TP 12717E

HIGH SPEED RAIL AND MAGLEV:

EVOLUTION, STATUS AND PROSPECTS

prepared for

Transportation Development Centre
Safety and Security
Transport Canada

by

Tony R. Eastham

Department of Electrical and Computer Engineering
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Kingston, Ontario, Canada

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Un sommaire en francais de ce rapport est inclus avant la table des matieres

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16. Abstract

This report begins with a macroscopic picture of the evolution of passenger transportation. It is shown that the introduction, growth and decline of a particular mode follows a Gompertz-type curve. Over a period of 200 years, passenger transportation shows a progressive transition from waterways to railways to roads to airways, with a periodicity of 50-55 years. Following this historical trend, a new mode should be introduced to provide mobility into the 21st century. It is argued that this mode is high speed ground transportation.

The development of high speed rail and Maglev systems is then reviewed, focussing on systems which are operational or under development in Europe and Japan, and concluding with some thoughts on the way in which these modes will evolve. The technology and potential applications of HSST, a low/intermediate speed Maglev system, are then described.

The report concludes with a discussion of potential intra- and inter-city applications for high speed rail and Maglev systems in Canada. It is argued that the speeds offered by high speed rail (200-320 km/h) will be adequate for passenger mobility when introduced as a component of an integrated multi-modal regional transportation system in the 21st century.

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16. Résumé

Ce rapport brosse un tableau macroscopique de l'évolution des transports de personnes en montrant que cette évolution obéit à une courbe en S ou Gompertz. Cette courbe montre comment un produit évolue depuis sa conception jusqu'à son déclin, en passant par des phases successives de lancement, d'expansion, de maturité et de saturation. Au cours des 200 dernières années, les modes de transport de personnes ont connu des cycles d'évolution se succédant à intervalle de 50-55 ans : d'abord transport fluvial, puis ferroviaire et routier et enfin aérien. Le rapport conclut à la nécessité d'un nouveau mode de transport de personnes pour le prochain siècle, qui sera celui des transports de surface grande vitesse (TSGV).

Le rapport traite ensuite des trains grande vitesse et de la sustentation magnétique, et décrit les systèmes en exploitation ou en développement en Europe et au Japon, donnant un aperçu sur leur évolution éventuelle. Il décrit ensuite le HSST qui est un train à sustentation magnétique (TSM) circulant dans la gamme des vitesses petites et intermédiaires.

Il termine en abordant le sujet des applications possibles des TSGV et TSM aux transports urbain et interurbain au Canada. Circulant à des vitesses entre 200 et 320 km/h, ces systèmes seront aptes à s'intégrer au 21e siècle dans un réseau de transport multimodal régional.

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SUMMARY

Some elementary ideas from biology and business / economics are introduced to discern patterns in the evolution of transportation over the past 200 years. The general Gompertz curve characterizes many different systems and technologies, and can be applied to transportation. Following the conception of a product or system, it shows how the market evolves from its introduction to a period of rapid growth, to saturation, and then to decline as a better or more competitive technology is introduced. This is analogous to the biological growth of competing bacteria in a niche with limited resources. At any time, the strongest bacteria survives to claim most of the resources, i.e. the “best” system survives to provide the passenger service in transportation terms.

The Soviet economist Kondratiev was one of the first to show that the world has experienced macroscopic cycles in business and industrial activity with a period of 50 - 55 years, and such swings from boom to bust are now evident since the beginning of the industrial revolution. Historically, the introduction and transitions in transportation have followed a similar pattern. Thus waterways were superceded by railways, then by roads, and most recently by airways as the dominant passenger-carrying mode. Following this trend, in consideration of the imminent saturation of airways in many corridors, there is a need and opportunity for a new mode to evolve to provide passenger mobility in the 21st century. It is argued that this new mode is high speed ground transportation (HSGT).

HSGT is a family of technologies capable of sustaining operating speed of at least 200 km/h. It is therefore quite distinct from conventional rail which peaked in its share of passenger transportation in the 1920s. HSGT includes both high speed rail and Maglev. Many high speed rail systems have become operational over the past 30 years and are now carrying hundreds of millions of passengers per year in high population density corridors in Japan and Europe. Operating speeds have reached 300 km/h (for the TGV Atlantique and Nord lines in France) and 350 km/h seems achievable within 5 years. Maglev vehicles are under development and have reached the stage of prototype testing. Such systems could be implemented in both Germany and Japan at 400 - 500 km/h before 2010.

North America is struggling with the implementation of HSGT. The problem is not one of technology, but of economics. Projected passenger utilization is such that it is unlikely that HSGT can pay for itself by farebox revenues alone. As for all other modes, a public - private partnership is essential.

At low and intermediate speeds, Maglev offers certain advantages (quiet, low vibration) for special purpose applications. It was implemented to provide shuttle service at Birmingham airport in 1984, and operated very successfully for 11 years. HSST has been under development in Japan since the early 1970s and, as a result of a rigorous program of testing in Nagoya, is now considered to be ready for implementation. The first application in Japan will likely be in Ofuna, then in Nagoya, and possibly in Hiroshima within eight years.

Passenger mobility in the Canadian corridor (Quebec - Montreal - Ottawa - Toronto - Windsor) has been studied on a number of occasions over the past thirty years, from an examination of the application of tracked air cushion vehicles in the late 1960s to the recently completed Quebec - Ontario High Speed Rail Project. The latter study concluded that TGV technology is the most appropriate mode of HSGT, but that the project is not economically viable at this time. With the

selection of a tilting version of the TGV (American Flyer) for the North-East corridor, it is hoped that consideration will eventually be given to a network of high speed rail lines as a component of a multi-modal regional (area bordered by Boston - Montreal - Chicago - Washington D.C.) transportation system in the 21st century.

SOMMAIRE

L'auteur invoque des principes fondamentaux de biologie et d'économie pour décrire l'évolution dans le domaine des transports au cours des 200 dernières années. À son avis, la courbe en S ou de Gompertz décrivant l'évolution suivie par des systèmes et des technologies très différents peut s'appliquer aussi au domaine des transports. Cette courbe de cycle de vie montre comment un produit évolue depuis sa conception jusqu'à son déclin, en passant par des phases successives de lancement, d'expansion, de maturité et de saturation. Ce processus est identique à celui des bactéries qui se font concurrence pour exploiter les ressources vitales dans une niche donnée. C'est toujours le plus apte qui parvient à survivre au détriment du plus faible. Transposé au domaine des transports, ce processus se vérifie, montrant que c'est le «meilleur» système qui dominera les autres.

Le soviétique Kondratiev a été le premier économiste à montrer que les cycles d'évolution des principales variables de l'économie et de l'industrie mondiales se succèdent à intervalle de 50 – 55 ans et que cette succession de périodes de croissance-décroissance se vérifie depuis le début de la révolution industrielle. Les transports ont eux aussi connu une évolution cyclique identique. Il y a eu d'abord le transport fluvial, remplacé par le transport ferroviaire, puis par le transport routier et plus récemment par le transport aérien, comme mode dominant en transport de personnes. Vu cet état de choses, et considérant la saturation prochaine des transports aériens dans un grand nombre de corridors, on conclut à la nécessité ainsi qu'à l'opportunité d'un nouveau mode de transport de personnes pour le prochain siècle. L'auteur avance l'idée que ce mode sera celui des transports de surface grande vitesse (TSGV).

Les TSGV constituent une famille de systèmes de transport de haute technologie, capables de circuler à des vitesses d'au moins 200 km/h. C'est ce qui les distingue des transports ferroviaires classiques qui ont dominé les autres modes de transport de personnes dans les années 1920. Dans les TSGV, on dénombre les trains grande vitesse et les trains à sustension magnétique. Les trains grande vitesse sont en service depuis déjà une trentaine d'années tant en Europe qu'au Japon, transportant des centaines de millions de personnes par année, dans des corridors à forte densité de population. En France, les TGV-Nord et Atlantique atteignent des vitesses de 300 km/h et pousseront jusqu'à 350 km/h d'ici cinq ans. Quant aux transports à sustentation magnétique, leur développement a atteint le stade de prototype expérimental. On prévoit qu'ils seront mis en oeuvre au Japon et en Allemagne avant l'an 2010 et que leur vitesse d'exploitation se situera entre 400 et 500 km/h.

Pour l'Amérique du Nord, l'implantation des TSGV relève de problèmes moins technologiques qu'économiques, étant donné que les projections concernant la fréquentation des TSGV montrent que le seuil de rentabilité ne pourra pas être atteint en comptant uniquement sur les recettes. À l'instar de tous les autres modes de transport, un partenariat public-privé sera indispensable.

Dans la gamme des vitesses petites et intermédiaires, les transports à sustension magnétique possèdent de grands avantages : faible bruit et faibles niveaux vibratoires, dans des applications spéciales. À Birmingham en Angleterre, la sustentation magnétique a été mise en oeuvre en 1984 pour la navette aéroportuaire et fonctionne bein depuis 11 ans. Au Japon, le HSST a connu un développement prometteur depuis les années 1970 au point que maintenant, après un programme expérimental très rigoureux sur le manège d'essai de Nagoya, ce système est jugé mûr pour une exploitation commerciale. Le premier HSST sera probablement implanté à Ofuna, puis à Nagoya et peut-être aussi à Hiroshima, d'ici 8 ans.

La question d'un TSGV au Canada dans le corridor reliant Québec, Montréal, Ottawa, Toronto et Windsor a été au centre d'un important débat au cours des trente dernières années. Il a commencé vers la fin des années 1960 par une étude sur un véhicule guidé à coussin d'air et la dernière en date a été l'étude exhaustive sur un projet de TGV, parrainée par l'Ontario et le Québec. Cette dernière a montré que la technologie TGV constitue le mode de TSGV le plus approprié, mais que le projet n'est pas économiquement viable pour le moment. Avec le choix d'une version pendulaire du TGV, appelée American Flyer, pour desservir le corridor nord-ouest des États-Unis, on espère que le 21^{e} siècle verra l'implantation d'un réseau de trains grande vitesse formant partie d'un réseau de transport multimodal régional desservent les grandes agglomérations urbaines du nord-est de l'Amérique du Nord, allant depuis Montréal jusqu'à Washington D.C. et s'étendant jusqu'à Boston et Chicago.

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1. INTRODUCTION

While on leave from Queen's University for the year 1995 - 96, the author spent six months as Japan Railways Central Visiting Professor in Transportation Systems Engineering at The University of Tokyo. He also attended two major international conventions on high speed ground transportation in Europe :

- 2nd World Congress on High Speed Rail (EURAILSPEED '95), Lille, France, October 4 – 6, 1995

- 14th International Conference on Magnetically Levitated Systems, Bremen, Germany, November 27 - 29, 1995

Early in 1996, the author was invited to serve on the "Committee for an Assessment of Federal High-Speed Ground Transportation Research and Development", established by the Transportation Research Board of the National Research Council to advise the Federal Railroad Administration in Washington D.C.

As a result of these activities, the author has gained an appreciation of current operations and R & D activities in high speed ground transportation in Japan, Germany and North America.

This report provides an assessment of the status and prospects for high speed rail and Maglev world-wide, and is presented in four chapters. The first chapter, following this introduction, provides a broad perspective on the evolution of transportation and the role of railways. The second chapter presents a review of the technologies and current status of high speed ground transportation around the world. The third chapter focusses on the development and application of low/intermediate speed Maglev systems. The final chapter then offers comments on Canadian applications of these technologies for inter-city and (for Maglev) intra-city transportation.

2. THE EVOLUTION OF TRANSPORTATION AND THE ROLE OF RAILWAYS

SUMMARY

Historically, the evolution of industries, systems and consumer products can be characterized by an S-shaped “Gompertz” curve, showing introduction, growth, maturity and decline. Such a curve is also representative of transportation systems. Furthermore, the rise and fall of industries and technologies tends to occur in “Kondratiev” cycles. The evolution of transportation can be likened to a biological process in which the fittest system over a period survives to dominate the resources, i.e. provide the transportation service. What does this teach us about railways ? If we separate high speed ground transportation (above 200 km/h) from old intercity railway services, HSGT systems would seem to have a bright future. The arguments presented in this chapter draw heavily upon data accumulated by other authors, particularly Marchetti (1987) and Davies (1992), to examine the role that railways have and can play in the mix of systems that provide mobility around the world.

2.1 TECHNOLOGY EVOLUTION

Before examining the evolution of transportation, some concepts from business, economics and biology are introduced.

2.1.1 Gompertz Curve

The evolution of industries and the development of the market for products can be characterized by a univariate time series S-shaped curve generally referred to as the Gompertz curve, as illustrated in Figure 2.1. This displays the conception and life cycle of a typical product or technology, from invention, through development, introduction, emergence, high growth, and saturation, to eventual decline once a better technology or product is introduced and begins the substitution process.

The time dependence of that part of the Gompertz curve from invention to maturity is usually represented by an equation of the form :

$$Y(t) = A \exp [- B \exp (- Ct)] \qquad (1)$$

where A is the saturation level, and B and C are constants (> 0) related to the time scale, Franses (1994).

A good example of a series of technologies that follow Gompertz - type curves is that for consumer products of sound reproduction. Figure 2.2 shows the market development. Edison introduced cylinders in the 1890s, and these were made obsolete by Berliner's 78 rpm disc records in the 1910s. Long playing records (LPs) gained ascendancy in the 1950s, until eliminated by compact discs (CDs) in the 1980s. Tapes barely acquired a foothold, while cassettes maintain but a small market share.

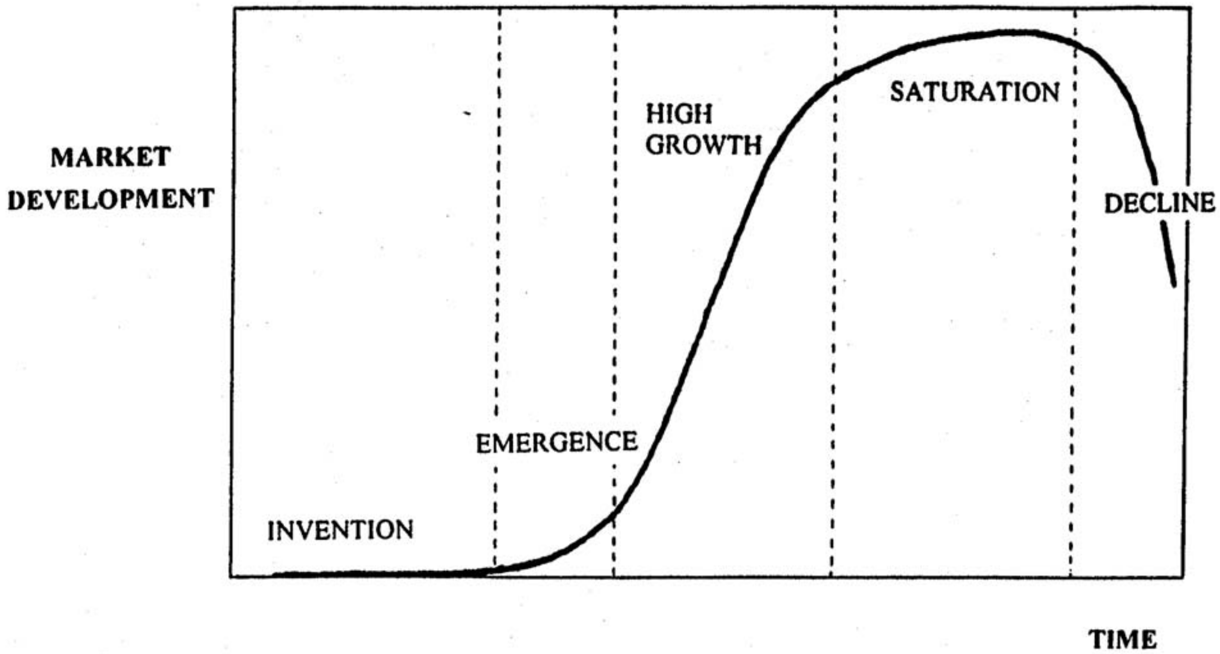


Figure 2.1 A typical Gompertz curve

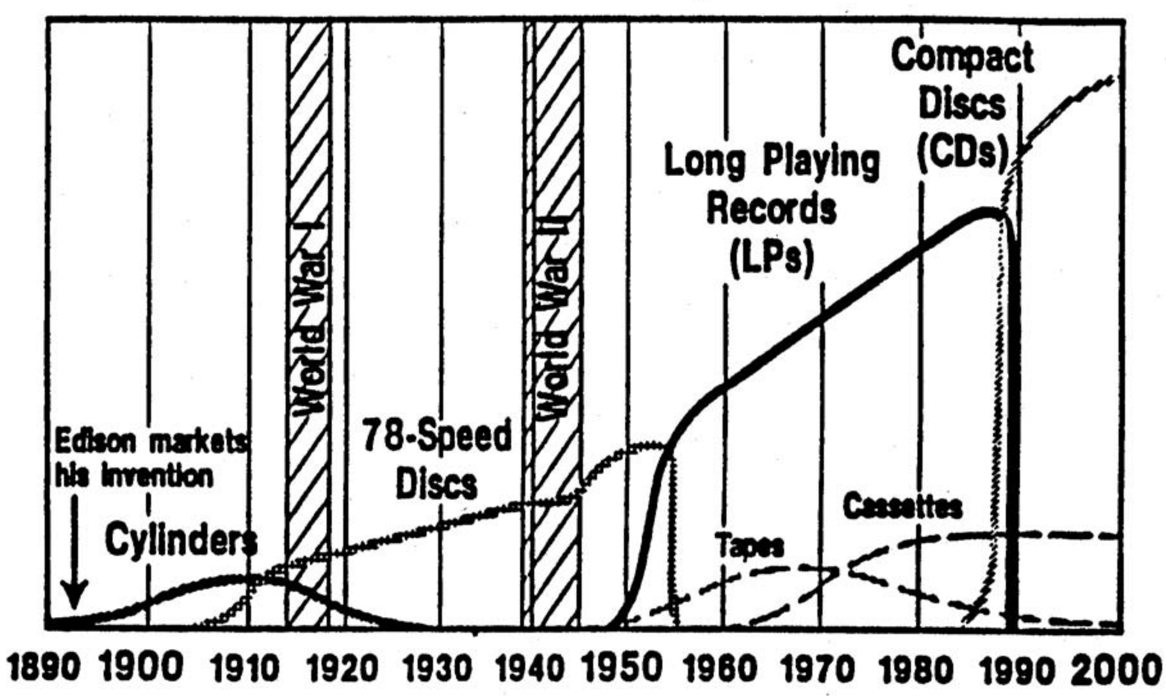


Figure 2.2 A century of sound reproduction, showing the dynamics of market development for a series of consumer products. From Davies (1992)

The decline or obsolescence of each mode of sound reproduction is a consequence of the introduction and market acceptance of a better technology. Presumably, CDs will reign supreme for a certain number of years and then disappear when the next wave of digital technology is introduced into the consumer marketplace. Presumably, there will continue to be a desire/demand for sound reproduction, and this will be met by the best available technology (as determined by the most advanced at an affordable price). This consideration can be applied to transportation.

2.1.2 Kondratiev Cycles

While still a topic for debate, most economists now accept that there are long waves of economic growth and business cycles. However, the causes and consequences are still fertile areas for research.

Some seminal early work on economic cycles was conducted by the Soviet economist/statistician Nikolai Kondratiev (1926). From a careful examination of world economic activity, he recognized cycles of boom and slump with a period of 50 - 60 years, back to the beginning of the industrial revolution. As schematically illustrated in Figure 2.3, these fluctuations reached their highest points around 1870, 1920 and 1970, and their lowest points around 1850, 1895 and 1935. Clearly, events subsequent to Kondratiev's work have substantiated his observations. In the recessionary 1990s, we are suffering through the low part of the Kondratiev wave/cycle, but we can optimistically look forward to a steady improvement in the world economy over the next 20 years.

