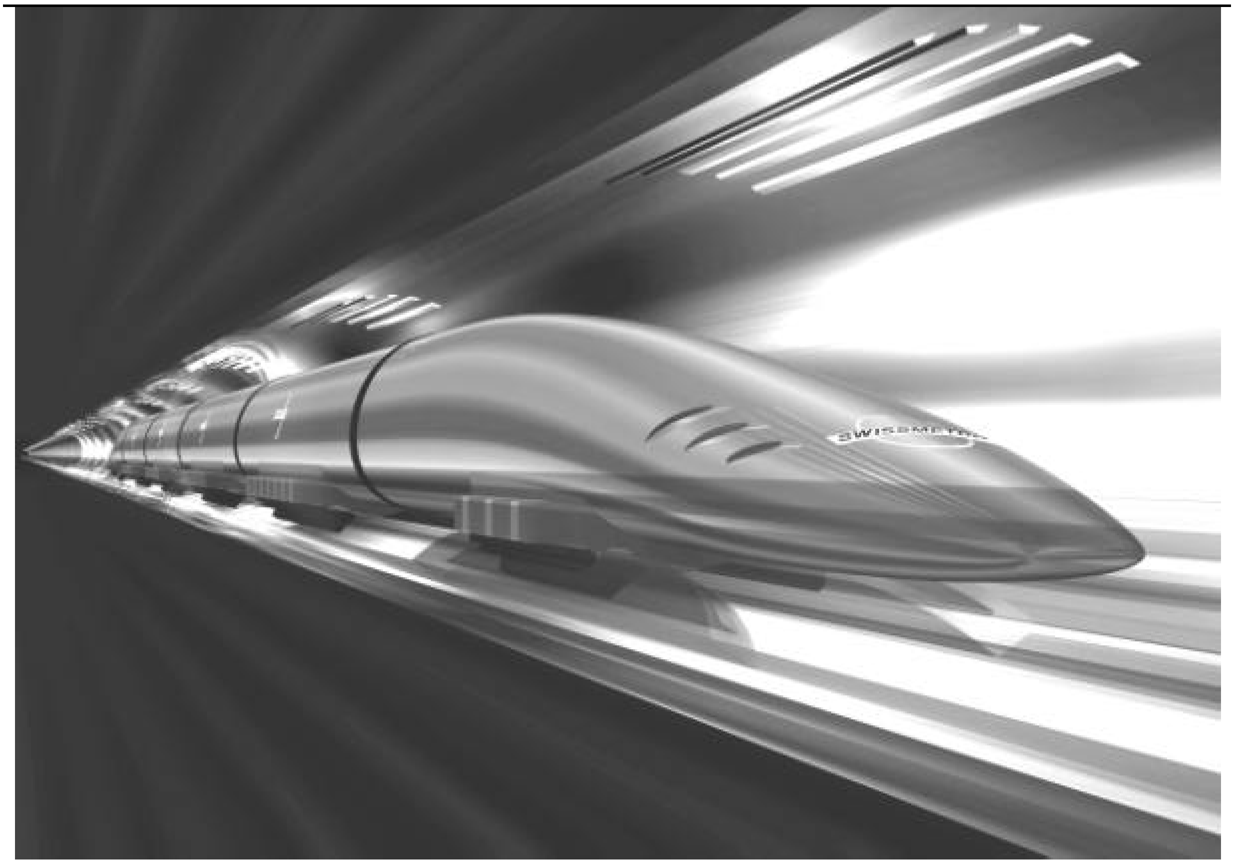

Swissmetro: a revolution in the high-speed passenger transport systems

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Abstract

The important increase in people and freight mobility observed in many countries results in a saturation of the infrastructures for air, sea and land transportation. During the last few years, different approaches appeared to counterbalance the negative impact of this global rise in mobility. Within this, the development of new environmental friendly, economical and ecological high-performance transport systems is vital. The Swissmetro Maglev vehicle occupies a leader position in this movement. The concept of Swissmetro is that of a vehicle travelling at high speed in a monodirectional underground tunnel maintained under a partial air vacuum. The infrastructure contains two parallel tunnels, one for each direction, connected by the stations to the surface transport networks. The Swissmetro passenger transport system is based on advanced technologies – such as linear electric motors and magnetic levitation – which allow it to reach speeds of over 500 km/h, guaranteeing economical energy consumption and minimum maintenance, whilst ensuring maximum passenger safety and comfort.

