ASSESSING THE FEASIBILITY OF TRANSPORT MEGA-PROJECTS: SWISSMETRO EUROPEAN MARKET STUDY

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ABSTRACT

This paper presents the results of the Swissmetro European Market Study. Swissmetro is a proposed high-speed passenger ground transportation system that would operate magnetically levitated trains in underground tunnels with reduced air pressure using linear motor technology. The market study considered the market feasibility of constructing Swissmetro on potential European corridors. It evaluated technology, market conditions, European policy, investment costs and risks associated with the project. The study conclusion was that there is not sufficient market potential for the Swissmetro system in European long-distance transport. The main problems with Swissmetro identified in the study were: the long time necessary to bring the technology to commercial deployment, the lack of obvious corridors (most high demand corridors will be served by high-speed rail by 2020), strong competition from other modes (flying, HSR), European Union policy of supporting an interoperable system of rail lines, Swissmetro's high capital and operating costs – and the risk that these costs may be significantly underestimated and Swissmetro's very long construction time.

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1. INTRODUCTION

This paper presents results of the European Swissmetro Market Study, which evaluated the potential for implementing a new form of high speed ground transportation in Europe. [*1*] In a nutshell, the Swissmetro would operate magnetically levitated trains in underground tunnels under semi-evacuated air pressure at speeds of approximately 500-km/h.

There is a growing literature assessing the problems of large transportation projects and how these problems were missed or ignored in the decision-making process. [*2*] [*3*] [*4*] The problems are relatively simple to list: the projects cost too much, take too long to build, don’t operate as expected and don’t generate the revenues that were forecast, but hard to address in the planning process.

Many projects that have these problems do provide very substantial transport benefits, it is just that these benefits do not outweigh the costs. Furthermore, many of these projects also generate substantial social benefits, but these benefits are often overstated in the planning process. In any case, feasibility analyses of mega projects need better and more rational information along with better institutional arrangements to reduce the number of underperforming and over-expensive transport projects. [*2*]

The Swissmetro project would implement a new high speed ground technology. Vuchic recommends asking the following questions when considering implementing a new mode:

1. Is there a demand for the new mode?
2. Is the proposed new mode feasible, and shown to be operationally ready for implementation?
3. What is the current state of existing modes serving this demand?
4. Does the proposed mode as a package of benefits and costs improve upon current modes? [*5*]

While Swissmetro is not a new mode of transportation, this paper uses the Swissmetro proposal as a case study for considering these questions and the problems of planning transport mega-projects. The Swissmetro European Market Study consisted of the following tasks:

- Summarize Swissmetro technology and operations;
- Compare Swissmetro to existing high-speed ground transport;
- Assess Swissmetro in terms of European Union transport policies;
- Evaluate Swissmetro market demand;
- Analyze the potential for Swissmetro implementation.

The market study did not investigate the project’s environmental impacts or complete a detailed economic analysis, but focused on developing initial conclusions regarding project feasibility.

The following sections summarize results of each study task, the final section presents conclusions and recommendations.

2. SWISSMETRO TECHNOLOGY AND OPERATIONS

Swissmetro is a high-speed passenger ground transport system based on the use of four innovative technologies illustrated in Figure 1:

- entirely underground infrastructure (tunnels, stations and maintenance facilities);
- operation under reduced air pressure (partial vacuum) to reduce propulsion energy;
- propulsion based on linear electric motors allowing speeds of about 500-km/hour; and
- magnetic levitation and guidance systems.

Swissmetro proponents believe the system could be (slightly) profitable, and cite the following additional benefits: less noise and surface land consumption than rail or highways, less energy use (assuming high capacity and occupancy) than systems operating at comparable speeds and its potential for reducing sprawl (by encouraging central development). Finally, proponents believe that it will become increasingly difficult to build other transport infrastructure (e.g. airports, HSR lines) given concerns over noise, land-consumption, etc., and therefore Swissmetro could help meet growing transport demand. [*6*] [*7*]

