The Role of Surface Transportation

History of Development and Prospects for the Next Century

Nebojša Nakićenović *

Abstract

The paper begins with an analysis of the growth of surface transport systems. We analyze *ex post* the convergent development of rail and road transport reaching divergent densities in different countries. This then serves as an illustrative case to investigate further the diffusion of the automobile, and to derive a global scenario for future automobile fleets. Based on our conclusions with respect to the future evolution of transport system structure and scenario of forthcoming global saturation in automobile diffusion, we then discuss the long-term development possibilities for more productive surface transport systems such as maglev trains. Ultimately, further increases in mobility would require the introduction of new and more productive and environmentally clean transport modes. This hypothesis will be used to determine what the possible effects would be if barriers to mobility are removed. Alternatives include examples of both the development of new physical infrastructures (e.g., a high-speed rail network) and the reduction of institutional and political obstacles (e.g., the former iron curtain). Imposition on new institutional and political barriers would have the opposite effect of reducing mobility and decoupling previous functional unities into separate entities.

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1. Introduction

As a rule, the infrastructures which are used for the movement of people, goods and information diffuse slowly and span many decades from their first introduction to obsolescence. Some of them are almost immortal, even though they often provide different services from those originally intended. Obsolete canals were reused to build railways a century ago in England. Ancient Roman roads have often been buried beneath modern highways. Old harbors are being converted into modern commercial and residential areas. While some of the old infrastructures are recycled, completely new systems that provide even greater possibilities are also introduced so that diversification and productivity increase in time leading to ever greater mobility. Technological changes from mail-coach to airplane have transformed and extended the spatio-temporal range of human interaction patterns, leading to unprecedented levels of performance in terms of speed, quality of service, spatial division of activities, and integration of economic spaces. Thus, complexity increases, resulting in numerous interlaced and overlapping niches occupied by competing modes of passenger travel, information channels and transport modes for goods and services. Beyond the explosive increase in mobility worldwide, this process has integrated distinct and specially separated locations into mutually and functionally interrelated entities. This decrease in the "friction of space" is the process by which not only economic but also cultural and social interaction have been transformed from regional into global phenomena.

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New transport technologies have been vital for economic development since the onset of the Industrial Revolution. In fact they have been so vital that economic historians have termed whole periods of economic development after various transport infrastructures, e.g., the "age of canals" in the first half of the 19th century, or the "railway and coal era", the expansion of which ended with the Great Depression in the 1930s. The oil and automobile alliance was the symbol, and one of the main contributing factors, to an expansion period unprecedented in the economic history of mankind, but this ultimately will also come to an end. The turbulence and volatility witnessed since the 1970s may be an indicator of a deeper structural transformation in the economy as a whole, and of transport sector in particular.

This process can be described by evolutionary envelopes of gradual replacement of old by new systems along structured development trajectories that can be formalized mathematically by simple, biological growth and interspecies interaction models. Evidence of long-term regularities in the evolution, diffusion, and replacement of several families of technologies that constitute our transport system emerges, thus facilitating a prospective look into the future. Older systems are made obsolete through technological advance and economic development, and new ones are introduced that are better adapted to continuously changing social, economic, and environmental boundary conditions.

Thus, the growth of individual transport systems is not a continuous process but time dependent. Based on historical analysis, we conclude that there was a time to build canals and railways, as there was a time to build highways and have increasing car ownership rates. However, despite the fact that the development of individual transport systems may be extremely successful over periods of several decades, any expansion period will ultimately be followed by a structural discontinuity, a *season of saturations.* The expansion of a particular technological system reaches limits in terms of market saturation, social acceptability, and environmental constraints. All booms eventually bust.

We suggest, again based on historical analogy, that it may be more creative to think about the opportunities generated by the transition to a new technological regime, rather than to consider further development along the trajectories and intensity levels of the previous, by now saturating and ultimately vanishing, modes of economic and infrastructural development. Based on this working hypothesis we sketch out a scenario for the future evolution of the transport sector. The scenario