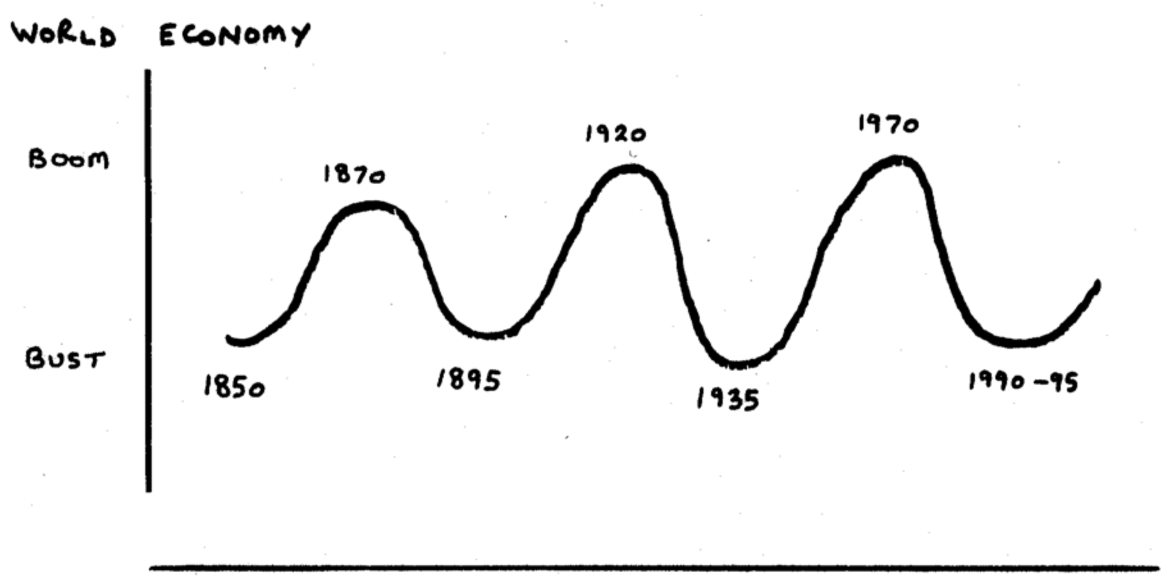


Figure 2.3 Kondratiev cycles. From a careful examination of world economic activity, the Soviet economist / statistician Nikolia Kondratiev recognised cycles of boom and slump with a period of 50-60 years, back to the beginning of the industrial revolution

Other researchers (e.g. Schumpeter (1939), Marchetti (1987)) have built upon the concept of economic long waves to examine business cycles and the dynamics of technological change, and have demonstrated a remarkably consistent pattern in the evolution of a wide range of systems.

A good example, from Marchetti and Nakicenovic (1979), is the time series representation of the total world energy consumption separated into primary energy source, as shown in Figure 2.4a. The peaks for wood, coal and oil, and the extrapolated peaks for natural gas and nuclear energy are separated from each other by a time of approximately 60 years.

A further example, with relevance to transportation, is the time series for propulsion technologies for the British shipping fleet (selected because data was available) over the past 200 years (Nakicenovic (1986)), as illustrated in Figure 2.4b. This clearly shows the transitions from sail to steam to electric drives.

2.1.3 Evolutionary Competition

Marchetti (1987) argues that the dynamic transition between technologies is analogous to a competition process. He finds that biological models of competition are "very efficient descriptors of the dynamics of change in our society". His concept is "that of a population growing into a resource niche and/or territory and of displacing another population inside the niche".

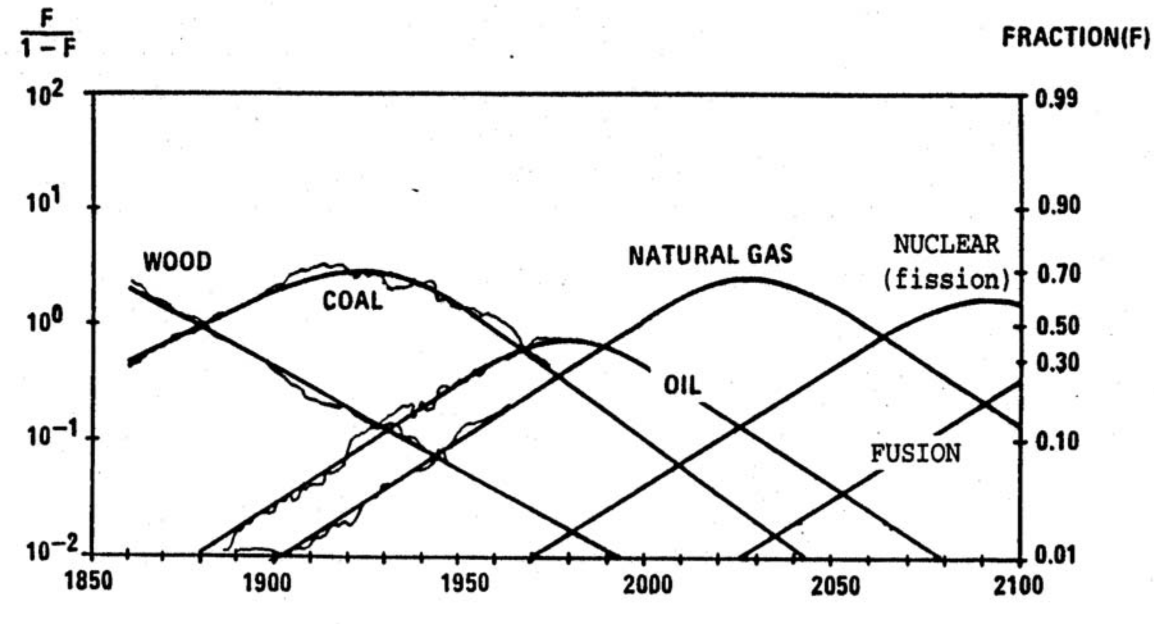
Fisher and Pry (1970) show that, for a simple system, the time growth of a population within a niche with limited resources may be characterized by the expression :

$$\log \frac{F}{1-F} = at + b \tag{2}$$

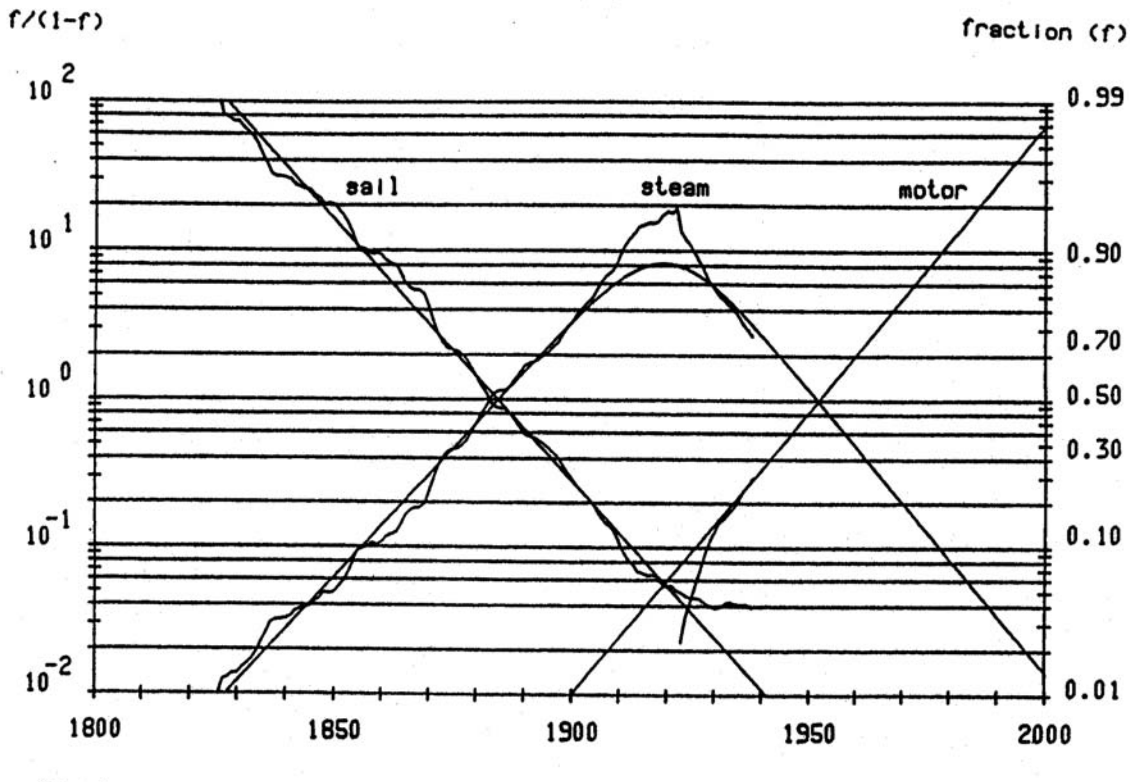
where $F = N(t) / \hat{N}$ is the fraction of the niche capacity $\hat{N}$ that the population fills at a given time t, and a and b are empirical constants.

This is the reduced form of the general Volterra - Lotka equation which predicts that a species initially grows exponentially with time and then approaches a saturation population as a consequence of resource constraints (i.e. it follows a Gompertz-type S curve) - Montroll and Goel (1971). When there is competition between two or more species of different fitness for the same resource (Haldane (1924)), behaviour as shown in Figure 2.4 becomes evident. Both (and some subsequent) figures use both F and F / (1 - F) on a logarithmic scale for the y-axis and time in years on a linear scale for the x-axis.

The dynamics of the "populations" shown in Figures 2.2 and 2.4 are such that major changes occur over time scales of 50 - 60 years, i.e. the Kondratiev period. Economists have devoted a great deal of thought and effort to explain and model such cycles in business and system behaviour - some still retain the view that certain perceived long term variations are little more than the summation of random events. However, as we will see, it is illuminating to view transportation dynamics in this manner.



(a) The competition between primary energy sources in terms of market share (in tons of coal equivalent). From Marchetti and Nakicenovic (1979)



(b) The competition between propulsion technologies used by the British shipping fleet (in tonnage in operation). From Nakicenovic (1986)

Figure 2.4 Typical Kondratiev cycles. In both cases, the statistical data is fitted to solutions of the Volterra – Lotka equations for competition between biological systems

2.2 TRANSPORTATION EVOLUTION

2.2.1 General

First, we take a macroscopic view of transportation, particularly in Europe and the U.S. because of the availability of data. Figure 2.5 shows the dynamics of modal substitution, from canals/waterways, to railways, to road vehicles (cars and buses), and to air travel. In Figure 2.5a, the length of each mode in service in the U.S. is plotted over a period of 200 years, using data accumulated by Nakicenovic (1987). The "saturation" lengths are determined by a best fit of the data, using Equation (2). A 55 year Kondratiev-type cycle is apparent from the spacing of the modal substitutions.

Another representation of transportation evolution is shown in Figure 2.5b. The sum of the lengths of all transportation modes in service at a particular time (from Figure 2.5a) follows an S-shaped Gompertz or logistic-type equation (Grubler (1987)). The fraction that each mode has of the total U.S. transportation infrastructure, when plotted over 200 years, is analogous to the competition model introduced in Figure 2.4, with the fittest mode surviving to absorb the resources (or, in transportation terms, provide the passenger service) in the longer term.

2.2.2 Railways

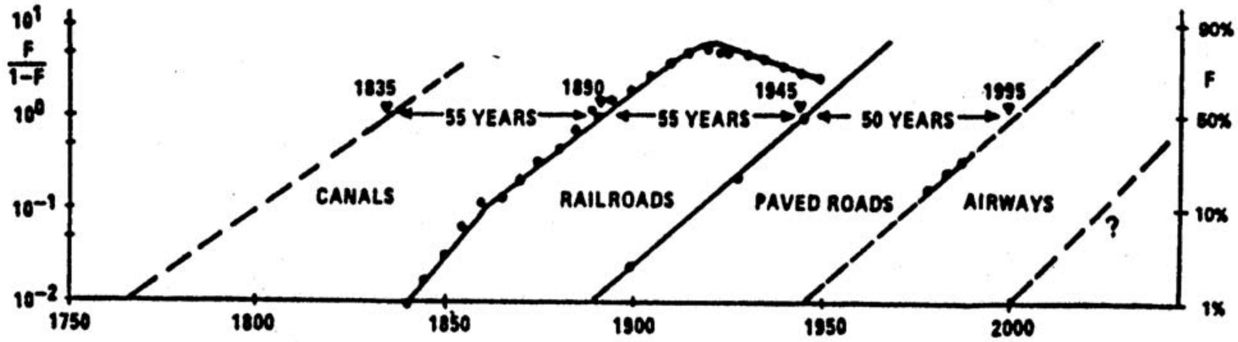
What does this cyclic variation imply ? Clearly, canals and waterways are long gone for passenger transportation. But what about railways ? Marchetti (1987) argues that intercity rail has served its purpose, reached its zenith in the 1930s, and has been in decline ever since, being superseded by road and then by air travel. He concludes that rail transport "is at the end of its product life cycle", and "much would be gained by facing the facts and taking the obvious measures" - a somewhat disconcerting notion for railway engineers and proponents !

Marchetti reinforces this view by examining the rate of construction of rail lines in Europe and in the world, as shown in Figure 2.6. Two distinct surges in growth are apparent, bringing the total line length to about 1.3 million km worldwide by the 1930s. This was followed by a period of stability. By analogy with many other case studies (e.g. coal production and steel production in U.K.), a period of stability after periods of growth is inevitably followed by a period of decline over the next Kondratiev cycle. By this argument, intercity rail (*of the conventional type*) will functionally disappear by the early years of the 21st century !

2.2.3 Roads

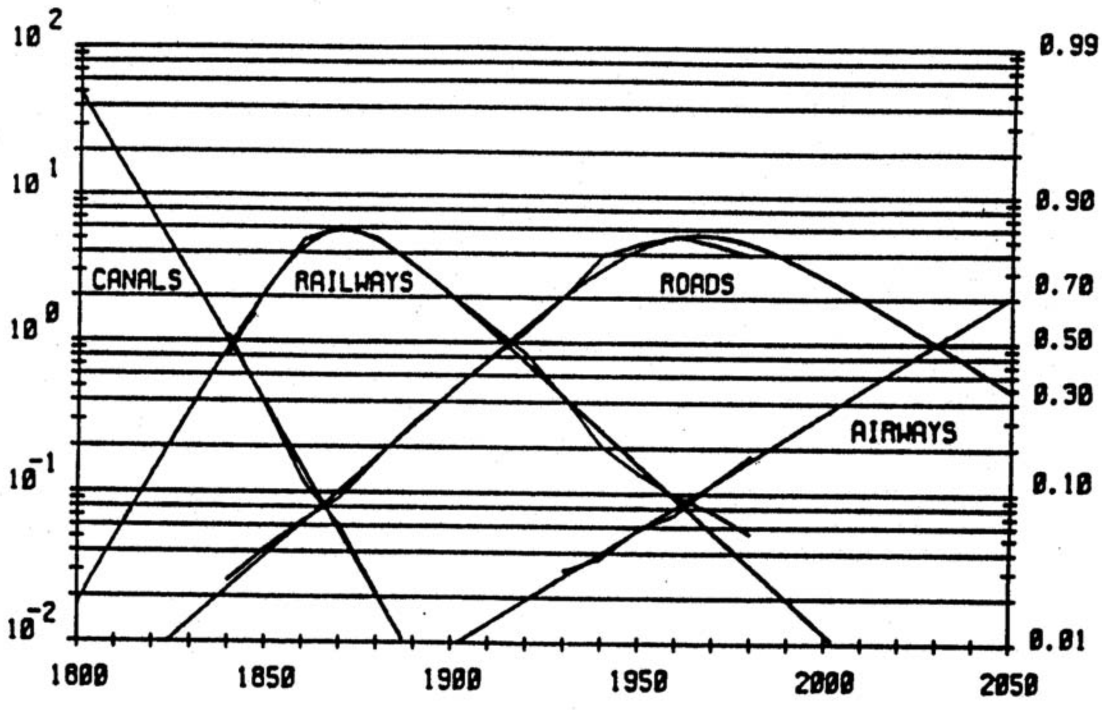
Where is passenger travel by road headed ?

Figure 2.5b showed that, in terms of competition for intercity passenger-km in the U.S., the car is losing market share to the aircraft. Although still growing in absolute terms, it reached its maximum market share around 1960. Industrially developed countries are not significantly increasing the length of auto-route networks, but rather are attempting to increase capacity (and safety) by



(a) Each mode is represented by its total length in operation in a particular year. A 55 year Kondratiev cycle is apparent from the temporal spacing of the growth pulses. Saturation levels are approximately :

Railways	0.5 million km
Paved roads	5.4 million km
Airways	5.1 million km



(b) Normalizing the length of each mode to the total length of transportation infrastructure by year (the "dynamic niche" from a. above), the "competition" between modes becomes apparent in relative terms

Figure 2.5 The development of transportation infrastructure in the U.S. (from Nakicenovic (1987))

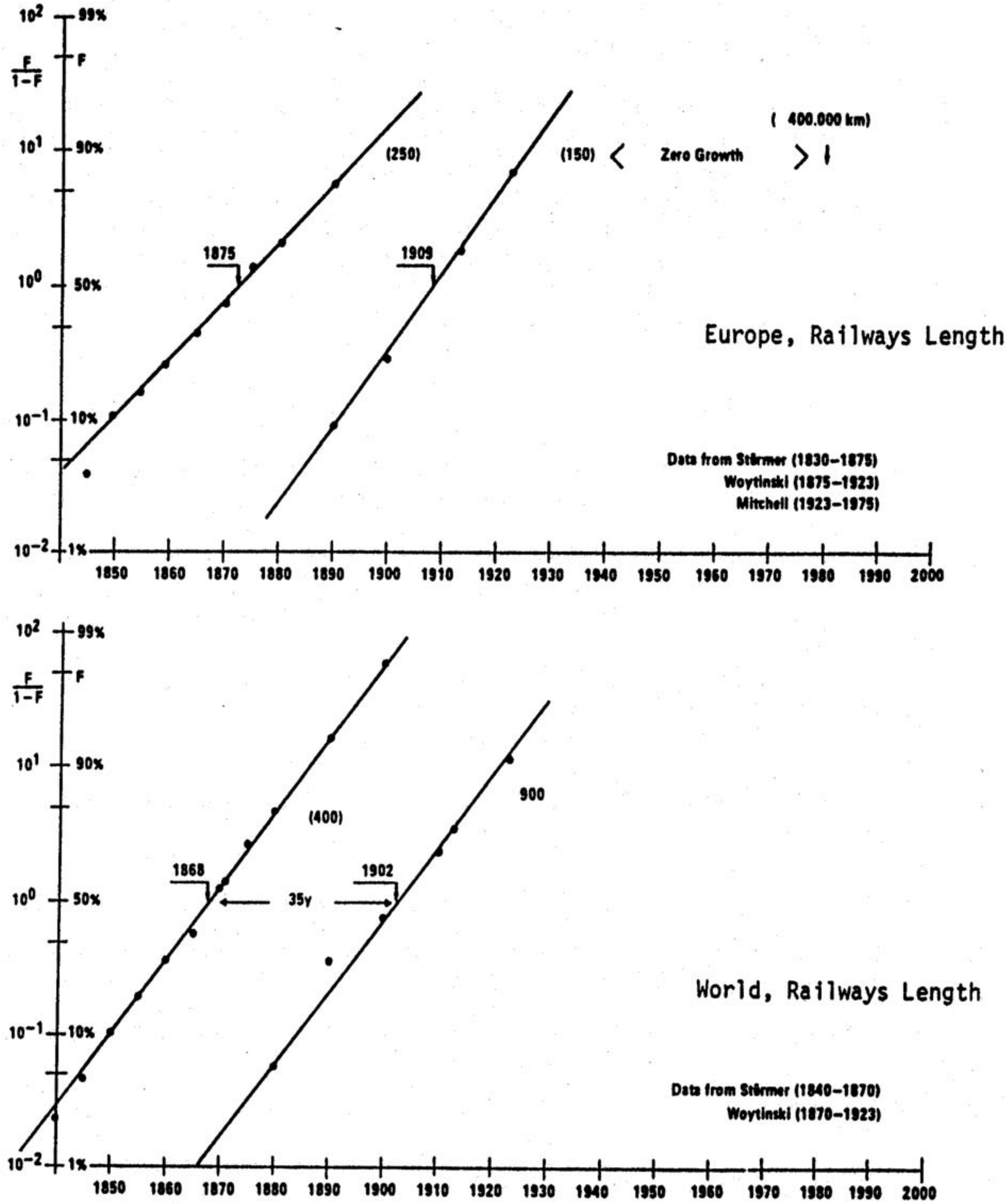


Figure 2.6 The growth of railways in (a) Europe, and (b) the World

Railway infrastructure was built in two phases, with surges in activity from 1860-1880 and again from 1890-1920. Little growth is apparent since, with total railway length worldwide at about 1.3 million km and in Europe at about 0.4 million km. From Marchetti (1987) intelligent vehicle/highway systems (IVHS) - now called simply intelligent highways. Developing countries will continue to build roads, but it is likely that air traffic to/from and within these countries will increase at a faster rate.