The present article gives the status of development of the Swissmetro project. It deals with a general overview of the Swissmetro passenger transport system and describes the present situation in terms of industrial development, market opportunities, pilot track, costs and time frame. It also shows how Swissmetro could become an alternative to the classical High Speed technologies.

Keywords

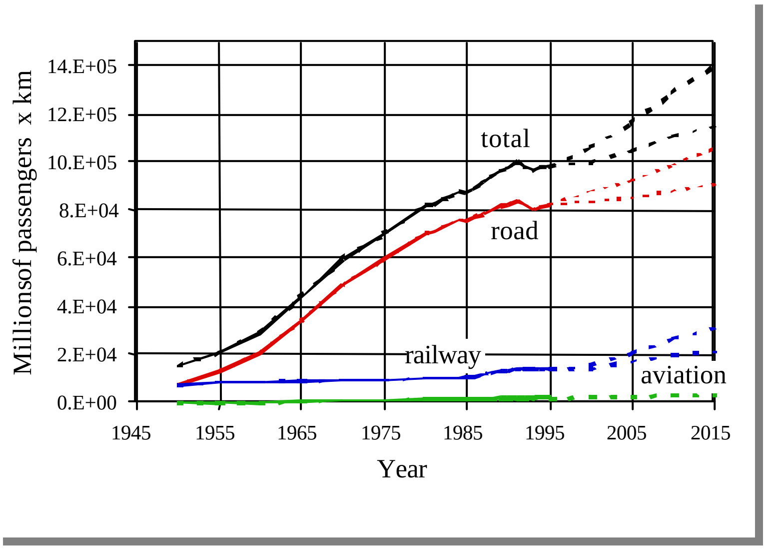
Swissmetro – Maglev – high speed – Swiss Transport Research Conference – STRC 2001 – Monte Verità

1. Introduction

1.1 Context

The continuous growth of people mobility and freight transport observed in many countries has resulted in a saturation of the existing infrastructures for air and land transportation. This has been leading to the improvement of existing ground transport systems, as well as the emergence of new environmental friendly, economical and ecological high-performance transport technologies. The Swissmetro Maglev[1] will occupy a leader position in this new trend.

Figure **Fehler! Unbekanntes Schalterargument.** Evolution of the passenger traffic in Switzerland.



1.2 The first concept of Swissmetro

Swissmetro is a project for an underground passenger transport system, initially planned to connect at high speed and high frequency the main cities and regions of Switzerland [1], [2].

1 The Maglev technology is based, on one side, on the linear electric motor as propulsion system and, on the other side, on the magnetic levitation as guidance system of the vehicles.

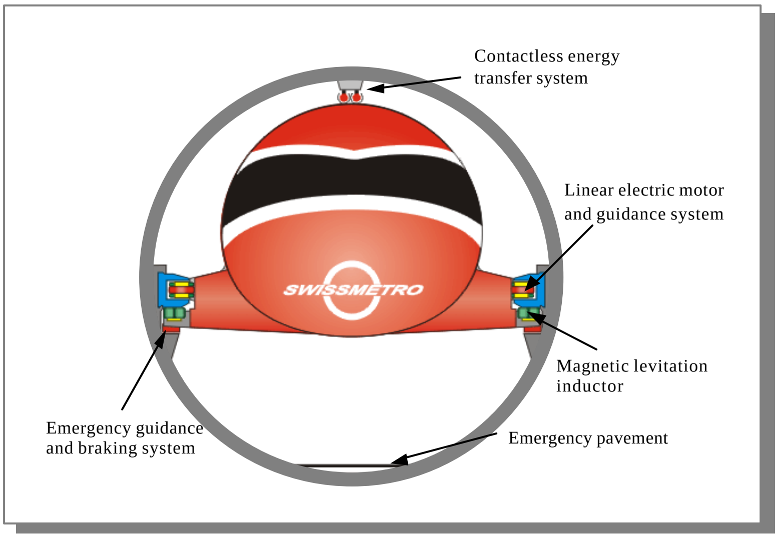
An extension to important European cities is also expected, transforming Swissmetro into a real Eurometro.