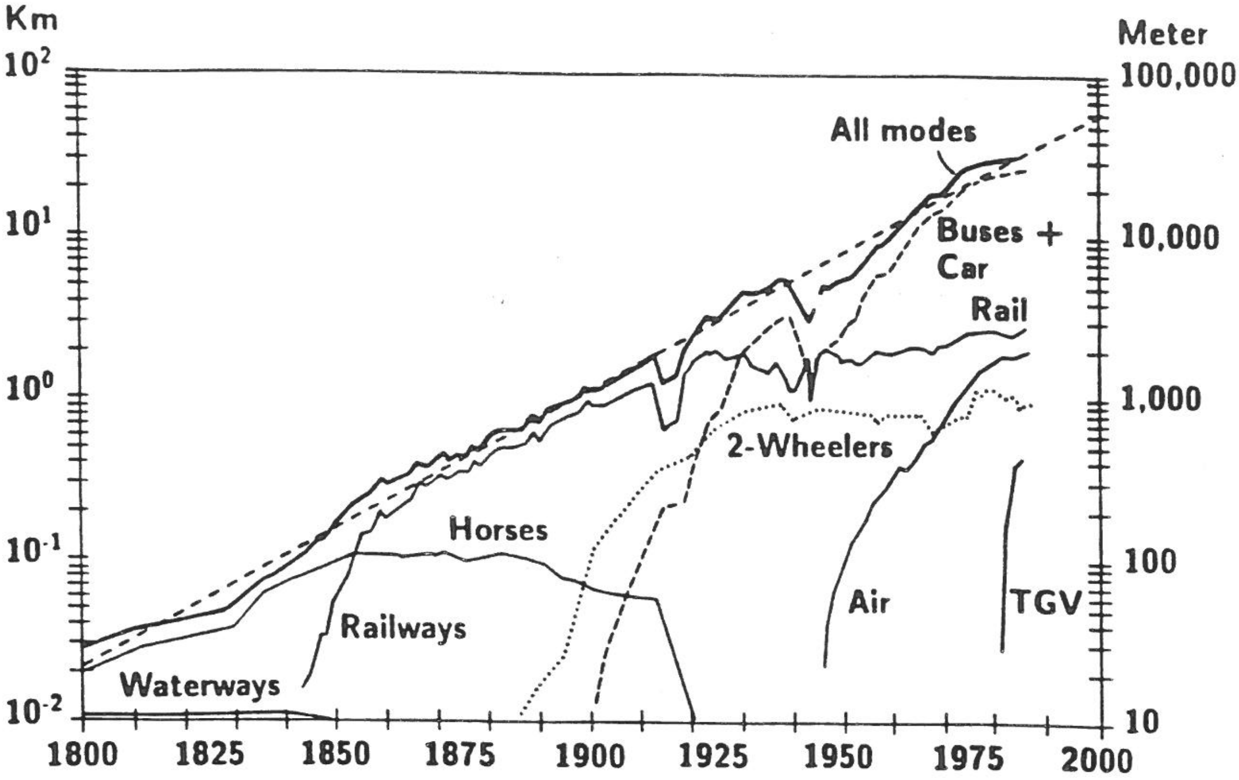

Figure 1. Growth of Mobility as Distance Traveled per Day per Capita, France (Grübler, 1990).

postulates a forthcoming saturation of automobile diffusion in industrialized countries with lower adoption levels in the developing countries. At the same time, we consider the possibility of further growth in passenger transportation, as well as the emergence of new transport modes, such as high-productivity super- or hypersonic aircraft fueled by methane or hydrogen, maglevs (magnetic levitation trains) based on superconductivity, or electric and hydrogen powered automobiles.

Such a scenario may appear unrealistic with current technologies and institutions, and in any case infeasible with a further intensification of traditional transport modes. It is however consistent with the historical trend towards greater spatial range of commuting and travel and increasing mobility in the world. *Figure 1* shows that the increase in mobility, expressed as the average daily travel range, has been a pervasive historical development. Mobility increased through four orders of magnitude (by a factor of ten thousand): For example, the spatial range covered by the population of France appears to grow along a secular trend that increased from about 20 meters per day per capita in 1800 to more than 35 kilometers today. These increases in mobility were primarily achieved by the introduction and growth of new transport modes, railways in the 19th century and buses and cars in the 20th century. Although the increase in mobility may be sustained over several decades by growth in the output of the dominant transport system, as illustrated by the growth in railway traffic between 1860 and 1920 and by the growth of road traffic since WW II, there are obvious limits to the further expansion of traditional transport systems. Current transport modes will ultimately have to be replaced by more advanced systems (in terms of productivity and environmental compatibility).

This explosive improvement in man's capabilities to move people, goods and information has drastically increased all manifestations of mobility: physical, geographical, social, economic, political, etc. In the context of transport and communication systems, mobility refers to the movement of people, goods and information to and from spatially separated locations. In a wider sense, the mobility of thought and freedom of ideas is a precondition for cultural development and societal capacity to adjust to a changing environment. Modern transport technologies, such as the automobile or airplane, together with modern communication technologies, such as the telephone or telefax, have dramatically transformed the patterns of economic and social interaction by integrating distinct geographical spaces into mutually and functionally interrelated entities. On a more abstract level *space* can also be defined along a "socioeconomic topology". Such an abstract topology of spaces can be represented, for instance, by various density and intensity indicators.

Substantial phenomenological evidence confirms the assertion that transport and communication infrastructures can reduce the distance between geographically separated cites by decreasing the "friction of space". Very productive infrastructures sometimes result in the "collapse" of an actual physical separation, yielding a single functional unit. These cases most clearly illustrate the effects of the removal of barriers. For example, a system of bridges and tunnels that is capable of handling a large flux of people and goods can connect separate settlements into a single functional city. A hypothetical maglev transport system of the more distant future, capable of carrying passengers and goods at speeds that exceed those of modern jet transports, could by analogy connect different cities and urban corridors into a continental settlement supercluster (a so-called *ecumenopolis*). In the past, urban clusters have condensed along important transport and communication infrastructures, such as railway lines with telegraph wires running next to them. Current examples include the Tokyo-Osaka corridor served by the Shinkansen train, the Boston–New-York–Washington corridor linked by rapid rail and air shuttles, and the Ruhr area in Germany transversed by Inter-City trains and *Autobahnen.*