Marchetti's logistic analysis of car registrations in Europe and the U.S. is shown in Figure 2.7. In both continents, growth is apparent in two phases, with saturation levels of 7.5 million and 150 million in Europe and 26 million and 125 million in the U.S. By analogy with many other systems, two up cycles are followed by a period of stability. Marchetti therefore concludes that, after the current period of growth (Kondratiev cycle) is completed around the turn of the century, the total number of cars on the roads of developed countries will stay approximately constant (a reasonable presumption in view of the populations of these continents). Thus their market share will further decline as total passenger-km continues to increase.

2.2.4 Air Travel

The growth in air travel has been dramatic over the past 50 years. Figure 2.8a shows the ton-km carried by the air system worldwide. It can be seen to neatly fit a smooth Gompertz-type or logistic curve, approaching 90% of saturation by 1995. A similar trend is evident for a subset of the market (e.g. air passengers in Europe - Figure 2.8b) and even down to individual carriers (e.g. Lufthansa). Marchetti argues that the approaching saturation does not mean the end of the growth of air transport, but rather the end of a Kondratiev cycle of growth - the next cycle to start around 2000.

The data presented by Davies (1992) is consistent with this picture. He shows, in Figure 2.9, billions of passenger-km per year over the past 60 years through many aircraft technology innovations, and suggests a saturation towards the end of this century.

Davies has considered future trends in air transport. He concludes that air productivity is reaching a plateau because :

- speed (discounting supersonic travel) is limited by the sound barrier
- range is already such that a two-engined plane can fly around the globe with only two stops
- utilization of aircraft is close to an operational maximum (B 747s spend almost half their lives in the air)
- load factor of aircraft is close to an operational maximum (now over 80% for B 747 aircraft)
- frequency/fleet size is limited by airport congestion, and few new airports are being constructed in developed countries
- capacity ?

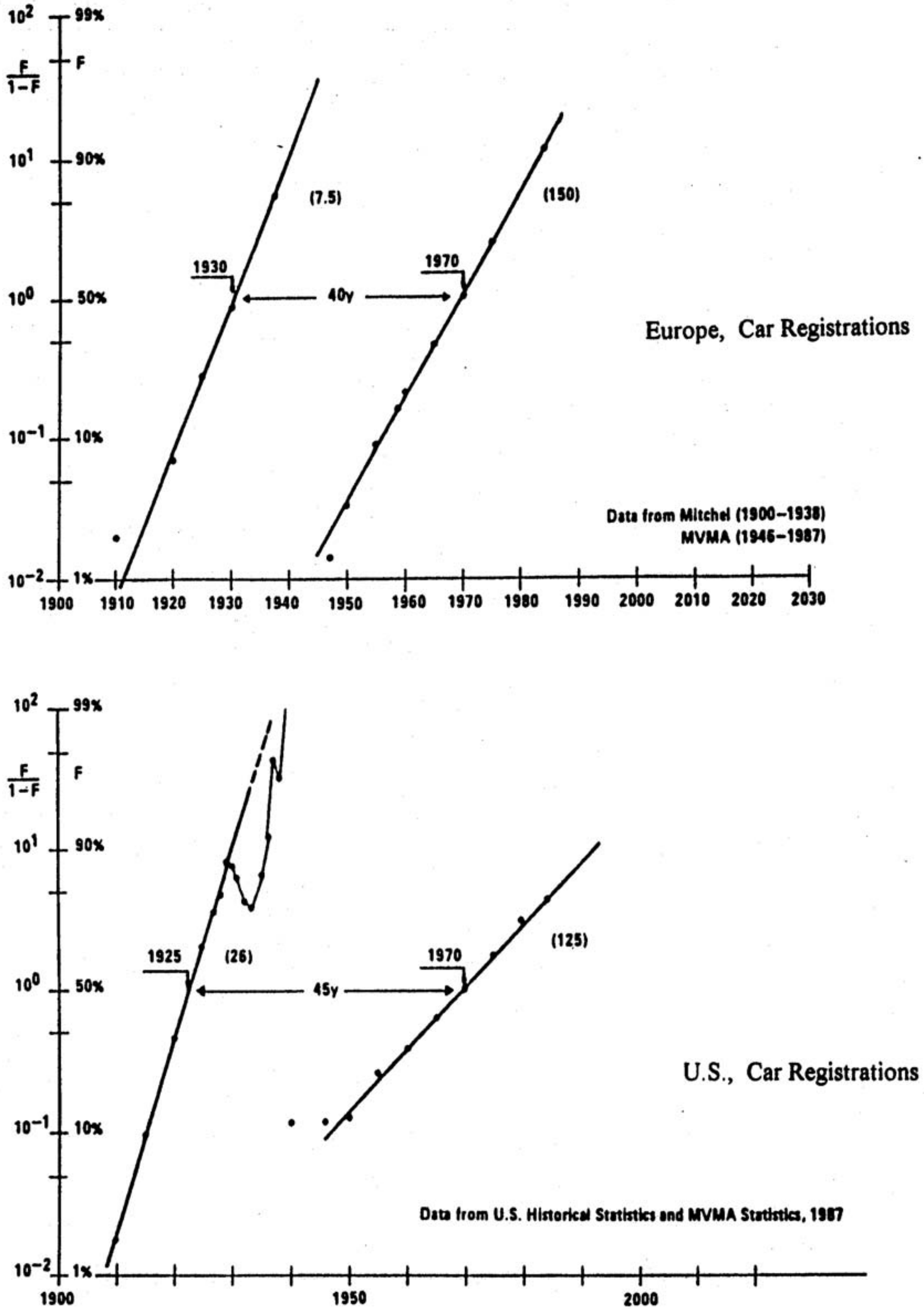


Figure 2.7 The growth in the number of registered cars in (a) Europe, and (b) the United States

Again growth is apparent in two phases, the first ending around 1940 and the second around 1990-2000, again consistent with Kondratiev cycles. From Marchetti (1987)

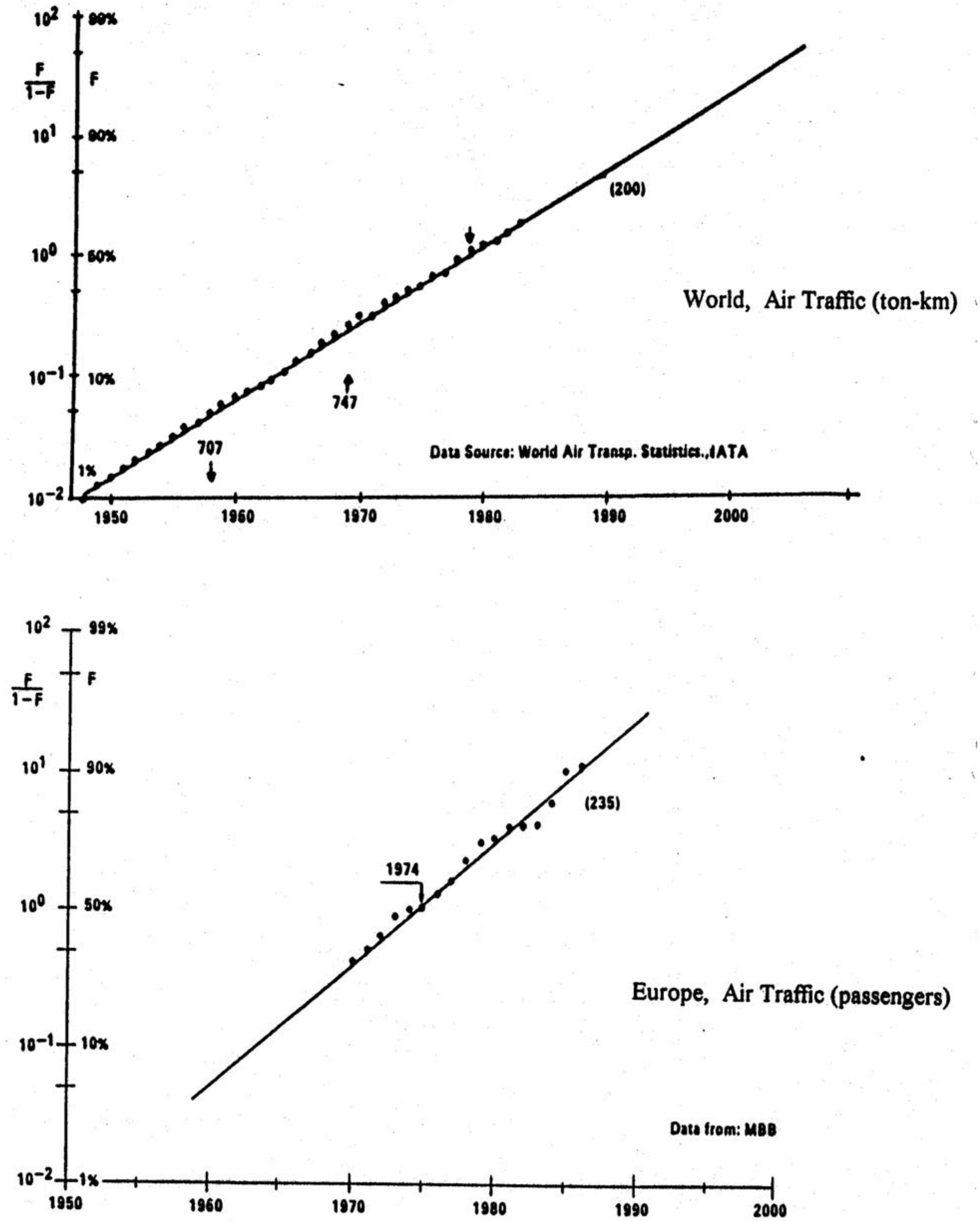


Figure 2.8 The growth in air traffic, in terms of (a) ton-km world-wide, and (b) passengers in Europe. The data fot a simple Gompertz-type or logistic equation. From Marchetti (1987)

With regard to speed, Davies argues convincingly that the development and operating costs of a supersonic airliner are so high as to preclude commercial implementation, except for a small, elite fraction of the market - such as that served by the Concorde.

How then can air travel evolve to accommodate the next Kondratiev cycle of growth - or are we destined to experience a substantial period of stability ? How about capacity ? Figure 2.10 shows the seating capacity of five generations of aircraft. It is evident that unit capacity has grown by a factor of 2-3 every 10-15 years. Is an 800-1000 passenger airliner a reasonable prospect for the early years of the 21st century ? - Figure 2.11. Aircraft manufacturers have produced conceptual designs [Covert (1995)], but the author is not aware of any programs to develop such aircraft for commercial purposes.

Therefore, it does indeed appear that there are near-term practical limits to growth in air travel.

2.2.5 HSGT

The passenger-km trends, as exemplified in Figure 2.5 for the U.S. and similarly for Europe (although displaced forward in time by 20-30 years), would seem to indicate that, for intercity transportation, buses and trains are almost extinct species and that automobile traffic is approaching saturation in absolute terms and is declining in relative terms (relative to air traffic). The application of Kondratiev cycles to transportation suggests that a new mode should soon start competing with air travel, at least in inter-city corridors. Perhaps it is better to argue that a new mode is needed to accommodate the increase in demand for passenger-km that the air mode is unlikely to be able to satisfy.

Davies (1992) identifies this new mode as high speed rail, Marchetti (1987) identifies it as Maglev. Perhaps these two modes should be integrated as service options of high speed ground transportation (HSGT) or as phases 1 and 2 of its evolution - although Marchetti discourages this thought.

HSGT is defined (by the author) as guided ground transportation that is capable of sustaining an operating speed of at least 200 km/h, with intercity trip times and passenger services such that most passengers choose the ground mode over air travel. Table 2.1 lists nine operational high speed rail systems which meet this definition, together with two Maglev vehicles that are planned for implementation in Germany and Japan, respectively, within 10 - 15 years. Metroliner service, from New York to Washington D.C., is clearly marginal in terms of operating speed, but must be considered HSGT by its proven ability to provide travel service that is competitive with air shuttles in this corridor. The technology and status of HSGT is described in chapter 3 of this report.

Figure 2.12 shows, again, two centuries of inter-city transportation worldwide, now adding HSGT services. The opening of the Shinkansen in 1964, the TGV seventeen years later in 1981, and a number of other systems over the past decade, has had a significant impact on capacity and clearly provides an opportunity to accommodate substantial passenger-km growth into the next century.

The reason for HSGT's ability to take market share from aircraft in densely populated corridors around the world is illustrated in Figure 2.13. Highway bus services and conventional rail with

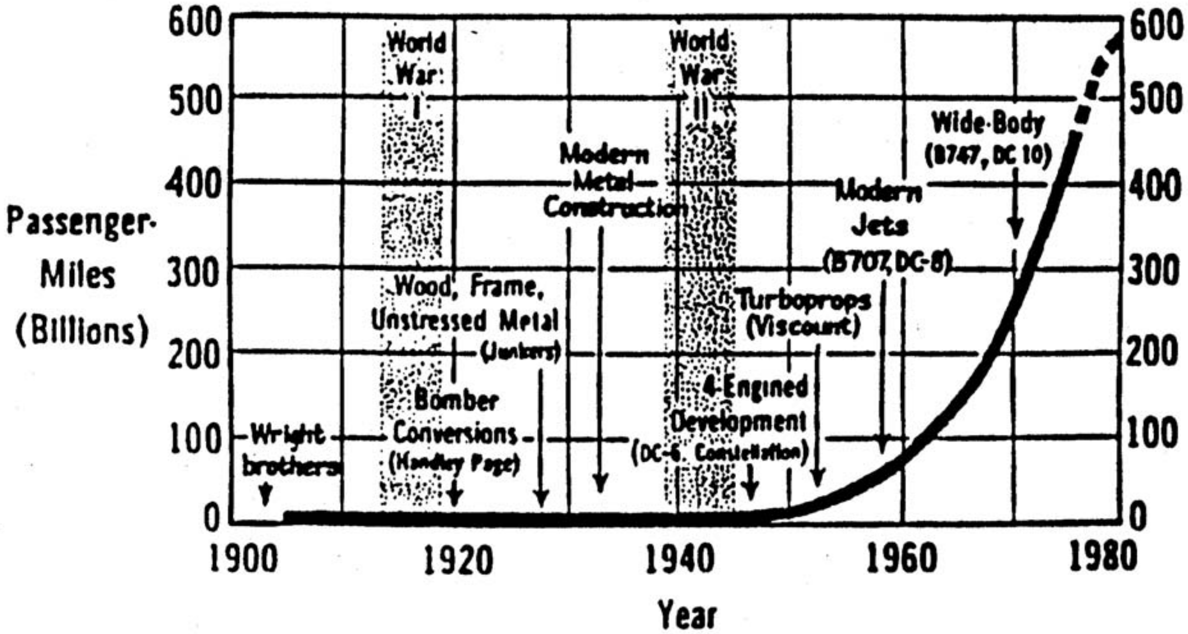


Figure 2.9	The growth in world passenger transportation by air. From Davies (1992).

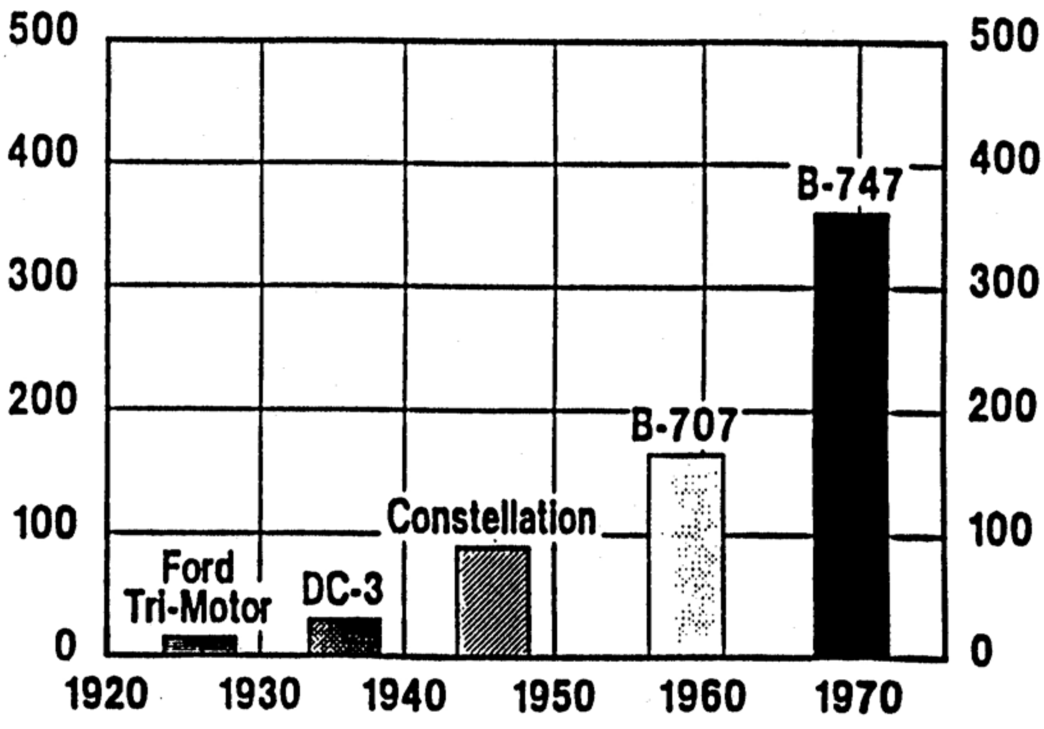


Figure 2.10	Typical seating capacity of five generations of aircraft. From Davies (1992).