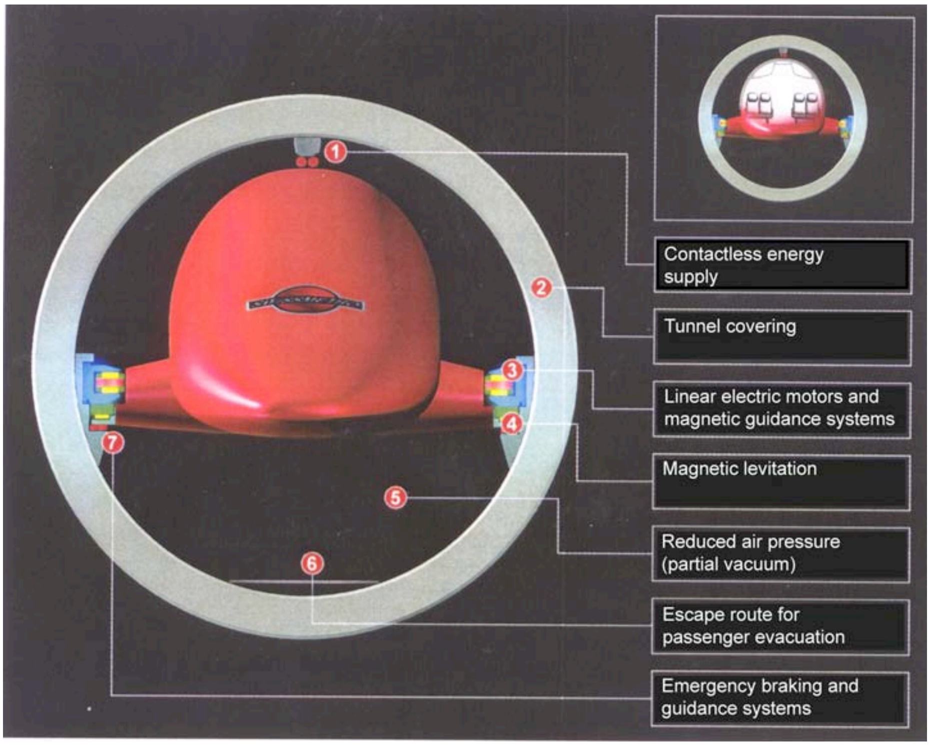

Figure 1: Swissmetro train in tunnel.

This rest of this section outlines Swissmetro's infrastructure, vehicles, and capacity.

Infrastructure and Vehicles

Guideway

Swissmetro's guideway consists of two parallel tunnels located approximately 25-meters apart. The tunnels would have an interior diameter of 5 meters and normally be used for a single direction of travel. For safety reasons, the tunnels would be linked by passageways approximately every 300 meters. The tunnel depth depends on various factors (e.g. topology) and would vary significantly. Tunnel access shafts would be built to the surface every 15-km for initial construction, maintenance and emergencies.

The tunnel system air pressure would be approximately 10% of atmospheric pressure during normal operations; this is equivalent to approximately 15,000 meters above sea level. This air pressure would be maintained by vacuum pumps. The tunnels would need to be carefully sealed and all openings would need to include some type of airlock devices to maintain the partial vacuum.

Since Swissmetro will be operated at high speeds, the guideways must have very large radii curves (the minimal horizontal radius for 500-km/h is 6,260 m for superelevated curves and 19,300 m for non-superelevated curves; the minimal vertical curve radius is 38,580 m). These very large radii requirements, combined with local topography and geology, severely limit the choice of precise vertical and horizontal alignments, complicating the ability to build stations in specific locations (e.g. at an existing main rail station) and governing the depth which stations must be built.

Stations

Swissmetro stations would have a main hall at the surface and an underground waiting area at train level. Passengers would buy tickets, have their tickets checked and probably also go through some type of security (similar to airports) at the surface level before boarding elevators to reach the tunnel level waiting areas. The tunnel level depth would depend on the station site geology and guideway vertical constraints (see above), but the goal is in the range of 40 meters underground.

Passengers would board Swissmetro trains via airtight telescoping passenger bridges from the waiting area (similar to airport jetways) as shown in Figure 2.

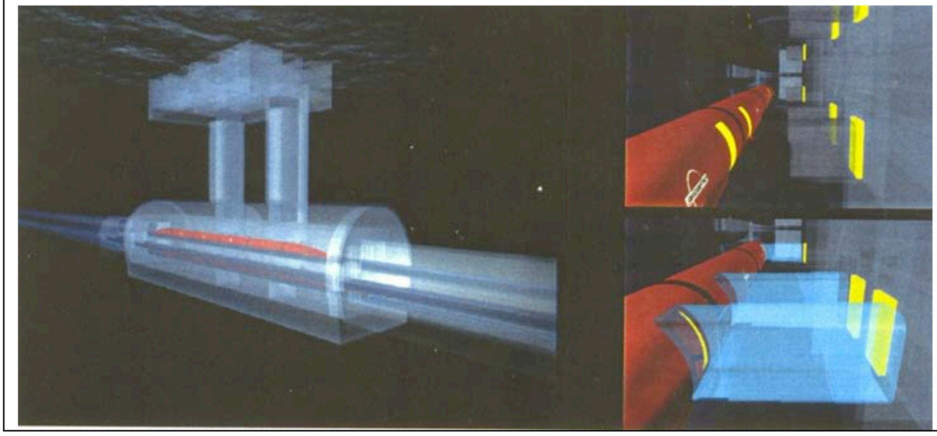

Figure 2: Swissmetro station with telescoping passenger access bridges.

Additional Infrastructure

Swissmetro's infrastructure will also include: vehicle transfer devices, vehicle maintenance facilities, infrastructure maintenance facilities, emergency facilities, etc. All these will involve special engineering and construction to address the semi-vacuum environment and the large radii curve alignment requirements.

For example, since Swissmetro vehicles will not be able to use normal switches, vehicle transfer devices will be needed at end stations and large intermediate stations to move vehicles between tunnels or to maintenance facilities. There are several possibilities for these devices including rotary barrel devices, which rotate an entire track section with a complete train, or linear transfer devices. In all cases these would need to be substantial machines to move an entire 130-meter train.

Vehicles

The planned Swissmetro vehicles are about 130 meters long and consist of six segments. The vehicles have room for between 250 – 300 people depending on the seating configuration and must be pressurized since they operate in a partial vacuum.

Swissmetro vehicles also have personal oxygen masks for use in emergencies, in particular for loss of cabin pressure (similar to airplanes). Therefore all passengers must have a reserved seat, in contrast with traditional railroad operations.

