Swissmetro: strategy and development stages

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Abstract

The studies carried out these last 10 years show that Swissmetro has all the potential to become a technological product fully satisfying the expectations of the new markets of high-speed passengers' transportation. It appears to be the only transportation system capable to offer both high performance and significant sustainability.

Swissmetro still being in a stage of project, the operational start-up of a first line necessitates proceeding to a series of development stages. After a brief description of the project, these stages are presented in this document, and in particular the ones including two new experimental test facilities:

- the aerodynamic test center HISTAR (High-Speed Train Aerodynamic Rig);
- the test center for mastership of the partial air vacuum SETUP (Safety, Equipment and Tunnel Under Partial Pressure).

1 The Swissmetro project

Swissmetro is a revolutionary project, considered today as one of the most innovative solutions as far as passengers' transportation for the 21st century is concerned. Entirely underground, it resembles at the same time a train without wheels and a plane without wings enabling passengers' transportation in total safety at more than 500 km/h.

Through a clever combination of high technologies, this project aims at optimizing a high-speed, modern, evolutive and environmentally friendly transport system, able to satisfy the sustainable development criteria.

1.1 The 4 technologies

The Swissmetro vehicle will circulate in a tunnel of small diameter located at a depth of approximately 50 meters (or deeper, depending on the topographical conditions). In a subsequent stage to the construction of a pilot line, it could link the centers of the major Swiss, European, and possibly even overseas cities. To be able to reach high-speeds in total safety, it will move in a state of magnetic levitation, without any contact with the ground, and will be propelled by linear electrical motors. In addition, in order to reduce the tunnel diameter and to ensure important energetic saving, the air quantity in the tunnels will be reduced to pressures similar to the atmospheric conditions usually found at an altitude of 15'000 meters (about 0.1 atm).

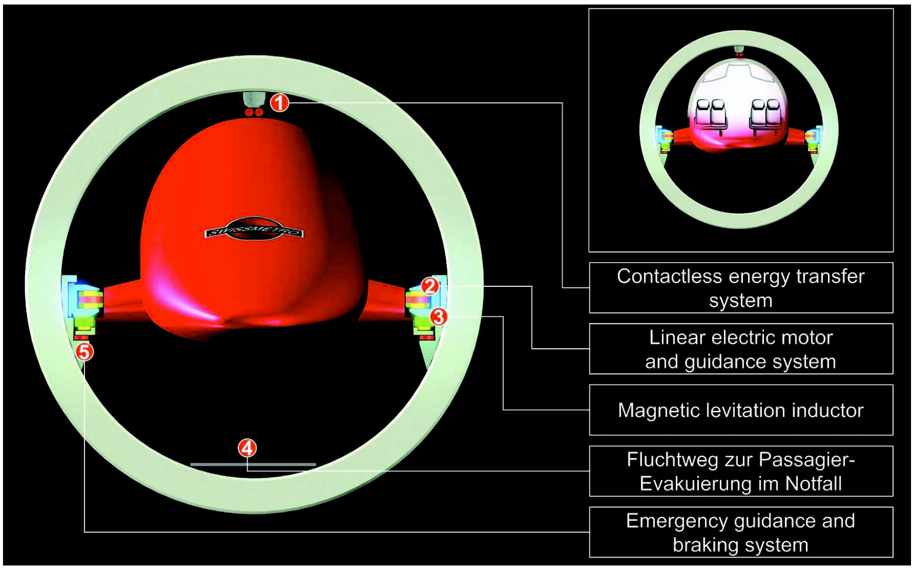

Figure 1 *– Vehicle and tunnel cross-section.*

The Swissmetro project is thus based on the application of the 4 following complementary technologies:

- an entirely underground infrastructure, comprising 2 mono-directional tunnels of about 5 m interior diameter;
- a reduction of air pressure in the tunnels (partial air vacuum);
- a vehicle propulsion system using linear electric motors, allowing speeds of over 500 km/h;
- a magnetic guidance and levitation system, avoiding direct contact and friction with the track.

