a means of transport offering the services of Swissmetro considerably alters these conditions of accessibility, and therefore the degree of mobility as well. Within an isochronous period of 90 minutes (Figs. 3.1 and 3.2), throughout the entire country it would practically no longer be possible to distinguish between degrees of accessibility related to location, for every person in Switzerland would be able to physically communicate with any other person in the country within a period of 90 minutes.

Contrary to what it was possible to conceive in the early stages, Swissmetro would be consistent with the principles of Swiss development planning, which advocate the encouragement of investments favouring decentralisation.

Thus the situation depicted on the mobility maps shows the potential benefits offered by a high-speed transport technology which would allow a greater cohesion of the Swiss economic and cultural regions, and as a result would strengthen the competitiveness of the Swiss urban system in a European context in the medium and longer term.

4 INFRASTRUCTURE

4.1 INTRODUCTION

Taking into account the financial significance of civil engineering for the overall Swissmetro project, which represents almost three-quarters of its realization costs, appeals have been made for the collaboration of a number of major partners in the private sector - companies, research organizations, geologists and geological technicians, etc. - with regard to the conception and evaluation of the tasks concerned.

The preliminary study served to clarify the choice of conception and implementation of the infrastructure tasks for Swissmetro, and to re-evaluate aspects relating to costs and construction deadlines. A number of options remain open, concerning both the individual sections of the line, and the stations. The main study to follow later remains indispensable for the consolidation of the project, for extending the definition of the infrastructure throughout the overall network, and for optimizing the choices with regard to its construction.

4.2 CONSTRAINTS

In view of the interdependence of the problems concerning the construction, equipment and operation of the system, it was necessary to determine a number of constraints and basic criteria for a study of the infrastructure, even if some of these remain subject to modification.

• Profile, lengthwise (gradients):

- minimum gradient	drainage	3 ‰
- maximum gradient	marinating rail	15‰

• Cross-section of tunnel:

- diameter of finished prescribed circle:	3.90 m
- thickness of interior facing	0.25 m

- thickness of support + seal 0.20 m
- dimensional tolerance 0.10 m
- diameter of tunnel 5.00 m

- Should a tube be put out of operation between two stations, the vehicles would travel in each direction alternately in the single tube remaining in use. The frequency therefore drops by two trains per hour per direction. At the stations, the trains would need to be able to transfer from one tube to the other.

- It will need to be possible for a vehicle that is out of service to be parked at a station.

The infrastructures of Swissmetro will be entirely subterranean, with the tunnels located at an average depth of around 100 metres below the network on the surface, and deeper for the Alpine and Jura transverses. Each section of the network is linked to the surface by means of urban stations, and by shafts or intermediate galleries intended to permit the implementation of civil engineering tasks and the operation of the transport system.

4.3 TUNNELS

In the basic version studied, the tunnels consist of two parallel galleries of narrow profile, each for one thoroughfare, excavated by tunnelling machine to approx. 5 m in diameter (Fig. 4.1). These are separated by a distance of roughly 25 m. The layout on level plane and in lengthwise profile is selected in such a way as to benefit as far as possible from the favourable geological and geotechnical conditions: maintaining the profiles in the rocky substratum whilst avoiding light soils, sub-lacustrian passages and other formations representing a hazard to the construction of the system.

In principle, the layer forming the seal sandwiched between the two rings will be constructed of a synthetic material, the quality of which has yet to be determined. It will need to fulfill the airtightness criteria corresponding to the operating conditions.

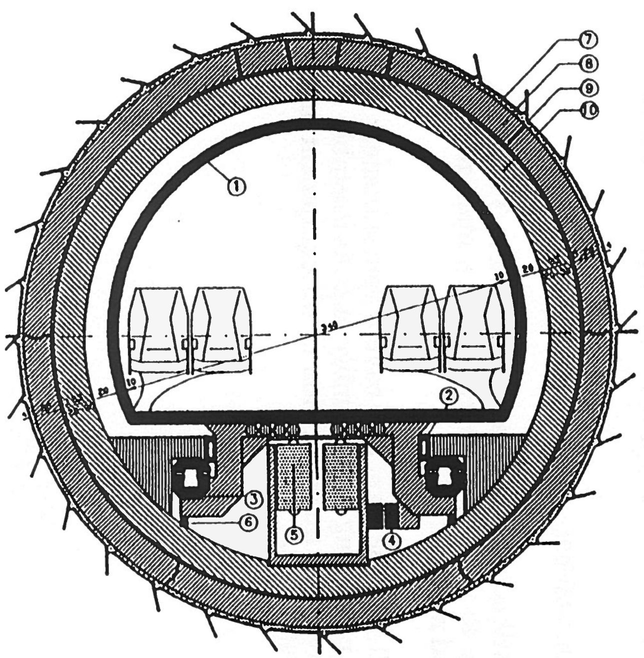
The excavation cross-section of this profile is 20 m^2.

There are conceivable alternatives to this two-gallery system: the addition of a third tube forming a service gallery if the operating conditions so require, or, by contrast, the construction of a single tunnel (Fig. 4.2) of fairly broad diameter - somewhere around 9.5 m (equivalent to those foreseen for the tunnels of the NLFA (AlpTransit), Nouvelles Lignes Ferroviaires Alpines, but still smaller than standard two-way road or railway tunnels). In the case of Swissmetro, this tunnel would be compartmentalised in order to place the vehicles in two separate depressurised channels, as well to provide continuous lateral service sections.

The completed tunnel profile would indicate an interior diameter of 8.30 m., an excavated diameter of 9.65 m and a cross-section of 74 m^2.

The utilisation and operation of the areas described would be consistent with the operating requirements if this alternative were to be chosen. The same applies with regard to the concrete structures (forms, resistance, airtightness, finish, etc.).

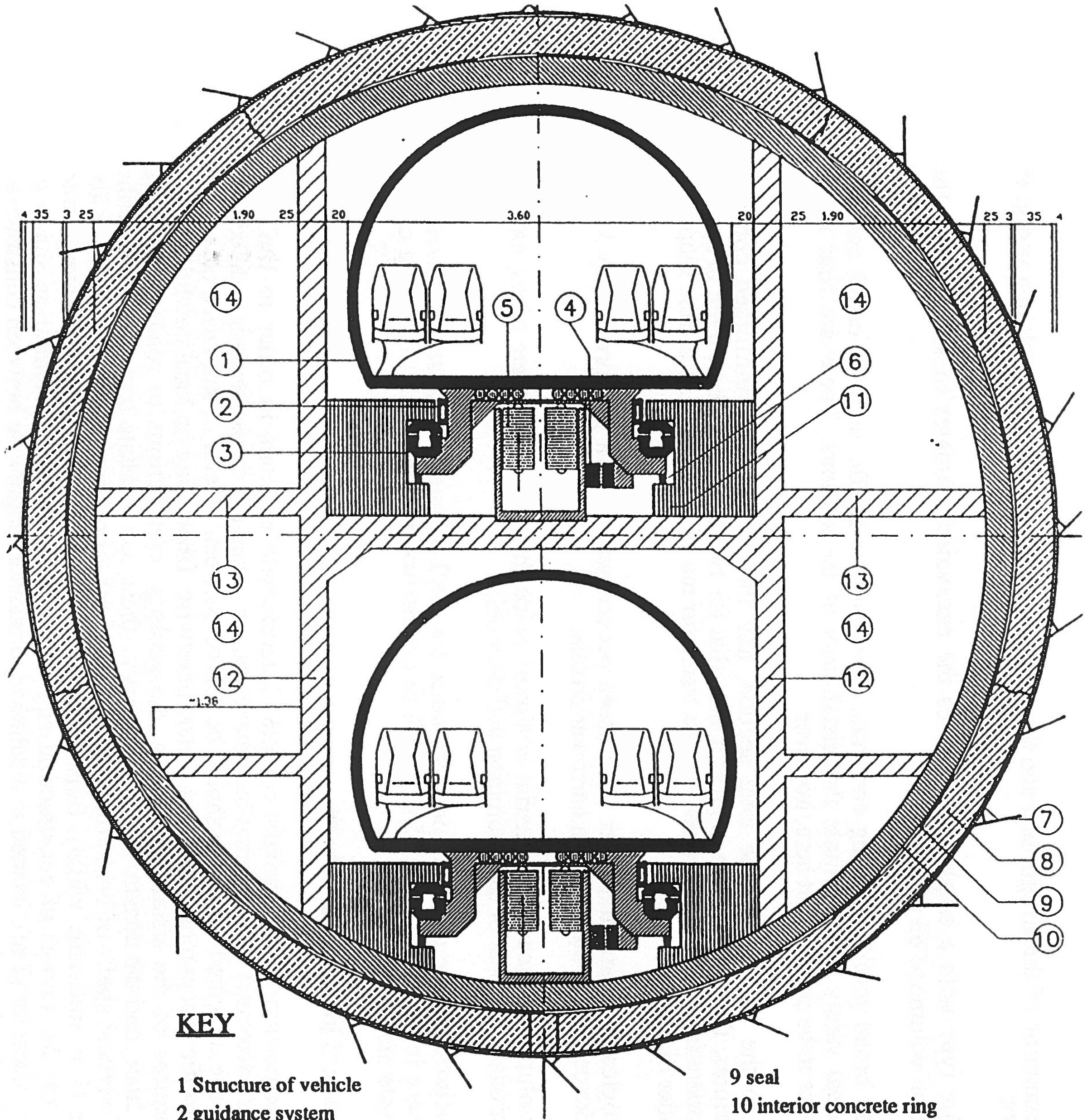
This profile would lend itself particularly well to a concept without an airtight layer, already mentioned at the time of the evaluation of the basic profile. If we commence with the concept that only the tubes enclosing the vehicles are to be in a partial vacuum, it is in fact only the upper and lower vault sections delimiting these spaces which will need to be airtight, other than the two concrete partitions, of course, the airtightness of which could be assured by means of copings applied on the faces on the opposing gallery sides.



KEY

1 Structure of vehicle
2 guidance system
3 levitation system
4 linear transformer
5 linear electric motor

Figure 4.1



KEY

1 Structure of vehicle
2 guidance system
3 levitation system
4 linear transformer
5 linear electric motor
6 emergency wheel
7 injected vacuum
8 outer ring
9 seal
10 interior concrete ring
11 base (concrete)
12 partition (reinforced concrete)
13 slab (reinforced concrete)
14 space for conduits, surveillance, ventilation, emergencies

Figure 4.2

The elimination of the airtight seal and the interior concrete ring could result in a saving of 5% to 7%.