Swissmetro Capacity Analysis

Swissmetro's capacity can be estimated by multiplying vehicle capacity by maximum train frequency. Given the high cost of underground infrastructure it is assumed that the network would operate in series (i.e. trains in the same direction would not pass each other). Therefore, the minimum train headway must be determined for each infrastructure element and the element with the highest value will establish system capacity.

The minimum headway is based on the absolute braking distance, which depends on operating practices, safety technology and, in the case of linear motor technology, the longstator motor segment block length. (On a Transrapid or Swissmetro Type A system, only one vehicle can be operated on a longstator motor segment at a time.) Finally, the technically possible headway must be increased by approximately 10% to account for normal operational variations. Swissmetro's technical and operational minimum headways are presented in Table 1.

Infrastructure Element	**Minimum Headway (Technical)**	**Minimum Headway (operational)**	
	[seconds]	**[seconds]**	**[minutes]**
Open track at 500 km/h:			
- with longstator sections of 15 km	114	125	2.09
- with longstator sections of 30 km	222	244	4.07
- Linear motor; alternative B	76	84	1.39
Stations:			
- Stop time: 5 min	354	389	6.49
- Stop time: 4 min	294	323	5.39
Vehicle Transfer System:			
- Carousel Type	181	199	3.32
- Track Shift Type	171	188	3.14
Total System:			
- 5 min stop time	354	389	6.49
- 4 min stop time	294	323	5.39

Table 1: Swissmetro Technical and Operational Headways

As shown in Table 1, the station stop process governs in setting the minimum headway. The minimum headway is approximately 6.5 minutes, and therefore the maximum number of trains is about 9.25 trains per hour and direction.

Swissmetro’s passenger capacity consists of the number of trains that can be operated multiplied by the number of passengers per vehicle. The number of passengers per vehicle is determined by the passenger compartment area and seating configuration. A seating density equivalent to typical HSR trains could carry approximately 250 passengers, while a seating density equivalent to the Transrapid (long-distance configuration) could carry approximately 300 passengers.

Using the maximum assumptions for train frequency and seating density, Swissmetro would have a maximum capacity of approximately 2,770 persons per hour and direction.

3. HIGH SPEED GROUND TRANSPORTATION TECHNOLOGY COMPARISON

This section compares Swissmetro technology to high-speed rail (HSR) and magnetically levitated (maglev) train technology with respect to network development, speed and capacity.

High Speed Rail

The first true HSR line was Japan's Shinkansen service between Tokyo and Osaka, which began operations in 1964. The first Shinkansen trains had a maximum speed of 210 km/h, but speeds have been raised gradually to 300 km/h. Interestingly, Shinkansen trains use European standard gauge (1435 mm) rather than the Japan’s standard gauge (1067 mm) and are therefore incompatible with Japan’s general network. To address this disadvantage, some lines include gauntlet tracks, allowing both normal and Shinkansen trains to use the tracks, thereby extending the direct reach of Shinkansen service. The Shinkansen network, on which no freight trains operate, is approximately 1,800-km. The Tokaido Shinkansen line’s existing maximum capacity is 32,000 persons per hour and direction.

The next big step for high speed rail occurred in 1981 with the opening of France’s first Train à Grande Vitesse (TGV) line between Paris and Lyon. The TGV had an initial maximum speed of 260 km/h, maximum speeds have increased to 300 km/h and the TGV Est (2007) is expected to operate at 320 km/h. The TGV trains use standard gauge track and are regularly operated off-of the high-speed tracks. France’s existing TGV lines amount to approximately 1,520-km out of an ultimate network of 4,700-km. The TGV’s existing maximum capacity is 15,000 persons per hour and direction.

The German HSR system, the InterCity Express (ICE), began service in 1992, and had a maximum speed of 280 km/h. Today's ICE3 trains travel at speeds above 300 km/h. Spain opened its first HSR line in 1992, in connection with the World Fair in Seville. Spain is particularly interesting because its HSR network is being built at European standard gauge to allow full interoperability, rather than at the Spanish standard (wide) gauge. The Barcelona-Madrid HSR line will be operated at speeds of 350 km/h using AVE trains based on the ICE3 concept. HSR service is also operated in Italy, the Netherlands, and Belgium.

In summary, the European HSR network is growing rapidly. The trains provide relatively high capacity transport on major travel corridors and can be operated on both the special high-speed network and the general railway network. All countries, operators and equipment manufacturers are making a strong effort to ensure that high-speed lines are fully interoperable. [*5*]

Transrapid

Transrapid is the first commercial application of magnetically levitated train. The German government began industrial development of the Transrapid in the 1970s. The Transrapid vehicle is levitated using an electromagnetic system and is propelled using a linear motor in the guideway. This means that only one vehicle may operate in a given track segment at a time and the segment length becomes the limiting factor for line capacity. [*8*]

The first commercial Transrapid service began operation in 2003 with the opening of a 30-km segment between Shanghai and its airport. Munich is currently planning a similar airport Transrapid link. [*9*] Transrapid has been considered but rejected for several long distance corridors, notably in the Berlin-Hamburg corridor.

The Shanghai Transrapid infrastructure allows the use of trains with 2 to 8 sections. The maximum possible train following distance is approximately 7.5 minutes, i.e. up to 8 trains can be operated per direction and hour. An 8-section Transrapid train can carry almost 800 passengers yielding a line capacity of slightly over 6,300 persons per hour and direction.