TABLE 2.1 HIGH SPEED GROUND TRANSPORTATION (HSGT)

SYSTEM	Distance (km)	Average * Operational Speed (km/h)	Top Operational Speed (km/h)	Maximum Test Speed (km/h)
1. High Speed Rail (in operation)				
TGV				515
(Paris-Lyon)	427	213	270	
(Paris-Lille)	227	227	300	
(Paris-Lemans/Tours)	202/224	225	300	
(AVE, Madrid-Seville)	471	210	270	
Shinkansen, Series 300 (Tokyo-Osaka)	553	221	270	350
ETR-450 (Roma-Firenze)	316	200	250	-
ICE (Hannover-Wurzberg)	328	173	250	407
IC 225 (London-Newcastle)	432	155	225	-
X2000 (Stockholm-Goteborg)	456	152	210	275
Metroliner (New York-Washington D.C.)	360	131	210	-
2. MAGLEV (planned for implementation)				
Transrapid (Hamburg-Berlin) 2005 ?	282	280	400	480
Linear Express (Tokyo-Osaka) 2007 ?	510	400	500	517

* for the fastest scheduled train service

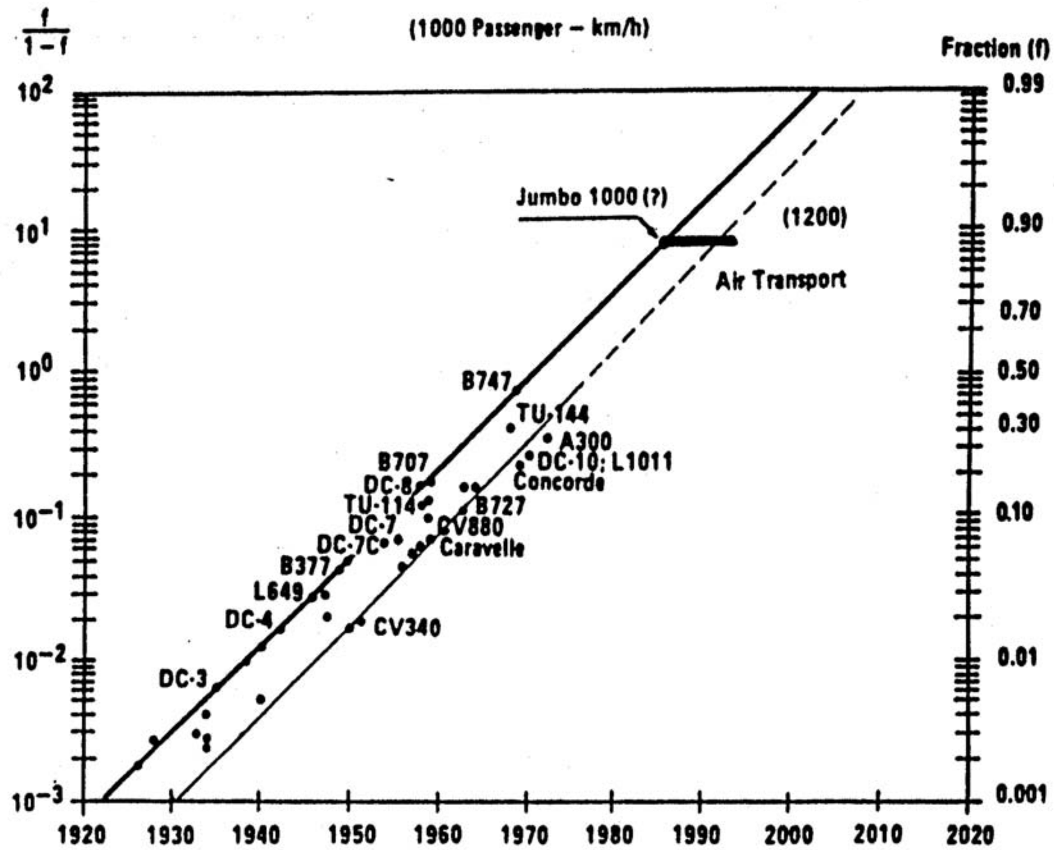


Figure 2.11 A pattern of passenger aircraft development, in terms of productivity and volume of traffic (in passenger – km/h). From Nakicenovic (1987).

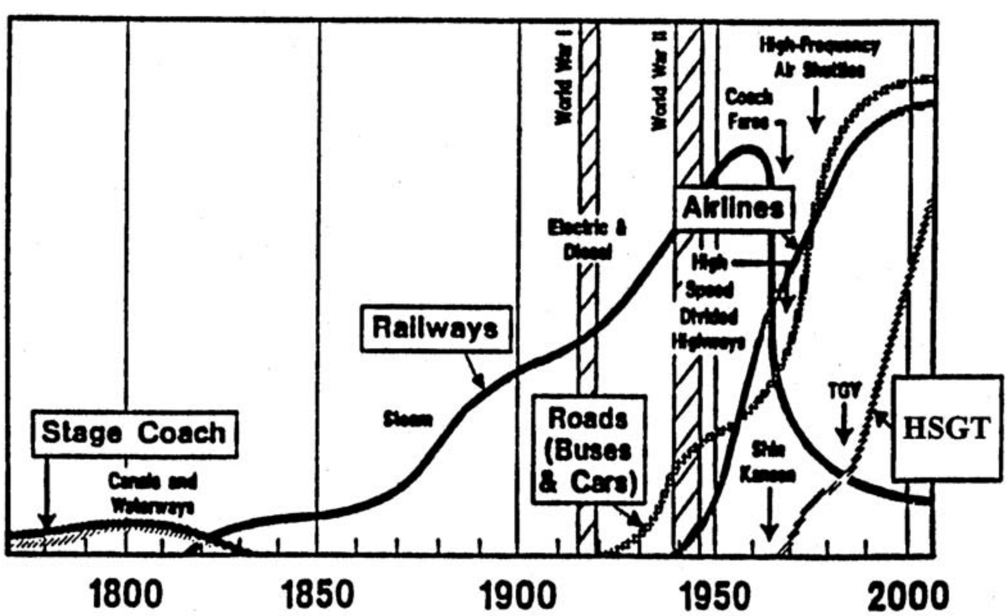


Figure 2.12 Two centuries of short-haul (inter-city) travel, presumably in terms of passenger-km worldwide. From Davies (1992)

average city centre - city centre speed up to 90 km/h are competitive in terms of trip time for distances only up to perhaps 200 km. This defines the limit to the market niche for these modes. High speed rail, with average speeds in the range 150 - 250 km/h, can compete up to 600 km and can capture intercity markets in many corridors worldwide. Maglev, with potential average speeds of 300 - 400 km/h can compete effectively with air over still longer corridor lengths.

Should high speed rail and Maglev be considered as one service mode, or should they be segregated as separate systems for inter-city transportation. Let us consider the situation in Japan. Shinkansen service between Tokyo and Osaka began in 1964, and was extended to Hakata, Morioka and Niigata over a period of 20 years. Utilization, in terms of number of passengers and passenger-km, has saturated over the past five years. Therefore, while the Shinkansen is still evolving (a new line to Nagano will be operational by 1998, and extension of the Tohoku line north of Morioka is under construction) it can be argued that the Shinkansen, in Japan, occupies the first phase of a HSGT Kondratiev cycle. The second growth phase, beginning around 2010, could be provided by Maglev - or by a second super-Shinkansen line from Tokyo to Osaka if Maglev does not mature to implementation.

The author therefore argues that HSGT, capable of sustained operating speeds of at least 200 km/h should be considered one mode - certainly distinct from "conventional" inter-city rail service which appears to be declining to insignificance in most developed countries.

2.3 DISCUSSION

The author has attempted to describe some patterns in the evolution of transportation systems. Extensive use has been made of data accumulated and presented by Marchetti (1987) and his colleagues at the International Institute for Applied Systems Analysis in Laxenburg, Austria, and by Davies (1992) at the Smithsonian Institution in Washington D.C.

It is shown that the temporal pattern of growth, saturation and decay of transportation modes is consistent with that of a wide variety of systems, progressing along an S-shaped Gompertz or logistic curve, followed by decline as a more competitive technology emerges and is implemented. It is further strongly suggested by data that the evolution of modes of transportation, again like many other systems, has a long-term periodic variation corresponding to the Kondratiev cycle.

It can be expected that, while patterns of transportation evolution are likely to be similar in many countries and regions, the time at which major changes occur will differ, i.e. there is a “phase” shift in the modal competition curves. This is evident between Europe and the U.S.

Thus, stage coaches and waterways were made obsolete by railways, which in turn declined after mass production brought cars within economic reach of the population and after a road infrastructure was built in developed countries. While still increasing in absolute passenger-km, the automobile is now steadily losing market share to aircraft. However, it seems apparent that the future growth of air travel within intercity corridors is limited by several factors, including operating speed, airport handling capability, and aircraft capacity. Thus a new mode is needed to accommodate the growth in passenger transportation into the 21st century. It is suggested that high speed ground transportation (HSGT) - high speed rail and Maglev (if it matures to implementation) - can fill this need.

Davies (1992) presents a very useful graphic representation of passenger traffic volume by distance into the next century, as shown in Figure 2.14. This illustrates the very substantial market opportunity for HSGT, namely intercity corridors up to 1200 km in length. Trans- and inter-continental travel must, of course, continue to be provided by aircraft.

The picture of transportation into the 21st century as shown in Table 2.2 therefore emerges. This pictures seems entirely reasonable and achievable with planning from the perspective of the mid 1990s. However, we must recognize that transportation has and will continue to evolve in the decades ahead, in response to many technological, social and economic factors. There seems to be a presumption in the analyses of Marchetti and colleagues that evolution is synonymous with growth. But there must be limits to many aspects of growth in this finite world. Thus, Kondratiev cycles must be attenuated over a sufficiently long period of time. Indeed, such cycles are only apparent apparent since the beginning of the industrial revolution, and the world has experienced only 3 or 4 periods over the past 200 years.

TABLE 2.2 TRANSPORTATION INTO THE 21st CENTURY

Mode	Market
Airlines	Should focus on long / medium - range services, i.e. inter- and trans-continental routes, between cities > 1000 km apart
HSGT	Should service medium-range (200 - 1200 km) high density corridors
Railways	Should continue to provide urban (incl. subways) and suburban passenger services. Should provide regional and inter-regional transportation of bulk commodities and freight
Roads	a. Within Cities Essential for buses, public services and deliveries. A luxury for personal transportation - use tolls as a revenue generator and disincentive for use to reduce congestion. b. Outside Cities Essential for bus services, trucks, commuting to regional intermodal termini, and for personal transportation for business, social, and recreational purposes
Shipping	Should continue to provide international and intercontinental transportation of bulk commodities and freight
Intermodality	Air, rail and road must become more complementary to provide a total integrated transportation system for efficient and cost-effective movement of persons, raw materials, food stocks and manufactured goods

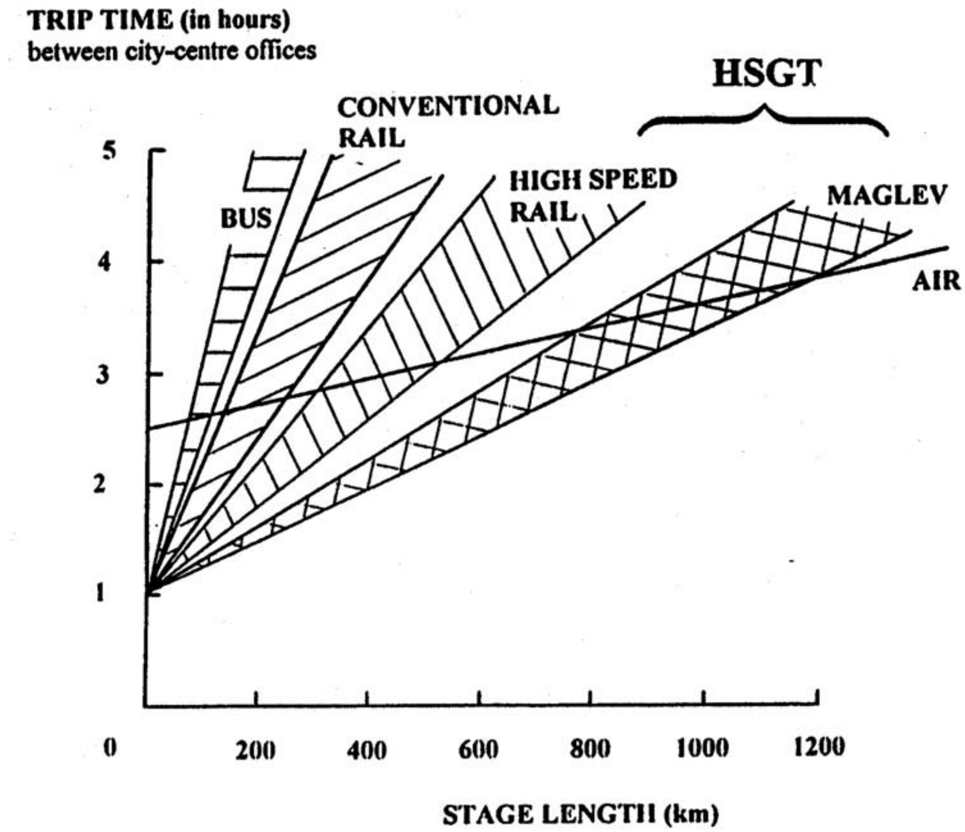


Figure 2.13 The average speed as a function of distance between city centres for various inter-city transportation modes

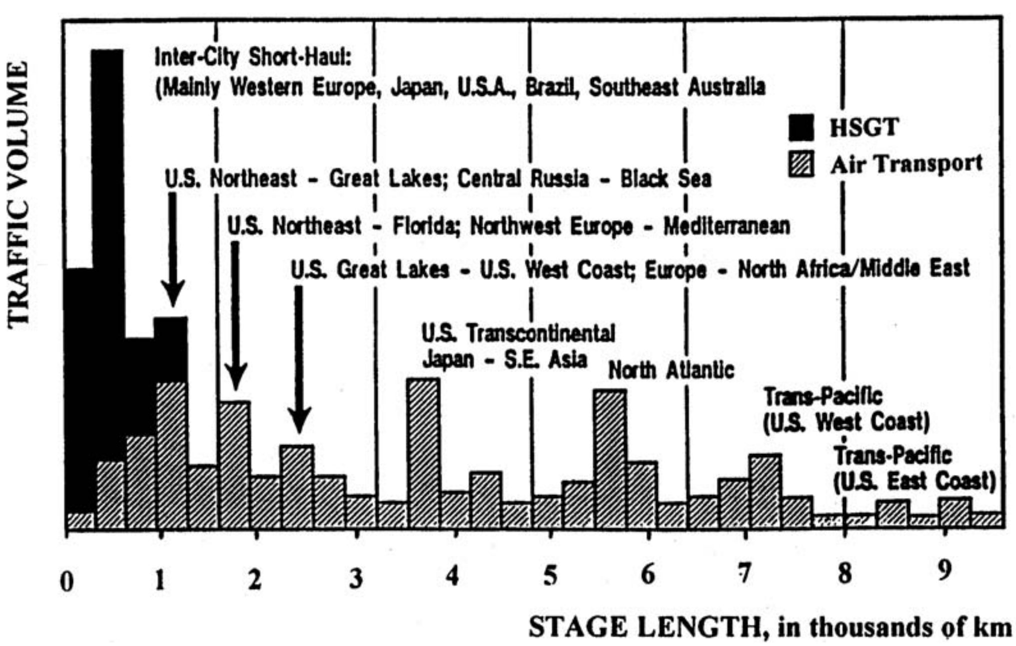


Figure 2.14 Passenger traffic volume as a function of stage length in the early years of the 21st century, showing the market opportunity for high speed ground transport (HSGT). From Davies (1992).

There is clearly a need for more research in this area, and for better longitudinal data to determine the utility of Gompertz curves and Kondratiev cycles, not just for reflecting on patterns of past evolution but for technological forecasting as a tool for policy development and to assist decision-making by government and industry to ensure that society has the mobility it needs and desires in the 21st century.

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3. HIGH SPEED GROUND TRANSPORT : OVERVIEW OF THE TECHNOLOGIES AND APPLICATIONS

SUMMARY

Considering high speed ground transportation (HSGT) as those systems capable of sustaining operating speeds over 200 km/h, the age of HSGT began in 1964 with the opening of the Shinkansen between Tokyo and Osaka. Over the past 30 years, a host of systems have been developed and introduced for speeds up to 300 km/h in Europe. Further R&D in Japan and Europe is likely to extend rail speeds to 350 km/h within five years. And Maglev systems may extend the speed range of HSGT to 500 km/h by 2010.

Unlike Europe and Japan, North America is struggling with HSGT. It can reasonably be claimed that the concepts of superconductive electrodynamic Maglev originated in the U.S. While much credible early research was conducted in Canada and the U.S., it is evident that leadership was lost to Japan by the early 1970s. By 1975, Maglev R&D in the U.S. was virtually non-existent. There was a brief renaissance in the late 1980s and early 1990s with the National Maglev Initiative. While a number of interesting ideas emerged, little was built, and Maglev in North America has now returned to its previous minimal state, with a few advocates promoting projects based on undeveloped technology. However, there is a growing realisation that an integrated multimodal national transportation system is needed in the 21st century in North America, and that high speed rail can play a role in enhancing mobility in high population density corridors.

3.1 DEVELOPMENT OF HIGH SPEED GROUND TRANSPORT

As described in chapter 2, the train has long been a vital transportation mode in North America, and indeed in all industrialized countries throughout the world. Trains were historically important for their role in linking the population centres on the east and west coasts of continental North America and for opening up vast tracts of land in the mid-west and south for development in the late 19th century.

Before World War II, trains were the dominant mode, and an extensive network of lines across the continent moved people, food stocks, primary resources and industrial products. However, with the post-war development of the U.S. interstate highway system and an extensive network of airways, railroads declined in significance and all but the mainlines have been abandoned. Most people in North America choose to travel by road for short trips and by air for longer distances. Remaining interurban and commuter rail services now account for less than 2% of passenger - km per year. Rail still moves substantial freight, but even here trucks have become the dominant carrier.

In the face of declining market share, it is difficult for North America to justify a major investment in HSGT and to claim any technological leadership in passenger trains. The situation is quite different in other countries. Steel wheel-on-rail trains are now operating at speeds up to 300 km/h, and Maglev vehicles are being developed and tested for introduction at speeds of 400 - 500 km/h, perhaps within ten years.

It is convenient to define HSGT as those guided systems which are capable of sustaining operating speeds in excess of 200 km/h (125 mph). By this definition, only one system in North America makes the cut - Metroliner service from New York to Washington, D.C. While this train covers the 360 km trip in a scheduled time of 2 hours and 45 minutes, for an average speed of 131 km/h (82 mph), cruising speeds of 210 km/h are achieved over certain track sections. Federal Railway Administration regulations limit operating speeds to 216 km/h because of safety considerations related to the shared right-of-way (with freight and lower speed passenger trains) and the signalling system.

By contrast, HSGT has been widely implemented and has carried almost 4 billion passengers without a single fatality in Japan and Europe.

In Japan, the famed Tokaido Shinkansen (bullet-train) opened between Tokyo and Osaka in 1964. Over the years, operating speeds have been raised from 210 to 270 km/h, and trip times for the 515 km trip from Tokyo to Osaka have been cut from 4 hours to 2 hours 30 minutes. Japan now has 1836 km of Shinkansen double-track in service, from Morioka in northern Honshu to Hakata in Kyushu. These lines carry over 275 million passengers per year. Active development programs are being pursued by the regional railway companies, and a STAR 21 (Super Train for the Advanced Railway of the 21st century) test train has achieved a speed of 425 km/h.