Many aspects of the revolutionary increase in human mobility and interaction, resulting from modern transport and communication infrastructure development, are well known. However, the effects of organizational aspects, such as formal and informal operation rules, and the institutional and political dimensions that can exert a repulsive or attractive force on mobility, are only partially understood. For example, it is not really known what the potential magnitude and range of effects of removing barriers would be. Similar to physical infrastructures, barrier removal certainly reduces the "friction of space". The difference, however, is that whereas the effects and impacts on the mobility of new infrastructures have been studied, the effects of barrier removal have not and are highly uncertain. Perhaps it could be said that barrier removal is equivalent to creating a potential for mobility, while only infrastructures allow the conversion of this potential into actual mobility increases. Conversely, an infrastructure built without a potential "attractor" will not be utilized. As an illustration, it is known that national borders in Europe tend to reduce the mobility between cities by a factor of four, compared to similar city sizes and distances within a given country (Grübler and Nakićenović, 1991). This means that European integration, or the effects of reforms and restructuring in Eastern Europe, could both lead to a reduction of the friction between flows of people, goods and information within a "wider Europe" (West of the Urals) and to the emergence of new political and institutional barriers that would hamper economic, social and cultural integration.

2. Growth of Transport Infrastructures

The great canal expansion was initiated in the United Kingdom between 1750 and 1850. It reduced natural barriers, connected coastal and inland waterways allowing for new flows of goods, unprecedented exchanges between regions, specialization of labor, and access to more distant energy and raw material resources. The successful English experience in canal development, and especially the "canal mania" of the end of the 18th century, became the development model on the Continent and in the United States, albeit with a considerable time lag. Despite the lag in the introduction of canals, growth proceeded much faster, and as a result the expansion reached saturation in most of the industrialized countries within a relatively short period of about two decades. For example, there is a pronounced catch-up period in canal construction of France and the United States compared with England: The diffusion occurred almost in parallel and ended in practically synchronous saturation toward the 1860s.

Canal construction never came to a complete standstill, even after the networks had reached their maximum size and proceeded to decline. For example, substantial canal network extensions occurred in Germany and Russia after the 1860s. However, these new constructions could not compensate for the overall network decline after the saturation. By the 20th century most national canal systems were in place, and many links already decommissioned. The canal business was so seriously eroded by competition from the railways that many important canals were abandoned and the lengths of the networks declined. Eventually they yielded to the vicious competition from railroads. The most vital of the canals, however, have survived to provide different services than originally envisaged. More than a century after the canal era, the remaining inland waterways are used for leisure activities, transport of low-value goods, and irrigation. There are also more sails today than in the heyday of ocean clippers, but most of them are on pleasure boats.

The first railways were constructed in the 1830s and extended the range, speed, and productivity offered by previous transport infrastructures, in particular turnpikes and the elaborate system of canals. More important, perhaps, was the capability to overcome even more imposing natural barriers. Bridges and tunnels were built for canals, but railways were capable of accommodating traffic and freight demands more directly – wherever demand existed it was almost always possible to build a railway line. In time, elaborate networks of railway systems were built in North America and Europe. Together with railways, a new era of coal, steam, steel, and telegraph began. The great railway era lasted until the 1930s.

The development of railways was initiated in the United Kingdom and within two decades the first major railways were built in other countries. *Figure 2* documents both the expansion and decline phases of the railway network in six industrialized countries, illustrating to what extent the development of railroads has converged internationally. It shows the diffusion of railroads in the United States, the United Kingdom, and Germany (top of *Figure 2*) and in the Austro-Hungarian