1.2 The potential markets of Swissmetro

The Swissmetro transportation system may be an interesting solution for the following categories of passengers' traffic:

Category	Distance	Targeted speed	Time horizon
Inter-city connections	50-200 km	400 km/h	2020
City-airport connections	50-100 km	400 km/h	2020
City nets and major inter-city corridors	300 km and more	600-700 km/h	2030 – 2050
Airport nets	100 km and more	400-700 km/h	2030 – 2050

In addition, it seems today that Swissmetro is the only transportation system capable of optimally and wholly satisfying these 4 categories of passengers' transportation in a sustainable development perspective.

As for the time factor, the interesting markets for Swissmetro can also be broken down into “short-term markets” and “long-term markets”.

Market	Distance	Targeted speed	Time horizon
Short-term markets	approx. 100 km	400 km/h	2020
Longer-term markets	300 km and more	600-700 km/h	2030 – 2050

As an example, Swissmetro will not be considered at European level as a competitor to the TGV high-speed train, but as an additional stage in the evolution of ground transportation, which then will comprise 3 levels: a basic railway network, a high-speed network and a third layer of very high-speed services. This long-term perspective (2030 to 2050, longer-term markets), comprising the Swissmetro system, will offer a very efficient and nevertheless environment-sensitive alternative to the short- and middle-haul flights till distances of about 1'000 km.

Therefore, in a medium-term perspective (2020, "short-term markets"), Swissmetro has to find very bearing niche markets, such as connections between cities not operated by the TGV (as it will be the case in Switzerland), inter-airport connections, city-airport connections or strategic corridors like Lyon-Munich in Europe.

1.3 Short-term markets

So, taking into account the needs of both transportation and environmental protection, the short-term markets – the ones of the Swissmetro pilot line – will certainly have to satisfy the following conditions:

Distance	Targeted speed	Infrastructure	Atmospheric conditions
100 km	400 km/h	underground	partial vacuum

1.4 What still has to be technically demonstrated to satisfy the short-term markets?

1.4.1 High-speed in a small tunnel

No existing transportation system circulates at more than 150 km/h in tunnels of small diameter, such as foreseen by the Swissmetro system. Reaching 400 km/h in a tunnel of 5 m of diameter necessitates, even at reduced pressure, a complete mastership of the dynamic and aerodynamic phenomena at stake.

Demonstrating experimentally and with the help of numerical simulations that we are able to master the dynamic and aerodynamic phenomena appears therefore to be necessary. Hence the proposal to implement the aerodynamic test facility HISTAR.

1.4.2 Tunnel and partial vacuum

No existing transportation system circulates in an underground environment and under partial air vacuum, no matter its propulsion system. In addition, the presence of the partial vacuum and the Swissmetro structure entirely in tunnel represent a series of technological challenges, in particular in relation with the air tightness of the stations and tunnels and with the safe management of the passengers in this environment.

Demonstrating experimentally at 1:1 scale that we are able to handle the vacuum constraints and consequences on the infrastructure and passengers' transportation appears to be equally necessary. Hence the proposal to implement the vacuum test center SETUP.

1.4.3 Propelling the vehicle and maintaining the trajectory at 400 km/h and above

The theoretical analysis and experimental models developed at both Swiss Federal Institutes of Technology in Lausanne (EPFL) and in Zurich (ETHZ) in the course of the Main Study[1] documented the technical feasibility and the conditions for market viability of Swissmetro.

In addition, at sea-level atmospheric pressure, vehicle propulsion and guidance technologies similar to those recommended for Swissmetro have already been applied with success in the case of the German Transrapid (450 km/h) and the Japanese Maglev (552 km/h). At last, even the classical system wheel/track used by the TGV has already proved the capability of operating at speeds higher than 400 km/h.

Therefore, the construction of a complete test facility in tunnel in order to demonstrate the feasibility of the propulsion and trajectory maintenance (guidance and levitation) systems guaranteeing 400 km/h does not have priority at this stage. This will however certainly become necessary in a few years.