France has the fastest train service in the world - the Train a Grande Vitesse (TGV). The TGV Atlantique and Nord lines have a maximum speed of 300 km/h. Paris forms the hub of a TGV network that extends north to Lille and the Channel Tunnel, west to Tours and Lemans, and south to Lyon and Valence. TGV trains operate to the mediterranean coast of France, into Belgium (Brussels) and Switzerland (Geneva), and have been introduced into service in Spain between Madrid and Seville. TGV service is planned for implementation in Korea between Seoul and Pusan.

Germany also has a high speed train, the Inter-City Express (ICE), which is now providing 250 km/h service between Hannover and Wurzburg and from Mannheim to Stuttgart. ICE, like TGV, can also operate on shared right-of-way (ROW) mainline. However ICE, like TGV and Shinkansen, is designed for operation on dedicated ROW. Passenger safety is assured by advanced control of train movements and no high speed at-grade crossings. Sweden has adopted a somewhat different approach by building a train, the X2000, that makes best use of existing railroad infrastructure by actively tilting the passenger compartment relative to the wheeled bogies to avoid subjecting the passengers to uncomfortable lateral forces while negotiating curves at high speed. The X2000 achieves a top speed of 210 km/h (to be raised to 250 km/h by 1998) on the 456 km line from Stockholm to Gothenborg. The ETR-450 tilt-body train provides similar service between Rome and Firenze in Italy.

Thus the technology of high speed trains has advanced and is providing invaluable passenger services in both Europe and Asia. In these countries, it represents the technological evolution of ground transportation infrastructure for societies that have never relied upon the automobile for mobility and which have not needed to develop an extensive network of airways for intermediate distance travel.

And what of the situation in North America? Public interest has remained high, but progress towards implementation of high speed rail has been frustratingly slow. There is recognition that the continent's mobility is being threatened by gridlock on arterial freeways in metropolitan areas and by so-called winglock at hub airports at peak times. A renaissance for rail is being proposed. Millions of dollars have been spent in technological evaluations, system design studies, route surveys and ridership assessments for corridors such as Pittsburgh - Philadelphia, Las Vegas - Los Angeles, San Francisco - Los Angeles - San Diego, Dallas - Houston - San Antonio, Miami - Orlando - Tampa, and Toronto - Ottawa - Montreal. Progress has been slow because the economics are marginal, and because of the reluctance of federal and state/provincial governments and the private sector to commit substantial funds for implementation.

However, 1996 promises to be a banner year for high speed rail. In February, Florida announced the selection of TGV technology for the Miami - Orlando - Tampa corridor and the granting of a francise to a consortium of companies led by Bombardier and GEC Alsthom. The state is also contributing $70 million per year for 30 years for the high speed system. Then in March, AMTRAK announced the selection of a tilting version of the TGV for operation in the North-East corridor (Boston - New York - Washington D.C.) by 2000. This $754 million contract, led again by Bombardier and GEC Alsthom, will see the construction of 18 high speed train sets. The "American Flyer" will run at speeds up to 240 km/h.

In the future, we may be able to travel at speeds up to 500 km/h in Maglev vehicles. Maglev is the generic name for a family of technologies in which the vehicle is suspended, guided and propelled by means of non-contact magnetic forces. While concepts for such systems can be traced back to the early 1900s, the age of Maglev was born in the mid-1960s. Following the pioneering work of two physicists, Jim Powell and Gordon Danby, working at Brookhaven National Laboratory on Long Island, N.Y., the U.S., Japan, Germany, U.K. and Canada all began R&D programs. Those in Japan and Germany have matured to the development, testing and pre-commercial demonstration of vehicle systems that could be operational by 2005 - 2010.

It is evident that there is a spectrum of technologies which either can or will soon be able to serve intercity corridors with HSGT in the speed range of 200 - 500 km/h.

3.2 HIGH SPEED TRAIN SYSTEMS

HSGT systems can be broadly categorised into three speed ranges :

200 - 250 km/h

- Diesel electric trains
  (including British HST)

- Electrified tilt-body trains
  (including Swedish X2000, Italian Pendolino, Spanish Talgo)
- Electrified non-tilting trains
  (including U.S. Metroliner)

250 - 320 km/h
- Electrified non-tilting trains
  (including Japanese Shinkansen, French TGV, German ICE)

400 - 500 km/h
- Magnetically suspended vehicles
  attraction (electromagnetic) mode ; German Transrapid
  repulsion (electrodynamic) mode ; Japanese Linear Express

Part of the gap from 320 - 400 km/h could be filled by further advances in the technology of electrified high speed rail over the next decade. Next generation systems may be able to operate at speeds up to 350 km/h.

Some of the characteristics of high speed systems are listed in Tables 3.1 - 3.3, and photographs of a number of trainsets and Maglev vehicles are presented as Figures 3.1 - 3.6.

Table 3.1 presents features of two operational tilt-body trains. Tilting systems make it possible to increase train speeds without modifying existing curved trackage while not exposing passengers to uncomfortable lateral accelerations. The train body control system acquires information from accelerometers at the front of the train and computes the required angle of inclination. This angle signal is used to control hydraulic actuators which tilt each car body on the train relative to its bogies by the appropriate angle related to train speed and local track curvature. An alternative approach, implemented in Japan, is to store track geometry information on-board and then to tilt the passenger cars by an angle appropriate to speed and local curvature without accelerometer feedback.

The ETR-450 was designed and built by Fiat Ferroviaria and is operated by Italian State Railways. This train entered revenue service in early 1988 between Firenze and Rome at a maximum speed of 250 km/h. The second generation ETR-460 was introduced in 1994.

The X2000 train (Figure 3.1) was designed and built by Asea Brown Boveri (ABB) and is operated by Swedish State Railways. The train entered revenue service on the Stockholm-Gothenborg line in September 1990 and operations have now been expanded to a network of mainlines. X2000 operates at a maximum of 210 km/h in Sweden but has been tested to 276 km/h in Germany. An X2000 trainset has also been tested and demonstrated in the U.S. North East corridor, and was operated very successfully in revenue service between New York and Washington, D.C. at speeds up to 225 km/h during spring 1993. Similar service demonstrations have been conducted with ICE and Talgo equipment.

Table 3.2 presents features of the highest speed rail systems in the world; TGV in France and Spain (Figure 3.2), ICE in Germany (Figure 3.3), and Shinkansen in Japan (Figure 3.4). All of these trains are non-tilting with ac drives and operate on dedicated rights-of-way of limited curvature (typically a

TABLE 3.1 FEATURES OF 250 km/h TILT-BODY TRAINS

CHARACTERISTIC	ABB X-2000	FIAT ETR-460
In commercial service	1990	1994
Top speed	276 kph	300 kph
Service speed	210 kph	250 kph
Vehicle type	locomotive-hauled with driving trailer	EMU
Consist	1-4-DT (in service)	M-T-M-M-T-M-M-T-M (9 cars)
Seating capacity	200 (all 1st class); 254 mixed	456 + 2 disabled
Propulsion	ac 3-phase asynchronous; 815 kW; 4 powered axles	dc; 500 kW, body-mounted; 12 powered axles/train
Braking	Blended regenerative, discs, magnetic rail brake	Blended rheostatic and discs
Power supply	OCS 15 kV, 16 2/3 Hz single phase	OCS 3 kV dc
Axle load	18.25 tonnes (max.)	12.5 tonnes
Unsprung mass	1.8 tonnes/axle	1.6 tonnes/axle
Maximum tilt	8^o	8^o
Other features	Steerable powered trucks	Partially active lateral suspension

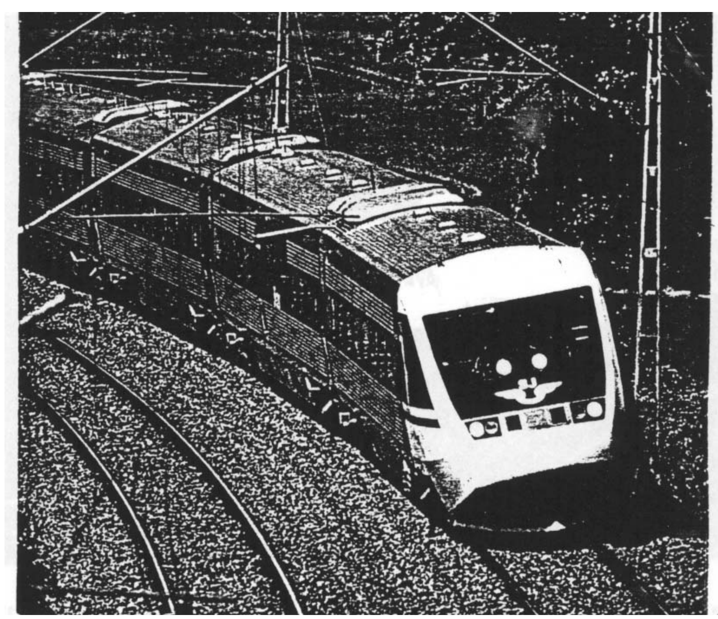

Figure 3.1 The X2000 tilt-body train rounding a curve on the Stockholm-Gothenborg line in Sweden

TABLE 3.2 FEATURES OF HIGH SPEED TRAINS WITH 300 km/h CAPABILITY

CHARACTERISTIC	TGV-Atlantique	ICE-1	SERIES 300 (Nozomi)
In commercial service	1989	1991	1992
Top speed	515.3 kph (1-3-1)	406.9 kph	325.7 kph
Service speed	300 kph	250 kph; 280 kph on some track segments	270 kph
Vehicle type	Articulated trainset	Loco-hauled	EMU
Consist	1-10-1	1-13-1 or 1-14-1	16:5(M-T-M) and cab car
Seating capacity	369 coach; 116 first	681 (1-14-1)	1,323
Propulsion	ac synchronous, 1100 kW, 8 axles powered	ac asynchronous, 1200 kW, 8 axles powered	ac asynchronous, 300 kW, 40 axles powered
Braking	Blended rheostatic, disc and tread brakes	Blended regenerative and discs	Blended regenerative, disc and eddy-current
Power supply	OCS 2 x 25 kV, 50Hz	OCS 15 kV, 16 2/3Hz	OCS 2 x 25 kV 60Hz
Axle load	17 tonnes	20 tonnes	11.3 tonnes
Unsprung mass/axle	2.2 tonnes	1.87 tonnes	1.86 tonnes

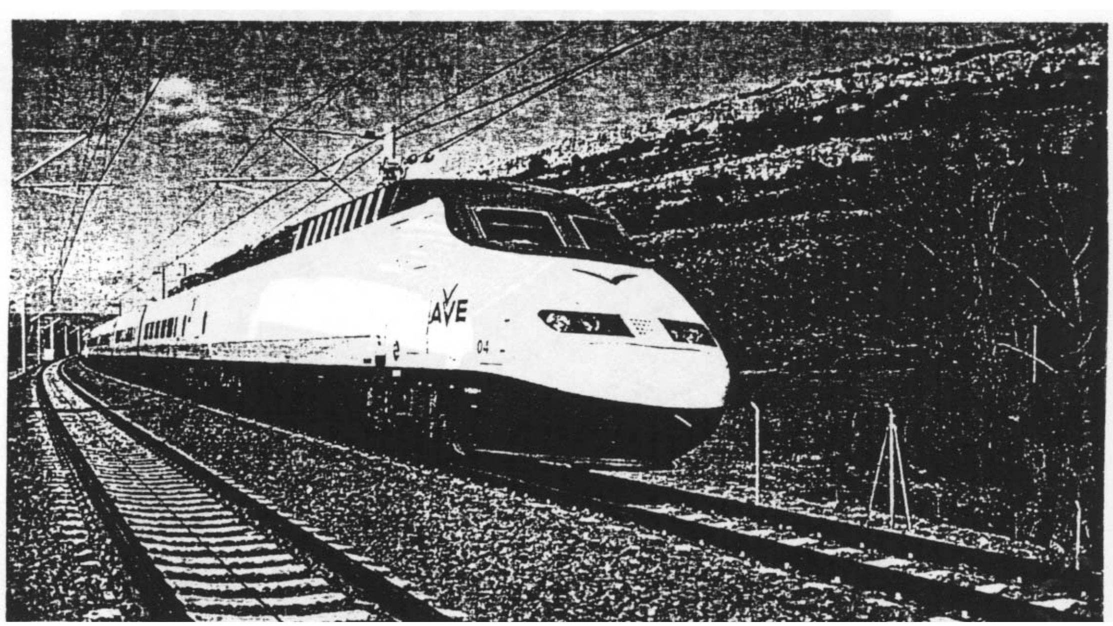

Figure 3.2 An AVE - TGV train on the Madrid - Cordoba - Seville line in Spain

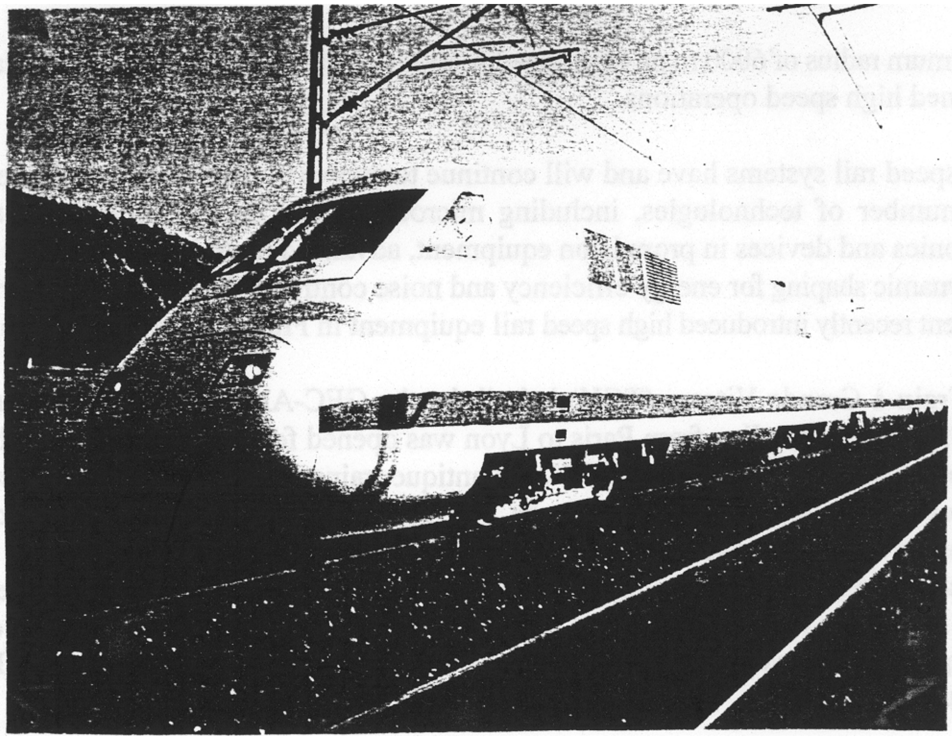

Figure 3.3 An ICE train on the Hannover - Wurzburg line in Germany

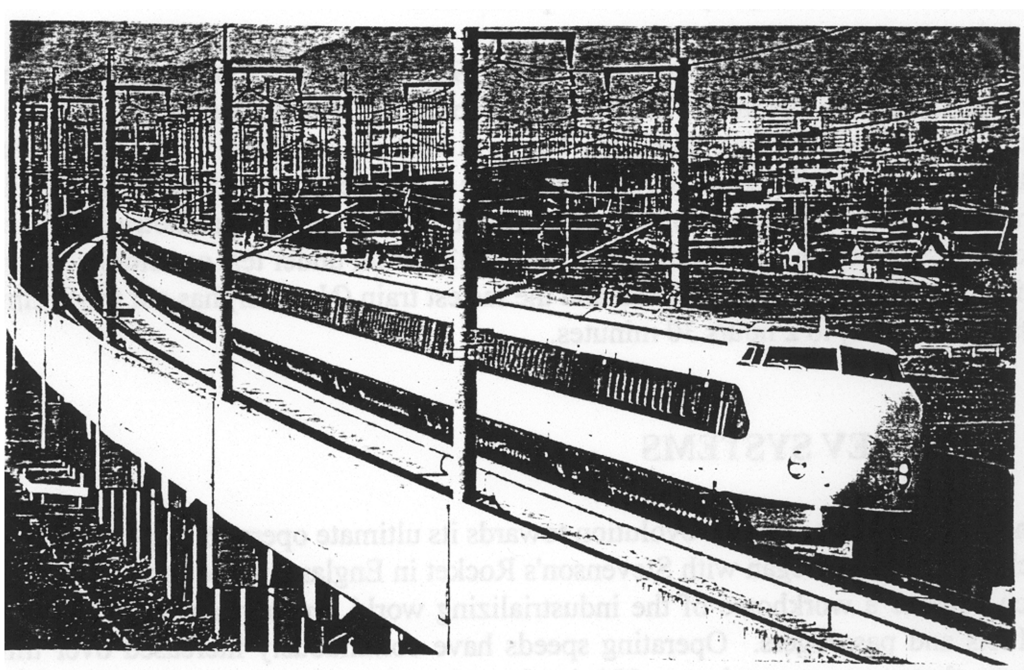

Figure 3.4 A Shinkansen train near Fukushima station on the JR Tohoku line

minimum radius of 6000 m on high speed sections), with infrastructure that is maintained to allow sustained high speed operations.

High speed rail systems have and will continue to evolve to take advantage of beneficial advances in a number of technologies, including microelectronics in controllers and signalling, power electronics and devices in propulsion equipment, advanced materials in car body construction, and aerodynamic shaping for energy efficiency and noise control. The train systems shown in Table 3.2 represent recently introduced high speed rail equipment in France, Germany and Japan, respectively.

The Train à Grande Vitesse (TGV) is built by the GEC-Alsthom consortium and is operated by SNCF. The Sud-Est line from Paris to Lyon was opened for revenue service in 1981 and operates at a top speed of 270 km/h. The TGV-Atlantique trains operate on the more recently built line to the west of Paris to Tours and Lemans. At 300 km/h, TGV-A equipment provides the fastest revenue service in the world, commencing operations in September 1989. Prior to being opened for revenue service, a specially equipped and shortened TGV-A trainset (1-3-1) was tested at speeds up to 515.3 km/h; a world speed record for any rail vehicle. The Paris-Lille section of the TGV-Nord was opened for revenue service, also at 300 km/h, in 1993 and extension to Brussels is under construction.

The Intercity Express (ICE) was designed and built by a Siemens-led consortium and is operated by German Federal Railways. ICE entered revenue service in June 1991 on a new line from Hannover to Würzburg. The ICE fleet is presently limited to 250 km/h by alignment geometry and superelevation compromises required to allow shared use of track with other equipment. Operating speed can be raised to 280 km/h over certain sections of track to recapture lost time. Second generation ICE trainsets (2/2) are now in production.

The first Shinkansen service was opened in 1964 between Tokyo and Osaka - in time for the Olympic Games of that year. The line was subsequently extended to Okayama, Hiroshima and Fukuoka by 1975. Additional lines from Tokyo to Morioka and from Tokyo to Niigata were opened in stages from 1982 to 1991. Shinkansen trains are currently restricted to 270 km/h by noise and vibration concerns (by local communities) and by the alignment geometry of the track. The new Series 300 Shinkansen equipment has achieved 325 km/h under test conditions. It entered revenue service with JR Central in mid-1992 and the fastest train (Nozomi) has cut travel time from Tokyo to Osaka (515 km) to 2 hours 30 minutes.

3.3 MAGLEV SYSTEMS

High speed rail represents the evolution towards its ultimate operational performance capability of a technology which began with Stevenson's Rocket in England in the early nineteenth century and which became a workhorse of the industrializing world for the transportation of raw materials, products and passengers. Operating speeds have continuously increased over time and it now appears that revenue service at 320 km/h and perhaps 350 km/h is technically feasible and achievable.

