Engineering 2 (2016) 402–408

Contents lists available at ScienceDirect

Engineering

journal homepage: www.elsevier.com/locate/eng

Views & Comments

High-Speed Rail: Opportunities and Threats

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The objective of this article is to analyze the impacts that changes in society may have on high-speed rail (HSR) activity and development. We are now in a transitional period between the second and the third industrial revolutions, as described by Rifkin [1]. The new revolution emerged from beneath the surface at least 15 years ago, and will take at least another 15 years to be fully fledged. Such a long transitional period is the result of many worldwide evolutions initiated by two main causes—the digital revolution and global climate warming—and we must confess to our inability to forecast their final outcomes. Thus, we have a strong motivation to try to understand what is at stake and to unravel the various trends and breaks that are presently active in the open as well as under cover. No field of activity will be shielded from the coming tsunami of change. The railway community is naturally involved in this irresistible move. Will HSR benefit or suffer from it? What attitude should we adopt in order to turn threats into opportunities?

There is no denying that the past 15 years have witnessed a boom in HSR development. After many years operating its first high-speed (HS) lines, Japan has at last been followed by European countries (mainly France, Italy, Germany, Spain, Belgium, the Netherlands, and the UK) and by other Asian countries and regions (Republic of Korea and Taiwan of China). By the year 2000, the HS network was about 5000 km long. It was more than six times longer (34 679 km[†]) 17 years later, principally, but not exclusively, because of China. New countries and regions are implementing this transport mode: Morocco, Saudi-Arabia, and California in the US. Other countries have plans for it, such as Indonesia, Iran, and Poland, to name just a few. A worldwide expansion is underway. In addition, and just taking into account the lines that are presently under construction, an almost 50% increase in the HS network length (15 790 km) is expected by 2022. Fig. 1[‡] shows the past, current, and projected worldwide HSR route length.

HSR ridership has steadily increased over the past half century (since 1964, to be more precise, when the first Shinkansen started its revenue services). Very few fields of activity can boast such a continuous growth.

How can we account for such a commercial and technical longevity? This dynamism is based on six quite strong assets:

Asset #1: The mobility market has been constantly growing.

Asset #2: By definition, HSR is very rapid, and provides customers with very competitive travel time and high service frequency.

Asset #3: Many railway stations were built many years ago and are now in the core of the cities they serve.

Asset #4: HSR is a mass transport system.

Asset #5: HSR is environmentally friendly.

Asset #6: HSR is reliable and safe.

Throughout previous decades, prophets of doom have been ringing alarms foretelling a reduction in mobility. Initially, the scaremongers argued that the telephone would dry up market mobility because people would no longer have to move to talk to each other. Reality has disproved their thesis in the best possible way. Not only has the telephone not, in any way, reduced passenger traffic volume; in itself, the telephone has evolved from fixed to mobile. By becoming mobile, the telephone has enabled people to travel more because they do not need to remain in one place to be informed or to give information and orders. Apparently, this was not enough of a lesson to silence the whistle blowers. With video conferencing, the business trip market was prophesied to shrink dramatically. Air transport, the most commonly

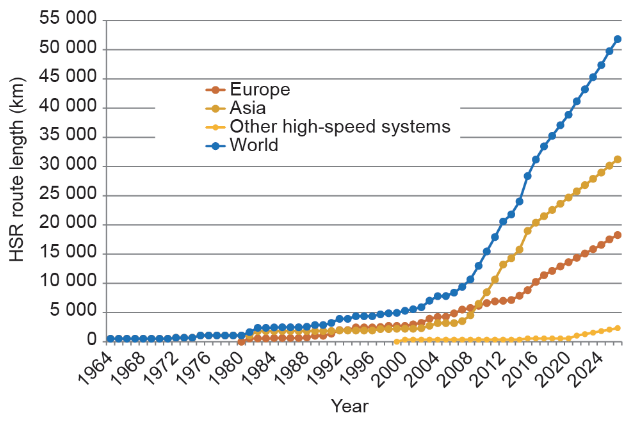

Fig. 1. Worldwide high-speed rail (HSR) route length.

† According to the International Union of Railways (UIC) Passengers Department statistics.