A profile type with a single ring reduces the excavated diameter to 9.25 m, and the excavation volume to 65 m^3/m.

A single broad profile offering continual access to the traffic sections could enhance operational safety and facilitate the installation of the stations. There are four major drawbacks to be pointed out here, however:

- due to the increase in the total section, and the presence of reinforced concrete structures, the construction is greater than that for two separate tubes, even in spite of the operating facilities provided for the transport machines by means of one section of broader diameter;

- geological mishaps and other unforeseen occurrences have a proportionately higher incidence than in the case of a narrower profile;

- the volume of excavated material is almost twice that of two separate tubes, causing additional problems of transportation and disposal;

- an estimate of the construction costs made for the Lausanne-Berne stretch reveals an increase in costs of around 25% to 30% in comparison with a profile consisting of two separate tubes.

Galleries and intermediate shafts

The construction of the tunnels requires intermediate sections in order to limit the distances excavated by the tunnelling machines, and thus the implementation schedules; studies have indicated that these should be spaced between 10 and 15 km apart, other than when specific topographical features dictate otherwise. Depending on local conditions - the configuration of the terrain, the depth, the geology, connections to roads or existing railway lines, and the constructed surroundings - these intermediate sections will take the form of vertical shafts of broad diameter (13 to 16 m), or of sloping galleries suitable for vehicles (7 m utilisable width). Between these main access shafts, which emerge into caverns for the storage of construction equipment, there are to be ventilation shafts of narrower diameter (2 m), located in a subdivided manner lengthwise between construction sites in 5 to 6 km sub-sections.

These galleries and shafts will also be used during the operational stage for the integration and maintenance of electromechanical equipment, air pumps, power supply channels, thermal extraction, etc.

At the extremities of each shaft or gallery there will be:

- a construction site on the surface, which will occupy an area of approx. 1 to 3 hectares, which in principle will be linked directly to the railway networks or a main road to permit convenient removal of the excavated material;

- a subterranean construction site which will take the form of a cavern approximately 35 m length, and 10 m in width and height, permitting the assembly and disassembly of tunnelling machines, as well as the removal and transportation of all equipment and materials necessary for the construction of the tunnel.

Ventilation shafts

Vertical shafts of 1.80 to 2.40 m diameter will be bored every 5 to 6 km between the access points. These shafts will provide the ventilation of the tunnels, as well as their electricity supply.

Removal of excavated material

Excluding stations, the volumes per kilometre to be excavated in order to realise the Swissmetro network are the equivalent of 39'000 m^3, or 95'000 tonnes of material, or 65'000 m^3 of expanded volume. For the entire network of 661 km, the corresponding quantity will be 26 million m^3, resp. 63 million tonnes and 43 million m^3. These quantities are roughly equivalent to those of the tunnels envisaged for the NLFA (AlpTransit) lines, or of the tunnels of the national road network.

Various options for storage or re-use of these materials have been considered:

- *disposal (estimate: 10% to 20%)*
- *raising of alluvial plains (estimate: 20% to 30%)*
- *embankments for development planning (estimate: 20% to 30%)*
- *Industrial re-use of materials (estimate: 30% to 40%)*

Construction schedule

The studies carried out by industrial partners on the 3 sections from Geneva to Lausanne, Lausanne to Berne and Basle to Zurich indicate that a period of 7 to 10 years has to be anticipated for the completion of one Swissmetro section, including the installation of electromechanical equipment, depending on the length of the section, assuming access points at every 10 to 15 kilometres, and the application of a number of tunnelling machines corresponding to that of the access points, with each tunnelling machine producing between 20 and 30 kilometres of tunnel, i.e. one double stretch between access points - the ideal distance for their amortisation.

General costs

The table below summarises the civil engineering costs (principal tasks excluding equipment) for the various types of work concerned, including the following items:

- excavation, supports, sealing, interior lining
- transportation - removal of debris : 50.- Sfr. /m^3 on site
- planning and management of tasks : 6-10% according to task
- installation of building site : 15-25% according to task
- miscellaneous, unforeseen tasks : 8-12%

Tunnel, diameter 5 m	Sfr./linear metre 14'800 - 16'000
Access gallery 60 m^2	Sfr./linear metre 25'000 - 30'000
Vertical shafts, 13 to 16 m diam.	Sfr./linear metre 70'000 -100'000
Ventilation shafts, diameter 2 m	Sfr./linear metre 3'000 - 5'000

Alternative: tunnel with 2 passages, 9.50 m diameter: Sfr./linear metre 35'000 - 45'000

Total civil engineering costs (excluding stations)

Per kilometre of double tunnel, diameter 5 m, with access points

Geneva-St. Gall	mill. Sfr. per km	32
Basle-Lucerne	mill. Sfr. per km	34
Lucerne-Bellinzona, St. Gall-Chur	mill. Sfr. per km	36

4.4 Stations

The basic solution studied foresees installations for vehicles 200 metres in length carrying 800 passengers, with a timetable based on 15-minute cycles, i.e. 3'200 passengers per hour in each direction. The vehicles are pressurised and travel in tubes in a partial vacuum. At stations, airlocks and automatic gates permit passengers to enter or leave the vehicle.

The stations are designed with two operating levels (Fig. 4.3):

- collection of passengers in a hall below the surface connected to other urban public transport networks;
- boarding at a lower level in two parallel caverns joined by galleries, one cavern for connections between vehicles and connecting lifts, the other serving as manoeuvring and "bypass" route in the event of a malfunction occurring in a tunnel.

The two levels are linked by 4 access shafts equipped with lifts.

The tubes are superposed within the station. Access to the vehicles is on the same side of both levels according to the destination of the passengers or the direction they have come from.

The lower level, then, has two caverns - one for special manoeuvres, with tubes and vehicles, and the other (the boarding cavern) providing space for movement between the Swissmetro vehicles and the lifts to the two levels. The two caverns are linked by galleries.

Reception station

The reception station is subterranean, though fairly close to the surface. This needs to be adapted to local conditions from case to case, so that it can be easily accessible and linked as directly as possible to the public transport networks on the surface. Its orientation should be as close as possible to that of the tubes.
Its length of 200 m corresponds to that of the Swissmetro vehicles. With a width of 30 m and a height of 17 m, the station will be able to fulfill its functions very smoothly.

Access shafts

The access shafts link the reception station to the boarding cavern. The depth of the shafts varies according to the local geological conditions. In the example studied for Lausanne, the depth is 45 m.
The 16 m diameter of the access shafts permits the installation of 4 lifts. These have two levels, corresponding to the Swissmetro tubes. Each lift can carry 100 persons (50 per level).

Boarding cavern - Liaison galleries - Safety galleries

The boarding cavern, which is circular in form, has a diameter of approximately 20 m and a length of 200 m. Caverns of these dimensions have already been realised in sandstone for the installations of CERN in Geneva, which confirms the feasibility of such constructions and permits a reliable assessment of their costs.

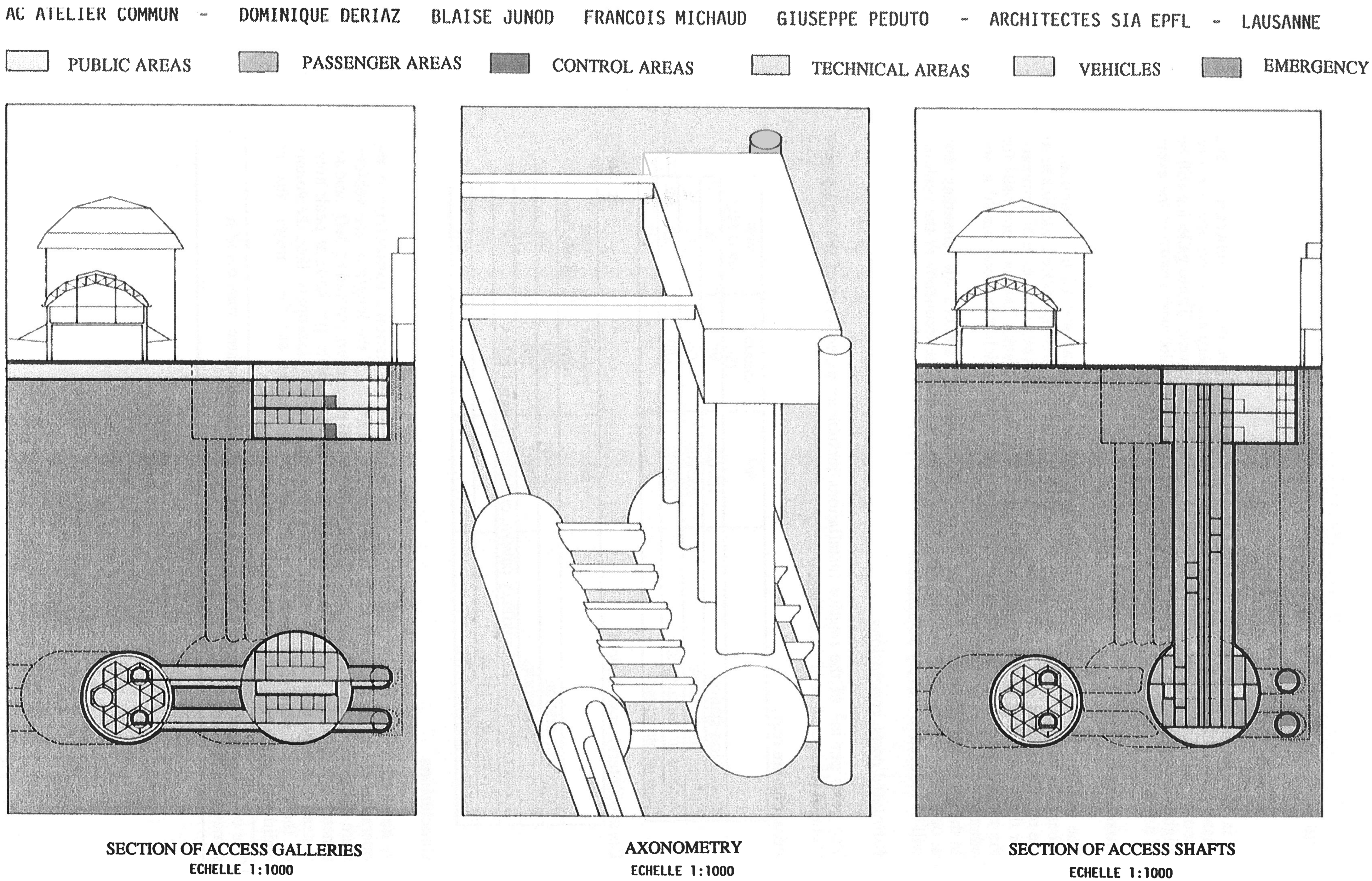


***Figure 4.3**: Preliminary study of Lausanne station*

It is also important to emphasise that in the event of a fire or other emergency, the passengers will be able to flee the cavern by means of emergency doors and via two security galleries, one on each level, located parallel to the cavern. These galleries will be slightly overpressurised in order to prevent them becoming filled with smoke in the event of a fire.