Swissmetro

Swissmetro technology is described above. While Swissmetro has been under research since the 1970s there are no operating prototypes or lines in commercial operation. The need for more research and industrial development, in combination with its long construction time, means that even under the best of circumstances it will take several decades before an effective Swissmetro network could be in commercial operation. The Swissmetro would not be interoperable with any other rail system (or the Transrapid). The capacity of Swissmetro is approximately 2,770 persons per hour and direction.

Technology Comparison

Comparing Swissmetro to competing high-speed ground transport systems leads to the following conclusions:

- High speed rail dominates today's high-speed ground transport market due to its high transport capacity, its high operational flexibility, its ability to operate on the conventional rail network, and its relatively simple and economical building method based on many years of experience and technological optimization.
- Magnetic levitation technology, despite Transrapid reaching the commercial stage, is still a niche product. Particular problems include its inability to operate on the existing rail network, the high cost of infrastructure (significantly higher than HSR) and operational inflexibility due to relatively complex switch designs. Maximum Transrapid capacity (theoretical) is 20%-42% that of actual capacity on operating HSR systems. The German government has spent a very large amount of money supporting Transrapid research and development over 30 years, and yet the system has met with very limited success in the marketplace. Most notable is rejection of Transrapid on the Berlin-Hamburg corridor. This leads to the question, if maglev is not feasible on the Berlin-Hamburg corridor, a corridor that connects the two largest German cities, has intensive travel demand, is long enough to benefit from Transrapid's high speed and has a relatively good alignment, then where is it feasible? [*5*] [10] [*11*]

- Swissmetro is more complex than Transrapid and at least three-decades behind it in terms of commercial development. Swissmetro shares many problems with Transrapid, it is not interoperable, its infrastructure costs are likely to be even higher and it will be even less flexible in terms of alignment and operations. Maximum Swissmetro capacity (theoretical) is 9%-18% that of actual capacity on operating HSR systems and only 47% of theoretical Transrapid capacity. Neither Swissmetro nor Transrapid would have enough capacity to meet demand on several existing HSR corridors.

4. EUROPEAN TRANSPORT POLICY

This section describes how Swissmetro would fit within the existing European transport policies.

Market Liberalization and Interoperability

The European Union’s goal for railroads is to liberalize the market and improve the efficiency of railroad companies through the implementation of the “railway packages.” The EU has approved three railway packages to date. The packages address the opening of rail markets (Open Access), technical specifications for creating an interoperable railroad network (interoperability), and implementation of interoperability on the most important European axes. [*12*]

Trans European Network - Transport (TEN-T)

The most important instrument of EU transport policy is the Trans European Network - Transport (TEN-T). The goal of the TEN-T is to build an internationally significant transport infrastructure by 2020. It consists of projects on 30 priority axes and is estimated to cost approximately €600 billion. [*13*]

The TEN-T includes building approximately 12,500-km of new railway line and rebuilding 12,300-km of existing lines at a cost of approximately €290 billion. In principle these projects are to be funded jointly between the EU (10%) and the country within which they are located (90%). However, the EU’s share may rise to 20% for high priority projects.

Magnetic Levitation in European Transport Policy

Magnetic levitation transport currently plays almost no role in European transport policy. The EU did support several studies of Transrapid-type transport in central and eastern Europe between 1997 and 2000. However, the project that advanced furthest in the process, the Hamburg - Berlin Transrapid, was halted by the German government in 2000 due to financing difficulties and overly optimistic demand estimates.

Swissmetro in European Transport Policy

Given current policy, it is safe to say that the Swissmetro system is unlikely to be supported by the European Union. The main reason is Swissmetro’s lack of interoperability with the existing European rail network (or even with Transrapid). Furthermore, given the degree to which the TEN-T has already been planned and constructed, Europe’s choice of future ground transport system has already been made. Finally, Swissmetro does not offer a solution for future European transport problems that cannot be solved, at a far lower cost, with existing transport systems.

5. SWISSMETRO MARKET ANALYSIS

This section summarizes Swissmetro’s potential market and outlines two corridor analyses completed in the market study: an existing conditions analysis of the Lyon-Geneva-Zurich-Munich-Vienna-Budapest corridor (identified as a potential corridor in previous Swissmetro studies), and a future demand evaluation of potential European corridors.

General Market Analysis: Speed and Travel Time

All forms of transport have particular distances for which they are ideally suited based on travel time. Travel time depends on the mode's maximum speed, when considering speed, it's necessary to keep the following points in mind:

- Travelers care about total travel-time not maximum speed, thus system access and network possibilities often play a more important role in travel decisions than maximum speed.
- While Swissmetro would be the fastest form of commercially operated ground transport, flying would still be almost twice as fast.
- Increasing maximum speed has decreasing marginal gains in travel-time savings. This means that the theoretical travel-time savings between HSR (300-km/h) and Swissmetro (500-km/h) with a station spacing of 100-km, is only a few minutes (not including access).
- Travel-time reductions due to higher speeds depend on the distance between stations since vehicles need a significant amount of time to accelerate, decelerate and stop. The higher the travel speed, the longer the distance between stations needs to be to take advantage of high speed.
- The marginal cost of increases in maximum speed (in system design, construction, operating costs, etc.) grows more than proportionately with speed increases. In other words, costs increase significantly as maximum speed increases.