‡ Source: UIC.

http://dx.doi.org/10.1016/J.ENG.2016.04.006

used method of long-distance business travel, has sky-rocketed even while the video conference has become a standard in many companies. The two major airplane builders have never had such a 5–10 years' backlog as they do now. The Internet was also supposed to curb mobility. Nowhere can a negative correlation between the extension of connectivity and mobility be objectively shown. And now, to cut a long story short, some ecologists are predicting or suggesting that mobility should be moderated and even checked in order to reduce greenhouse gas emissions. If such political measures were to be enforced, as they are in some cities where alternate circulation is imposed[†], HSR is likely to be one of the last transport modes on which volume constraints would be laid. It would rather be the other way round: People would be incited to use the rail mode instead of road and air modes. At the end of the day, such measures could favor rail and particularly HSR.

Thus, it is obvious that HSR rides the wave of mobility, and that this is probably one of the best and most solid points (Asset #1) HSR should continue to build on.

Another favorable aspect comes from the analysis of the respective market shares of HSR and air mode. Many corridors have been under scrutiny, and it has become a constant in HSR history that the market shares of these two competing modes are strongly linked to rail travel time. Fig. 2[‡] indicates the HSR market share on the Rail + Air market; for a sample of origin-destination (OD) pair, follow the same sharing pattern based on rail travel time in all countries operating HSR. Points under the curve correspond to OD pairs, with airports located particularly close to the served city or well linked to it, whereas points situated above the curve correspond to cases where the airport is far from the city or badly linked to it.

For travel times up to 2 h (120 min), rail is extremely competitive and sometimes capture more than 90% of the market. Residual air traffic is mainly due to connecting flights. For travel times in the range between 2 h and 4 h, rail is the dominant mode. Beyond 4 h, air takes the lead. And beyond 6 h, rail plays a marginal role on the market.

This split of the market is now well known, and nobody challenges it since it is proven worldwide. However, how can we account for such performances? It seems paradoxical that rail occupies the highest traffic volume when its travel time is between 2.5–3.5 h, whereas the same trip normally only needs 1 h by air! Is this situation due to the difference in ticket prices? No, that is not the obvious cause; when rail was operated with conventional rail, although it was cheaper than air, it did not hold the major share. Thus, price is not enough of an explanation, particularly since low-cost air companies sometimes propose cheaper tickets than HSR operators. There are two likely reasons why passengers select HSR and reject airplanes in this range of travel times.

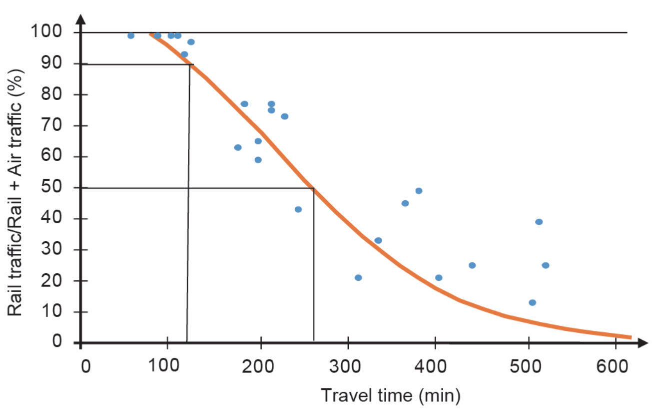

Fig. 2. Rail market share according to the best rail travel time.

The first reason is that, within this range of rail journey times, the door-to-door travel times by air and by rail are generally of the same magnitude. The second reason is that the time spent while traveling on rail can be used more easily than the time spent while traveling by air. Fig. 3 depicts the door-to-door travel times by rail and by air for a trip between Paris and Marseille, in France. Over a 700 km distance such as this one, the train is much more comfortable than an airplane. By analyzing this diagram, it is easy to understand that both Assets #2 and #3 jointly contribute to capturing the market.

Similarly, when it comes to competition with road, HSR can perform very well on the city-to-city trip market; as in France[††], for example, where HSR holds over 50% of the market (Fig. 4).

One of the reasons why HSR fares so well is that most car trips are run by people driving alone in their own car, which is more expensive and more time-consuming than travel by train.

However, it is understood that there is no permanent certainty regarding such things. Leaving aside the mobility aspects that support the HSR fare-box revenues, then, let us focus on the investment and operating costs. These lead us to the rail production function.