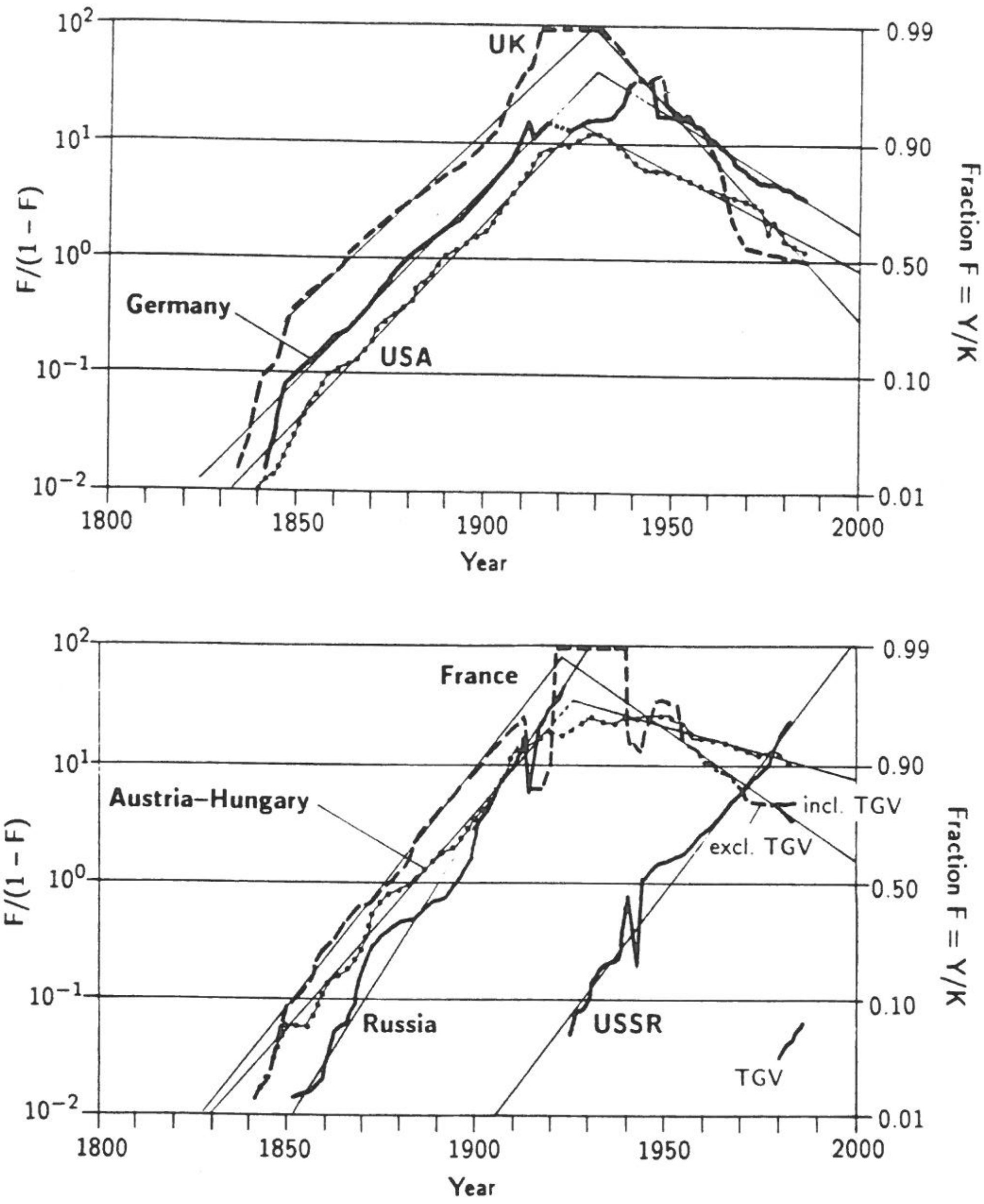

Figure 2. Diffusion of Railroads in the United States, the United Kingdom, and Germany (top) and in the Austro-Hungarian Empired (Austria after World War II), France, and the two growth pulses of the railways in Russia and the former Soviet Union (bottom).

Empired (Austria after World War II), France, and the two growth pulses of the railways in Russia and the former Soviet Union (bottom of *Figure 2*). While the railway construction processes differ both in rates of growth and duration, there is a high degree of congruence in the ultimate saturation of railway networks in the industrialized countries during the 1920s.

The most interesting cases are France and Russia; they show departures from the development pattern of the other countries. In France there are two unusual features worth noting. The first is that the turbulence during the saturation phase is very large compared with other countries; the second feature is the introduction of the TGV (*train á grande vitesse*) during the 1970s. Without the additional infrastructure dedicated to the introduction of the TGV, the length of the French railway system continues to decline along the historical path, while the inclusion of the TGV links could indicate the beginning of a trend reversal. Thus, one could speculate whether the introduction of rapid rail transport systems does not, in fact, represent the beginning of a new transport infrastructure. To document this possibility, the growth of TGV lines is plotted in the lower right corner of the graph.

The development path of railroads in Tzarist Russia is almost identical to the patterns observed in the other countries, until the onset of saturation in the 1920s. This period also coincides with the October Revolution. The reconstruction period is the possible reason for the further expansion of railroads in the former Soviet Union. Thus, two consecutive expansion pulses of the railway network are evident. (They are analogous to the two phases of canal construction in Tzarist Russia and the former Soviet Union, respectively.) After saturation of the first pulse, the second followed a similar trajectory with a slightly longer duration, and is now entering its own saturation phase.

These six examples clearly show that the development of a particular techno-economic trajectory can follow similar paths even in countries with fundamentally different social and economic relations, different technological bases, and certainly different cultures. In this sense we can speak of international "bandwagons" in the diffusion of pervasive techno-economic systems. *Figure 3* compares the diffusion of railroads in Europe, the United States, and in the "rest of the world" illustrating the extent to which their development was synchronized globally. While the processes differ both in rates of growth and duration, there is a high degree of congruence in their ultimate saturation in the industrialized countries towards the 1930s.