Auxiliary cavern

The auxiliary cavern is 200 m in length with a diameter of around 22 m. It contains 3 tubes. The two main tubes, in which the vehicles will travel, are superposed and linked to the reception galleries. The third tube is for storage of vehicles or, in the case of terminals, for their transferral to the maintenance halls. A "cylinder" system has been proposed for the rotation of the tubes, and to permit the passage of a vehicle from one tunnel to the other.
In the event that a tube should be out of operation between two stations, the remaining tube in operation will be used for both directions, and as a result the frequency of the vehicles will be reduced to 1 every 30 minutes.

Estimated costs, conclusions

The costs per m^3 of the interior installations include an assessment of the equipment required for operation of the station.

Infrastructure costs

	m^3	price/m^3 (Sfr.)	cost (mio Sfr.)
Reception station	100'000	300	30
Subterranean works	200'000	475	95
Access to building site	40'000	450	18
Total infrastructure			143

Costs of interior installations

	m^3	price/m^3 (Frs)	cost (mio Frs)
Reception station	90'000	290	26
Subterranean works	100'000	180	18
Subterranean works, auxiliary cavern, cylinder system + tubes			13
Total cost of interior			57
Total cost of station			**200**

Conclusions

A number of options are conceivable with regard to the stations, particularly if the operating characteristics should be modified. For example, if the length of the vehicles were to be reduced to 50 m instead of 200 m (with 200 passengers instead of 800), and the timetable frequency were to be increased to up to 15 vehicles per hour at peak hours instead of 4 large vehicle compositions per hour carrying 800 passengers, then the volume of the caverns required would be considerably decreased, and there might also be additional options regarding the location of the airlocks.

The costs resulting from such alternatives still need to be calculated; they could lie somewhere between 75 and 150 million Swiss francs.

5 ELECTROMECHANICS

5.1 PROBLEMS

The electromechanical aspects of Swissmetro include the following components:

- acceleration, velocity and braking capacities associated with the vehicle's course;
- propulsion by linear motor;
- magnetic levitation and guidance;
- frequency rectifiers and converters for the power supply of the motors, levitation and auxiliary equipment;
- the overall power supply infrastructure and the distribution of energy for propulsion, for the vehicle and the stations;
- the transmission of energy to the vehicle.

The initial specifications are based on a number of principal fixed magnitudes, with a parametric analysis permitting an interdisciplinary choice with a view to a better balance of technology and costs. The following principal magnitudes have been adopted:

- a vehicle with a diameter of 3.6 m, a length of 200 m, an unladen weight of 100 tonnes and a payload of 180 tonnes. As alternatives, vehicles with a length of 100 m (for 95 tonnes), and of 50 m (for 50 tonnes) are under consideration
- a typical travel time of 12 minutes for an average distance of 65 km, with a three-minute stop;
- propulsion by means of fixed linear motors;
- magnetic levitation and guidance;
- energy transmission to the vehicle without contact or arc;
- distribution of energy in the tunnels and stations via shafts and the stations.

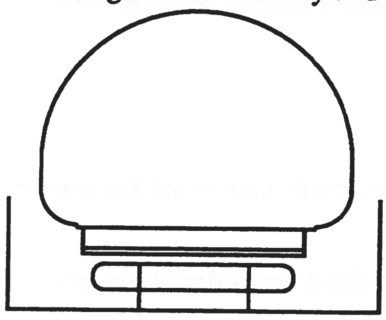
5.2 OPERATION

The operation of the system is based on the following capacities:

- initial acceleration of 1.3m/s2, with drift control upon departure, up to a speed of 160 kph;
- from 160 kph onwards, acceleration at constant power of 10.4 MW up to maximum velocity, for a vehicle of with a length of 200 m (5.5 MW for a vehicle of 100 m, and 2.9 MW for a vehicle of 50 m);
- a maximum speed of 372 kph, +/- 5% for journeys of up to 70 km. Beyond this distance, a higher speed becomes necessary, or else a variable travel time is required.

5.3 PROPULSION

Propulsion and braking are provided by means of linear motors of which the stators (supplied with power from the network via an electronic converter) are affixed to the ground. A reaction element (inductors, poles, etc.) is linked to the vehicle along its entire length (Fig. 5.1). The air gap between rail and stator is 20 mm, which constitutes a compromise between guidance security and degree of performance.



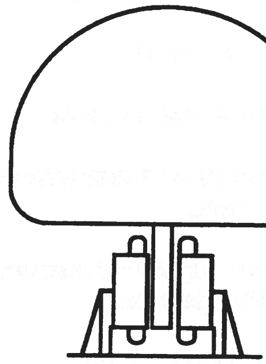


Figure 5.1

Two alternative means of propulsion have been rejected:

- propulsion by asynchronous linear motor, due to low efficiency and power factors;
- propulsion by short synchronous linear motor with standard excitation, due to the high mass of the poles linked to the vehicle.

Two propulsion options have been held in reserve:

- propulsion by short homopolar synchronous linear motor (Fig. 5.2), characterised by a low mass linked to the vehicle, and medium efficiency and power factors;
- propulsion by standard long synchronous linear motor (Fig. 5.3), characterised by great flexibility of operation, a low mass linked to the vehicle and good efficiency and power factors. In addition, the levitation can be combined with the propulsion system (German "Transrapid" system).

The financial advantage of the homopolar motor indicates a preference for this solution at the current stage of the study. The cooling of the motors does not present any particular problem.

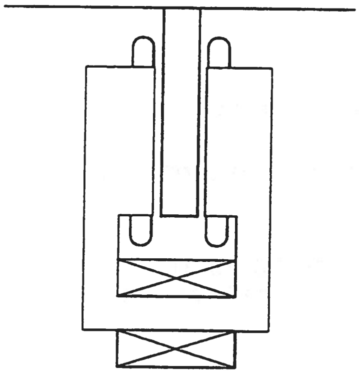


Figure 5.2

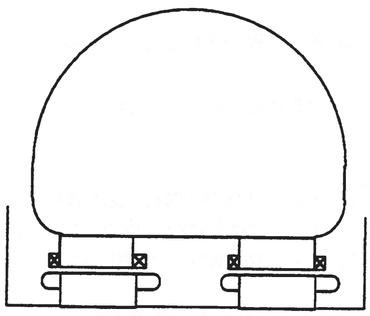


Figure 5.3

5.4 LEVITATION AND GUIDANCE SYSTEMS

Levitation and guidance must guarantee an airgap of 20 mm between the vehicle and reaction elements connected to the tunnel, for curvature lengths of 5 km at low velocity and 10 km at high velocity. The only solution retained for these two functions is the recourse to electromagnetic technology by attraction.

The levitation system requires 60 elements of 30 cm in length for a vehicle 200 m long, with a total mass of 5'800 kg and an average capacity of 330 kW, or 32 kg/tonne and 1.83 kW/tonne.

The main functions of the guidance system are to hold the vehicle in bends by deformation inductors, and to maintain the dynamic position of the vehicle. The system requires 48 deformation inductors of 4'640 kg and 72 dynamic guidance inductors of 2'530 kg (total mass, 7'170 kg), i.e. 39.8 kg/tonne of vehicle. The total mass of the levitation rails and integrated guidance system is 400 kg per metre of tunnel (one tunnel). Figure 4.1 shows the section of the vehicle and the tunnel, with the integration of the motor, the reaction poles, and the levitation and guidance elements. The air in the tunnel, plus ventilation introduced at the station, permit the cooling of the inductors.

5.5 FREQUENCY CONVERTERS

The static frequency converters are intended for the supply of power to the synchronous linear motors in such a way as to control the thrust for providing velocity and general operation (motor or brakes). In particular, these are required to permit the recuperation of energy in the breaking process. The chosen option was a U converter (Fig. 5.4), which contains a rectifier/undulator connected to the network, an intermediate condensor, a three-phase undulator from 0 to 215 Hz, and control elements. The power components are GTO thrysistors, 4'500 V, 4'000 A (4 in series), for an intermediate voltage of 10.8 kV and an effective line voltage of the motor of 6.6 kV. The overall efficiency is 95%.

Assembly of a frequency converter, from intermediate circuit to continuous voltage (U converter)

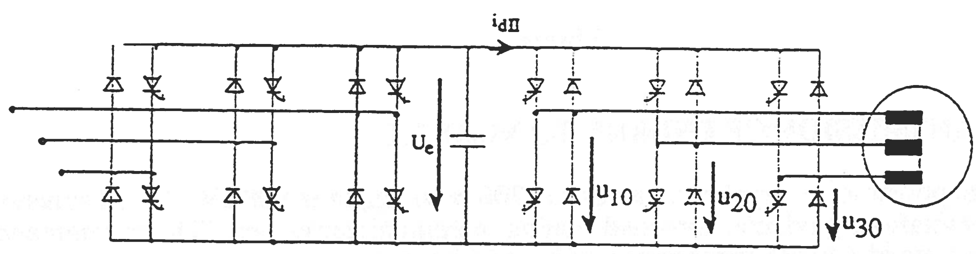


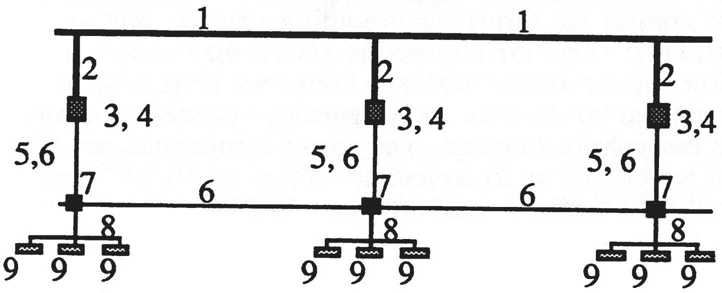
Figure 5.4

5.6 POWER SUPPLY AND DISTRIBUTION OF ENERGY

The following facts have been derived from the preliminary study of the power supply and distribution of energy:

- the Swissmetro network can be supplied from the high-tension network, 50 Hz;
- three alternative methods of power supply have been analysed. Their optimisation in terms of losses and costs allows the consideration of a hybrid solution as depicted in Figure 5.5;
- a technical gallery under atmospheric pressure would offer certain advantages with regard to reliability, safety, operation and maintenance;
- the operating system and timetables concerned have a direct influence on the magnitude of the energy distribution installations;
- the same clearly applies to the size of the vehicle. All measurements have been carried out for a vehicle 200 m in length. Since the acceleration capacity is directly proportional to the length of the vehicle, a significant reduction in electrical installations could result if vehicles 50 or 100 m in length were to be used;
- the integration of the motors (acceleration), the brakes (decelerating motors), rectifiers, undulators, and connecting units, still need to be dealt with.