The market study analyzed the potential travel market for Swissmetro considering these points and competition in the long distance travel market.

Swissmetro's competitors in long distance travel market are HSR, Transrapid and flying. As part of the market study, travel times for each of the four modes was estimated over a variety of distances. High-speed rail was assumed to have a maximum velocity of 300-km/h and an access time of 5 minutes; Transrapid was assumed to have a maximum velocity of 400-km/h and a 5-minute access time; flying was assumed to have a maximum velocity of approximately 800-km/h and a 60-minute access time.

Several different scenarios were tested for Swissmetro parameters. In the most likely scenario, Swissmetro was assumed to have a station spacing of 200-km, a maximum velocity of 500-km/h and a 30-minute access time based on the assumption of longer station spacing. This access assumption is probably low since the Swissmetro boarding process would be more like an airplane than a HSR train (i.e. passengers would need to check-in before taking the elevator to the tunnel level, it would take time to reach the tunnel level and security would be necessary since incidents taking place in 300-person vehicles traveling at high speeds through semi-vacuum conditions in underground tunnels would be serious).

As expected, Swissmetro's optimal market falls between flying and HSR. Figure 3 illustrates travel time versus distance for HSR, Transrapid, Swissmetro and flying. The analysis leads to the following conclusions:

- Swissmetro stations should be located at least 100-km (optimally between 200 and 300-km) apart to take full advantage of the system's high cruising speed.
- At distances of 200-km, Swissmetro travel times equal HSR, but on distances less than 500-km the difference in travel time is marginal, and therefore travelers are likely to prefer HSR for comfort and access reasons.
- At distances of 600 km, Swissmetro travel times equal Transrapid service (with a 400 km/h maximum speed).
- At distances of approximately 1000-km, air transport is faster than Swissmetro and travelers are likely to fly.

The optimal market distance for Swissmetro trips is therefore between 500 and 1000-km. It should be noted that the Swissmetro and Transrapid systems have almost identical optimal market distances.

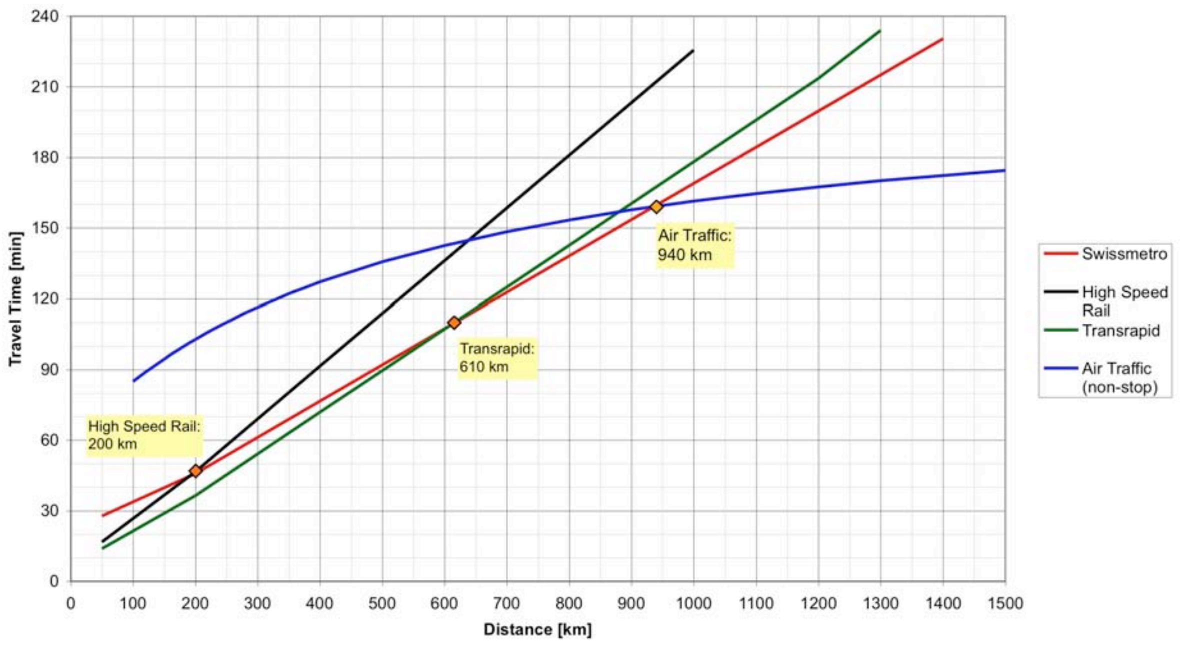

Figure 3: Travel time comparison for Swissmetro (maximum speed 500-km/h, 200-km station spacing) and its competitors.

Lyon-Budapest Corridor Existing Conditions Analysis

The Lyon-Budapest corridor analysis was completed to obtain an understanding of how a potential Swissmetro line would fit within the existing transportation offers in a corridor. Results of the analysis, completed using actual travel times for the different modes, confirmed the general findings outlined above.

The most interesting aspect of the existing corridor analysis was the ticket price variability in the corridor. Prices varied significantly between different modes, within modes and based on advance purchase. This indicates that any new mode of transport introduced in the corridor would face strong competition and would need to have a very sophisticated ticket pricing system to be successful.