The diffusion cluster of railway networks in *Figure 3* that reached saturation by the 1930s accounts for almost 70 percent of all railroad lines constructed to date. This implies that the particular development trajectory (the "railway bandwagon") was not repeated by latecomers, i.e., by those countries that did not participate in the expansion pulse

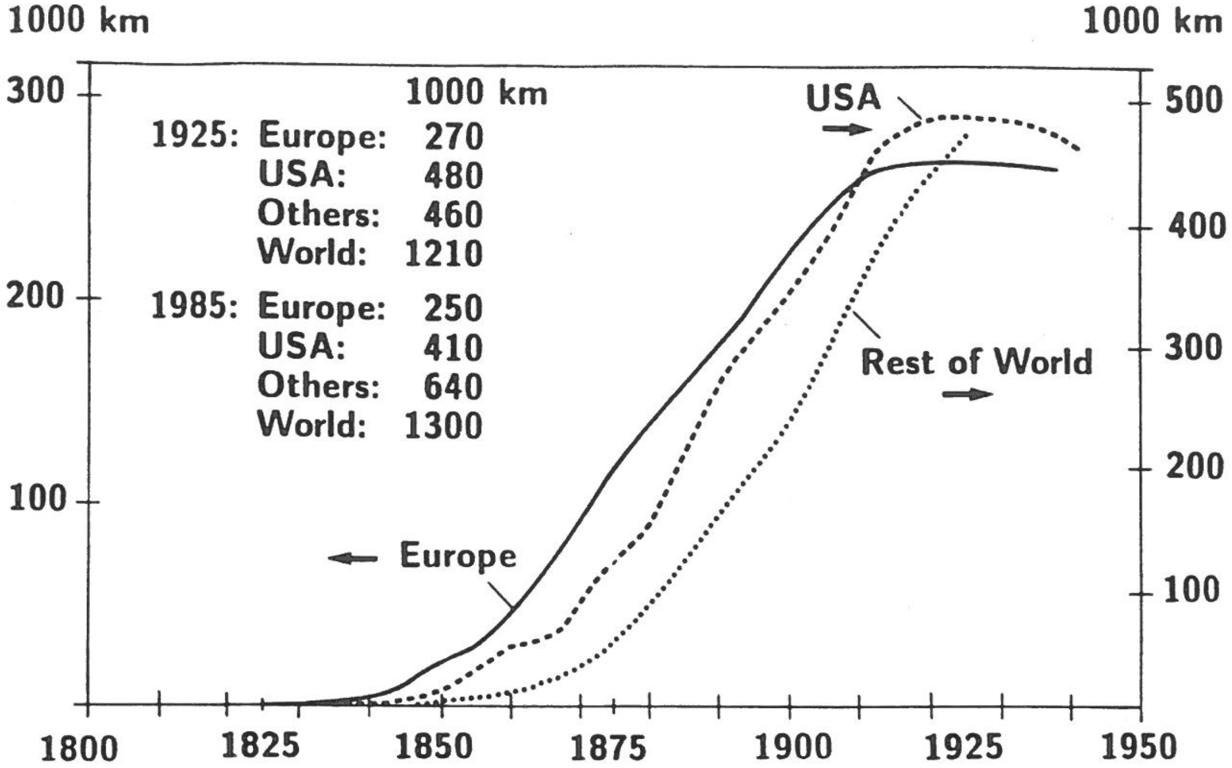

Figure 3. Growth of Railway Networks, in 1000 km.

of the 19th century. In fact, the global railway network reached a length of about 1.3 million kilometers by the 1930s and has remained at that length ever since. Decommissioning of lines in the core regions (Europe and North America) was compensated for by new construction in the developing countries. In the core countries the railway bandwagon focused as it evolved, converging toward the saturation period. In other words, although the introduction of railroads occurred with great lags between the early and late adopters, such as between the United Kingdom and Scandinavia, the late adopters achieved faster diffusion rates with a pronounced catch-up effect converging towards saturation. The railway bandwagon focused as it evolved, converging toward the saturation period. This focusing of the expansion pulse of the railway era is most noteworthy when one considers that the whole development process lasted about 100 years in the leading countries and only a few decades in the late adopters. The absolute level of adoption is however much lower for the late adopters compared to the early adopters. The ultimately achieved railroad density is in general higher the earlier the railroads are introduced; leaders achieve the highest diffusion levels. This phenomenon is not unique to railways.

The development of canal networks (in the United Kingdom, France and the United States) saturated between the 1850s and 1860s, with the follower countries catching up to the British "canal mania" initiated at the end of the 18th century. Again, the adoption level of canals remained to be the highest in England.

The advent of the automobile around the turn of the century initiated a new era in the development of transportation. Increased mobility became the symbol of industrial development along with oil, petrochemicals, electricity, telephone, and (Fordist) manufacturing. The flexibility offered by an individual mode of transport became affordable for a wider social strata, and only recently have the disadvantages of the automobile become socially transparent although they have been known for a long time. This perception lag illustrates the extent to which the automobile became accepted as one of the preconditions for modern industrial development. This perception appears to continue in many regions of the world.