In neoclassical micro-economics, the production function states the quantity of output (Q) that a firm can produce as a function of the quantity of inputs. Most often, two kinds of production inputs, called factors of production, are considered: capital (K) and labor (L). Other production factors may be identified, such as land and raw materials. Land is rarely integrated into the calculation, except when land is of the essence in the production process (e.g., agriculture). Raw materials are often ignored because their cost is mainly composed of capital (machines for extraction and transportation) and labor. However, when addressing the rail production function, it is difficult not to mention energy (E) as a production factor, particularly because its cost is largely independent of the rail production process and may vary according to external and unpredictable causes. And finally, while extrapolating the present situation over the next 50-year period, we must consider an immaterial production input, the data (D).

$$Q = f(K, L, E, D) \tag{1}$$

As far as HSR is concerned, capital is mainly composed of linear infrastructure (by and large the costlier item), stations (or part of them when shared with other rail services), maintenance depots and sidings, track maintenance tools and machines, computing devices, and rolling stock.

At a given moment, in order to increase production, several options are possible:

- Increasing the occupancy rate of trains;
- Increasing train capacity (this option is only available by coupling two train sets);
- Increasing the number of trips of the train sets (generally, however, the operator has committed to a particular fleet size, so there is not much leeway in rolling stock productivity increase);
- Replacing one-deck with double-decker trains;
- Buying additional train sets (there is a several-year gap from drafting a request for proposal to the rolling stock delivery);

[†] The effect on mobility is not direct, since vehicle occupation may increase.
[‡] Chart initially established by French National Railway Company (SNCF) Mobility and regularly updated with data coming from SNCF and UIC. Last version was released in 2015.
[††] Source: SNCF Mobility.

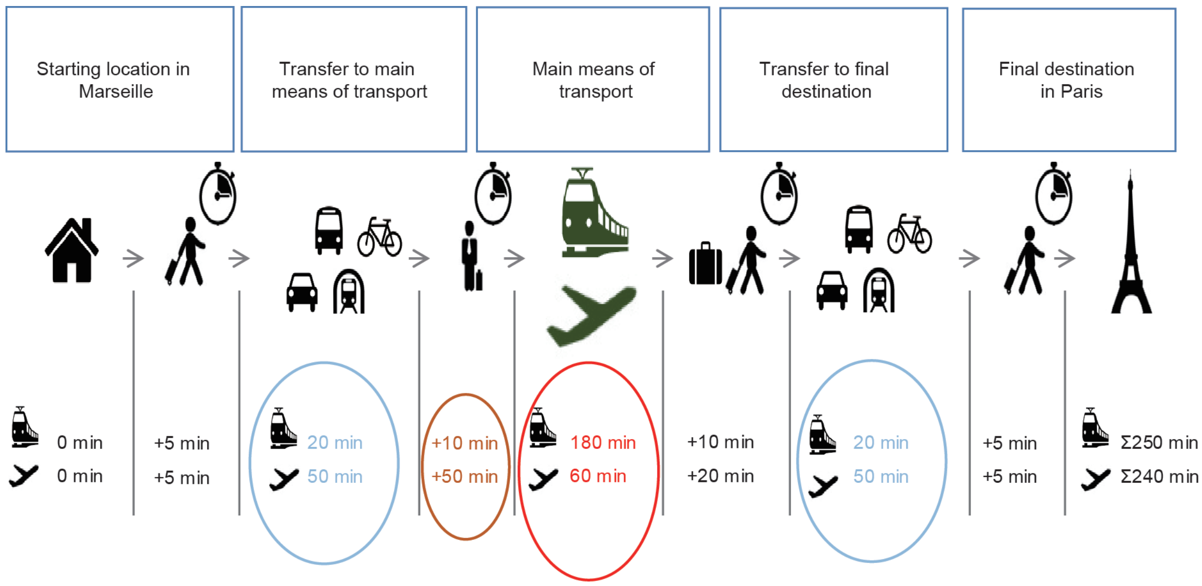

Fig. 3. Typical door-to-door trips between Marseille and Paris by rail and by air.

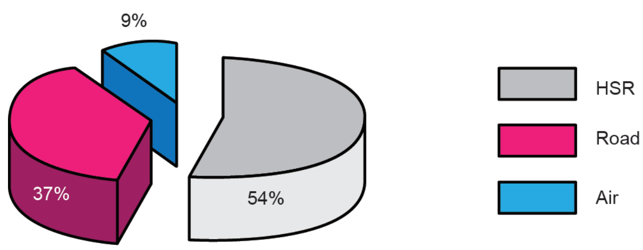

Fig. 4. Market shares on the medium-distance trip market in France.

and

- Extending stations and/or creating new tracks (this is exactly what HSR fulfils, but once the line is created, the expansion of its capacity is very complicated and quite long).