1.4.4 Conclusion

Thus, in order to demonstrate experimentally the industrial feasibility of the Swissmetro, both on the technical and safety sides, as well as on the economical and financial sides, the implementation of the experimental HISTAR and SETUP facilities is an essential step. Beyond the technical goals, these facilities will enable to guarantee a reasonable precision in cost estimates for the construction and operation of the Swissmetro.

HISTAR and SETUP also have also the objective to convince politicians and financial actors of the technical feasibility and economical viability of Swissmetro, which should encourage the financing of a pilot line. Besides, these facilities will create appropriate conditions for the optimization of the Swissmetro system during the industrial development.

1.5 Towards a marketable product

In order for the Swissmetro system to evolve from the status of project to the one of a marketable product and, in parallel, for the market analysis to result in the operational start-up of a pilot line, it is necessary to jointly proceed:

- in the industrial development of the Swissmetro transportation system;
- in the choice of a pilot line and the filling of a license application.

1.6 Industrial development of the Swissmetro transportation system

1.6.1 Objectives

The objectives of the industrial development of Swissmetro are:

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1 The Main Study was carried out on the Swissmetro project from 1994-1998 by both Swiss Federal Institues of Technology in Lausanne and in Zurich as well as over 80 Swiss and European companies.

- the design, development, building and testing of all the components of the Swissmetro transportation system;
- the legal approval of the Swissmetro transportation system.

These objectives can be achieved by:

- developing and building by steps all the components of the Swissmetro transportation system;
- obtaining progressively the legal approval for the various components of the Swissmetro transportation system.

1.6.2 Stages

The industrial development will be carried out through four major processes (see planning hereafter), i.e.:

1a. the aerodynamic test facility HISTAR;

1b. the vacuum test center SETUP for the infrastructure, the safety and the fixed equipment (e.g. lining of the tunnel, partial air vacuum, repressurisation operations, safety concept, airlock systems);

2. the industrial development of the system (vehicle, stations, equipment, etc.);

3. the test line implementation (a tunnel 20 km long, allowing the testing of the complete system at full scale and at full speed).

HISTAR

The aerodynamic test facility HISTAR, developed at the EPFL since 1999, aims at experimentally demonstrating the mastership of dynamic and aerodynamic phenomena bound to the passing of a high-speed vehicle (speeds of over 400 km/h) through a tunnel of small diameter. In addition, HISTAR will help defining the Swissmetro tunnel diameter and vehicle geometry.

Test center SETUP

The SETUP test center aims at demonstrating experimentally and at real scale the partial air vacuum constraints mastership and consequences on the technical and safety levels. More specifically, this facility will allow the optimizing and the legal approval of the functioning of an infrastructure under partial vacuum and a passengers' transportation system moving in such an environment.

Industrial development of the system

The aim of the industrial development of the system is to conceive and develop all the necessary technologies and equipment for Swissmetro, as well as designing and building the first prototypes of the Swissmetro vehicle. These prototypes will then be tested on the test line.

Test line

The aim of the test line is to test at full speed and scale, on an infrastructure approximately 20 km long, the totality of the Swissmetro technologies, and to consequently finalize the system development. The test line will very probably be implemented on the site of the pilot line, of which it will constitute the first element. It will also have to make possible the legal approval of the vehicle (with the definitive technologies for propulsion, levitation and guidance systems) as well as the safety concepts.

1.7 The pilot line

1.7.1 Objective

The objective of the choice and the construction of the pilot line[2] is:

- the operational starting up of a first line using the Swissmetro technology. This line of approximately 100 km will connect two underground stations by two mono-directional tunnels (for example between two city centers or two airports).