The growth of the automobile to the present number of more than 425 million passenger cars (and 133 million trucks and buses) registered worldwide went through two distinct diffusion phases marked by different growth rates divided by a structural discontinuity in the 1930s. The first phase was initiated during the last century when horse-driven vehicles were the predominant form of road travel. In the United States, for example, the number of road horses peaked at more than 3 million in the 1920s, and declined rapidly thereafter. The horseless carriage was introduced toward the end of the last century and its adoption was very swift until the 1930s: It diffused rapidly into market niches previously held by horse–drawn carriages. By the end of the 1930s horses had virtually disappeared from the major roads in most industrialized countries. Thus, the replacement process lasted about 30 years. The second phase of diffusion was much slower and lasted longer. After the 1930s vehicles went through a fundamental transformation when numerous innovations in production methods and vehicle design were introduced that provided for higher performance, more comfort, and lower prices. Several changes in other sectors also made the automobile more attractive and accessible to the public and it became a serious competitor for traditional transport modes, in particular railways. Examples include innovations in the steel and petrochemical industries, and a host of other institutional changes that eventually led to automobile "compatible" settlement patterns. Incidentally, automobile use today is usually associated with numerous environmental problems, but in a historical perspective the replacement of horses by cars alleviated one of the grave environmental problems of the cities of the last century, namely, horse manure in the streets.

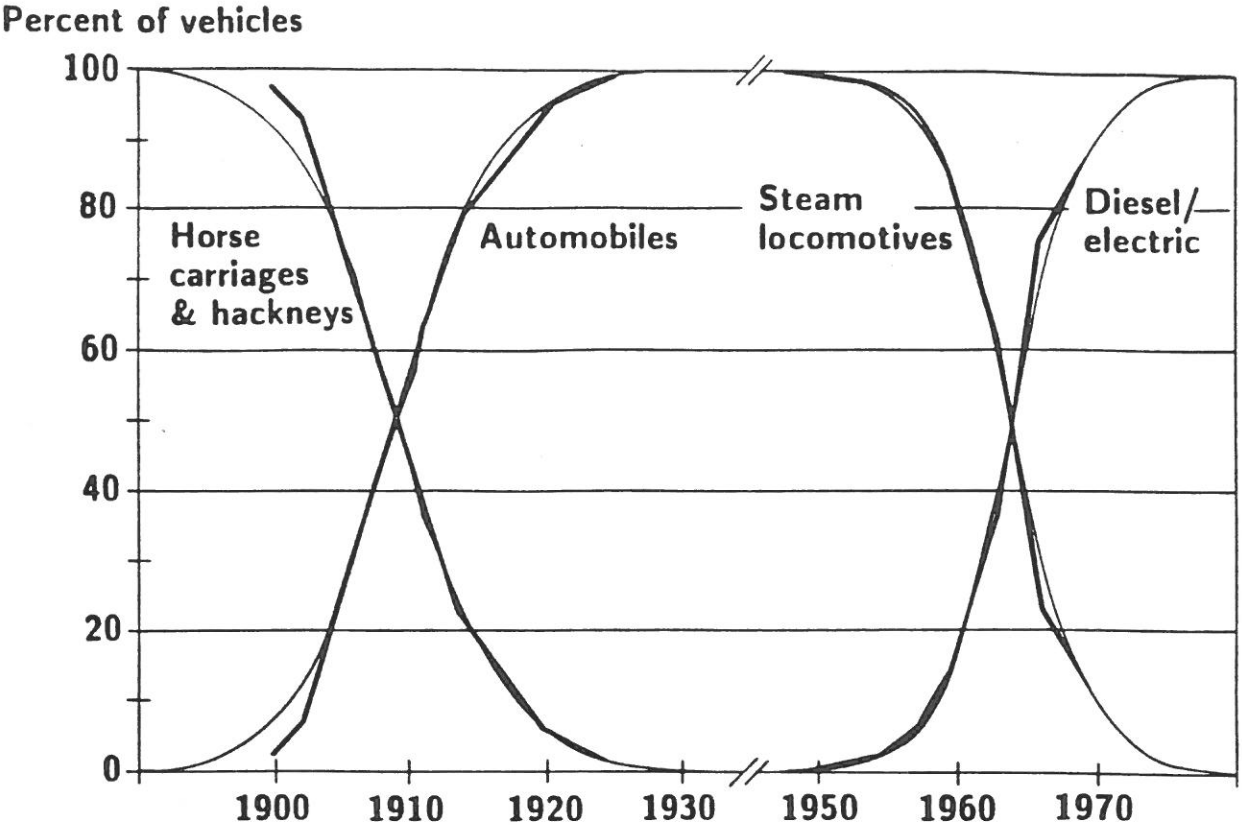

Figure 4. Substitution of Horse-drawn Vehicles by Automobiles and Steam by Diesel and Electric Locomotives, U.K., in Share in Total Number of Rolling Stock.

Figure 4 illustrates the first, rapid phase of automobile diffusion as it replaced horse-drawn vehicles in the United Kingdom, together with a similar substitution process in the railway transport system a few decades later when diesel and electric locks replaced steam propulsion in the rolling stock.[1] This example is typical of similar replacement processes throughout the world including the former centrally planned economies and developing countries. Technological change and substitution in road and railway vehicle fleets lasted in general between two to three decades.[2]

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[1] The fractional shares, F, are plotted as the share taken by the new and old competitors of the whole market or "niche", i.e., the share of the cars in the number of all cars and horse–drawn vehicles together. This form of presentation reveals S–shaped substitution paths of old by new technologies and systems as formulated by Fisher and Pry (1971). In most cases, this process can be described by logistic functions.