A quick glance at this list is enough to be convinced that, in the short run, it is very difficult to enhance the order of magnitude of HSR production. The other way round, that is, reducing the output, is even more complicated since timetables are published and reservations are opened six months in advance; it can be quite forbidding to cancel trains. Therefore, in the very short term, the flexibility of the production as a function of the capital (the derivate of the production function to capital) is quite limited. In the long term, this derivate is greater, but the investment steps (such as creating new tracks or extending a station) are very high. The allocative efficiency of capital can be characterized as follows:

$$\delta Q/\delta K \quad (2)$$

where,

- In the short term: quite limited;
- In the long term: quite strong, but hanging on huge investment steps.

Thus, with a given production function, rail has a limited maneuvering capital cost freedom to fight competitors.

Outside Europe, where the decision was taken to split the rail sector into infrastructure management and train operation, the marginal cost in terms of capital is roughly limited to the rolling stock, that is, the fleet of train sets. This means that the marginal cost corresponds to the operation of an additional train set, since the increase in the infrastructure maintenance due to this additional train is likely to be quite low. How can we compare this marginal capital cost to the corresponding marginal cost in aviation and road?

In Europe, the marginal cost is higher than in Asia, because it includes the track access charges that are levied by the infrastructure manager. European regulations state that the track access charges should be equal to the direct infrastructure cost, but allow infrastructure managers to add a markup on it, in order to cover more than the marginal social cost that already includes the cost of the external effects such as pollution.

When dealing with aviation, the marginal cost is mainly equal to the cost of an additional flight, including the airport taxes. However, the infrastructure needed by the aviation system is much smaller than the one required to run trains. In addition, because a flight is shorter in time than any ground transportation system, the productivity of airplanes is better in terms of covered distance. The only handicap of aviation when considering the marginal cost due to the capital is the higher acquisition cost of an airplane.

Let us now compare the rail and air fleets. As a metric for comparison, the HSR fleets numbered about 3600 HS train sets in the world in 2015[†] (Fig. 5).

Over the next 20 years, this fleet size will grow because of the network extension and should reach something like 6000 train sets. If it were necessary to renew all existing train sets, 6000 train sets would have to be built during the next 20 years (Fig. 6). The average manufacturing output would be around 300 train sets a year.

Fig. 7[‡] indicates airplane orders and deliveries during the last decade for the two current major airplane builders (Airbus and Boeing). These companies are now producing about 1500 aircraft a year and taking orders for about 3000 aircraft per year, meaning that future production will increase up to this magnitude.

Train set production is and still will be outnumbered 10 to 1 when compared to the air industry. The two industries do not appear to be playing in the same industrial league. Innovation and re-

† Source: UIC Passenger Department statistics.
‡ Source: *L'Usine Nouvelle*, March 2016.

duction in capital costs cannot be expected in the same proportions regarding the future productivity of the capital production factor of air and rail operating companies.

It is also worth focusing on the road, which is and will remain the strongest competitor to rail. Today, people own their cars. Thus far, car ownership has been viewed as a token of freedom and success, and people have been proud of driving powerful and comfortable cars of their own. However, the car industry is moving toward an organization based on a totally different paradigm. Car ownership will less and less be the dominant means of road travel. Today, carpooling (i.e., the driver shares his or her costs with passengers gathered by a website application, such as Blablacar[†] in France) and car sharing (the car owner allows somebody else to use the car in exchange for of money through a web application, instead of keeping the car idle) are rapidly developing. The car capital production factor will decrease, since, on average, a privately owned car is idle more than 90% of the time. In the next 20 years, we expect another change in paradigm: driverless cars. Such cars, belonging to companies, will pick people up at their true origin point and drive them to their final destination, then serve a second client, and so on. A dramatic reduction of the car capital cost has to be factored in from this point on.

Fig. 5. High-speed (HS) rolling stock fleet (number of train sets) in 2015.