1.3 The Swissmetro technology

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

- an entirely underground infrastructure, comprising two tunnels of about 5 m interior diameter, one for each direction;
- a reduction of air pressure in the tunnels in order to diminish the energy consumption for propulsion of the pressurised vehicles;
- a vehicle propulsion system using linear electric motors, allowing speeds of over 500 km/h;
- a magnetic levitation and guidance system, avoiding direct contact and friction with the track.

Figure **Fehler! Unbekanntes Schalterargument.** Vehicle and tunnel cross-section



Source: Swissmetro SA, Geneva; B&G, Lausanne

This set of technologies represents a potential which, even if it already has a history, must be evaluated especially concerning its possibilities of implementation, and in this case, the stages which must be gone through in order to achieve this. In order to break away from a strictly "push" vision of the R&D of such a system and place the project management this R&D implies in a realistic framework, different parameters and processes must be documented relating to the innovation management of Swissmetro.

1.3.1 Entirely underground infrastructure

The underground solution has many advantages:

- it is ideal for protecting the environment and avoiding the generation of noise, vibration, pollution and damage to the landscape;
- there is ease of penetration to the city centres;
- topographical conditions have little effect on construction and none whatsoever on operation;
- climatic conditions do not influence the movement of vehicles;
- the use of two separate tunnels, one for each direction, makes collision between two vehicles impossible; etc.

1.3.2 Partial air vacuum

In proposing a vacuum level of about 1/10th of the atmospheric pressure and a small tunnel diameter, an effort was made to strike a compromise between investment costs (small diameter and pressure level as close as possible to atmospheric pressure) and operating costs (minimum energy consumption), while at the same time providing for safety, heat accumulation, construction aspects and other criteria. The retained air pressure level in the tunnels corresponds to pressure at about 15,000 m, the altitude at which Concorde flies. The partial vacuum is created by two vacuum pumps of 300 kW placed every 15 km of double tunnels.

1.3.3 Propulsion by linear electric motors

The use of linear electric motors allows a frictionless propulsion system. The mechanical constraints, volume and maintenance are reduced. As compared to the electric locomotive with a rotary engine, the linear motor does away with the overhead power line and pantograph arm. Without these elements, the tunnel diameter can also be reduced.

1.3.4 Energy transfer to the vehicle

The energy transfer to the vehicle is assumed by a contactless linear transformer.

1.3.5 Magnetic levitation and guidance systems

Only magnetic levitation can ensure economical and safe guidance at speeds in excess of 350 km/h. Furthermore, it eliminates all wear-and-tear, thus resulting in considerable savings on maintenance and equipment renewal costs. The mechanical stress of the structures is also reduced. Another noteworthy advantage is that magnetic levitation and guidance generate practically no noise.

1.3.6 Aerodynamics

Due to the very high speed and the small tunnel diameter, aerodynamics is clearly an essential element for the design of the Swissmetro line

1.3.7 Performances

The Swissmetro vehicle, today on a design phase, should offers very high performances:

- very low energy costs, as little as half those of a conventional intercity train;
- a maximum speed of over 500 km/h; such a speed is sufficient for sections less than 100 km long, as is the case in the Swiss network; a higher speed can be reached by enlarging the tunnel diameter;
- a frequency of 6 to 10 vehicles per hour and per direction;
- stations designed to keep traveller waiting times to a minimum;
- a high safety level for passengers;
- operation of the system in close co-operation with the local railways and urban transport companies.

With a vehicle carrying 400 seated people every 6 minutes at rush hours, Swissmetro has a transport capacity of 4,000 travellers an hour in each direction, and this capacity could be even further increased by lengthening the vehicles or allowing the transport of standing passengers. Vehicles stop only 3 minutes at stations.

1.3.8 Operation

At the stations, automatic airlock doors enable efficient transfer of passengers. The tunnels remain in a partial vacuum and airlocks are applied to each vehicle door, enabling passengers to board and leave the train at atmospheric pressure. The asymmetrical layout of the station makes it possible to have airlock doors on just one side of the vehicle, offering the advantages of low cost and high safety.