Competition would be especially dangerous for Swissmetro because of its extremely high infrastructure costs. In contrast, competing rail operators already have a network in place and airlines can redeploy planes almost immediately with very low capital costs to begin new service. Both could lower ticket prices on competing routes to drive Swissmetro out of business by either cross-subsidizing or based on lower operating costs. Competition from ferry operators in the English Channel has caused huge financial problems for EuroTunnel operators even though ferry service can take eight-times longer than Eurostar service. [*2*] This type of competition would be a significant risk for potential Swissmetro investors.

Market Demand on Potential Swissmetro Corridors

The market study analyzed future demand on potential European Swissmetro corridors. The first step in the process was identifying potential corridors. This was done by connecting Europe’s largest cities and regions in logical corridors considering the Swissmetro’s optimal market (e.g. station spacing). We started with the nine largest cities all of which have a population over 2 million (Moscow, Istanbul, London, St. Petersburg, Berlin, Madrid, Rome, Kiev and Paris), then added the 20 next largest cities (populations over 750,000) and five large regions (populations over 2 million). This resulted in 20 potential high demand corridors.

Next, these 20 corridors were compared to the Year 2020 HSR network. [*14*] [*15*] The comparison, shown in Figure 4, clearly shows: first, that almost all potential corridors in western and central Europe will be served by new HSR systems; second, that most corridors without HSR competition are in Eastern Europe; and, third, there are plans to improve rail service on most of the corridors without HSR competition.

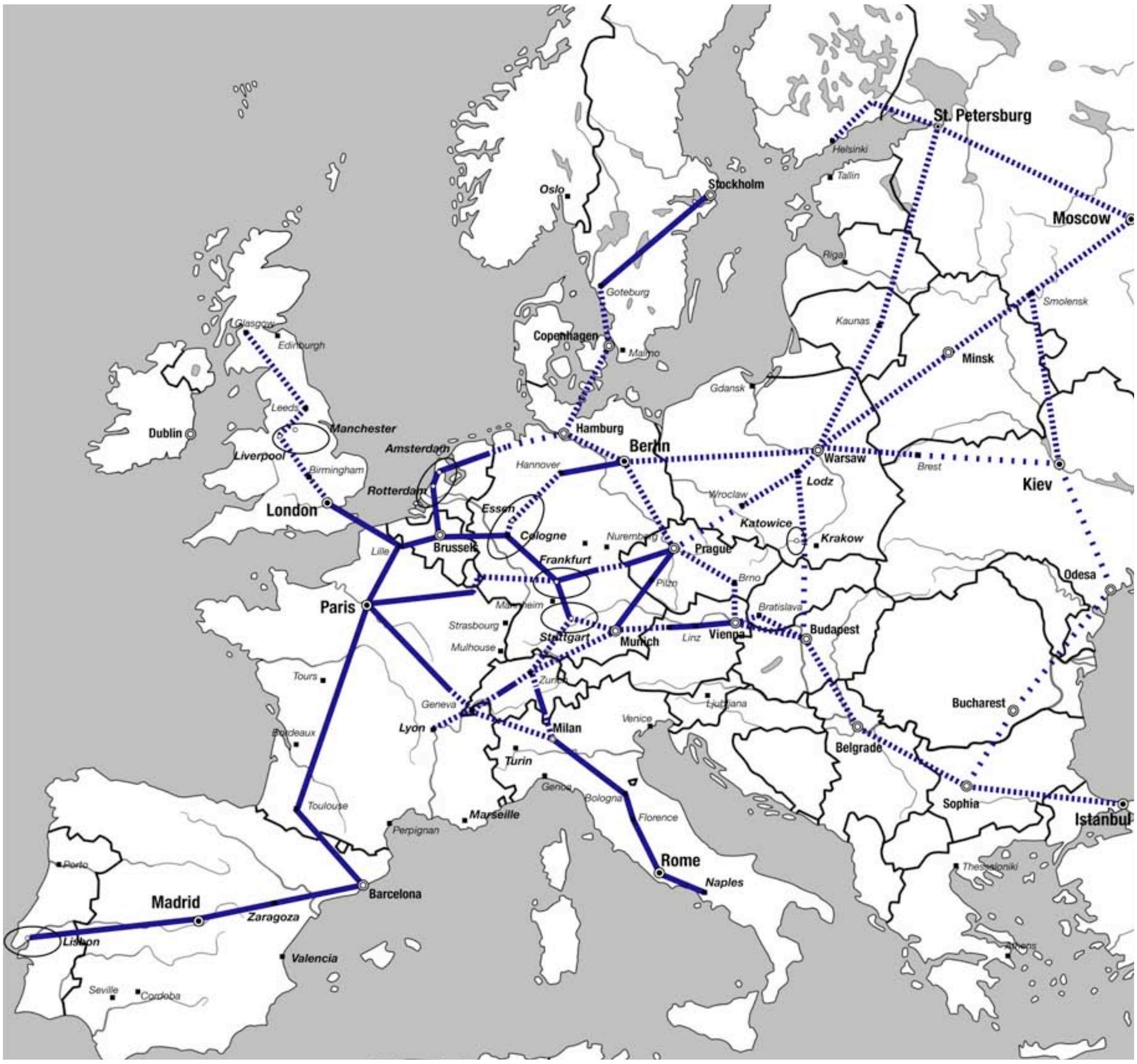

Figure 4: Potential European Swissmetro corridors, classified by rail competition: solid lines = HSR lines in operation by 2020, narrowly-spaced dashes = upgraded conventional rail lines in operation by 2020, widely-spaced dashes = no current plans for upgrading rail in these corridors.