Maglev has been developed in the belief that very high speeds, in the 400-500 km/h range, are desirable to achieve trip times that are competitive with short-haul air travel, to relieve winglock at major airports and gridlock on freeways in metropolitan areas, and to meet the mobility needs of tomorrow's post-industrial society in an environmentally sustainable manner.

Maglev is a revolutionary form of transportation which has been researched, developed, tested and brought to the stage of pre-commercial demonstration over a period of 30 years. It uses magnetic forces for the non-contact suspension, guidance and propulsion of vehicles at speeds up to 500 km/h. Table 3.3 presents the features of the two superspeed Maglev systems; the German Transrapid (Figure 3.5) and the Japanese Linear Express (Figure 3.6). Note that both HSGT systems are at least 10 years away from revenue service. Most of the features in Table 3.3 therefore refer to planned operational vehicles.

The Linear Express, as being developed and tested (in 1997) at full scale by Japanese Railways, is magnetically levitated by electrodynamic suspension (EDS) by means of the repulsive force generated between superconductive magnets carried by the vehicle moving adjacent to and inducing current in discrete short-circuited aluminum coils mounted along the guideway. The EDS system is characterized by a guideway clearance of 100-150 mm at high speed. However, the levitation force is speed dependent and the vehicle requires wheels at low speed. An EDS Maglev vehicle must achieve a forward speed of 60 - 120 km/h (dependent on design) to generate magnetic levitation, above which its wheels may be retracted. EDS is dynamically stable but underdamped. Passive damping in the primary suspension and a secondary suspension are required to achieve good ride quality.

TRANSRAPID, as being developed and tested by Magnetschnellbahn GmbH, is magnetically suspended by electromagnetic suspension (EMS) by means of the attractive force between vehicle-borne iron-cored electromagnets and ferromagnetic guideway components. This mode of suspension is inherently unstable and must be dynamically stabilized by active feedback control of the magnet excitation in response to changes in the gap. The suspension gap is 10-15 mm, i.e. an order of magnitude less than that for EDS, but is nearly speed independent. An EMS vehicle therefore does not need wheels. EMS technology has also been developed by HSST Corporation in Japan for intermediate and low speed applications, and has been implemented as a low speed shuttle for the Birmingham Airport People Mover in England (see chapter 4).

Both EDS and EMS vehicles have magnetic guidance, whereby a lateral displacement generates a strong restoring force towards the centre of the guideway. The Linear Express uses "null-flux" guidance produced by cross-coupled coils mounted on each side of the guideway. Transrapid uses a separate set of controlled electromagnets carried by the vehicle and interacting with ferromagnetic rails on the sides of the guideway structure.

Maglev vehicles require a non-contact means of propulsion and braking which is compatible with the operating clearance of the magnetic suspension. The EDS Linear Express uses an air-cored linear synchronous motor (LSM). Three-phase excitation of armature coils produces a magnetic wave into which an array of on-board superconductive magnets is locked. This same magnet array is used for levitation and guidance. The speed of the magnetic wave is determined by armature input frequency, providing precise speed control of the vehicle with high power factor-efficiency operation. As the vehicle moves along the guideway, successive coil groups are powered up and the vacated sections

TABLE 3.3 FEATURES OF SUPERSPEED MAGLEV SYSTEMS

CHARACTERISTICS	EMS System Transrapid TR-07	EDS System JR Linear Express
Country of origin	Germany	Japan
Status	Pre-deployment testing	Development testing
Geometry	Up to 10% gradient, 5800 m radius curve	Up to 4% gradient, 8000 m radius curve
Guideway	2.8 m wide, simply-supported guideway, steel or concrete	2.8 m U-shaped concrete guideway, simply supported
Power supply	20 kV, 3-phase VVVF to windings in guideway	VVVF inverters feeding windings in guideway
Control and communications	Unique ATC/ATO with moving block; VHF vehicle-wayside communications	Under development, but similar in principle to that used by Transrapid
Key guideway features	Guideway carries windings for iron-core LSM, guidance rails, waveguide. Required alignment tolerances +/-0.6 mm for stator packs	Guideway alignment tolerances are less critical than for EMS system due to larger air gap [100-150 mm vs. 8-10 mm]; air-core LSM
Vehicle type	Articulated EMU	Articulated EMU
Dimensions (l x w x h)	25.5 m x 3.7 m x 3.95 m	21.6 m x 2.8 m x 2.85 m
Consist size standard	2, 4, or 6	14
Capacity standard	200, 400, 600	988
Propulsion	Iron-core LSM	Air-core LSM
Braking	LSM thrust reversal; eddy-current emergency brakes	LSM thrust reversal; aerodynamic emergency brakes; aircraft discs on undercarriage wheels
Guidance	Non-contact magnetic attraction	Non-contact magnetic repulsion
Body structure	Aluminum alloy	Aluminum alloy
Suspension	Magnetic primary; pneumatic secondary	Magnetic primary; spring secondary
Axle load	1.6 tonnes/m	1.0 tonnes/m
Design speed	400-450 km/h	500 km/h
Hotel power collection	Non-contact linear generator	Non-contact linear generator
Noise level	84-86 dB(A)	N.A.
Key operational features	Propulsion, braking are not adhesion-limited	Larger air gap; inherently stable suspension; faster

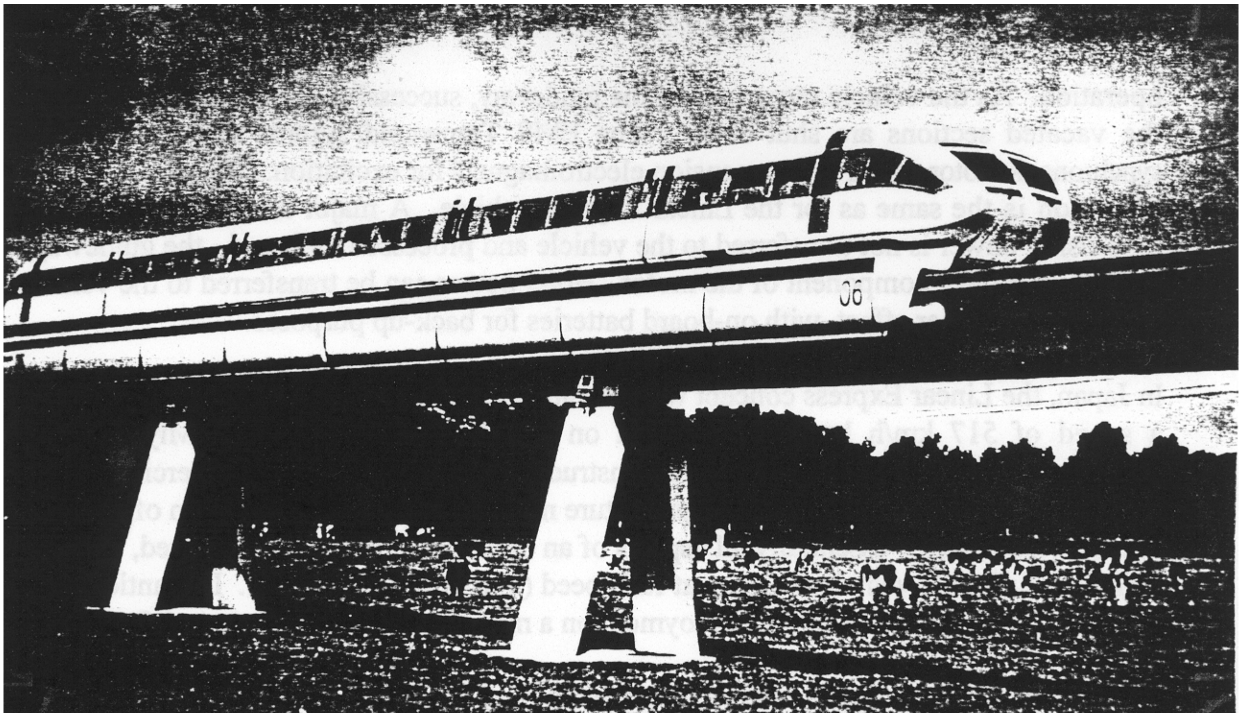

Figure 3.5 A TRANSRAPID 06 vehicle on the Emsland test track in northwest Germany

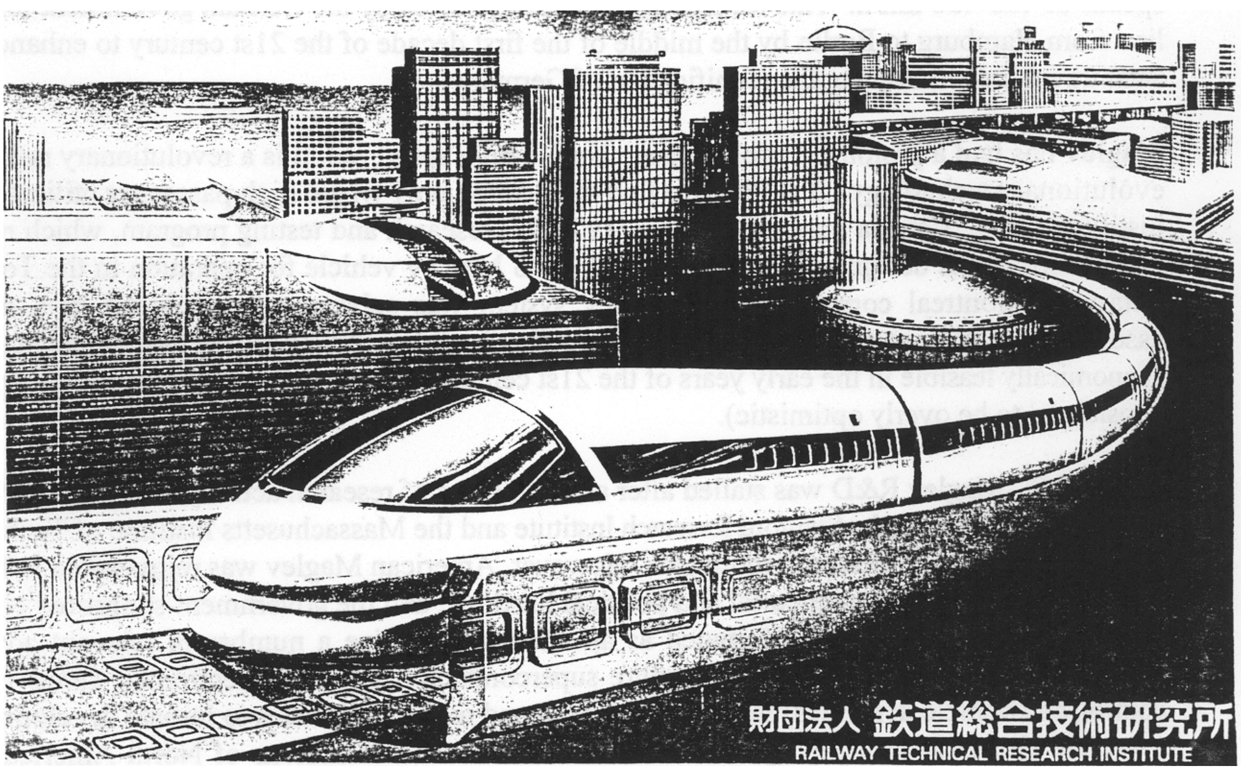

Figure 3.6 An artist's rendition of a Linear Express Maglev vehicle in Japan

are shut down. The EMS Transrapid system uses an iron-cored linear synchronous motor, using the suspension electromagnets for excitation. The principle and mode of operation is the same as for the Linear Express vehicle. A major advantage of the LSM is that propulsion power is not transferred to the vehicle and processed on board - the guideway armature is the high power component of the motor. Hotel power can be transferred to the vehicle by non-contact transformer effect, with on-board batteries for back-up purposes.

In Japan, the Linear Express concept was developed through a series of test vehicles until by 1979 a speed of 517 km/h had been reached on the 7 km test track near Miyazaki in Kyushu. Development has continued towards the construction of a 41.8 km pre-commercial vehicle test and demonstration facility in Yamanashi prefecture near Tokyo. The first 18.4 km of this double track guideway will allow essentially all aspects of an operational system to be tested, starting in 1997, including full scale vehicles passing at full speed (500 km/h) in a tunnel. It is anticipated that 500 km/h Maglev could be ready for deployment on a new line between Tokyo and Osaka by 2007.

In Germany, the attraction mode electromagnetic "TRANSRAPID" Maglev system has been under development for high speed ground transportation since the late 1960s. Evolutionary development through a series of test vehicles led to the construction of the Emsland facility in the early 1980s. This 31.5 km figure-of-eight shaped guideway allows full scale vehicles to be tested and demonstrated under close to operational conditions. The pre-production vehicle TR-07 has been under evaluation for almost five years, and has now shown itself to be ready for implementation at speeds of 400-450 km/h. This technology has been selected by the German government for a new line from Hamburg to Berlin by the middle of the first decade of the 21st century to enhance east-west travel links following the reunification of Germany.

Maglev has had a prolonged adolescence. Unlike high speed rail, it is a revolutionary rather than evolutionary technology. It is likely to find application only where high passenger utilization can justify the cost. Canada pursued a 5-year (1972-77) research and testing program, which resulted in the conceptual design of a 450 - 500 km/h EDS Maglev vehicle for operation in the Toronto - Ottawa - Montreal corridor. This Maglev system was subsequently included in a detailed assessment of transportation modes in the Canadian corridor. It was shown that Maglev could be economically feasible in the early years of the 21st century with certain ridership assumptions (now considered to be overly optimistic).

In the U.S., Maglev R&D was stalled after a brief period of research activity in the early 1970s at Ford Motor Company, the Stanford Research Institute and the Massachusetts Institute of Technology in parallel with that in Germany and Japan. However, American Maglev was rejuvenated in the late 1980s as a result of entrepreneurial and political hustling , and the government-sponsored National Maglev Initiative (NMI) was initiated as an attempt to utilize a number of relevant advanced technologies (cryogenics, high temperature superconductivity, power electronics, aerodynamics, control, and vehicle dynamics) from the aerospace and related industries to initiate development of a second generation Maglev system to meet the needs and conditions of North America. This generated a lot of interest and activity, a number of interesting ideas, but little follow-through. Again, Maglev R & D activity declined to a low level in North America as a consequence of the completion of the NMI program, the limited federal commitment to on-going R & D, and a reluctance by the private sector to commit to long term Maglev development. By 1994, Maglev R&D in North America had returned to its previous minimal state, with a few entrepreneurs promoting undeveloped technology for various projects.

20-25 years ago, R & D in Maglev was justified by the perceived need for ground transportation at 450-500 km/h to provide intercity trip times in high population density corridors up to 800 km in length that are competitive with air travel, amid concerns about the cost and availability of oil-based fuels. At that time, the practical speed limit for steel wheel on rail was thought (by many) to be about 250 km/h. However, as we have seen, high speed rail has continued to be developed, as researchers have gained a better understanding of wheel-rail dynamics, aerodynamics, and power pick-up by pantograph from a single-phase catenary, and operating speeds have reached 300 km/h. Even more impressively, a high speed train (a shortened specially-equipped TGV consist) has been tested at speeds up to 515.3 km/h. While it is not claimed to be feasible to run a passenger train at this speed, 350 km/h is considered to be technically and operationally possible. The margin of speed advantage for Maglev is therefore being cut, and it remains to be seen whether any government is prepared to proceed with investment for the implementation of a radically new ground transportation technology for a rather limited number of very high speed lines when proven advanced high speed rail can offer trip times that exceed potential Maglev capability by only 20 - 60 minutes for a typical intercity trip (depending on Maglev speed) at significantly lower capital and operating cost.

3.4 COUNTRY DEVELOPMENTS

The operational status and development plans for HSGT in a number of countries around the world are briefly reviewed in the following sections.

3.4.1 Europe

The countries of the European Union (EU) are planning to network their high speed rail lines in an incremental manner over the next 25-30 years. The near-term goal builds on the existing high speed routes to form some regional networks. Routes that are operational in 1995 are:

Hannover - Wurzburg (328 km)
Madrid - Cordoba - Seville (472 km)
Mannheim - Stuttgart (130 km)
Paris - Lyon (427 km)
Paris - Lemans/Tours (202 / 224 km)
Paris - Lille (227 km)
Rome - Firenza (318 km)
Stockholm - Gothenborg (456 km)

The mid-term plan supplements the existing routes to form a mid-European network with the perimeter of London-Glasgow-Hamburg-Munich-Marseilles-Lisbon-Bordeaux, but is still poorly connected to Italy and Scandinavia.

The long-range vision would form a truly continental network, with harmonized standards (e.g. for signalling and electrification) and inter-operability of equipment. Such a network requires 9,000 km of high speed lines and 10,000 km of upgraded lines. With the addition of 11,000 km of link and feeder lines, this configuration has 30,000 km of rail line throughout Europe, representing an investment of over 100 billion ECU. To quote from a publication of the Community of European Railways (1989), "a high speed rail network which is energy-efficient, environmentally-friendly, economical and technically advanced, will reshape the transport scene. It can help to resolve the worsening congestion problems in air and road travel. It will bring fast, reasonably-priced and comfortable travel to the people of Europe. It will also provide a unique opportunity for regional, social and economic development within the EU. It represents a powerful catalyst for European integration".

France

Following the opening of the Paris Sud-Est and Atlantique TGV lines in 1981 and 1989, respectively, the TGV Nord is being extended from Paris to Brussels. The Paris-Lille section is now operational, and speeds up to 320 km/h are planned for revenue service within two years. The TGV Rhone Alpes extended TGV service from Lyon to Valence in 1994. Intermodality has been enhanced by the opening of a TGV station at Ch. de Gaulle Airport, as part of the “Jonction” high speed loop around Paris. Meanwhile, following completion of the Channel Tunnel, Eurostar service was introduced in 1994 to provide a direct rail link between Paris and London. Near-term plans include the extension of the Sud-Est and Atlantique lines to Marseille and Montpelier and to Rennes and Angers, respectively, and the construction of the TGV Est to Strasbourg. Longer term plans include the development of the 350 km/h TGV NG (Nouvelle Generation), and the construction of a high speed network of approximately 7,000 km of line with 220 km/h capability, with Paris as the primary node. TGV links to Italy, Spain and Switzerland are being studied.

Germany

ICE service is now operating on new lines from Hannover-Würzburg and from Mannheim-Stuttgart and on a network of older trunk lines in Germany. The first power unit for the second generation ICE-2 trains was completed in 1995. Near term-plans include a Cologne-Frankfurt link. The German Infrastructure Plan makes provisions for a 4,500 km network of high speed line, with 800 km of new infrastructure (including the ICE lines already constructed).

The Transrapid Maglev system has been undergoing development and testing on the 31.5 km Emsland loop near Bremen for the last 10 years. The current 07 vehicle is a pre-deployment prototype. Planning is underway to implement Transrapid between Hamburg and Berlin by 2005.

Italy

Rome-Firenze Directissima service became operational in 1990, using ETR-450 equipment. Plans include the completion of a T-shaped "alta velocita" network, formed by a north-south route from Milan-Rome-Naples, and by an east-west route from Torino-Milan-Venice. New tilt-body Pendolino (ETR 460) and non-tilting ETR 500 trainsets with 300 km/h capability are being introduced to revenue service. A joint France - Italy project will establish a high speed rail link between Lyon and Turin through a 54 km Trans-Alpine tunnel, perhaps by 2002.

Netherlands and Belgium
TGV service from Brussels to Paris and from Amsterdam to Paris will open in 1996. High speed lines in the Netherlands and Belgium should be ready for operation with “Thalys” equipment (a TGV derivative) from 1997. Dutch Railways have purchased six ICE 2-2 trainsets for the Amsterdam - Cologne/Frankfurt and Berlin routes from 1999.