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. Finally, a barrel system makes it possible, if necessary, to move a vehicle from one tunnel to the other by rotation.

1.3.9 Safety aspects

For a new underground transport system such as Swissmetro, safety is a sensitive subject conditioning the acceptability and profitability of the project, whether the objective safety level or the subjective feeling of safety. As compared to similar networks such as railways or undergrounds, Swissmetro offers safety advantages inherent to its design (intrinsic safety). As in classical forms of transport, there are nonetheless hazards which can threaten the safety 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. In case of serious incident, a procedure of emergency tunnel repressurisation is launched, with the objective of reaching in 2.5 minutes an air pressure level of 60,000 Pa.

As a general comment on safety issues, problems can be seen as innovation opportunities. Risk perception is to a great extend a combination of state-of-the-art engineering knowledge and cultural acceptance, which defines indirectly the level of investment made in this domain. R&D in safety aspects, in information technologies, intelligence, procedures and automation related to safety aspects of Swissmetro, taken as specific technologies or considered within the global concept through the experimentation of a pilot track, represents certainly a significant step towards such an innovative know-how. Details can be found in [3].

2. High speed competitors

If we acknowledge that commercial transport systems represent not only performances, but rather services backed up by performances, speed is only one of the parameters of mobility, and the forms of the latter may vary considerably.

To define our concerns, let us specify that by high speed we mean systems capable of travelling at above 300 km/h and over distances of more than 100 km, on a routine and commercial basis.

Today, high speed on long distances (over 500 km) is mainly embodied by the aeroplane, probably because it combines high performances and flexibility of use even if, historically, its development came later than that of rail technology. The expansion of air travel continues and, according to a number of studies, is not likely to stop. However, this success now scarcely conceals certain problems such as: noise pollution in the vicinity of airports and on their main access routes, exhaust fume pollution, high energy consumption, a propensity for congestion, particularly in Europe and the United States, with its consequences in terms of not only stress and risk, but also delays and financial compensations. Overall, an increase in air traffic will also mean an increase in these problems.

It is thus quite natural that high ground speed, that is the TGV, ICE and Shinkansen, has tried to compete with the aeroplane for certain distances and, henceforth, not only for journeys of less than 500 km, but also longer distances, up to 1000 km (soon Paris-Marseilles for example).

Thanks to an intense European process of standardisation, high speed rail systems will become compatible, facilitating even greater development over the next thirty years. In many cases, with a more favourable ecobalance, these systems therefore compete with the plane and will be able to accentuate this strategy even more in the future.

Two reservations must however be made concerning this expansion. Firstly, the profitability of TGV routes is not infinite, but highly dependant on the human corridors they serve. By about 2020, most of the profitable lines will be equipped and all the less important lines or connections between main lines will tend to diminish the profitability of the high speed sector already in place. Secondly, it is clear that high speed technology tends to implement higher and higher performances. But if the speed can be increased to over 350 km/h, on a commercial basis and not only to set records, this will not be done without major inconveniences: greater equipment maintenance, increased development of computer-assisted driving, search for more robust materials, crucial noise management (in general and especially surrounding towns where high speed systems must slow down) and ever greater energy losses, in wheel-rail friction, but also on the electricity distribution lines and finally, on the aerodynamic level. Moreover, important reinforcements are needed to improve the transfer and support of mechanical constrains by the track. Consequently, the speed of the TGVs, ICEs and other means of transport of this type will probably not be increased beyond 350 km/h without a corresponding raise in cost and therefore fares.

3. Maglev hypothesis

It is thus worth analysing transport systems based on linear electric motors (propulsion technology) and on magnetic levitation (guidance technology) as precisely attempts at exploring the possibilities of doing better than their ground or air competitors, not only in terms of performance (velocities of over 500 km/h are possible), but also service to passengers, and more broadly, if the social and environmental aspects of transport are considered, to citizens in general.

Thanks to the absence of a direct mechanical contact and thus of important shocks between wheels and rails, the Maglev (magnetic levitated) technology allows an important improvement on the transfer of mechanical constraints to the tracks and their support. On one side, mechanical vibrations on the vehicle can be reduced, which increases the comfort level for the passengers, even at high speed; on the other side, the absence of direct shocks with the track allows a drastical reduction of maintenance costs.