The potential corridors parallel to new HSR lines were eliminated since it is unlikely that national governments would fund Swissmetro where it would compete with HSR service. The remaining corridors, summarized in Table 2, were analyzed in more detail.

Potential Corridor	Length (km)	Stations	Travel Time (hh:mm)
Lyon – Geneva – Zurich – Munich – Prague – Lodz – Warsaw – Minsk – Moscow	2,600	9	07:29
Hamburg – Berlin – Prague – Brünn – Vienna – Budapest – Belgrade – Sofia – Istanbul	2,100	9	6:12
Berlin – Warsaw – Brest - Kiev	1,250	4	3:30
Helsinki – St. Petersburg – Tallinn – Riga – Kaunas - Warsaw – Lodz – Krakow – Budapest – Bratislava – Vienna – Linz - Munich	2,825	13	8:29
Four Corridor Swissmetro Network	8,775	26	na

Table 2: Potential Swissmetro European Corridors

A long-distance transport demand model developed at the IVT was then used to estimate future demand on these potential corridors. [*16*] The model compared travel times on Swissmetro with competing travel times on the rail network and flying to estimate the share of travel demand on these corridors that would be attracted to Swissmetro service. Given the number of assumptions and quality of existing data, the model estimates cannot be considered exact, but they did provide a qualitative assessment of corridors.

The demand forecasts, based on actual rail and air traffic demand, showed that the Hamburg - Berlin - Prague - Munich corridor would have the highest potential demand. Demand on the Munich - Zurich - Geneva - Lyon corridor and the Warsaw - Lodz - Krakow corridor would be less than half that on the Hamburg – Munich corridor. The other corridors in Eastern Europe exhibit a very small potential demand.

Swissmetro Market Analysis Summary

Swissmetro's high speed makes it ideally suited for long distance transportation in the range from 500-km to 1000-km, a range it shares with maglev technology. Many of the highest demand European corridors will be served by HSR by 2020. The corridors without HSR service are generally located in Eastern Europe and have relatively low demand. This places Swissmetro in a difficult market position; it can build lines in locations with strong competition and/or in locations with low demand. In summary, there are no obvious corridors where Swissmetro could be operated successfully.

6. IMPLEMENTATION FEASIBILITY

The key implementation question for any large infrastructure project is who will provide funding for construction and operation. This section outlines several key issues regarding Swissmetro costs and funding possibilities.

Swissmetro Cost and Timing Risks

It is the nature of projects at early stages of development to have substantial cost and schedule risks. This problem is compounded for projects that involve substantial amounts of new technology. Hall describes "a general suspension of disbelief about costs and technical problems" involved in the decision-making process for San Francisco's BART system. [*3*] Swissmetro, since it combines four complicated technologies (underground construction, operation in a partial vacuum, linear motor propulsion, and magnetic levitation and guidance), is likely to face many very complex issues in the process from idea to commercial implementation. This significantly increases its cost and timing risks.

The first risk is timing. Since Swissmetro would be intensively used (frequent trains operated throughout the day all year round) by people, it will have very strict safety and operational tolerances.

Therefore, all system components must be developed and extensively tested in a real operating environment before large-scale deployment (e.g. hundreds of kilometers of tunnels that can maintain the partial vacuum, maglev vehicles that can operate in small-radius tunnels, air-tight passenger bridges, magnetic levitation and guidance systems, linear drive motors, inductive energy transfer etc.). Given the high technology being proposed, this development and testing phase is likely to take many years. As development of these components proceeds, it is likely that the cost of these highly sophisticated components would increase significantly over early planning-level estimates.

Another risk is that operating practices will become much more complex than considered in the early planning. In the case of Swissmetro several key operational practices have the potential for causing large increases in costs and operations assumptions. The most obvious operations issues include developing procedures and designing facilities for: infrastructure maintenance, vehicle break-downs and emergencies. These types of issues have often been overlooked in early stages of transport technology development (e.g. BART). [*17*]

For example, how will Swissmetro’s guideway be maintained: will the tube be re-pressurized (which takes much energy and time), will workers perform maintenance in pressurized suits, will robots perform maintenance? How much maintenance of the sophisticated new technology will be needed (the TGV tracks are inspected and adjusted every night)? Clearly there are solutions to these problems, but they need to be analyzed in detail before precise cost estimates can be made.

Swissmetro construction is a third major timing and risk factor (and construction cannot even begin until the industrial development is complete). Swissmetro’s underground construction will be expensive and slow even though it will use small radius tunnels. This risk is compounded by the fact that Swissmetro’s optimal market distance is over 500-km, which means that a huge amount of construction must be completed before it can start operating efficiently. The classic solution of splitting a long construction project into segments (to speed-up completion) is complicated by the fact that underground construction requires highly specialized resources (workers and equipment), of which there is a limited supply. Splitting projects also increases soft costs associated with managing many different contractors. [*18*]

These are only the most obvious risks involved in taking Swissmetro from the conceptual planning level into commercial operations on long corridors. Given the amount of time it has taken to bring the (relatively) simple Transrapid technology into the market, it is hard to imagine that a usable Swissmetro system could be in operation anytime before 2045.