Spain
Spain has decided to adopt standard gauge for all new high speed lines to facilitate integration with a European network. TGV technology was selected for the new AVE Madrid-Cordoba-Seville high speed train, which entered revenue service in 1992. Maximum speed will be raised to 300 km/h in 1996. Near-term plans include the completion of a line from Madrid-Barcelona with future extension to the French border. Longer term plans include 1,750 km of new or upgraded line, much of which will be served by Talgo Pendular equipment with 200 km/h capability.

Sweden
The X2000 tilt-body train entered revenue service on the upgraded Stockholm-Gothenborg route in 1991. The scheduled time for the 456 km trip is now 2 hours and 55 minutes. X2000 service has now been extended north to Sundsvall and south to Malmo. Near term plans include a Malmo - Gothenborg - Oslo - Karlstad link to form a network of high speed operations in southern Sweden.

X2000 technology has been tested and demonstrated both in Germany (to 275 km/h) and in the U.S. North East corridor, and is being promoted for implementation as a cost effective solution for HSGT in many intercity corridors worldwide. Demonstration runs have also been completed in Australia.

U.K.
British Rail is upgrading and completing the electrification of three main trunk routes; London-Birmingham-Manchester-Glasgow, London-Newcastle-Edinburgh, and London-Bristol-Cardiff. New IC 225 trainsets hauled by Electra powercars with 225 km/h capability are being introduced. The U.K. government has announced plans for a high speed rail link from London to the Channel Tunnel, reducing Eurostar trip times by up to 40 minutes by 2002.

3.4.2 Asia

Japan
The Japanese bullet train represents the quintessential high speed train. Designed and built in the 1950s by means of a World Bank loan to re-establish the infrastructure of Japan and opened for revenue service between Tokyo and Osaka in 1964, the Shinkansen has carried over 1 million passengers in one day (in 1975) and almost 3 billion passengers over 30 years without a single passenger fatality (perhaps fortuitously in consideration of the infrastructure damage caused by the Hanshin earthquake of January 1995, which occurred early in the morning before the scheduled start of Shinkansen operation). The current Shinkansen service comprises the following lines:

Tokyo - Osaka (1964) - Okayama (1972) - Hakata (1975) ; 1070 km
Tokyo - Sendai - Morioka (1982) ; 496 km
Tokyo - Niigata (1982) ; 301 km

The Shinkansen continues to evolve. New Series 300 rolling stock has been introduced. A new line is being built to Nagano in time for the 1998 Winter Olympics. R & D projects include the development of 350 km/h Shinkansen equipment, and various advanced trains are being tested (including STAR 21, WIN 350 and 300X). Future plans include an extension of the Tohoku line to Hachinohe and, perhaps, to Sapporo, a new line from Tokyo-Toyama-Osaka (for which the Nagano Shinkansen is the first link), and an expansion of the Sanyo line from Hakata to Nagasaki and to Kagoshima in Kyushu.

The Japanese Maglev program continues apace. The first 18.4 km of a new 42.8 km test line is under construction in Yamanashi prefecture, west of Tokyo, at a cost of 300 billion yen (approx. U.S. $3 billion) for a 5-year development program. The double guideway line will be 70% in tunnel and will allow test vehicles to pass at high speeds. While no committment has yet been made for Maglev implementation, detailed plans have been prepared for a new 500 km/h Chuo line from Tokyo-Nagoya-Osaka for revenue service in 2007. This would relieve congestion on the (then) 40-year-old Tokaido Shinkansen line and would cut minimum travel time from 2.5 hours by Shinkansen to about 75 minutes by Maglev. Advanced Shinkansen is also an option for this new line.

Pacific Rim

The industrializing countries of the Pacific rim represent a huge market for new transportation infrastructure. In the near-term, both Korea and Taiwan are planning high speed rail lines.

The Korean government is constructing a new line with 250 km/h operating speed from Seoul-Pusan, a distance of 400 km, for completion in 1998. TGV technology has been selected for implementation, and civil works are well underway. In Taiwan, planning studies have been completed for a 345 km, 250-300 km/h link between Taipei and Kaohsiung perhaps by 2000.

The economic development of China is presently inhibited by inadequate transportation services. The Beijing - Shanghai corridor is being examined for implementation of HSGT.

3.5 LOOKING AHEAD

Why the difference between North America and the rest of the world? Travellers to Europe and Japan are delighted with the fast, frequent, clean, comfortable intercity services provided by high speed rail. They return wondering -- why not in our country?

Figure 3.7 shows the relative modal usage for domestic intercity travel in North America, Europe and Japan. Automobile travel is clearly the dominant mode in all developed countries. An almost negligible number of passengers travel by rail in North America (except in the U.S. North East corridor). This is perhaps both a consequence and a cause. The travelling public does not use rail because it finds the service non-existent or inadequate, and much prefers the privacy and convenience offered by the automobile or the speed of air travel. Hard-nosed financiers are extremely reluctant to consider investment in new rail infrastructure, even in partnership with province/state and federal governments because of uncertainties in ridership and therefore in revenue and a perceived marginal return-on-investment.

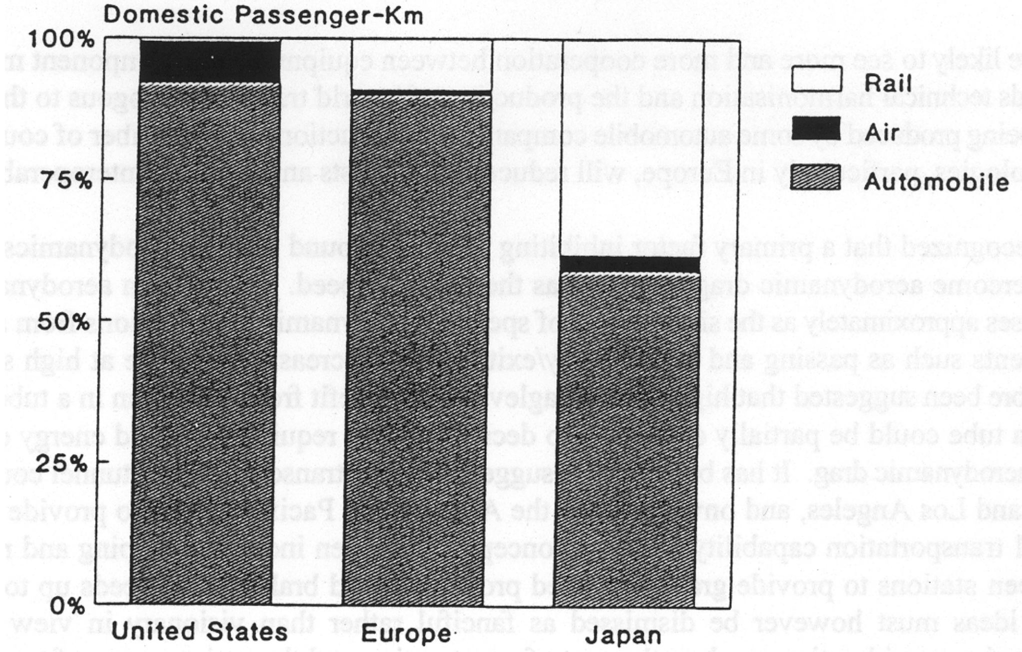

Figure 3.7 Modal distribution of domestic passenger travel in the United States, Europe and Japan

North America has invested massively in road and air infrastructure over the 40-50 years following World War II. These modes have served the continent well, providing the facilities for inexpensive, convenient mobility of people, food products and industrial goods. However, mobility is being threatened by congestion (gridlock) on highways in major metropolitan areas and by delays and the limited available take-off and landing slots at hub airports (winglock). And the situation can only deteriorate into the 21st century as the economy continues to grow, albeit slowly.

Historically, rail transportation was used as a tool for regional economic development. It was the railroad that led to the development of the Florida coast and opened up the continental mid-west. Today, the economic growth of the continent is being threatened by inadequate transportation. And yet, high speed rail is continually put to the test of economic viability (benefit/cost ratio and adequate return-on-investment, etc.). Governments have insisted that high speed rail must pay for itself, while ignoring the fact that the road and air modes have had and continue to receive massive subsidies through government allocations and taxation revenues. HSGT should not be regarded solely as a competitive mode, but as a partner to maintain mobility. There are signs now that the message is getting through - HSGT can be an effective component of a multi-modal national transportation system for the 21st century.

So, where is HSGT going in the next 20-30 years?

On the technology side, there is likely to be a convergence towards high speed train design with distributed motive power, integrated power electronics, and increased use of lightweight advanced materials for carbody structure to reduce dynamic loading of the track. Aerodynamic styling will continue to improve to slow the growth in motive power requirements as operating speeds increase. We are likely to see more and more cooperation between equipment and component manufacturers towards technical harmonisation and the production of "world trains" - analogous to the global cars now being produced by some automobile companies. A reduction in the number of country-specific technologies, particularly in Europe, will reduce capital costs and enhance interoperability.

It is recognized that a primary factor inhibiting speed at ground level is aerodynamics. The power to overcome aerodynamic drag increases as the cube of speed. Noise from aerodynamic sources increases approximately as the sixth power of speed. And dynamic perturbations from aerodynamic transients such as passing and tunnel entry/exit become increasingly severe at high speed. It has therefore been suggested that high speed Maglev might benefit from being run in a tube. And if so, such a tube could be partially evacuated to decrease thrust requirements and energy consumption from aerodynamic drag. It has been further suggested that a transcontinental tunnel could link New York and Los Angeles, and onward under the Atlantic and Pacific oceans to provide the ultimate global transportation capability. Such a concept might even include a dipping and rising profile between stations to provide gravity assisted propulsion and braking for speeds up to 2000 km/h. Such ideas must however be dismissed as fanciful rather than visionary in view of practical engineering considerations such as the cost of construction and the maintenance of tunnel integrity. However, a 500 km/h system in which alignment curvature restrictions necessitate extensive tunnelling might benefit from being operated in a low pressure environment in a continuous tube. Such a concept would seem to merit detailed techno-economic evaluation.

On the operational side, we can expect the steady enhancement of high speed rail systems in terms of speed, comfort and passenger services/amenities. European high speed rail services will become increasingly networked. More lines will be built in Asia, including the completion of a national network in Japan and new lines in Korea, Taiwan and China. North America is clearly a follower rather than a leader in the new high speed rail infrastructure, but the U.S. could see a rejuvenated passenger rail system, starting with the North-East corridor. However, there needs to be a greater threat to mobility to achieve this, such as steadily increasing road and air congestion as a limiting factor to economic growth or perhaps another oil crisis.

A mitigating factor may be the increasing use of telecommunications for video conferencing, thus reducing the necessity to travel and saving time and costs. However, there is no evidence yet that such communications facilities are slowing the growth of business travel. Notwithstanding impressive advances in telecommunications and the benefits which accrue from it, our cultures have not yet changed (evolved ?) to the stage at which the telephone, videophone, videoconferencing, the Internet or, eventually, virtual reality are adequate substitutes for direct human interaction. So, HSGT must be a growth industry well into the 21st century.

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4. LOW / INTERMEDIATE SPEED MAGLEV

4.1 MODES OF SUSPENSION

As discussed in section 3.3, there are two modes of magnetic suspension that may be used for transportation :

- electrodynamic suspension (EDS), utilizing forces of magnetic repulsion

- electromagnetic suspension (EMS), utilizing forces of magnetic attraction

EDS vehicles are not magnetically suspended at rest and require wheels for support. A forward speed of 60-120 km/h (dependent on magnet and ground conductor configuration) is required for magnetic lift-off. The speed dependent lift force at low speed is accompanied by a high drag force which must be overcome by the propulsion system. The characteristics of EDS therefore make it suitable only for high speed ground transportation.

If there is a requirement or opportunity for non-contact suspension at low and intermediate speeds, EMS must be used, i.e. the same mode of suspension as used by the German TRANSRAPID high speed vehicle. In the case of high speed ground transportation, it is highly desirable *not* to transfer and condition propulsion power on board the vehicle. Hence linear synchronous motors are favoured for such applications. For low and intermediate speeds, propulsion power is more modest and the technology of "third rail" power pick up is well established. For such systems, a linear induction motor (LIM) is favoured, for which power (usually 600 V or 1500 V dc) is picked up by sliding contacts and conditioned on board by a variable-voltage variable-frequency inverter for LIM excitation.

Technological development for low and intermediate speed applications of EMS were considered by a number of countries in the 1970s, including Germany, Japan, U.K. and U.S.A. Only those in U.K. and Japan evolved to extensive test and demonstration programs.

4.2 BIRMINGHAM AIRPORT PEOPLE MOVER

The first Maglev vehicle to be licensed for passenger transportation was the Birmingham Airport People Mover. A simplified cross-section of the vehicle is shown in Figure 4.1, and characteristics of the vehicle, suspension and guideway are listed in Table 4.1.

The Birmingham Airport Maglev People Mover was opened in May 1984 to provide a free automatically-controlled shuttle link between Birmingham International Railway Station (adjacent to the National Exhibition Centre) and the Birmingham Airport terminal. The system was operated very successfully over a period of 11 years, to the extent that the operating authority entered into negotiations to extend the system at Birmingham Airport with General Electric, the company that had assumed development rights from British Rail (the original R & D organisation). However, over this period, there was little on-going development in U.K. and the system that was implemented at

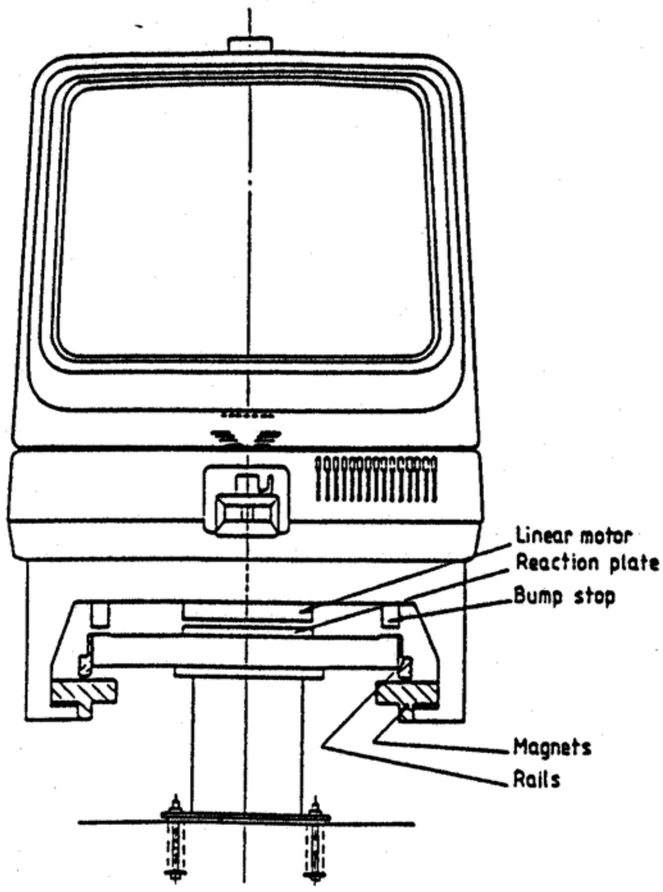

Figure 4.1 A cross-section of the Birmingham Airport People Mover, showing the electromagnetic suspension and linear induction motor components

Birmingham airport gradually became dated. In fact, it became increasingly difficult to find spare parts for electric / electronic components in the original system design, as the technologies of power electronics, integrated control and microelectronics became more sophisticated. As a result, it was no longer possible simply to repeat or extend the Birmingham system. The airport authority was not prepared to pay the costs of re-engineering, and the Birmingham Airport People Mover was finally shut down in 1995. Shuttle service between the airport terminal and railway station is now provided by buses.

TABLE 4.1 CHARACTERISTICS OF THE BIRMINGHAM AIRPORT MAGLEV SHUTTLE

VEHICLE :	
Length	6 m
Width	2.25 m
Height	3.08 m, above top of rail
Weight (empty)	5 tonnes
Capacity	3 tonnes (32 passengers and luggage)
Speed	15 m/sec
SUSPENSION :	
Type	EMS, axial flux
Magnets	8, E-core
Gap	15 - 20 mm
PROPULSION :	
Type	Linear induction motors
Supply	Inverter (on-board)
Power pick-up	600 V dc
Thrust	10 kN, peak
GUIDEWAY :	
Length	610 m
Height	6 m above ground (average)
Type	Steel track, concrete supports
No. of tracks	Two independent, parallel (separated by walkway)

4.3 HSST

EMS Maglev has been developed in Japan for low speed (urban transit) and intermediate speed (commuter and airport access) applications. Milestone developments are shown in Table 4.2.

4.3.1 HSST - 03 at EXPO '85 and EXPO '86

For the Tsukuba demonstration, the HSST-03 vehicle was operated on a 350 m straight track at ground level. The vehicle was continuously levitated. However, the linear induction motor was switched on only briefly at the start of a run to accelerate the vehicle. The vehicle cruised with no drive control over the central section, and was then braked at the end of the run by phase reversal of the LIM. The inverter was based track-side, and the vehicle picked up variable-voltage variable-frequency three-phase power for the LIM by sliding contacts from track-side conductors.

TABLE 4.2 HSST MILESTONES

1974	Development plan initiated by engineering group in Japan Airlines
1975	HSST-01 levitated on 1.3 km test track in Kawasaki
1978	HSST-01 achieved 307.8 km/h
1978	HSST-02 tested and demonstrated as a passenger-carrying vehicle at Kawasaki, at speeds up to 80 km/h
1985	HSST Corporation founded
1985	HSST-03 carried more than 600,000 passengers at Tsukuba Science Expo '85, on a 350 m track at speeds up to 30 km/h
1986	HSST-03 carried more than 450,000 passengers at Vancouver Expo '86, on a 450 m track at speeds up to 40 km/h
1987	HSST-03 installed in Okazaki City for three-year test and demonstration program
1988	HSST-04 carried more than 240,000 passengers at Saitama Expo, on a 300 m track at speeds up to 40 km/h
1989	HSST-05 carried more than 1,200,00 passengers at the Yokohama Exposition, YES '89, on a 560 m track at speeds up to 45 km/h
1991	Construction and testing of HSST-100S on 1.3 km elevated guideway in Nagoya. Two-car train had 110 km/h capability
1995	Construction and testing of HSST-100L vehicle on Nagoya test track
1998 (?)	Introduction of HSST-100L on Ofuna Dreamland line, south of Tokyo.

In subsequent demonstrations, various elements necessary for a passenger transportation system were introduced progressively.

For Vancouver EXPO '86, the same vehicle as for the Tsukuba demonstration was used. The track was still at ground level, but included two curves, allowing the curving performance of the Maglev modules to be assessed.

4.3.2 HSST - 04 at Saitama

For the Saitama Expo, the HSST-04 demonstration incorporated some new features, representing a significant step towards implementation readiness. Firstly, the vehicle was operated on a curved elevated guideway through the exposition grounds. Pedestrian and vehicular traffic could freely pass between the single peer supports. Secondly, the vehicle carried an inverter of advanced design to control the LIM drive. The 762 kVA inverter used GTO thyristors with a heat-pipe cooling system to reduce both size and weight over conventional railway equipment. The vehicle picked up 750 V dc from track-side conductors.

4.3.3 HSST - 05 at Yokohama, YES '89

The demonstration and operational experience of HSST-05 at Yokohama, YES '89 during the summer of 1989 represented a further step towards the acceptance and implementation of HSST as a transportation system. Most significantly perhaps, the HSST Corporation was issued with the first operating license in Japan to deploy its system for passenger service.