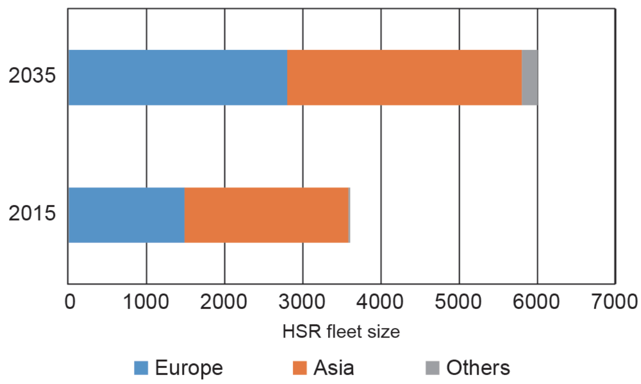

Fig. 6. HSR fleet size (number of train sets) extension in 20 years.

In summary, the rail capital production factor is not very flexible (i.e., it is difficult to adjust to swift changes in seasonality or competition) in the short term. It is even more difficult or expensive in the long term because it supposes a major change in the production function. Considering the industrial aspect of the capital, rail is expected to improve its productivity much less (in relative terms) than air and road because the industrial market sizes are not of the same magnitude of order: Rail train set manufacturing is a very small industry compared with the aircraft and car industries.

As predicted by some well-known economists such as Rifkin [2] and Anderson [3], we are moving toward a society that is governed by very low marginal costs because of the digital revolution and the prevalence of the economy of "data" above the economy of the "atom." Therefore, the previous analysis is not in favor of HSR versus air and road in the perspective of paving the way toward the economic rules that will govern future markets.

However, the prospects for rail are not discouraging, because HSR still owns a capital capability that outranks the other transport modes: the transport capacity. Within the infrastructure surface of the ground, rail (including HSR) is the only mode capable of handling very high traffic flows. Even an Airbus 380 cannot match the capacity of an HS train composed of two train sets and offering more than 1000 seats. Japanese double-decker trains can hold roughly 1200 seats and future train sets, which will be ordered by French National Railway Company (SNCF), once coupled, will reach a similar capacity. Therefore, drawing on being a mass transport system is the best strategy while dealing with the capital production factor of HSR (Asset #4). Nevertheless, the rail capacity remains strongly governed by the number of trains running, on the same track, at

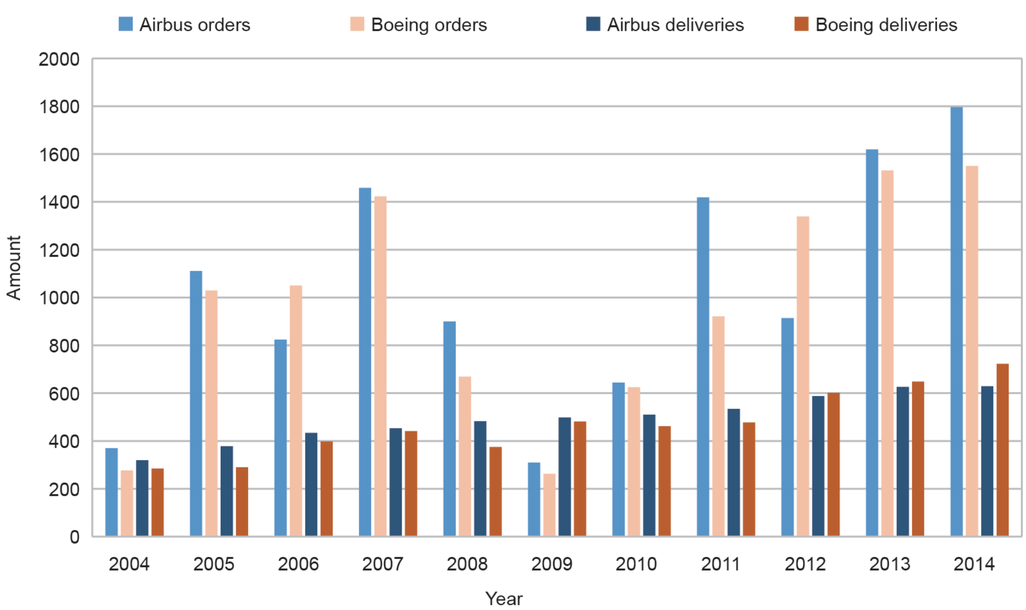

Fig. 7. Airplane orders and deliveries by Airbus and Boeing.

[†] Blablacar is the dominant carpooling company in Europe.