However, even if it offers an interesting reduction of the energy and maintenance costs and an important increase of the transport performances, this Maglev propulsion and guidance technology cannot reduce alone the large environmental impacts produced by an on the ground high speed line. This justifies the difficulties encountered by the German Transrapid and the Japanese MLX to find the political support for the construction of a pilot line.

Thus, the introduction of an entirely underground infrastructure, possible thanks to the benefits of the partial air vacuum as proposed by Swissmetro, seems to be the only possible technological innovation, able to offer at the same time high performances and important reductions of the environmental impacts.

4. Obstacles to development of the Swissmetro technology

If Swissmetro has been unable to pass the test of real-scale experimentation up until now, this is essentially due to the following factors:

- doubts concerning finance, to a great extent dependent on public subsidies in the version proposed for a licence application for a pilot track between Geneva and Lausanne (in November 1997) and not sufficiently profitable (approximately 3%) to really attract important private actors, nonetheless necessary for the system's industrial development;
- the large public investments on transport infrastructures planed for the next 20 years in Switzerland (Rail 2000 and NEAT projects);
- cultural reticence regarding the risk involved in an unknown system, presenting uncertainties resulting from very specific technological and situational characteristics (Maglev technology, automatic system, tunnel, vacuum); Swissmetro, to cross this barrier of mistrust, should not be satisfied with postulating that its promoters do not have to offer superior guaranties to those found for other systems (aeroplane, car, TGV in tunnels, etc.), but on the contrary should take into account the fact that risk perception is constructed socially and culturally. As proposed by the new strategy of Swissmetro, gradual familiarisation, organised around real-scale experimentation and a strong safety concept, is the only way to create the necessary apprenticeship for everyone concerned;
- the tendency of any new transport system to generate new mobility, disapproved of by environmentalists, whilst long-term strategy probably consists of demonstrating that this system can capture mobility linked with development of the TGV, ICE and aeroplane and thus prove a particular source of net gain for the environment, taking all parameters into consideration;
- tendencies (tunnel and centralising effects) inevitably shown by any high speed system to reinforce the predominance and attractiveness of large cities, as they are even better interconnected; the question here is above all knowing how to deal with this problem, probably by supporting the areas concerned, by the development of nearby surface routes and especially thanks to an effect of global competitiveness capable of benefiting a maximum of actors, including peripheral ones, if ad hoc negotiations are correctly conducted.

5. The "Gemini stage"

As the race to the moon meant surmounting certain key technical difficulties by means of intermediate experiments[2], Swissmetro must make progress in reducing the uncertainties concerning it.

Up until now, important internal research has been carried out, innovative in terms of propulsion by linear motor, electro-magnetic guidance and energy transfer by linear transformers, principally in the Department of Electricity of the Swiss Federal Institute of Technology Lausanne (EPFL), and in the aerodynamics field (in the Department of Mechanics of the same institution); in addition, Swissmetro benefits from a tremendous store of knowledge of the feasibility of the Maglev systems formed by the German and Japanese projects (thanks to them, we know that a Maglev vehicle is possible and works at over 500 km/h).

It is therefore up to Swissmetro to go one step further and document the elements which make it a new and remarkable system.

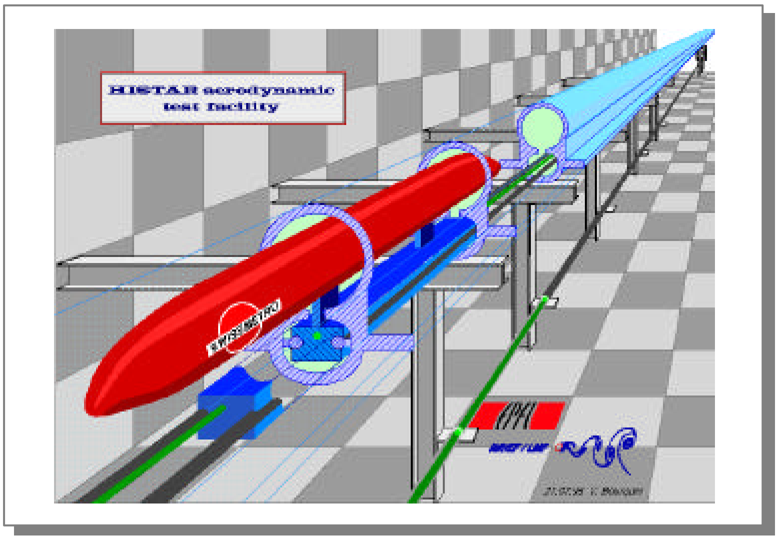
In this context, let us mention the research the two most important experiments soon to be started, one on the aerodynamic behaviour of moving objects in tunnels, the other on all the constraints linked with vacuum and various static and dynamic problems affecting the vehicle.