1.7.2 Stages

The operational stat-up of the pilot line will be carried out by:

- choosing the pilot line;
- carrying out a certain number of detailed studies concerning the line (traffic and territory development, geology, infrastructure, ecobalance, impacts, economic, socio-economic and financial analyses, etc.);
- filling a license application;
- obtaining the necessary financing guarantees;
- obtaining a license application (in phase with the subsequently technological developments);
- producing a safety report;
- getting plans approval in order to make possible the start of construction;
- building the pilot line;
- getting the authorization for the exploitation of the system (after final approval).

1.8 Planning and costs

The following planning has been proposed for a realistic operational start-up in 20 years (see Figure below) .An important political and financial support could lead to a more ambitious planning and thus to a shortening of the development phase. The planning below also indicates the costs relative to each development and construction phase of a 100 km long pilot line.

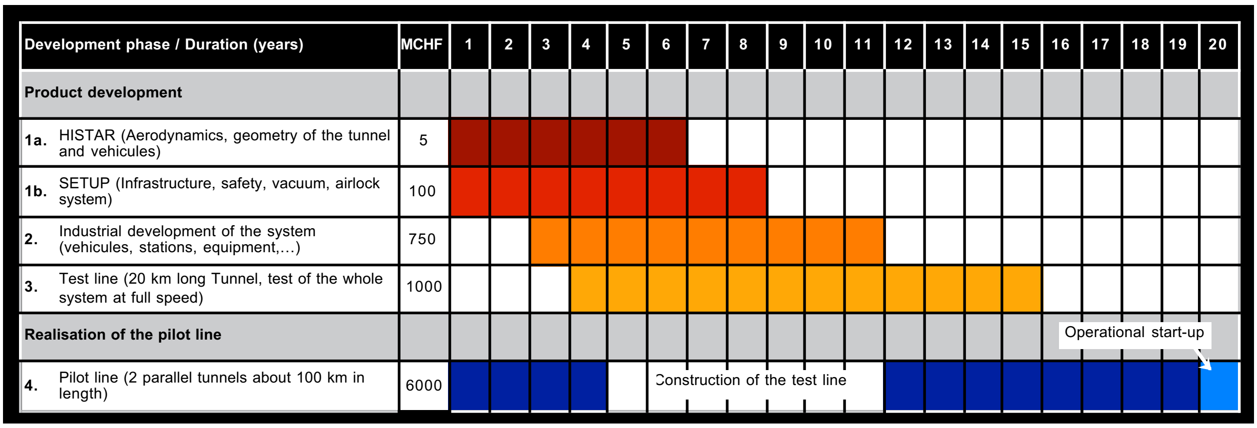

Figure 2 – Planning for the development of the Swissmetro into a marketable product and the implementation of a pilot line. According to the present state of knowledge, these two phases will cost less than CHF 8 billions.

[2] First operating line using the Swissmetro technology.

2 Test facilities

2.1 Introduction

The industrial development of the Swissmetro project, even up to now with very limited funds, has just started with the construction of the aerodynamic test facility HISTAR and with the preliminary design of the vacuum test center SETUP.

2.2 The aerodynamic test facility HISTAR

2.2.1 Project

HISTAR (High-Speed Train Aerodynamic Rig), currently under construction at the EPFL, will be soon a worldwide unique test facility, allowing for a vehicle ten times smaller than Swissmetro (diameter of 32 cm and length of 8 to 12 m) to reach similar speeds (up to 500 km/h) in a tunnel 500 m long and 50 cm diameter. An hydraulic propulsion of a power over 1.5 MW will allow the acceleration of the vehicles up to 20*g* and the reaching of 500 km/h on less than 50 m and in less than a second. These characteristics will allow the generating of aerodynamic phenomena identical to those encountered by the real Swissmetro at full scale or also in general by high-speed trains in small tunnels.