The adoption level of the automobile in different countries follows the same pattern as the observed saturation levels of railroads. Among the industrialized countries, the diffusion rate was slowest in the United States and Canada, faster in most of the European countries, and fastest in Japan. The adoption of the automobile was even faster in developing countries, albeit that it started only recently and has led, at least for the time being, to relatively low levels of car ownership.

3. Technological Substitution

The evolution of transport infrastructures can also be seen as a substitution process: from canals and turnpikes to railways and roads. Each successive transport system expanded into an infrastructure that was ten times larger than the previous one. For example, the length of transport infrastructures in the United States has increased by almost five orders of magnitude during the last two centuries. Each successive transport infrastructure was not only larger than the one it was replacing, but also faster. A hierarchy of space and time territories emerges. As Simon (1988) noted, most of the natural and man-made systems are hierarchical, i.e., they have boxes-within-boxes architecture; transport systems portray a similar structure. A man walking or using waterways can cover a mean circle of a few kilometers diameter in one hour, the size of a village or small town. A person traveling by rail or horse could travel more than a dozen kilometers in the same period a hundred years ago. The automobile and rapid rail systems offer a larger range – up to 100 km – and can, thus, effectively connect cities collapsing whole regions into one functional entity. As connected territory increases so does travel, tangible goods transport, and information flow.

Infrastructures can be viewed as systems that replace each other in time. The sequence of development of canals, railways, and roads appear in *Figure 5* as regular diffusion processes when their size is plotted as a percentage of the saturation level. In addition, the figure shows the development of telegraphs and oil and gas pipelines. This illustrates the increasing complexity and diversification of transport systems. While ancient roads and later canals were used for all

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[2] The duration of the diffusion process is measured as the time that elapses between the achievement of 1 percent and 50 percent (and from 50 to 99 percent) of the complete replacement of old by the new or the achievement of so-called market saturation. We call this measure Δt. Δt also approximates the time required to grow from 10 to 90 percent of the saturation level.

transport and communication activities, telegraphs evolved along with the railways as a specialized communication system. Oil pipelines also represent a dedicated transport system related to the development of roads, the automobile, and the oil industry. The six S-shaped growth pulses can be subdivided into three groups: canals followed by railways and telegraphs, followed by oil pipelines, roads, and gas pipelines.

The evolution of transport infrastructure can also be seen as a substitution process. Instead of analyzing their development as a sequence of individual diffusion processes (as the succession of growth pulses shown in *Figure 5*), they can be viewed as systems that replace each other in time. *Figure 5* reproduces the growth of transport infrastructure length in the United States as a substitution process and for comparison the equivalent substitution process in the Soviet Union.[3] It shows the successive substitution of four transport infrastructures in the two countries: canals, railroads, surfaced roads, and airways. The shares of each infrastructure in the total length are plotted as the ratio of the share of one infrastructure divided by the sum total shares of all others on a semi-logarithmic scale. This particular representation shows the relative importance of competing infrastructures and the dynamics of the evolution process since 1800. In any given period, there is a clear market dominance (i.e., more than a 50 percent share) and simultaneous spread of transport activities over two or three different systems. Thus, while competing infrastructures are all used simultaneously, their mix changes over time. Projecting this competitive process into the future leads to the increasing importance of airways, notwithstanding the likelihood of a new competitor emerging in the coming decades, such as magnetic levitation trains (maglevs) for continental distances and advanced forms of air transport (e.g., hypersonic aircraft) for transcontinental distances.

Even the former planned economies have undergone similar evolutionary transitions as market economies. The pattern of temporal changes in Russia (the former Soviet Union since the October Revolution), like in the United States, is marked by a high degree of regularity and a quest for higher speed and productivity. The phase transitions in the infrastructure substitution in the former Soviet Union, however, are

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[3] The fractional shares, F, are plotted as the linear transformation, i.e., $F/(1-F)$, as the ratio of the market share taken by one infrastructure over the sum of the market shares of all other competing systems. Every competitor undergoes three distinct substitution phases: growth, saturation, and decline as shown by the substitution path of railways (and later roads), which curve through a maximum from increasing to declining market shares (see *Figure 6*). A detailed description of the model is given in Nakićenović, 1979.