For a section such as Lausanne-Bern, the investment costs for a vehicle 200 m in length are 98 to 140 million SFr., depending on the solution chosen.



SURFACE POWER SUPPLY: 50 Hz:
1. HT network
2. connecting lines

TRANSFORMER STATION
3. HT/MT transformer
4. rectifier: AC-DC

POWER SUPPLY OF TUNNELS: DC
5. shafts, access tunnels: DC
6. cables/tubes: DC
7. undulators: DC-AC

POWER SUPPLY OF MOTORS: AC
8. cables/tube: AC
9. commutators/motors

Figure 5.5

5.7 TRANSMISSION OF ENERGY TO VEHICLE

The average power to be supplied to a vehicle 200 m in length is 800 kW, for all functions, including levitation, guidance, air-conditioning, communications, etc. The recommended solution consists of a linear transformer, with or without iron, with an airgap of 20 mm and a performance greater than 0.8.

5.8 ENERGY BALANCE

The energy balance for the operation of Swissmetro is summarised in table 5.6 below, which reviews the main factors, i.e. the permanent consumption of power (which varies according to the method of distribution), acceleration, the vehicle, the vacuum pumps and, separately, the stations. These figures correspond to the Geneva/St. Gall stretch, for operation with a maximum capacity (180 tonnes per vehicle 200 m in length) over a period of 18 hours a day. The consumption for 6 stations corresponds to 140.4 TJ/year

Annual consumption Geneva-St. Gall, 2 tunnels	**6.6 kV, 0-215 Hz**	**10.8 kV, DC**	**6.6 kV, 50 Hz**
power supply, auxiliaries	51.65	109.55	167.5
acceleration, re-acceleration	638.3	638.3	638.3
recovery	-139.15	-139.15	-139.15
vehicle	236.5	236.5	236.5
pumps, maintenance of vacuum	13.9	13.9	13.9
Total: [TJ/an] / [GWh /an]	**801.1 / 222.5**	**859.1 / 238.6**	**917 / 254.7**
Consumption: [Wh/t*km]	**72.37**	**77.61**	**82.84**
Consumption : [Wh/passenger * km]	**16.3**	**17.5**	**18.6**

Table 5.6 Power supply options

By way of comparison, the following two points can be noted:

- for Transrapid 06, the figure indicated is 90 Wh/passenger * km. However, the assumptions leading up to this figure are not specified in detail;
- a comparison with energy consumed in Switzerland in 1990 produces the following figures:

Total consumption in Switzerland:		778'930 TJ/yr	100 %	100 %
Traffic:	100%	253'470 TJ/yr	32.5 %	
Rail:	4%			1.3 %
Road:	77%			25 %
Air:	18%			5.85%
Other:	1%			0.35%
Swissmetro, without stations [1]:		917 TJ/yr	0.117%	
Swissmetro, with stations [1]:		1057.4 TJ/yr	0.136%	

[1] Geneva-St. Gall line, "cautious" version (power supply 3)

5.9 DETAILED ANALYSES

The main study should concentrate on the following aspects:

- Propulsion. Further evaluation of the short synchronous homopolar and standard long synchronous options. Choice technical/financial balance. Further study of the model of the selected alternative. Dimensioning, virtually static and dynamic simulation, including interaction with power supply. Realization of prototype. Tests.
- Levitation and guidance. Complete dimensioning, including integration with propulsion, according to choice of latter. Dynamic simulation, including power supply and control, as well as general behaviour of vehicle. Construction of a prototype element.
- Frequency converter. General analysis of combinations of a converter and of power supply for several brake motors. Determination of the command procedure allowing passage from one medium to another without thrust surge. Dimensioning of a converter and its control. Production of a prototype, tests on a motor.
- Power supply and distribution of energy. Choice of voltage and frequency of the network in the tunnel on the basis of technical and financial criteria. Full dimensioning of installations in one section. Virtually static and dynamic model of behaviour. Analysis of security and protection aspects.

- Transmission of energy to vehicle. Analysis of options at low frequency with iron and high frequency without iron. Choice of one technology. Dimensioning of chosen solution. Choice between long or short options. Integration with distribution network. Evaluation of energy balance. Production of prototype element, tests.

6 MECHANICAL ASPECTS

6.1 PROBLEMS

The mechanical aspects of the Swissmetro project include the following components:

- the design and structure of the vehicle;
- the aerodynamics of the vehicle in the tunnel, and the choice of pressure;
- the vacuum, leaks, generation of the vacuum;
- the airlocks intended for the transfer of passengers;
- peripheral aspects connected with security and the vacuum;

The initial specifications primarily concern the data relating to the vehicle and constraints regarding energy and safety aspects. The following principal magnitudes and constraints have been adopted:

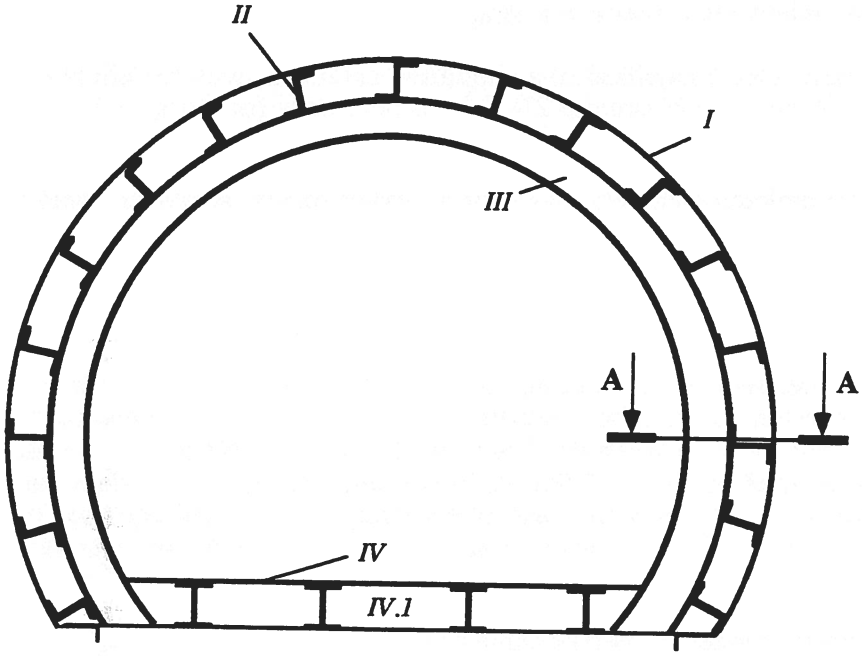
- a vehicle 3.6 m in diameter, with a length of 200 m, an unladen weight of less than 100 tonnes and a payload of 180 tonnes. This requires a light structure of an aeronautics type;
- a tunnel 4 m in diameter, airtight, in which a partial vacuum is generated;
- curvature of 5'000 to 10'000 m, according to speed;
- a minimum operating lifetime of the vehicles of 20 years;
- the choice of a pressure in the tunnel permitting a reduction of the aerodynamic drag and the corresponding energy requirements, i.e. a value below that of the kinetic energy;
- the design of pumps for generation and maintenance of the vacuum;
- airlocks permitting passenger transfer from the station to the vehicle in complete safety and within a period not exceeding 3 minutes;
- a series of valves permitting safe utilisation of the tunnels and stations, plus rapid repressurisation in the event of an accident.

6.2 THE VEHICLE

The vehicle is mainly susceptible to cycles of fatigue resulting from decompression and compression in stations and from the curvature. Only one type of vehicle, 200 m in length, has been considered. The vehicle also has to integrate a certain number of peripheral elements such as reaction elements of the propulsion, guidance and levitation components, energy transmission, safety shoes, air conditioning, doors, etc.

In principle, the vehicle is of circular section, hemispherical at each extremity. It is subjected to an internal pressure of around one atmosphere. The wall thickness required to contain such a pressure is 2 mm, with Al 2024 as used in aeronautics. Furthermore, a curvature of 5'000 m of track only bears a stress of 22.5% of the admissible limit, whereas one would expect 42% for steel.

The structure chosen is illustrated in Figure 6.1, including rigidifying elements such as strakes, girders and frames. Thus defined, the vehicle on its own presents a linear mass of 31.4 tonnes, i.e. 157 kg/m (Transrapid vehicle, 203 kg/m). The total unladen weight (vehicle and extremities, doors, seats, levitation, guidance, propulsion, air-conditioning and security elements), is 100 tonnes, or 500 kg/m. The cost of such a vehicle is estimated at 30 million Swiss francs.



(Diagram of principle with)

I Facing
II strake
III frame
III.1 part of frame receiving electro-mechanical elements
IV flooring
IV.1 structure of flooring

Figure 6.1
Section of a structure of the semi-monocoque type for Swissmetro

Table 6.2 presents a comparison between the Swissmetro project, the Japanese system MLU 02, the German Transrapid 07 system and the MD 81 aircraft.

	Swissmetro	*MLU*	*Transrapid*	*MD-81*
No. of passengers	**800**	950	200	125
Weight of vehicle (t.)	**180**	270	90	64.4
No. of passengers/t.	**4.44**	3.52	2.22	1.94
Length in metres	**200**	315	51	45
No. of passengers/m	**4.0**	3.0	3.9	2.8
Weight of vehicle t./m	**0.90**	0.86	1.76	1.43

Table 6.2

6.3 AERODYNAMICS

Since the vehicle behaves like a piston in the tunnel, it is important to reduce the effects of drag (resistance to forward motion and friction) by a lessening of the pressure in the interior of the tunnel. In a conventional tunnel, the section is in fact roughly 7 times that of the vehicle (Swissmetro, 1.25 times). Displacement occurring when a vehicle is moving at high speed gives rise to several phenomena:

- a blockage of the peripheral flow by sonic limitation;
- pressure at the front and rear, generating drag;
- turbulent lateral friction which also gives rise to drag.