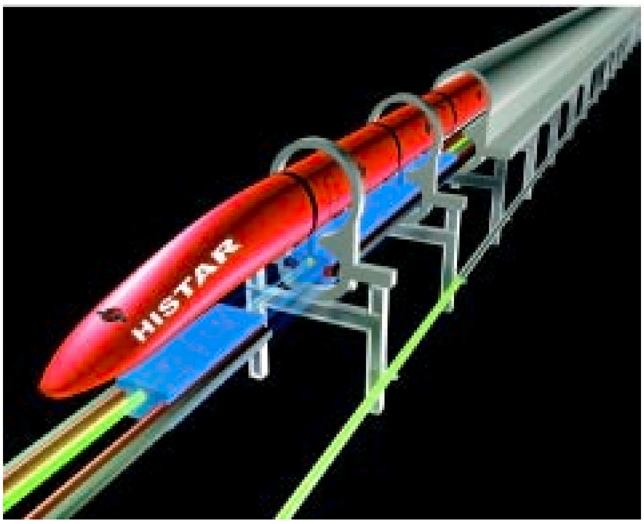

***Figure 3** – Aerodynamic test facility HISTAR.*

2.2.2 Aims

The first aim of the HISTAR project is to evaluate the aerodynamic impacts of the high-speed in a tunnel of small diameter. The key issue is to show the impact of the conception of the vehicle, tunnel, station and related equipment on the aerodynamic characteristics of the system. HISTAR will enable to validate numerical simulations upon which the present conception of Swissmetro is based. Besides the geometry of the vehicle, it will also be decisive for the dimension of the Swissmetro infrastructure (tunnels diameter and geometry at first) that represents 80% of the construction costs.

2.2.3 Planning and costs

The HISTAR project started in 1999 as a CTI project (CTI stands for "Commission pour la Technologie et l'Innovation, a Swiss Federal office encouraging applied research) pooling several laboratories of the EPFL, Swissmetro SA and different industrial partners. The construction cost amounts to CHF 2.5 millions and the foreseen budget for operating the facility also amounts to approximately CHF 2.5 millions. The operational start-up and the first test at 500 km/h are foreseen in 2004.

2.3 The vacuum test center SETUP

2.3.1 Project

The aim is to build a test facility at 1:1 scale, comprising a station approximately 30 m long, a tunnel 200 m long and a short vehicle moving under partial vacuum. This test facility, called SETUP (Safety, Equipment and Tunnel Under Partial Pressure) should be built at surface.

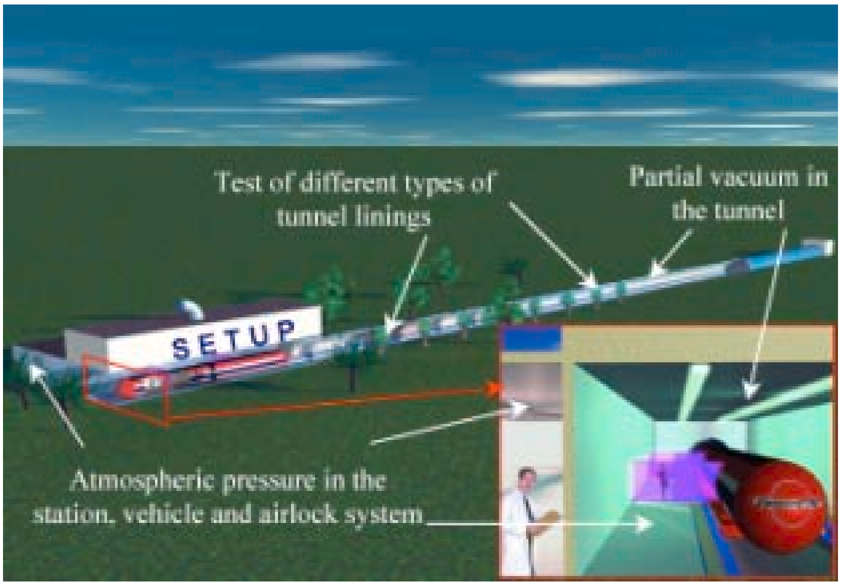

***Figure 4** – Sketch view of the SETUP test center which will have the objective to demonstrate mastership of partial vacuum and its implications.*

2.3.2 Aims

The main aim of the SETUP test center is to show experimentally and at real scale that it is possible to control vacuum and more specifically the functioning of an infrastructure under partial vacuum and a passengers' transportation system in such an environment. The SETUP facility will thus aim at studying and testing the creation and maintenance of the partial air vacuum, the emergency repressurisation of the tunnel, the tunnel structure and its behavior under partial vacuum (air tightness in particular), the fully safe functioning of the passengers' embarking and disembarking through tight airlock doors, and the setting of a global safety concept.