300 km·h^{-1}, during one hour. So far, no project is as ambitious as the HS2 High Speed Line, which is designed for 18 trains an hour running at the commercial speed of 360 km·h^{-1}. Should this aim be reached in 2026 (the expected infrastructure commissioning date), it remains an ultimate limit because railway is a low-grip transport mode. If its low-grip characteristic allows the hauling of very heavy loads with a minimum energy effort, it has a downside: The braking of a train requires a much longer distance than a vehicle with rubber wheels on tarmac does. Rethinking rail safety and signaling systems in order to outperform this constraint should be a possible lead for research programs.

When it comes down to the labor production factor, onboard staff productivity is increased with speed since staff is paid by the hour, and the longer the distance run in one hour the better. Once the speed is set at a given value, onboard productivity can only be increased by driverless trains or by providing fewer onboard services. The first option should be considered since HSR is a guided system, keeping in mind that driverless cars, which are not guided, are now under experimentation and are part of the foreseeable future. In addition, such a change would probably positively affect the track capacity, which is an even more important objective. Providing the client with fewer onboard services is the strategy followed by low-cost airline companies, and now by SNCF with its Ouigo trains on specific markets. If this strategy allows better resistance on a very competing market, the average revenue per passenger diminishes. Labor productivity has already been strongly improved in the commercial area by partially and sometimes exclusively relying on the Internet distribution channel. However, this approach is now already used for the other transport modes. Finally, the last remaining labor productivity field is system maintenance and cleaning. A balance must be found between a low-maintenance system (with many redundancies) requiring higher acquisition costs and a more high-maintenance system that would probably be cheaper in capital terms. The trend is in favor of the first option, since reliability and availability are to be factored in with a high coefficient. In conclusion, there is no evidence of a strong potential increase of a future labor productivity factor for HSR, except if the staff management rules and regulations can be made more flexible. Therefore, barring any major change in the automation of train driving or in staff regulations, the marginal labor productivity will remain unchanged at a low level.

$$\delta Q/\delta L \tag{3}$$

where, in the short and long term: somewhat fixed.

By contrast, the car production function is likely to improve, because carpooling means that the driver's cost as well as the car maintenance costs are shared (or at least divided by a factor of two), aside from the perspective of driverless cars, for which car use will be much more intensive and shared by many users. In competitive terms, the car will be a stronger competitor than it is today for the train. However, there is a silver lining with car improvements, because the more automatized the car, the better for access and egress trips to and from stations for passengers during their door-to-door trip. Therefore, although not many expectations should be laid on the productivity of the rail labor production factor, it is possible to build on the car breakthroughs in order to facilitate the first and the last mile of the rail passenger.

Considering a wider perspective, labor is about to change its nature. Thus far, most employed people have been on the payroll of firms in factories or office buildings. Now, however, there is a trend toward self-employment, with people wanting to master their own agenda instead of working within rigid rules. People may also work for several companies instead of only one, and may change their activity within a short period of time. These new kinds of jobs are an alternative to wage earning that is more flexible than conventional working conditions and contracts. Thus far, rail companies have not shown much ability to open to such changes in the labor force; for example, public companies are slow in adopting teleworking. In the long term, such an inertia on the labor market may change rail competitiveness [4].

Its low environmental impact has always been a highlighted quality of rail, including HSR, although higher speeds require more energy consumption. Fig. 8[†] illustrates the external costs of the various transport modes in Europe, and clearly demonstrates that rail is—head and shoulders—the most environmentally friendly mode of transport.

The reason for rail's environmental sustainability is its energy efficiency, which outperforms the other transport modes, as shown in Fig. 9[‡], which is based on European average values. Even in non-European countries with less nuclear electricity, for example, the ranking of the transport modes should remain the same.

However, here also, the competition is making big strides toward better energy efficiency, so rail should not rest on its laurels. Of course, the main change will be in the car powering source. There is no doubt that cars powered by gasoline will be progressively replaced by cars powered by hydrogen [5,6]. Hydrogen is the most common atom in the universe and is an inexhaustible source of energy, since it is present in water and can be separated from oxygen using electricity by electrolysis. The electricity needed for this process can be produced whenever available (with solar panels, windmills, or nuclear power plants), since hydrogen is the way to stock it. Then, using a fuel cell, the hydrogen combines with oxygen to form water, leaving nothing more as pollution. In other words, the future car, perhaps at the 2030 horizon, will be a hydrogen, non-polluting car, because its fuel (hydrogen) will mainly be produced using the sun's energy. Some firms [7] are already providing the market with a simplified low-investment distribution system based on hydrogen cartridges that can be inserted in sockets aboard vehicles.