All of these phenomena have been modelised in a simplified approach, with the adoption of "cautious" hypotheses. A pressure of around 2'000 Pa is necessary for a drag effect of 16'000 N.

A more thorough study (completed elements) based on an experimental approach should confirm these results.

6.4 VACUUM

The generation and maintenance of a vacuum requires the utilisation of pumps. Considering a section of two tunnels of 15 km, situated between two shafts, the necessary flow in order to obtain a pressure of 7'000 Pa (0.07 atm) in 12 hours is 40'000 m^3/h, whilst a flow of 60'000 m^3/h is required to achieve 2'000 Pa in the same period. Such values can be obtained by a combination of Roots pumps and pallet pumps, with a unitary flow of 20'000 m^3/hour for a capacity of 50 kW, a water consumption of 20 m^3/h and a unitary cost of 300'000 Sfr.

The introduction of air into the tunnel has two possible causes:

- insufficient airtightness of the tunnel. A permeability value of the walls of 0.25 gr/m^2h of air would need to be obtained to achieve leakage of less than 5%,
- the airlocks which re-inject air into the tunnel on each operation.

We can generally expect flows of 15% to 30% of that of the vacuum generation, or approx. 12'000 m^3/h for a section of 15 km.

The physiological effects of the vacuum are such that the following measures are necessary:

- the design must prevent all risk of significant depressurisation,
- oxygen masks (aeronautics type) must be capable of compensating any partial loss of pressure in the vehicle,
- in the event of a serious accident, it must be possible to reinstate pressurisation rapidly (within a few seconds). This requires the availability of a technical gallery.

6.5 AIRLOCKS AND VALVES

The purpose of the airlocks is to permit passengers to transfer from the station to the vehicle without risk, in spite of the vacuum in the tunnels. The use of airlocks surrounding the doors has been abandoned for technical as well as safety reasons. Only the use of a general airlock for the entire vehicle can guarantee all operational and safety requirements (Fig. 6.3). In the basic option, the procedure after arrival of the vehicle at the station consists of isolating the vehicle by means of two tunnel doors, reinstating pressure, opening the station airlocks, then opening the vehicle doors. This procedure is reversed prior to departure. For shorter vehicles, a solution with pre- and post-airlocks and a station constantly under pressure would be conceivable.

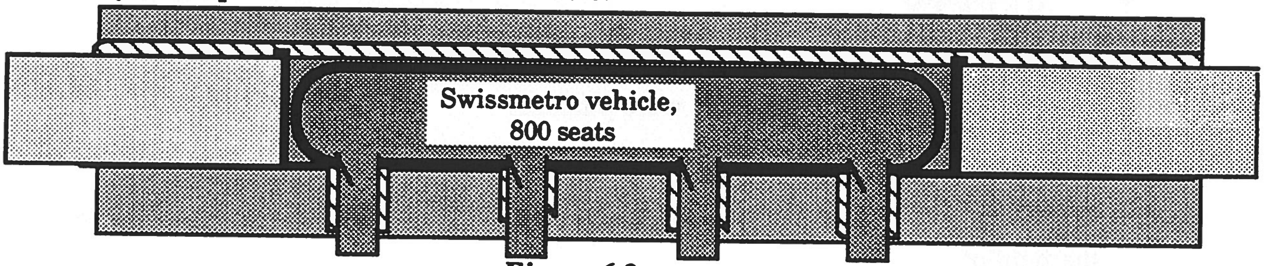


Figure 6.3

Several types of valves need to be installed for operation of the tunnel under vacuum:

- between 80 and 160 airlock valves of the slide valve type, approx. 2.4 m^2 for the complete network,
- 12.5 m^2 sliding doors between station and tunnel 8 per station, or 80 for the whole network,
- partitioning valves in the tunnel (safety), one every 8 to 15 km, 12.5 m^2 section, sliding valve type, 100 to 200 for the complete network,
- safety valves in the event of a significant leak at a station, 4 per station and direction, total network 80.

The total cost of these valves and airlocks (excluding civil engineering) is Sfr. 60 million, or Sfr. 7 million per section.

6.6 DETAILED ANALYSES

The main study should deal with the following aspects:

- *Vehicle*. Design and full dimensioning of a light vehicle. Analysis of door structure and its influence on the vehicle. Integration of peripherals (levitation elements, guidance system, propulsion, brake shoes, energy transmission).
- *Aerodynamics*. Analysis by finished element in transitory conditions of the air displacement of the vehicle in the tunnel. Tests in an aerodynamic tunnel (Emmen). Comparisons. Choice of a tunnel pressure.

- *Vacuum*. Design and full dimensioning of the vacuum pumps. Analysis of repressurisation in tunnel following a defect at a station. Study of the technique of rapid reinstatement of pressure. General and detailed safety aspects in connection with vacuum conditions.
- *Airlocks and valves* Study and conception of various types of valves and airlocks. Realization and testing of one vehicle type and one airlock element. Thorough analysis of inherent safety.

7 SAFETY

The preliminary study of the safety of Swissmetro only represents a first tentative approach. The following objectives were pursued:

- a survey of safety aspects of the system in general;
- determining the state-of-the-art based on existing methodologies for assuring safety in the field of public transport;
- drawing up recommendations for the Swissmetro work group concerning the demands and methodologies associated with safety;
- urging those responsible for the Swissmetro project to take appropriate measures to ensure a sufficient level of safety.

This approach led to a subdivision of the Swissmetro project into three conceptual elements (propulsion and magnetic levitation, tunnels with reduced pressure), and to the identification of existing systems which could serve as references in connection with safety aspects. The specifications regarding safety aspects of Swissmetro can therefore be drawn up through analysis of the corresponding material for other projects. The project will need to take both Swiss and foreign laws into account, as well as norms and regulations pertaining to transport projects.

One critical aspect is the small-diameter tunnel, which poses problems regarding evacuation. British norms call for the possibility of lateral evacuation of the vehicle. Evacuation from its extremities gives rise to a number of problems regarding construction and accessibility. This is one of the key problems to consider for the Swissmetro project.

It is recommended that the promotion and development group should contact the authorities as soon as possible with regard to questions of safety. International experience has shown that agreement on the design features is necessary in such a way as to ensure that the development groups do not waste too much time on unacceptable solutions.

The procedure for the conception of a new system, as well as for any modification of an existing system, needs to be planned with great care. All proposals should be checked against existing regulations.

Accident scenarios have been identified and analysed from a point of view of various specific occurrences, based on experience from similar work carried out on vehicles using magnetic levitation technology or in the field of aeronautics. Only the problems relating to small-diameter tunnels and to vacuum have not been analysed. It is primarily this aspect which needs to be thoroughly investigated within the framework of the main study.

It should be emphasised that risk management is a vital and complex aspect in a project of this magnitude.

It is also important to emphasise that the preliminary study only dealt with safety aspects to a limited extent, and focused mainly on the identification of risks and on those aspects necessary for obtaining an operating licence. Risk management itself still needs to be dealt with.

8 OPERATION OF THE SYSTEM

8.1 REFERENCE SYSTEM

Specifications and constraints

Features of vehicle composition

- total capacity, 800 seats
- overall length, 200 m

Operating times of the vehicle composition between two boardings

• boarding time	1'
• time required for establishing partial vacuum of airlock passage at station	30"
• travel time in one section '	12
• time required for reinstating atmospheric pressure in airlock passage at station	30"
• disembarkation time	1'
Total	15'

Times required for passenger transfer at station

• access to reception area lift - boarding zone	1'15"
• descent to boarding zone	1'15"
• exit from lift and access to boarding platform	1'15"
Total	3'45"

Journey time from reception zone of origin to reception zone of destination

•

• reception zone - boarding	3'45"
• journey of "n" sections	n* 15'00"
• from beginning to end of boarding procedure	3'45"
Total	n* 15' + 7'30"

Cycles and capacity reserves

In order to ensure optimum operation with two tunnels (one for each traffic direction), the maximum cycles (without interruptions) are determined by the method of operation and the access capacities of the boarding zones at the stations.

In the case of one block per section, i.e. of one single composition per section at any given time, the maximum cycle is 4 vehicles per hour, with the exception of the Lucerne-Bellinzona section.

In the case of 2 sections between successive stations, the cycle can be doubled to 8 vehicles per hour, or every 7'30", which corresponds to the capacity limit for the access operations, which require 7'30" if divided lifts are utilised and entry/exit procedures do not occur simultaneously.

The minimum station stop of a vehicle travelling at maximum speed is 3 minutes, which determines the minimum time of subsequent vehicle compositions.

The maximum theoretical cycle for one airlock per station is 15 vehicles per hour; this is governed by:

• the disengagement time of the airlock		30"
• time of airlock entry for subsequent vehicle		30"
• pressurisation of airlock		30"
• boarding - disembarkment		2'00"
• generation of partial vacuum of airlock		30"
	Total	4'00"

In order to attain such a frequency, it would clearly be necessary to double the number of lifts between the reception and boarding zones, and to plan a waiting area at embarkment level.

Operation with reduced capacity

When a tunnel is out of service in one section, an alternative operation of the tunnel still in service is required.

For sections not equipped with several security blocks, the frequency would have to be reduced by at least half. With regard to the possibility of operation at shorter intervals (every 7.5'), it is the time required for operations at the station, and for the transfer of vehicle compositions from one tunnel to the other, which is the determining factor.

Location of the stations

The Swissmetro stations will be located at the heart of the public transport services in each region concerned. For the greater part, this means within the railway station area of each town served. Stations beneath the airport railway stations of Geneva and Zurich are also conceivable.

It will therefore be possible to ensure access to the Swissmetro network, regardless of the developmental policies of the regional transport services, since it would necessarily be the railway stations which would be adopted as preferred access areas.

Furthermore, for these same regional transport services, new parking facilities will gradually ensure good connections between the road and motorway networks and the public transport networks.

Swissmetro could therefore constitute the principal structural element of the Swiss public transport network, with impacts on inter-urban traffic, regional and local traffic, freight carriage, and international traffic.