The site SETUP should in addition lead to a legal approval of a functioning under partial vacuum of the tested systems (from the infrastructure to the safety concept for the passengers' management under partial vacuum), with all their implications, and this as independently as possible of the technology used for the propulsion and guidance of the vehicle. This approval constitutes one of the main objectives of the test facility.

These tests which will be carried out in this framework will therefore concentrate primarily on the following fundamental aspects:

Creation and keeping the level of vacuum

Testing of pumps and repressurisation systems, analyses of different material behavior (structure of the tunnel and equipment), heat exchanges.

Tunnel structure

Design, selection and detailed testing for both structure and linings (voussoirs of concrete-metal sandwich type, with joint, without joint, stainless steel, reacting powder concrete).

Airlock system and station

Building of the airlock systems allowing the passengers' embarking and disembarking in total safety. Testing procedures for passengers' embarking and disembarking timing, testing of the anchoring systems of the vehicles in the station.

Safety systems

Break down simulation with and without repressurisation, development of innovative approaches and demonstrator effect, passengers' evacuation with walking in the tunnel, analysis of emergency processes.

Vehicle, equipment, etc.

In a second stage, which must be phased in parallel with the industrial development of the vehicle, behavior testing under vacuum will be carried out for the vehicles, electromechanical equipment, control and communication systems, etc.

2.3.3 Planning and costs

The preliminary and detailed conception studies of the SETUP test center conducted during the years 2001, 2002 will be pursued in 2003, could lead way to construction of the site at the beginning of 2004. After construction, tests will be carried out for several years, in parallel with the evolution of the industrial development of the vehicle while expecting operational start-up of a pilot line 20 km long.

In order to achieve first stage, which aims at approving different elements under partial vacuum and the final safety concept, an estimated amount of CHF 100 millions is budgeted.

2.3.4 Approval

As mentioned above, one of the main objectives of SETUP is the legal approval of the vacuum concept by the concerned Swiss federal Offices, in a tight collaboration with these Offices (and in particular with the Swiss Federal Office for Transportation and Telecommunication). This collaboration is indispensable for the test facility to meet official requirements.

2.3.5 Companies' interests

The SETUP test facility and in particular the getting of a legal approval for the partial vacuum concept, should interest of a certain number of companies not only in the civil engineering domain but also in the mechanical and electromechanical industry. In this perspective, promising contacts have already been established with important Swiss and European companies.

In addition, the building of the HISTAR and SETUP tests facilities will offer real opportunities for Switzerland and all the other involved countries, as well as for their higher education institutions and industries, thanks to the development of a world-wide unique know-how and thus to the building-up a leadership in this area of activity.

3 Conclusion

Swissmetro is a feasible project. Certain technical aspects nevertheless still need to be tackled in order to get specific expertise in fields such as partial vacuum control and related aerodynamic phenomena. Therefore, the further development of the Swissmetro towards an industrial product will necessitate the construction of two test facilities: HISTAR, currently under construction, and SETUP. These facilities shall also enable to obtain realistic and accurate cost estimates for the construction and operation of a pilot line; this will contribute to demonstrate the industrial and economical viability of the Swissmetro.

References

1. Mossi M., *Swissmetro: strategy and development stages*, GESTE Engineering SA, Lausanne, September 24th, 2001.

2. Mossi M., *Swissmetro: costs and time schedule*, GESTE Engineering SA, Lausanne, September 24th, 2001.