Prior to certification for the YES '89 line, the Ministry of Transportation had to revise two railway ordinances to include "the railway of the electromagnetic levitation and linear induction motor drive". By these amended ordinances, the HSST YES '89 line was licensed as a public transportation system (specifically for the Yokohama application) in April 1988. In practice, this permitted the vehicle to move passengers from one end of the line to the other, rather than operating as a simple go and return demonstration, as at previous expositions.

In addition to its operational certification for passenger transportation at YES '89, the most notable technical advance over the Saitama HSST-04 demonstration was the coupling of two vehicles. The HSST-05 vehicle operated in Yokohama for six months during 1989. During this time, it carried over 1,200,000 passengers and maintained an availability of 99.88 %.

4.3.4 HSST 100S and 100L

The next step towards the implementation of HSST was the establishment of the Chubu HSST Development Corporation as a collaborative venture between HSST Corporation, the Aichi Prefectural Government and the Nagoya Railroad Company in 1989. The primary objective of this new company was the development, testing, commissioning and marketing of HSST technology.

A test implementation of CHSST-100 was completed in 1991 in East Nagoya in order to accumulate data on an urban-type Maglev vehicle. General features of the test track and vehicle are given in Table 4.3. The CHSST-100 vehicle is illustrated in Figure 4.2, while the horizontal and vertical profiles of the Nagoya line are shown in Figure 4.3. It is evident that this guideway incorporated many characteristics which provided a rigorous test of HSST-100 technology.

TABLE 4.3 FEATURES OF CHSST-100 IN NAGOYA

TRACK :	
Length	1.3 km, elevated guideway
Minimum curvature (horizontal)	25 m
Minimum curvature (vertical)	700 m
Maximum grade	7 %
Maximum superelevation	8 degrees
TRAIN :	
Formation	1 two-car train
Unit dimensions	2.6 m wide 3.6 m high 17.6 m long
Unit weight	21 tons, empty 30 tons, loaded
Structure	Welded Al alloy
Suspension	Controlled electromagnetic 48 magnets per unit
Gap	8 mm, magnetic 6 mm, mechanical
Propulsion	Linear induction motor 12 per unit
Rated thrust	3.2 kN per LIM
Power collection	1500 V dc
Maximum speed	110 km/h

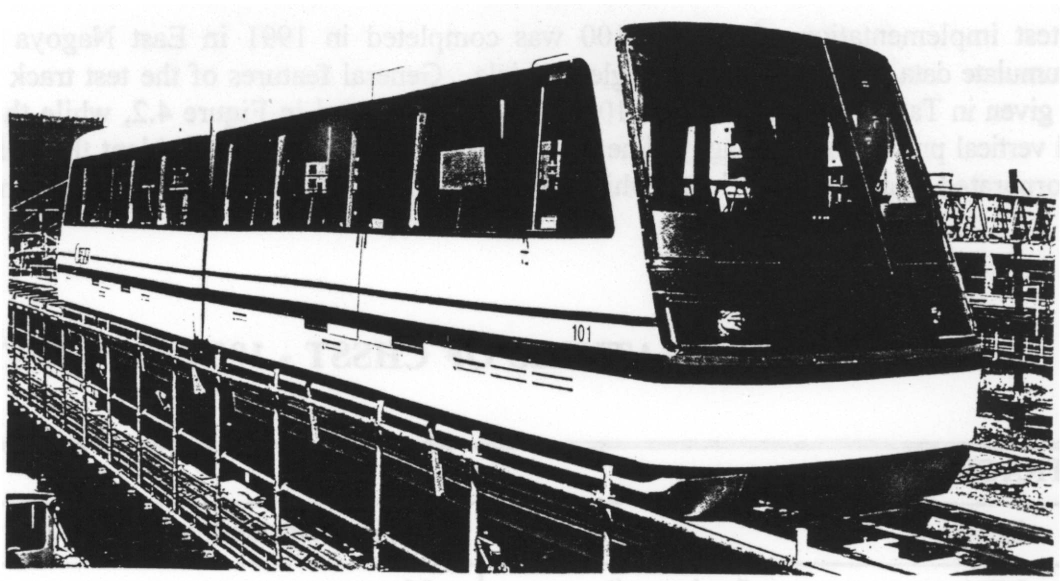

Figure 4.2 The CHSST-100 vehicle as tested in Nagoya

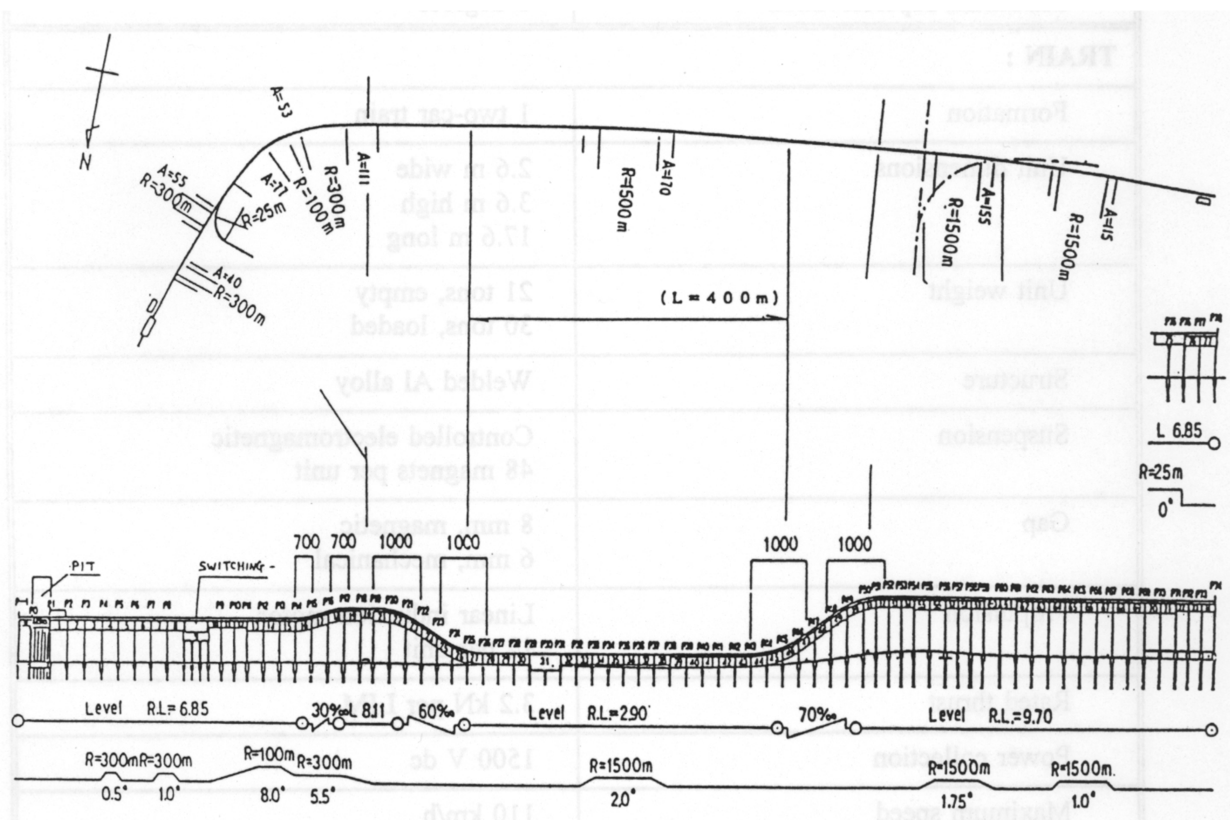

Figure 4.3 The horizontal and vertical profiles of the CHSST-100 guideway at Nagoya

The Japanese government established a "Feasibility Study Committee for Urban Mass Transit by Linear Motor Driven Maglev". This had senior representation from academia, national and local governments, Ministry of Transport and industry. The Committee assisted in the design of the Nagoya test track in order to provide a rigorous test of CHSST-100 and to assess its readiness, safety and reliability for urban transportation. The Committee carefully monitored and reviewed the test results.

By mid-1993, the total distance travelled by the test vehicle was over 35,000 km. The Committee conducted a detailed assessment of 95 items. While the results of this evaluation indicated the potential to improve the technology associated with three items, it was judged not necessary to demonstrate these improvements prior to proceeding to implementation. For the remaining 92 items, the Committee found that commercialisation was possible with the existing technology.

At this stage, the HSST development company could plan for a specific implementation with reasonable expectation that HSST-100 would receive regulatory approval as a public urban transportation system. HSST technology was essentially ready to proceed to commercialisation as an urban transit system at speeds up to 100 km/h.

Having demonstrated HSST-100 to be safe, reliable and essentially ready for implementation, the developers re-examined potential markets. They concluded that there were opportunities for two variants, labelled HSST-100S and HSST-100L, with basic specifications listed in Table 4.4 (taken from an HSST Development Corporation brochure). In order to test certain technology enhancements (primarily a simplified and reduced cost magnetic bogie arrangement), a 2-car HSST-100L vehicle was constructed and officially opened on the Nagoya test track in June 1995. This pre-commercial test / demonstration vehicle is shown in Figure 4.3. By the end of 1995, this vehicle had been operated on many occasions at its design speed of 120 km/h.

4.3.5 Applications for HSST

Over the years, HSST has been proposed for a number of applications, both within Japan and in other countries. Two applications which progressed to detailed engineering design studies in North America were for implementations of the HSST-200 system in Las Vegas and in Orlando.

In Las Vegas, it was proposed to instal an HSST-200 line from Clarkson Airport to the downtown core, via the casino strip. In Orlando, it was planned to implement a 22 km HSST-200 line from the Airport to International Drive, a commercial and hotel/motel area adjacent to the Disney World complex. Neither system was built because of a combination of local politics, commercial interests, management issues and financing difficulties. Readiness of the technology was not the major issue.

Other potential applications for HSST for airport access in the New York / New Jersey area and for a metropolitan line in Mexico City have also not matured

TABLE 4.4 BASIC SPECIFICATIONS OF HSST VEHICLES

	HSST-100 L	HSST-100 S
Track		
Maximum gradient	7 %	7 %
Minimum curve radius (horizontal)	50 m	25 m
Minimum curve radius (vertical)	1,500 m	700 m
Maximum cant angle	8 degrees	8 degrees
Vehicle performance		
Maximum speed	130 km/h	100 km/h
Acceleration: Maximum	3.5 km/h/s	4.5 km/h/s
Deceleration: Maximum (normal)	3.5 km/h/s	4.5 km/h/s
Maximum (emergency)	4.5 km/h/s	5.3 km/h/s
Vehicle dimensions		
Vehicle length (end car)	14.1 m	8.5 m
(mid car)	13.3 m	8.4 m
Width	2.5 m	2.5 m
Height	3.6 m	3.6 m
Weight/car (empty)	15 t	10 t
(maximum)	25 t	15 t
Passenger capacity		
Seated/standing/total (4-car train)	148/336/ 484	112/188/300
Seated/standing/total (6-car train)	232/512/ 744	176/290/466
Seated/standing/total (8-car train)	316/688/1,004	240/392/632

Figure 4.4 The HSST-100L test vehicle at Nagoya

The author has previously expressed the view that HSST should be implemented in Japan before the system is moved off-shore. Developers would like to see Japan express confidence in and a committment to its own technology by commissioning a domestic application. Inevitably, the first "real" application will reveal elements of the system that need re-engineering.

In this regard, it is pleasing to note the intention to proceed with an HSST-100 line in Ofuna, south of Tokyo by 1998. The 5.5 km elevated line will link JR Ofuna Station with a residential area and with the Dreamland Theme Park. Studies are also underway for an HSST-200 link from the planned new Hiroshima Airport to the Shinkansen Station and to Hiroshima City centre. This line has some steep gradients, making it attractive to consider a Maglev link. However, this would be a post-2000 project.

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5. POTENTIAL INTRA- AND INTER-CITY APPLICATIONS IN CANADA

5.1 REVIEW

Magnetic suspensions and high speed ground transportation have been high interest topics in Canada for over thirty years. In the late 1960s, the application of tracked air cushion vehicles in the Canadian corridor (Windsor - Toronto - Ottawa - Montreal - Quebec City) was studied. The author then (in 1972) joined a multi-university (Queen's, Toronto and McGill) and National Research Council team of scientists and engineers that conducted research, testing and conceptual design studies for operation of an electrodynamic Maglev system in the Toronto - Ottawa - Montreal corridor. This research program was followed by a techno-economic evaluation of transportation services, by the Canadian Institute of Guided Ground Transport, in order to identify the modes that could best service the Canadian corridor in the early years of the 21st century.

VIA Rail then conducted two studies which focussed on passenger services and mainline electrification in the Canadian corridor. Air Canada examined the use of magnetic suspension technology in the early 1990s. Most recently, the federal government and the Provinces of Ontario and Quebec each contributed $2 million towards the most comprehensive study so far. This study, which was released in August 1995, concluded that high speed rail of the TGV type would be the most appropriate technology for the Canadian corridor, but that capital costs are too high and projected ridership too low to make implementation economically viable as a private sector venture. A public - private partnership is now being proposed by Bombardier, which holds the license for TGV technology in North America.

Thus, over a period of thirty years, the Canadian corridor has been studied once every 5 years or so. While the analytical and evaluation approaches have become more sophisticated, we are no closer to seeing a high speed ground transportation system being implemented. Quite simply, the economics preclude it -- and will continue to do so until the social benefits are perceived to be sufficient to justify a substantial public sector contribution to right-of-way and infrastructure.

Lower speed systems involving non-conventional advanced transportation technologies have also attracted public interest. At the dawning of the Maglev age in the early 1970s, there was a proposal to instal Krass Maffei's TRANSURBAN (a low speed electromagnetically suspended vehicle with linear induction motor drive) around the Canadian National Exhibition in Toronto. This project was abandoned, but led to an examination of the market for new urban transportation technologies by the Ontario Transportation Development Corporation. Under the banner of the Urban Transportation Development Corporation (UTDC - initially a Crown Corporation of the Province of Ontario), the magnetic suspension of the urban transit vehicle was replaced by small-diameter steel wheels and a steerable-axle truck. The non-contact LIM propulsion system was retained in view of perceived advantages for automatic headway control and operation on grades up to 8 %. The Intermediate Capacity Transit System was researched, developed, tested and commissioned at UTDC's facilities near Kingston, Ontario, and the system was installed first in Scarborough as an extension to the west-east Toronto subway line in 1985.

ICTS was then built in Vancouver as the Skytrain in time for EXPO '86 and in Detroit as the Downtown People Mover in 1987.

UTDC was purchased first by SNC-Lavalin and then by Bombardier. This leading transportation company in North America continues to develop and market this system internationally and has secured a major contract in Kuala Lumpur, Malaysia.

The Japanese HSST system (see section 4) has also been promoted in Canada, and proposals for Mirabel - Montreal, the Niagara Gorge, and Pearson International Airport - downtown Toronto have been examined at a conceptual level. The author is not aware of any detailed engineering studies for implementation of HSST in Canada.

After 30 years of research and development worldwide, much progress has been made. High speed rail provides invaluable transportation service at speeds up to 300 km/h in Japan and Europe. Linear induction motors are now accepted as the propulsion system for certain applications in urban transit in North America and Japan. Electromagnetic Maglev is close to being ready for implementation at a range of speeds up to perhaps 450 km/h, with the low / intermediate speed HSST system in Japan and the high speed TRANSRAPID system in Germany. Very useful operating experience was gained with the Birmingham Airport People Mover in England. Electrodynamic high speed (500 km/h) Maglev is in an advanced developmental stage in Japan.

What then are the possibilities for advanced ground transportation technologies in Canada ? The next and concluding section of this report discusses prospects.

5.2 PROSPECTS FOR CANADA

5.2.1 Low / Intermediate Speed Applications for Maglev

The urban cores and suburban regions of Canadian cities are presently served by subways (Montreal, Toronto, Vancouver), light rail vehicles (Toronto), and buses (all cities). Dedicated ROW intermediate capacity transit link the downtown core to satellite centres in Toronto and Vancouver, while commuter rail provides rush hour services in Toronto, Montreal and Vancouver.

Additional urban and regional transportation must provide cost-effective service and must be designed such as to enhance intermodalty for the travelling public. An EMS Maglev system of the HSST type offers :

- very low noise and pollution-free operation
- speeds up to 100 km/h (for HSST-100) and to 200 km/h (for HSST-200)
- route flexibility as a result of low environmental impact and grade-climbing capability
- low maintenance costs (although this may be offset by higher capital and energy costs)

- an elevated guideway that is as unobtrusive and aesthetically pleasing as any elevated structure can be, and which could be installed along the median strip of highways and freeways.

EMS Maglev therefore offers the potential for :

- downtown people movers, for which stations could be located within office, commercial and residential complexes

- regional and commuter feeder operations

- an airport access transit system

While planners should be aware of the transportation opportunities presented by EMS-type Maglev, the author would not advocate the implementation of such systems in the near future. It would be prudent to wait until HSST-type systems have been proven in revenue service, first for 100 km/h systems (within 3-4 years) and then for 200 km/h systems (within 8-10 years).

5.2.2 High Speed Systems

Technological feasibility of high speed ground transportation (HSGT) is not an issue - X2000, ICE, Shinkansen and TGV trains now safely carry almost one billion passenger per year at speeds up to 300 km/h. And further advances in high speed rail and Maglev systems will likely extend operating speeds to 350 km/h and to 500 km/h, respectively, within 10 - 15 years. The problem is economics. Implementation of any high speed intercity ground transportation system is a multi-billion dollar project. Such systems must carry many millions of passengers per year to recover operating costs and to provide a modest return on the capital investment from farebox revenues.

In Canada, various routes have been considered for high speed ground transportation, including :

- Windsor - Toronto - Ottawa - Montreal - Quebec City

- Edmonton - Calgary

- Vancouver - Seattle - Portland

- Montreal - Albany - New York

The central portion of the Canadian corridor is the obvious candidate for consideration of high speed service, in view of the populations in Toronto, Ottawa and Montreal. As noted in the previous subsection, this route has been studied repeatedly over the past 30 years. The magnitude of the capital cost and the very modest projected ridership makes HSGT uneconomic, even under the most favourable financial scenario.

There is now an appreciation that HSGT cannot be built as a private sector venture anywhere in North America. A substantial contribution from the public sector is essential. In order to justify such a contribution, the broad societal benefits and externalities of HSGT must be considered, including job creation, developmental impact, reduced congestion of other modes, reduced noise and pollution, use of electricity rather than oil-based fuels, etc. The concept of a social return-on-investment is thus gaining favour.

The most recent study of the Canadian corridor concluded that TGV technology is the most appropriate mode of HSGT, but that the project is not economically viable at this time. The author concurs with the recommended technology, noting that variants and derivatives of the TGV are now being accepted for operation in Europe (France, Spain, U.K., Germany, Belgium, Netherlands, Italy), in Asia (Korea), and in North America (Florida and the North-East corridor). TGV is becoming a world train.

The selection of TGV-type technology for the North-East corridor (Boston - New York - Washington D.C.) is particularly significant for Canada. The provisions of NAFTA are facilitating north-south trade links, allowing the industrial heartland of Canada to become a more integral part of an economic zone extending south to Washington, D.C., east to Boston, north to Montreal, and west to Chicago. It is therefore appealing to consider an integrated rail network that would link major population centres in this region and which would use similar equipment for high speed passenger services. Clearly, Bombardier is well placed to be the major supplier of such equipment.

It is the author's opinion that the speeds offered by high speed rail (at 240 - 320 km/h) will be entirely adequate for passenger transportation when introduced as a complementary component of a multi-modal regional / national transportation system in the 21st century.

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