Thus far, it is difficult to imagine HSR powered by fuel cells. The HSR requires an amount of energy and power that can only be delivered through the nationwide high voltage grid.

Moving 10–20 years into the future, the handicap created by the environmental impact of the car (the most important competition for the train) will be resolved by hydrogen technology.

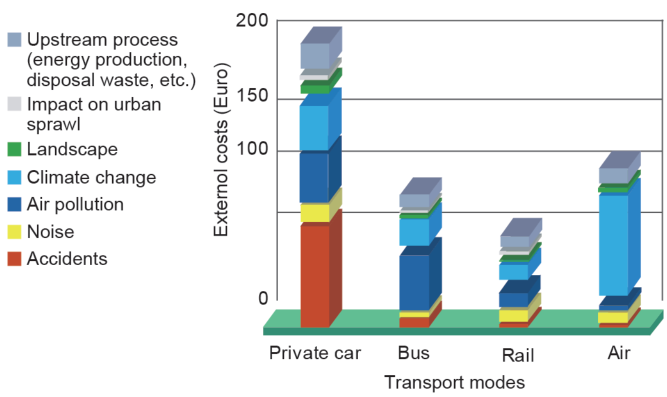

Fig. 8. External costs in euros of various transport modes in Europe per 1000 passenger-km.

[†] Source: UIC Environment Department.
[‡] Source: SNCF ADEME, 1997.

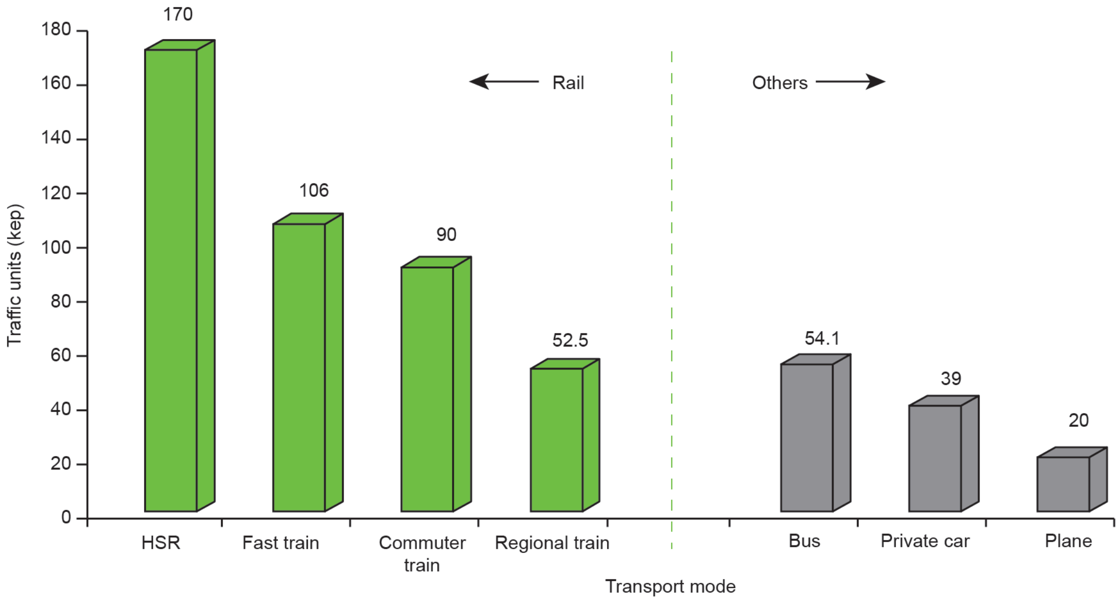

Fig. 9. Energy efficiency of various transport modes based on European average values. Traffic units carried (number of passengers × km) for one unit of energy (kilo-equivalent of petro, kep). Note that 1 kWh = 0.086 kep.

Therefore, if Asset #5 is to remain a strong quality of rail, it will no longer be a competitive advantage versus the car. For this reason, it is essential to continue to improve rail efficiency and to grasp any new opportunities to obtain better energy autonomy by producing electricity, building on the vast domain that is covered by rail facilities. For example, many square meters of rail stations (particularly the marquees covering platforms) could be covered with solar panels so as to fuel the future electricity smart grids (Fig. 10).