For the first of these two points, the HISTAR project (high-speed train aerodynamic rig), has begun and aims at construction of a reduced-scale model of Swissmetro in order to analyse the involved aerodynamic phenomena. The test facility coupled with numerical simulations will allow a precise design of the Swissmetro vehicle and tunnel in terms of diameter, geometry and air pressure level. HISTAR will reproduce on a small scale (around 1:10) the Swissmetro tunnel and vehicle: the track length will be about 500 m, on which a high-performance hydraulic propulsion system will tow vehicles at speeds up to 500 km/h with accelerations of more than 20g. The test facility will be sufficiently long to study the whole process of wave generation and propagation in a long tunnel (more than 5 km at full scale), and will give sufficient information about characteristics of the air flow around the vehicle. The

[2] The GEMINI programme had in particular allowed testing of the techniques for inter-docking between two spacecraft and behaviour of equipment and astronauts in space.

design phase of the facility is finished, construction should begin during the next spring, and the first measurements are expected in autumn 2001.

Figure **Fehler! Unbekanntes Schalterargument.** The HISTAR aerodynamic test facility.



Source: V. Bourquin, EPFL, Lausanne.

The second of the points referred to will be explored by the Swissmetro Vacuum Test Site, which will reproduce life-size, over a distance of about 200 meters, the tunnel and a part of a station of the real system. The main objective of this site is to test the vacuum, with the tunnel structure, the behaviour of the vehicle and equipment in a depressurised environment, the creation of a vacuum and the tunnel repressurisation. An associated aim is to test dynamic factors of the vehicle, particularly structural articulations allowing it to negotiate bends and slopes, levitation and its shutdowns, positioning of the vehicle in relation to the tunnel, solutions selected in stations for electricity supply, embarkation and disembarkation of passengers, including escape routes, and airlock system.

6. Strategies of development

6.1 Sustainable development

In the next decades, very limitative norms will be applied in the domains of environment, safety, land policy and air pollution (see Kyoto agreements). These restrictions will reduce the use of some of the present transport means (typically, in air transport, the shuttle flights).

They will need the development of new attractive approaches in the transport systems domain.

Swissmetro with its particular specifications (performances, energy balance, environmental friendly) could take a significant place in this trend.

6.2 Potential markets for Swissmetro

Beyond the problematic of the development of the Swissmetro project in Switzerland, an analysis of the potential markets for such a system is partially proposed in [3]. Globally, three types of markets have been identified:

- links between the centre of the main European cities, creating high-speed corridors and cities networks
- links between airports, allowing the creation of airports networks and offering a better flight organisation and distribution;
- links between the city-centre and its new airports, built far from the city-centre.

For the moment, Swissmetro SA and GESTE (operational direction of the Swissmetro project) are analysing in details a combination of the two last solutions. The key idea in this case is to play on the complementarities with air travel rather than on competition with the rail regime already established. Currently, two projects are being studied, illustrating this procedure (or, depending on the turn of events, a combination of the first two solutions): on the one hand, a link between the cities of Basle and Zurich, with possible extension to the EuroAirport near Basle and the Unique Airport near Zurich; on the other hand, a link between Lyon, the Saint Exupéry Airport and the Geneva Airport. Results on the technical, economical and financial feasibility of such connections are expected during the next months.

6.3 From a project to a marketable product

Today, after more than ten years of technical and feasibility studies, the Swissmetro project and idea have been thoroughly developed and have reached a sufficiently high level of maturity to consider its development into a marketable product. To achieve this goal, it is necessary:

- to carry out the industrial development of the Swissmetro transport system by constructing the aerodynamic test facility HISTAR, the vacuum test site at full scale and a test line of about 20 km in order to reach 500 km/h;

- to choose, in collaboration with the political authorities, a pilot line of interest, probably Basel-Zurich or Lyon-Geneva or even Geneva-Lausanne.