Revenue Model

A simple model was developed to estimate the revenues from operating a 1,000-kilometer Swissmetro line. The revenue model assumed a service level of 100 trips per day and direction on workdays, and 88 trips on weekends/holidays. The model considered four scenarios defined by combining two values for average utilization rate (i.e. occupancy divided by capacity) and two values for ticket prices. The two utilization rates were 50% and 70%; they assume that the trains are occupied at the given level over the entire 1,000 km corridor all day long. The two ticket prices were 0.22 CHF/km (based on French TGV fares) and 0.34 CHF/km (50% higher). Both utilization and ticket price assumptions may be optimistic given market demand and the highly competitive long distance transport market.

Swissmetro operating costs (estimated based on previous studies [*7*]) were subtracted from gross revenues to obtain annual net revenues. These net revenues were converted to an investment amount using the present value of the future revenue stream assuming a Swissmetro service life of 100 years and an interest rate of 5%. The cost of construction financing and major system renewal was not included; therefore, for these and the reasons discussed above under risks, the cost estimates are likely to be highly optimistic. Table 3 summarizes results of the revenue analysis.

Description	Units	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Utilization Rate		70%	50%	70%	50%
Person trips per day		40,530	28,950	40,530	28,950
Ticket Price	CHF/km	0.225	0.225	0.337	0.337
Annual Transport Supply	Mio. Pkm	14,793	10,567	14,793	10,567
Financial Analysis					
Annual Gross Revenues	Mio. CHF	3,329	2,378	4,985	3,561
Annual Operating Costs	Mio. CHF	693	693	693	693
Annual Net Revenues	Mio. CHF	2,636	1,685	4,292	2,868
Investment Sum	**Mio. CHF**	**32,730**	**20,921**	**53,293**	**35,611**
CHF = Swiss Francs Pkm = Passenger kilometers Mio. = Millions					

Table 3: Swissmetro European System Revenue Model Results

The rough financial analysis showed that there would be between 20.9 and 53.3 billion CHF available for the building a 1,000-km Swissmetro line.

The cost of building Swissmetro has been estimated at approximately 58 million CHF per kilometer for the guideway (tunnels, track, trackside equipment, etc.). [*7*] Therefore it would cost approximately 58 billion CHF to build a 1,000-km Swissmetro line. (As discussed above, we believe these cost estimates are very optimistic.)

Comparing the revenue generated to the capital cost shows that, even using optimistic assumptions regarding costs and revenues, the project would not have a positive rate of return.

Implementation Analysis

It will be very difficult to justify moving forward with the Swissmetro project. The project has the following significant problems from the perspective of financing:

- The project is very expensive, its costs are very likely to be underestimated (due to risks associated with its complexity and construction method) and even using optimistic assumptions would not generate sufficient revenues to justify investment.
- It will take a long time to build a commercial Swissmetro line at the optimal market distance due to the need for substantial industrial development of very complex technology before construction can begin and the slow speed of underground construction.
- The prognosis for government funding is poor due both to the low investment value and competition from other modes (particularly the TEN-T HSR systems).

Swissmetro proponents have argued that the system will have other non-financial benefits. Examples include energy efficiency (since it would operate in a partial vacuum), noise reduction (since it would operate underground), its potential to encourage higher density development (around station areas) and its ability to substitute for air transport should oil prices rise significantly. These issues were not specifically considered in the market study, but experience with other transportation mega-projects indicates that analysts should be skeptical of these types of benefits, especially at such an early stage in the planning of a totally new technology. [*2*] [*3*]

7. CONCLUSIONS

This paper describes the results of a market study for a European Swissmetro system in the context of questions regarding introduction of a technologically new mode of transportation and transport mega-project planning. [*1*] The market study conclusions are:

- Swissmetro's main benefit over other modes of high speed ground transportation is that it requires a very small surface land area and has very low noise emissions (since it is underground).
- Swissmetro technology appears to be feasible, but will require a long period of time to move from the conceptual research and development phase through industrial development and into construction. We believe it is unlikely that Swissmetro could be deployed commercially in an effective configuration before 2045.
- There are no obvious European corridors for Swissmetro; all high demand corridors will be served by HSR systems by 2020 and corridors without HSR have relatively low demand. Furthermore, Swissmetro does not have sufficient capacity to meet current travel demand on several existing HSR corridors.
- If Swissmetro were built it would likely face stiff competition from HSR and airlines, both of which could reduce fares in competing corridors relatively easily.
- Swissmetro's natural market of 500-km to 1000-km is almost the same as Transrapid's market; while Transrapid technology has been commercially available for years no long distance lines have been built; since Swissmetro has a lower capacity and higher costs, it is hard to imagine that Swissmetro would be more successful in this market.
- The European Union has a goal of completing the Trans European Network Transport (TEN-T), which includes a large network of new high-speed rail lines. The EU is unlikely to support creation of a new alternative ground transport system.
- The Swissmetro system would be extremely expensive to construct – even based on today's estimated costs, which are very likely to be quite optimistic.
- The estimated revenues generated from operating Swissmetro on an efficient segment, even using optimistic assumptions, are not sufficient for financing the infrastructure and vehicles.
- There are very high risks that capital and operating costs will increase significantly as development proceeds.

Considering these conclusions we do not believe that there is sufficient market potential for the Swissmetro system in European long-distance transport and thus do not believe that the system as currently configured is relevant for Europe.

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