By constituting the most rapid means of travel between the different regions of the country, Swissmetro will also promote economic and cultural exchange.

8.2 OPERATING OPTIONS

By way of an alternative, a general operating concept allowing an adaptation of Swissmetro services to the demand according to daily, weekly or seasonal fluctuations has been drawn up.

This concept permits an assimilation of Swissmetro technology with that of an urban subway system, partly due to the utilisation of a smaller vehicle carrying 200 passengers and a vehicle composition reduced to 50 m in length, and also thanks to a peak hour frequency equivalent to that of an urban subway, i.e. 4'

The features of this alternative are described below. Its main advantages concern the lower investment required as a result of the reduction of the size of the stations by a factor of 4 in comparison with the 800-passenger proposal, and of the reduction in costs relating to the construction and the operation of the vehicles.

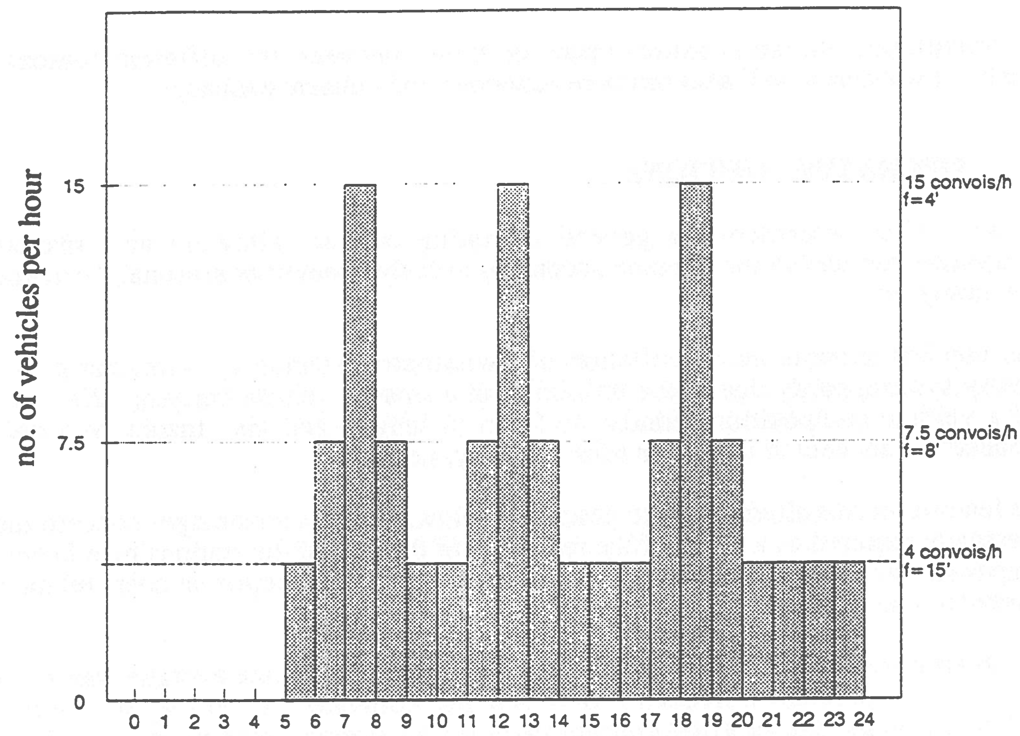
This alternative concept also offers the advantage of reducing the average waiting times at stations. At peak hours, a frequency of 4' is in fact equivalent to a highly desirable waiting time of 2', whilst the original concept calls for an average waiting time of 7'30" for a frequency of 15'. Operation could be adjusted according to periods and the according flow rate required (Fig. 8.1).

This concept is based on the following operating principles (Figure 8.2):

- all valves of airlocks separating the vacuum zone and the area under atmospheric pressure need to be separated in order to protect the passenger area,
- the airlocks at each extremity of the stations perform the function of operation control, as well as of physical protection of the passengers (the vehicles move at very low speeds within the station zones),
- the stations are operated entirely under atmospheric pressure: there are no vacuum zones directly in contact with the stations,
- swift transfer from one tunnel to the other (max. 3'), both at terminals at each extremity of the system, and at the individual intermediate stations,
- maximum timetable capacity: 3'000 passengers per direction and platform.

The main drawback with this alternative lies in the permanent obstruction of the tunnel at the station by the airlock doors. This could constitute a risk in the event of a braking malfunction.

The two options need to be thoroughly analysed in the main study with a view to the choice of an optimum method of operation.



$\sum$ Vehicles = 130

Seats available (total daily) = 130 vehicles * 200 seats per vehicle = 26200 seats per 24 hrs per direction

Figure 8.1 Diagram of reference operation

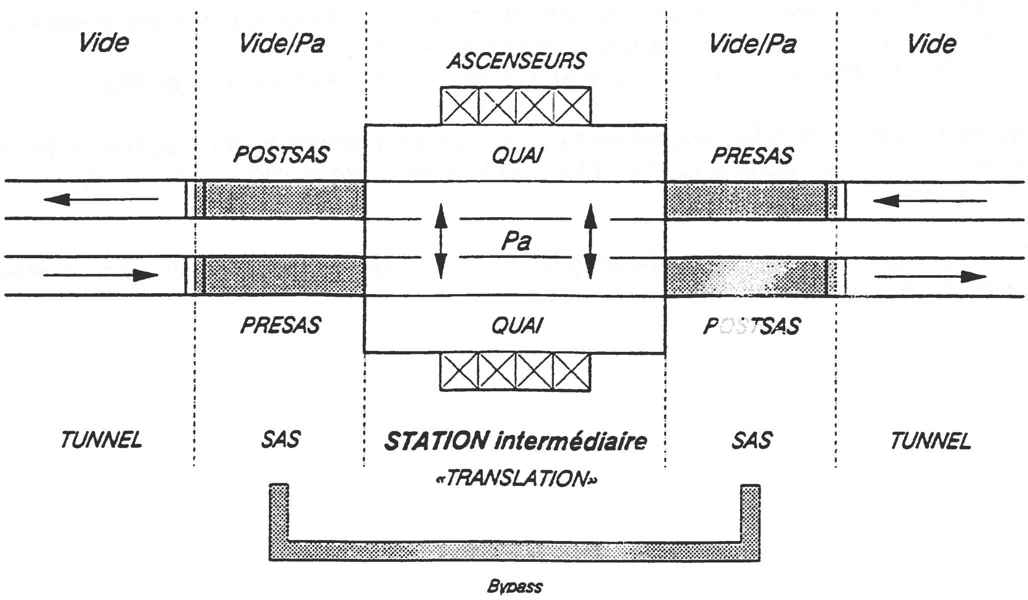


Figure 8.2 Planned configuration of station

9 SOCIOLOGICAL ASPECTS

Swissmetro was studied right from the start from a point of view of the specific resistance certain population groups were likely to show with regard to the project, and of the negative arguments likely to dominate debates which were bound to take place in the future.

The method consisted of carrying out a preliminary inquiry among various specialists on the subjects of transport, energy and regional development in Switzerland, and subsequently to study in greater depth two categories of the population expected to be reticent with regard to Swissmetro: ecologists, and those in geographical and economic peripheral regions, considered in terms of the Jura range. The persons interviewed were not chosen from the point of view of their representativity, but rather their exemplarity (decision-makers, opinion leaders). Finally, discussions with members of the Swissmetro development group, perusal of the press dossier, and a number of additional discussions permitted a full analysis of the results of this inquiry.

Basically, the environmental organizations are opposed to the project. Their representatives are not in favour of higher speeds, or of the greater mobility of systems which give rise to displacements that are too technological and too far-reaching for the landscape and the country. They fear the centralising impact of Swissmetro and, as far as costs are concerned, feel that there are other priorities. The points of view of the environmental organizations vary considerably. The fundamentalists are practically impervious to negotiation, whilst the moderates, by contrast, are more open, in return for the realization of certain conditions aimed at counterbalancing particular effects of Swissmetro which they judge to be hazardous. The influence which one or other of these has on the general population is by no means negligible, though has not yet been fully analysed. Their arguments are also not entirely without contradictions.

The inhabitants of "peripheral" regions do not like the use of this term, but they readily claim to enjoy a better situation in comparison with the central regions. In general, Swissmetro does not interest them a great deal, though the dossier appears to be little known and approaches tend to change with more intensive discussion. The inhabitants of the Jura region seem to be opposed to the idea of centralisation on principle, but fairly quickly begin to feel involved when matters of public interest (particularly the maintenance of an open and competitive Switzerland, for example) are being discussed.

Other peripheral regions of Switzerland can be viewed in much the same light (with local variations), but on the whole the Jura region displays all the characteristics of the various types of peripheral regions (rural, rural-industrial, touristic, service-oriented), and thus the study provides valuable indications concerning the way in which the inhabitants of such regions tend to think.

Generally speaking, two arguments give rise to reservations or questions: high speed as a promotional factor, and the costs. The question of high speed appears to be more a source of perplexity than a genuine trump, if one forgets to link this with the positive benefits concerned. The costs give rise to misgivings since they are not discussed in detail (the comparatively low cost dimensions of Swissmetro), but are included in general discussions on the various realization combinations, means of transport, life styles in the next two decades, and especially on the financial repercussions of the project.

A certain number of more open approaches were nonetheless displayed during discussions which demonstrated that Swissmetro would have a clear interest in integrating, as basic objectives, not only technological accomplishments and the functional benefits these would offer, but also a range of fundamental impacts on the country in general. These include the following factors in particular:

1. a heightened cultural unity and national cohesion,
2. a reawakening of the capacity for innovation and enterprise;
3. the development of a genuine metropolitan logic, in which certain problems could then be dealt with to to the extent they warrant;
4. a variety of economic impulses
5. the introduction of an exportable technology.

Once we make the hypothesis that speed is an element of progress as far as we associate it with co-factors of development, we can see that something which permits speed, in geographical and cultural terms, though also in terms of technology and capacity for mobility, is at least as important for the country as the basic fact of going to this or that place in so much time. These are by no means secondary aspects, but on the contrary are integrated elements, in some way inscribed in the logic and potential of the concept.

Metropolitan dynamics (for example, analysing and resolving major problems to the extent they warrant), and the relations between Switzerland and Europe, are equally far-reaching dimensions which incite the Swiss as participants to reflect generally on matters such as transport, life styles and the control of certain "evils" which sooner or later will concern everyone on this continent.