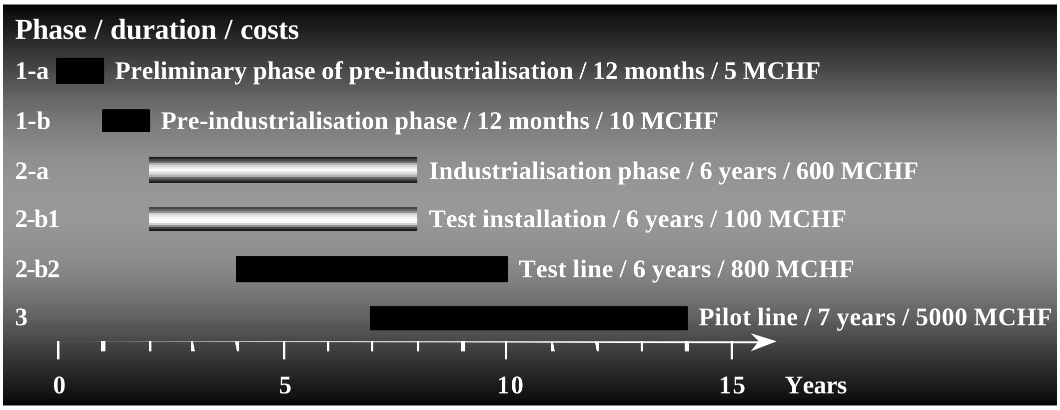
To realise a marketable product from the Swissmetro project, the direction of the project follows four distinct and complementary axes with the following objectives:

- the continuous development of the Swissmetro concept through the undertaking of particular studies (HISTAR, vacuum test site, …) and the updating of the technologies involved;
- in the frame of an industrial working group, the planning and preparation of the industrial development and the realisation of a pilot line, by estimating their duration, their costs and the risks for the companies involved;
- in the frame of an economic-political working group for the Basle-Zurich link, the detailed definition of the Swissmetro line and a strategic thinking on the consequences and the advantages of such a high-speed connection (traffic analysis, town and country planning, impacts analysis);
- the realisation of a business plan for the pilot track, the seeking of the funds necessary to the financing of each development stage and – by analysing the legal and economic aspects and by proposing financial models – the continuously analysis if the considered solutions are commercially and legally viable.

6.4 Planning

According to current state of knowledge developed within the Swissmetro transport system and the duration of the industrial development as well as the construction of a pilot line of about 100 km, the operational start-up of the first line could be done in 14 years.

Figure **Fehler! Unbekanntes Schalterargument.** Stages leading to the realisation of the marketable product “Swissmetro” and to the operational start-up of a 90 km pilot line.

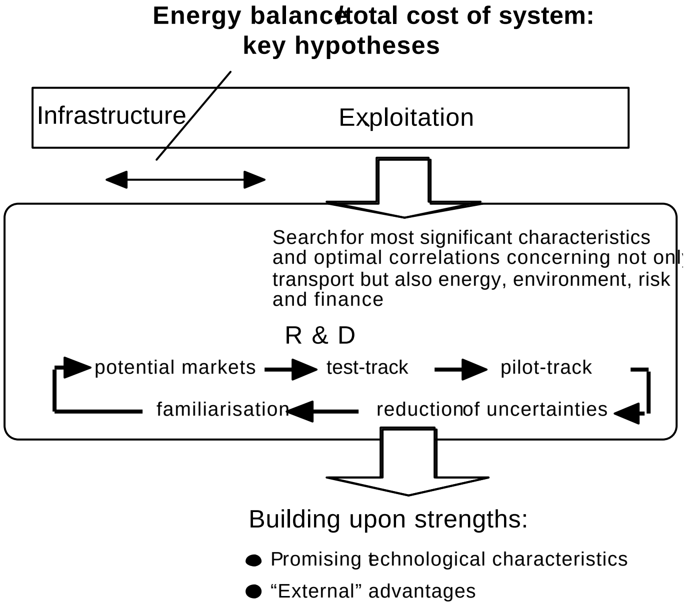


The current phase, named here preliminary phase of pre-industrialisation, joins the studies in progress and programmed as well as the activities of the previously defined working groups.