All that remains is the last production factor: the data. Although one might try to estimate the labor and the capital needs to gather and organize the data, this will not lead to a correct estimate of its value because there is no direct correlation between the data acquisition cost and the data strategic value. There are at least two ways to get a vision of the data value, and both should be considered attentively by the HSR sector.

The first way is to consider the power data gives to some actors, who aim at playing a role between the final client and the rail operator. This role is called "intermediation" [8]. Thus, a client wanting to book a trip by rail will prefer to use an external (to the rail sector) application rather than the railway website itself, because he or she is already used to such an application for other purposes, or because that application is easier to access and compute. In this case, the application operator may try to give its customer provider a role, in order to get a percentage on the sales. GAFA (Google, Apple, Facebook, and Amazon) and the like tend to work this way while providing the customer with free information services. Of course, rail operators are at risk, since they lose direct contact with their customers. Therefore, the value of gathering data is quite crucial and goes far beyond the cost of capturing client details, as many carriers do. It is also the only way to commit the customer to a loyalty program with rewards if the traveler often travels with the company.

The second way data can be considered regards security. Society is threatened more and more by cyberattacks, which endanger operations; and not only cyberattacks, but also malevolent actions up to terrorism. Several large terrorist actions have occurred in Europe. Not only have they damaged the rail image and cause a loss in revenues (e.g., the terrorist attack on Thalys on August 21, 2015 has caused a loss of ridership[†]), but they have also imposed new constraints on rail. For example, Thalys has been driven to install security gates at the entrance of the corresponding platforms. Customers have to arrive in advance and are fenced off until they are allowed

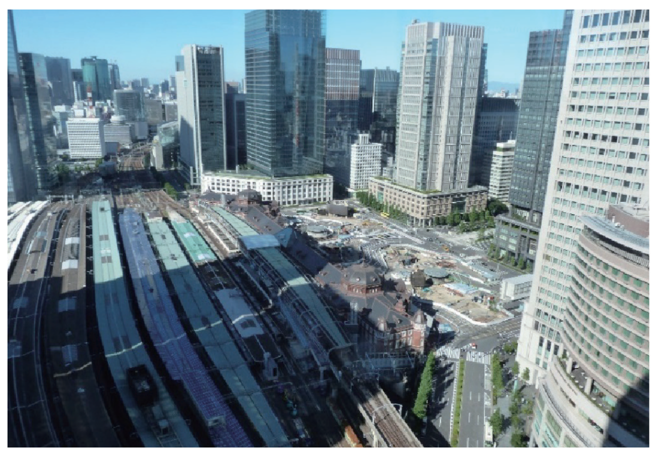

Fig. 10. Solar panels on the platforms of Tokyo Central Station.

Fig. 11. Security checkpoint with safety entry at the entrance of the Thalys platform.

[†] 20%–30% of traffic was lost during the months following the Thalys terrorist attack (*Le Figaro*, March 2016).

go through these gates (Fig. 11). Regardless of the cost of these equipment and their operations, this constraint affects modal choice because the time spent in the station is longer; as a result, rail loses part of its door-to-door advantage versus air. Of course, this aspect threatens collective transport modes much more than it does private ones [9]. Once again, an asset (Asset #6) is diminished, since the safety advantage may be counterbalanced by a loss of security due to collective transport modes being vulnerable to terrorism.

To conclude, the assets that have assisted the development of HSR still contribute to the commercial success of this transport mode. However, HSR is not invincible or invulnerable and its assets cannot be regarded as permanent, particularly in relative terms, because the competing modes are making progress and may sometimes outrun HSR on its own ground. This is particularly true regarding the environmental qualities of rail and the vulnerability to security of collective transport modes that are being challenged by the car.

In addition, the rail production function is not very flexible and therefore may not be reactive enough in the competition landscape where both the air and the car sectors, due to the size of their industrial markets, prove to be very innovative. The best way to maintain a leading position on the medium-distance market trip is, of course, to internally optimize productivity, as well as taking advantage of changes in the car and air paradigms through modal complementarity. In particular, access to and egress from the station can be strongly improved by the new car business model.

Finally, the one HSR asset that should never be challenged is its capacity. There is, so far, no mode to surpass rail when it comes to moving heavy flows of people over short and medium distances.

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