Finally, Swissmetro is not merely a series of vehicles in a double tunnel. It also involves a tremendous economic impact, both upstream and downstream, and is a vital stimulus for the spirit of enterprise, interdisciplinary cooperation, and the capacity to think and act universally, including for outlying areas. Swissmetro as a catalyser - why not? The country certainly needs one.

10 ANALYSIS OF IMPACTS

10.1 ENVIRONMENT

The recent development of the modal distribution of transport indicates a stagnation within the railway sector. On the one hand, certain major arteries of the network are overloaded. And on the other hand, the transfer to road traffic also gives rise to saturation at peak hours, and places a very great deal of pressure on the environment. Projects for new transport axes on the surface give rise to fierce opposition, which leads to prohibitive costs for the routes and constructions concerned, if these have not quite simply been rejected altogether.

Swissmetro will attract a proportion of rail passengers (Intercity passengers) and road users, which will ease the burdens on the main railway and motorway networks. This will mean being able to avoid the construction of additional arteries on these axes. Such extensions would create worse "evils" than those caused by the construction and operation of Swissmetro.

The operation of Swissmetro would permit the saving of between 190 and 350 million litres of motor fuel per year, which represents an important development as far as air pollution is concerned. This figure is equivalent to 7% to 13% of motor fuel consumption.

An evaluation of the Berne-Zurich motorway axis allows the prediction that current noise levels could be reduced and kept at a level below that of over 30 years ago.

The only impacts of a more or less lasting nature are:

- the effect on the soil, flora and fauna in the storage areas of the excavated materials,
- the effect on the landscape caused by electricity supply lines for the high-tension network.

Other effects connected with the period of construction are the traversing of the water tables and the expropriation measures for building sites.

10.2 ENERGY BALANCE

The amount of energy required for mobility purposes depends on the means used. For a section of 65 km, the energy consumption rates pertaining to mass and per passenger are indicated in Table 10.1 below. In each case, the vehicle is at half payload. For motor vehicles, the figure concerns the total gross thermal energy requirements, whilst for electric vehicles it concerns the total electric energy demand.

Means of transport	Consumption in Wh/t*km	Consumption in Wh/passenger*km
Motor car	930 (465)	465 (233)
Train	35	56
Swissmetro	77	35 (17.5)
TGV	50	108
Heavy goods vehicle	100	200
Freight train	15	30

Table 10.1

In order to produce a complete balance, it would be necessary to take the traffic transfers brought about by Swissmetro into account. The suppression of Intercity trains would permit an increase in rail freight carriage, which in turn would give rise to a transfer of a proportion of road freight transport. Each such transfer occurring would result in a saving of energy. The following balance can thus be drawn up:

Transfer of passenger traffic:

• from rail to Swissmetro	2*15 suppressed Intercity trains	2'590*10^6	passengers per km per year
• from road traffic to Swissmetro		744*10^6	passengers per km per year
Total		3'334*10^6	passenger km per year
• Swissmetro	2*72 compositions per day	13'660*10^6	passenger km per year
Transfer of freight carriage from road to rail	2*15 additional freight trains		

The energy balance is composed as follows:

Transfer of passenger traffic	kWh electrical /year	thermal kWh/year
from rail to Swissmetro from road to Swissmetro	$-145 * 10^6$ $+91 * 10^6$ $+26 * 10^6$	$-346 * 10^6$
Transfer of freights carriage		
from road to rail	$+214 * 10^6$	$-1'426 * 10^6$
Total annual energy balance	$+186 * 10^6$	$-1'772 * 10^6$ or $-190 * 10^6$ l de carburant

Table 10.2

10.3 COMPLEMENTARITY WITH OTHER MEANS OF TRANSPORT

The incorporation of Swissmetro into the transport system requires a change of method. But this inconvenience, which can be compared with that involved in the introduction of the TGV in France, is subsequently compensated by the proximity of the Swissmetro/railway/bus stations, and the considerable time gains involved.

Parking areas close to the stations or easily accessed by means of transport would permit a high degree of complementarity with road traffic. The homogenisation of speeds on the railway network and the alleviation of the road network would give rise to an enhancement of the quality and overall capacity of Swiss public transport, especially through the augmentation of the role played by the railways in the freight carriage sector. Furthermore, Swissmetro would permit a better quality of access to the airports and would practically eliminate air traffic between Geneva and Zurich.

10.4 OTHER NON-QUANTIFIABLE ADVANTAGES

A number of non-quantifiable socio-economic impacts would arise from the introduction of Swissmetro, such as:

- a reduction in the number of road accidents,
- the overall time gains for passengers, estimated at 20 million hours per year, or 10'000 man hours * working year,
- socio-cultural impacts related to cyclical traffic. A general coherent transport and land development policy ought to make it possible to counterbalance any possible negative effects,
- the implementation of Swissmetro will create jobs and permit a revitalisation of Swiss industry on both the domestic and foreign fronts,
- such a network will help promote exchange between the principal language regions of Switzerland, and contribute towards a heightened national identity.

11 ECONOMIC ANALYSIS

11.1 REVISED FINANCIAL DATA

A full economic analysis was presented in the first part of the preliminary study. However, this was based on technical details that were still only approximate. The figures presented here have been brought up to date (1992) on the one hand, and better substantiated on the other hand. They apply to the Geneva-St. Gall line.

The retained hypotheses for estimating the current net value of the project, calculated in terms of direct viability, i.e. without external effects (safety, time gains, investment savings), are as follows:

Commencement of schedule	1993
Duration of project	49 years
Commencement of construction tasks	1996
Commencement of operation	2004
Duration of research and development	3 years (1993 to 1995)
Duration of construction tasks	8 years (1996 to 2003)
Operating lifetime of installations and vehicles	35 years
Renewal of installations and vehicles	2035

Investments (mill. Sfr.)

Research and development	1'300 ± 20% (300 in 1993, 400 in 1994, 600 in 1995)
Fixed installations	1'262 ± 10%
Civil engineering (tunnels + stations)	11'290 ± 10%
Average cost per station	150 ± 10%
Average cost per vehicle (800 passengers)	30 ± 10%
No. of vehicles	17
Total cost, Geneva-St. Gall	13'062, 1992 estimate (10'695, 1991 estimate))

Operational expenditure (mill. Sfr.)

Staff, 1000 persons * 90 x 10 3 Sfr. per year	=	90
Energy	=	20
Maintenance, 3% on fixed installations + vehicles	=	50
Total annual outlay		160

Income (mill. Sfr.)

No. of passenger km/yr in 2004	2'000 * 10 9 million
Annual growth rate:	
most likely rate	2.0%

Tariffs (probable)		0.25 Sfr./per passenger km
Probable income,	2004	500
	2050	1218

11.2 CURRENT NET VALUE OF SWISSMETRO PROJECT AND DIRECT VIABILITY RATE

Phase 1: Geneva-St. Gall

Direct viability

The current net value of the project (balance between the amount of income and the amount of investments and operating expenditure) is over 20 million Sfr. for a capitalisation rate of 0%. The internal viability rate of the project is 3% (0% in the most cautious hypothesis, and 4% in the more optimistic hypothesis).

Sensitivity analysis

The most sensitive variable is the income (receipts) which represents 82% of the total variation of the net actual value of 3%. The civil engineering costs represent 7.5% of the potential variation of the net actual value, whilst the operating expenditure represents around 6% of this dispersal.

The estimated expenditure of Sfr. 1.3 billion for analyses, research and development represents less than 3% of the total variation of the viability of the project.

Insofar as the gross operating surplus (that is to say, the surplus of receipts in comparison with the operating and renewal expenditure) should improve by 1%, 2% or 3% per year for the duration of the project, the internal direct viability rate would increase to 3.6%, 4.1% or 4.7% respectively.

Phase 2: Complete network

The viability of the complete network is appreciably greater than that of phase 1 (Geneva-St. Gall). The internal viability rate is in fact 3.60% (as opposed to 3%).

A comparison of the actual net values of phases 1 and 2 is given below (Fig. 11.1).

By varying the gross operating expenditure by 1%, 2% or 3%, the internal viability rate of the complete Swissmetro network would increase to 4.6%, 5.5% or 6.6% respectively.

DEVELOPMENT OF NET ACTUAL VALUE

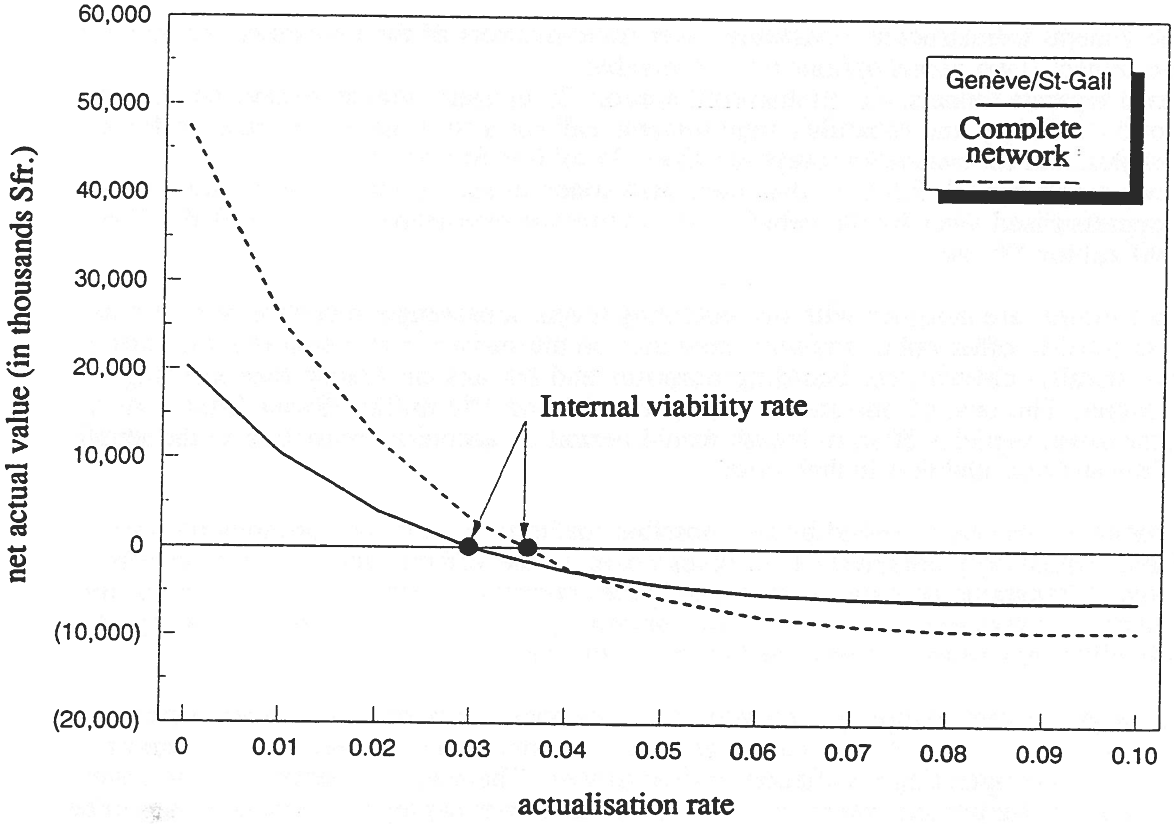


Figure 11.1

12 SUMMARY

Swissmetro is a concept for a means of transport based on the combination of four principles: an underground network running through tunnels under partial vacuum, with vehicles propelled by fixed linear motors, and using a magnetic levitation and guidance system.