7. The entry cost: the main barrier to overcome

Apart from the cost of development, Swissmetro is characterised by its underground installation entailing the excavation of two parallel tunnels of a certain length. In other words, even if these constructions have a relatively long life (there are tunnels over a hundred years old in Switzerland), and consequently amortisation spread over approximately a century, the principle investments have to be made within a short time, representing a penalising entry cost. The scenario to insist on is therefore to show, or demonstrate, via an initial experiment, that exploitation of the system is economically and environmentally more favourable than that of all its competitors for an identical or even better service. By competitors is meant the TGVs, ICEs, etc., but also the aeroplane and naturally the other Maglev systems. It is therefore thanks to less energy consumption, for an equal service, and also greater respect of environmental or territorial dimensions (energy, pollution, noise, damage to the landscape, risks, etc.), that Swissmetro can interest different actors and particularly the public authorities, to compensate the relatively lower profitability of the first years due to the famous entry cost linked with the system and the realisation of its infrastructure.

Figure **Fehler! Unbekanntes Schalterargument.** Iterative process needed to define the specifications of the technologies involved.



Globally, this scenario which, by optimising the factors involved, can allow the costs of the infrastructure to be reduced to 15-35 % of the total over 100 years (depending on the context, configuration developed and parameters taken into account), may be described in terms of the following diagram (Figure 5).

To show on which key dimensions the effort of Swissmetro SA must be concentrated in terms of innovation management, it is worth going into some detail concerning the supposed strong points of this technology referred to at the bottom of the diagram in Figure 5. It is these which, if they are confirmed during the R&D of the system, will mean that the hypotheses presented here on the economic and environmental advantages of Swissmetro may eventually interest current or potential partners of the project, both public and private. To consider them in more detail, we must first refer to the project's technological aspects and then the most significant external factors.

Some promising technological characteristics (in comparison with competitors) are the following:

- lighter vehicle structure;
- very efficient power supply, guidance and energy transfer technologies;
- a vehicle shape optimised for a tunnel environment;

- very effective dynamic and aerodynamic configuration (thanks to the vacuum, but also the vehicle's morphology and structure, and the stability of the system, very close to the tunnel's centre of gravity, as the diagram above shows).

While some interesting "external" advantages are:

- more favourable balance of risks than the other systems (as long as the technology's reliability can be established experimentally, of course) especially because of the protective effects of the tunnel, beneficial regarding several types of risk (insensitivity to climate and weather, impossibility of falling objects and undesirable access to rails) and the mono-modal and mono-directional function of the system (two tubes, one for each direction, used by one single transport system);
- very low occupation of ground surface;
- very low environmental impact (regarding landscape impact and direct or indirect pollution) and a very interesting ecobalance;
- no noise pollution;
- considerable inter-modal gains possible, in combination with the aeroplane on the one hand (one of the objectives of the Basle-Zurich section), and regional transport on the other (different options being studied).

It is thus on the basis of these potential advantages that the various projects allowing the construction of this breakthrough technology will have to be conceived and validated. In this sense, the indications presented here have both the value of strategic mission (diagram on the search for a favourable competitiveness) and blueprint for specific improvements or developments (likely to generate spin-off know-how).

8. Conclusions

The 14 years long studies of the Swissmetro technology have demonstrated that this revolutionary passenger transport system is not only technically feasible but also economically and financially viable.

Reaching speeds of over 500 km/h and carrying up to 400 or even 800 passengers every 6 minutes, Swissmetro will be the ideal passenger transport system for high-speed connections as links between airports or the city centre and its airport, as cities network or as corridor lines.

The Swissmetro SA company and the project direction (assumed by the company GESTE) are presently working on one side on the planning of the industrial developing phase and, on the other side, on the research of a financial and political agreement around a pilot track. This track could be between the Basel and Zurich as well as between Lyon and Geneva, connecting in the same way two important regions and airports.

The transformation of the Swissmetro project into a marketable product could be done in 10 years while the operational start-up of the first Swissmetro line could be as early as 2015.

9. References

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