The specifications require the following principal characteristic magnitudes:

- length of vehicle composition 200 m, weight 180 tonnes, capacity 800 passengers,
- highest speed 410 kph, which can be increased to 600 kph if necessary,
- average travel time 12 minutes, with a 3-minute stop at stations.

The preliminary study has demonstrated the feasibility of the project. The following aspects in particular have been established:

- In the transport sector, Swissmetro would enable Switzerland to maintain a significant volume of rail (Intercity) and road (motorway) traffic for medium distance travel. Its effect would be comparable to that of the TGV in France;
- from one cantonal capital, it would be possible to reach practically any other cantonal capital in less than 90 minutes. This would permit a greater economic and cultural unity

of the country, and thus heighten national identity and competitiveness in a European context;

- the general infrastructure constitutes over three-quarters of the investment needed for the project. Two *tunnel* options are conceivable:
  - two separate tunnels, 4 m in diameter, approx. 25 m apart, with an excavated diameter of 5 m. Safety and reliability requirements call for a third gallery in reserve for air, cables, and for evacuation purposes. Cost: 34 million Sfr. per km;
  - one single tunnel, 9.5 m in diameter, partitioned in such a manner as to contain two depressurised tubes for the vehicles, and to provide pressurised service galleries. Cost: 40 million Sfr. per km;

- *the stations* are designed with two operating levels: a passenger reception area in a hall connected to other public transport networks on the surface, and a boarding platform in two parallel caverns, for boarding purposes and for any necessary manoeuvring of vehicles. The cost of one station is between 75 and 150 million Swiss francs. As an alternative, vehicles 50 m in length would permit an according reduction in the length of the stations, and thus in their costs;

- *propulsion* can be provided by two possible methods: a short synchronous homopolar motor which only comprises steel poles linked to the vehicle, and a long synchronous motor (Transrapid solution) with excited poles connected to the vehicle. Technical and financial considerations indicate the suitability of the former, whilst safety and reliability requirements would tend to favour the latter;

- although *the distribution of electricity* does not pose any particular problem other than the extensive length of the cables required, it nonetheless constitutes an important aspect of the operating installations of Swissmetro. The static converters need to ensure both power supply and control of the motors. The power supply to the vehicles has to be provided by a linear transformer;

- *the levitation and guidance* systems are governed by electromagnetic mechanisms connected via a airgap of 20 mm;

- *the vehicles* are to be constructed of aluminium, using light aeronautics technology, with a weight of 500 kg/m. The estimated cost of a vehicle is Sfr. 30 million (200 m);

- in order to reduce losses due to aerodynamic drag in a tunnel of narrow section, a relative thrust *partial vacuum* is required, estimated at 2'000 Pa (0.02 atm.). This figure, however, still has to be confirmed within the framework of the main study. The generation and maintenance of this vacuum do not pose any particular problems;

- the solution selected for the *airlocks* is the vehicle airlock option, in which the complete vehicle is pressurised to permit the boarding and disembarkment of passengers;

- *safety* is the key element of the concept and operation of Swissmetro. Whilst solutions to many of the problems have since been found, the problems of repressurisation of the tunnel, and of evacuation in the event of an accident, still remain to be dealt with. This is also a vital factor in connection with obtaining an operating licence;

- *the operation* of Swissmetro is considerably simplified by the unidirectional character of the tunnels and by the safety criteria requiring one single vehicle per section. A higher rhythm is conceivable, especially if smaller vehicles are put into operation with greater frequency. It will be possible for one section of a tunnel to be put out of service by introducing a "bypass" system for manoeuvring vehicles in stations, using a "cylinder" system or laterally operated carriage.

- two *sociological* aspects of Swissmetro have been analysed: the points of view and arguments of environmental organizations, and those of inhabitants of peripheral areas, in particular the Jura region. From these analyses it is possible to deduce the main factors regarding opposition to the project, as well as draw up according promotion policies;

- *the impact analysis* demonstrates the significant advantages Swissmetro would bring with regard to undesirable effects (no noise, no expropriation of land, low energy consumption). In particular, the network would give rise to reductions in the consumption of motor fuel amounting to 190 to 350 million tons, as a result of the reorganisation of passenger and freight transport;

- *the financial analysis* of the project indicates an internal viability rate for the project of 3% for a duration of 49 years. The invested funds required for the Geneva-St. Gall line amount to 13 billion Swiss francs (1992 estimate).

On the basis of the above, it can be concluded that Swissmetro would be a feasible transport system, suitable for operation in Switzerland, and with financial viability. Certain aspects still remain to be dealt with in greater depth, such as safety, aerodynamics, the vacuum, the airlocks and the transmission of energy to the vehicles. Others merely need to be passed on to the conception phase.

The main problem that still exists is of a socio-political nature. The question is whether it is opportune and necessary to realise such a project. Our answer is in the affirmative, on the following grounds:

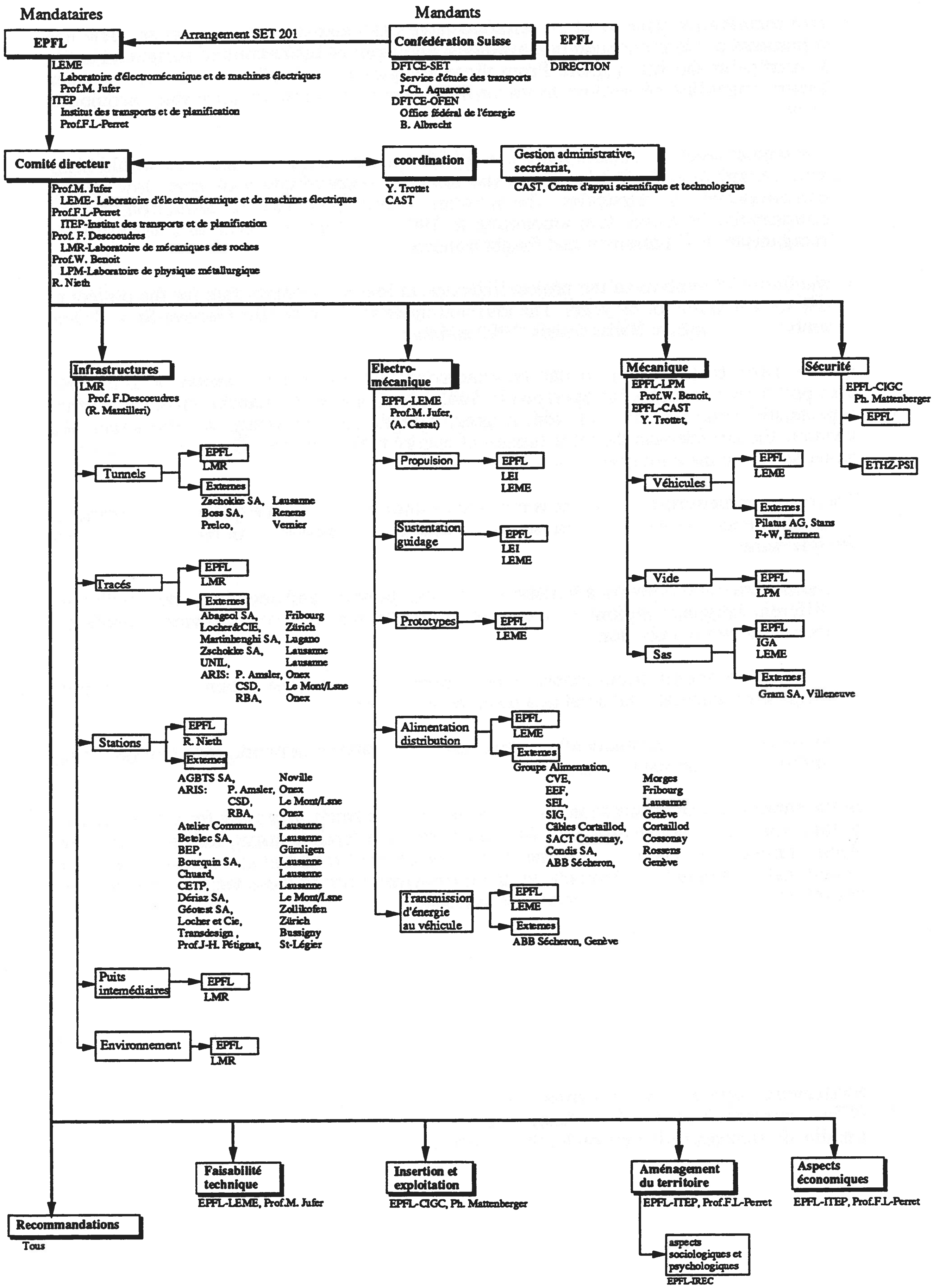
- Swissmetro would permit a heightened cultural, political and economic identity for the different language regions of the country, which are currently showing a tendency towards a loss of cohesion;

- the Swiss economy could receive a new lease of life, and also attain a powerful new image at an international level as a result of such a project;

- Swissmetro could subsequently expand into a Eurometro network, thus strengthening our links with our natural partners.

In the current economic situation, there is a risk that the funds necessary for the realization of this project may not be available. Only an overall conception, taking Rail 2000, the new Alpine railway connections, Swissmetro, and the national road and air routes into account would make it possible to demonstrate the complementarity of these technologies and the realisable finances in view of a concerted solution.

13 ORGANISATION CHART



Organigramme

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