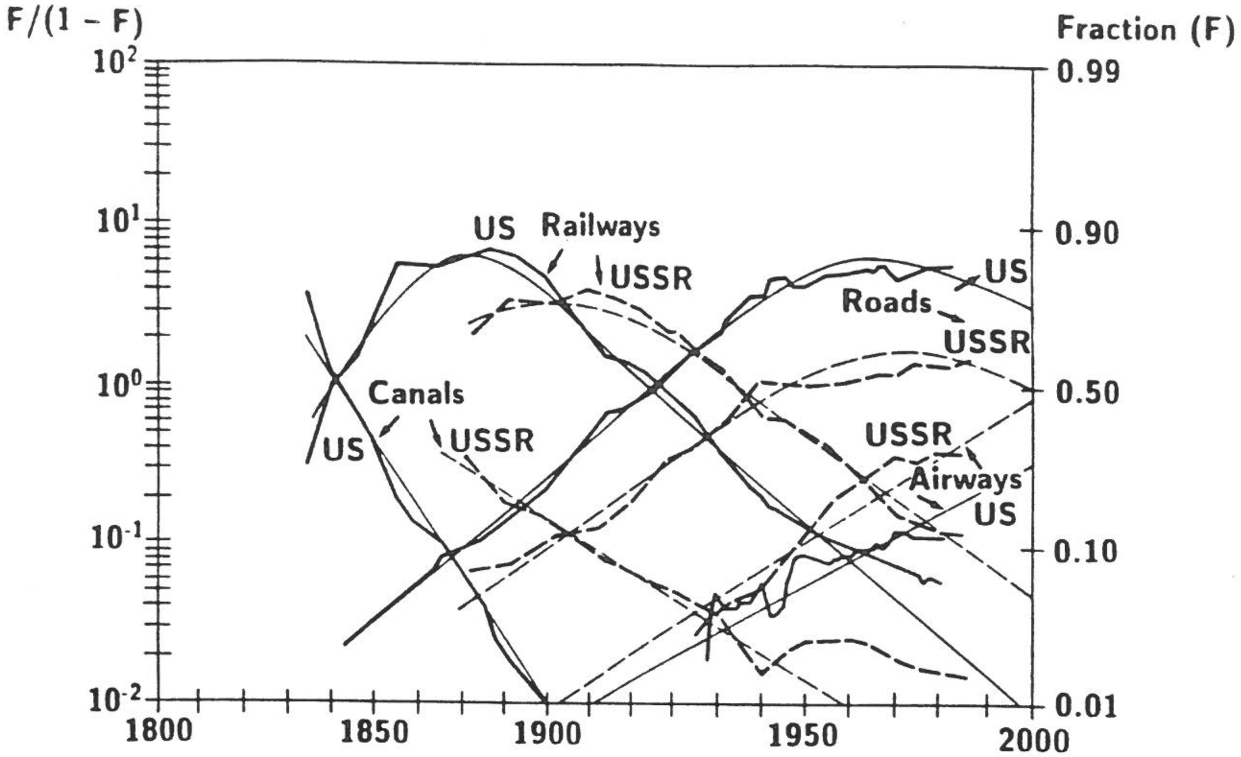

Figure 5. Substitution of Transport Infrastructures in the United States and the Former Soviet Union, Fractional Shares in Length (Grübler and Nakićenović, 1991).

lagged by a few decades when compared with the United States. For example, the dominance of railways lasted until the 1940s while in the United States it ended two decades earlier. The decline of canals occurred much later as well, while the growth of national airways follows the same path as in the United States. During the last decades, development of transport infrastructures in the two countries has been converging. The rate of relative growth in the importance of road infrastructure and their saturation also appear synchronized. However, road infrastructures are used differently in the two countries: by individual road vehicles (cars) in the United States and by collective ones (buses) in Russia. Thus, there is an increasing congruence and similarity in the structural and functional evolution of the transport system in the two countries. To a large extent this is also due to the fact that both countries have relatively low population densities and vast territories that modern transport systems must bridge in a matter of hours.

The substitution of older transport infrastructures for new ones and the high degree of synchronization in the diffusion of transport systems are not coincidental. They reflect strong linkages and similar pervasive changes in the overall evolution of the social and economic system denoting major techno-economic paradigm shifts. The diffusion of railways is linked with the spread of steel, coal and many other related technologies throughout the world. The same can be said about cars, the internal combustion engine, oil, petrochemicals, etc.

This process of evolutionary change is nevertheless only a proxy for the real dynamics in the development of transportation systems, which should be measured in some common performance unit. Because transport systems provide a whole range of services, such a common descriptor is difficult to define. Two obvious choices for an appropriate indicator are ton- or person-kilometers per year. These units distinguish between freight and passenger services, but they do not distinguish between short and long distances. As there is no obvious shortcut it appears necessary to analyze passenger and freight transport separately for both short and long distances. Fortunately, the available data make it possible to reconstruct the dynamics of these substitution processes for at least some countries. For example, *Figure 6* shows the actual usage of transport infrastructures. It gives the long-distance passenger modal split in the United States (top of *Figure 6*), the former Soviet Union and China (bottom of *Figure 6*). These examples are representative of the developments in most countries and illustrate a certain convergence in the development of transport systems.

Comparison of the three countries shows that in the past the intercity passenger transport development portrayed a phase-shift. Rail and bus are virtually extinct in the United States, while in the former Soviet Union and China they are still an important means of transport. Thus, while many characteristics of the former Soviet Unon's intercity modal split changes lag by several decades compared to the United States (with the exception of air travel growth), China's lag of some 20 years behind the Soviet Union is even larger (note the different time axes on the bottom of *Figure 6*). The above indicates that by the end of the century airways may become the dominant form of intercity travel in both the United States and the former Soviet Union. In both countries road transport currently has the largest share, albeit by automobile in one case and by bus in the other. The developments in the former Soviet Union may serve as a guide for the modal split changes in China over the next decades. What is important is that the average choice of different modes of passenger travel changes consistently and favors faster and more productive systems.

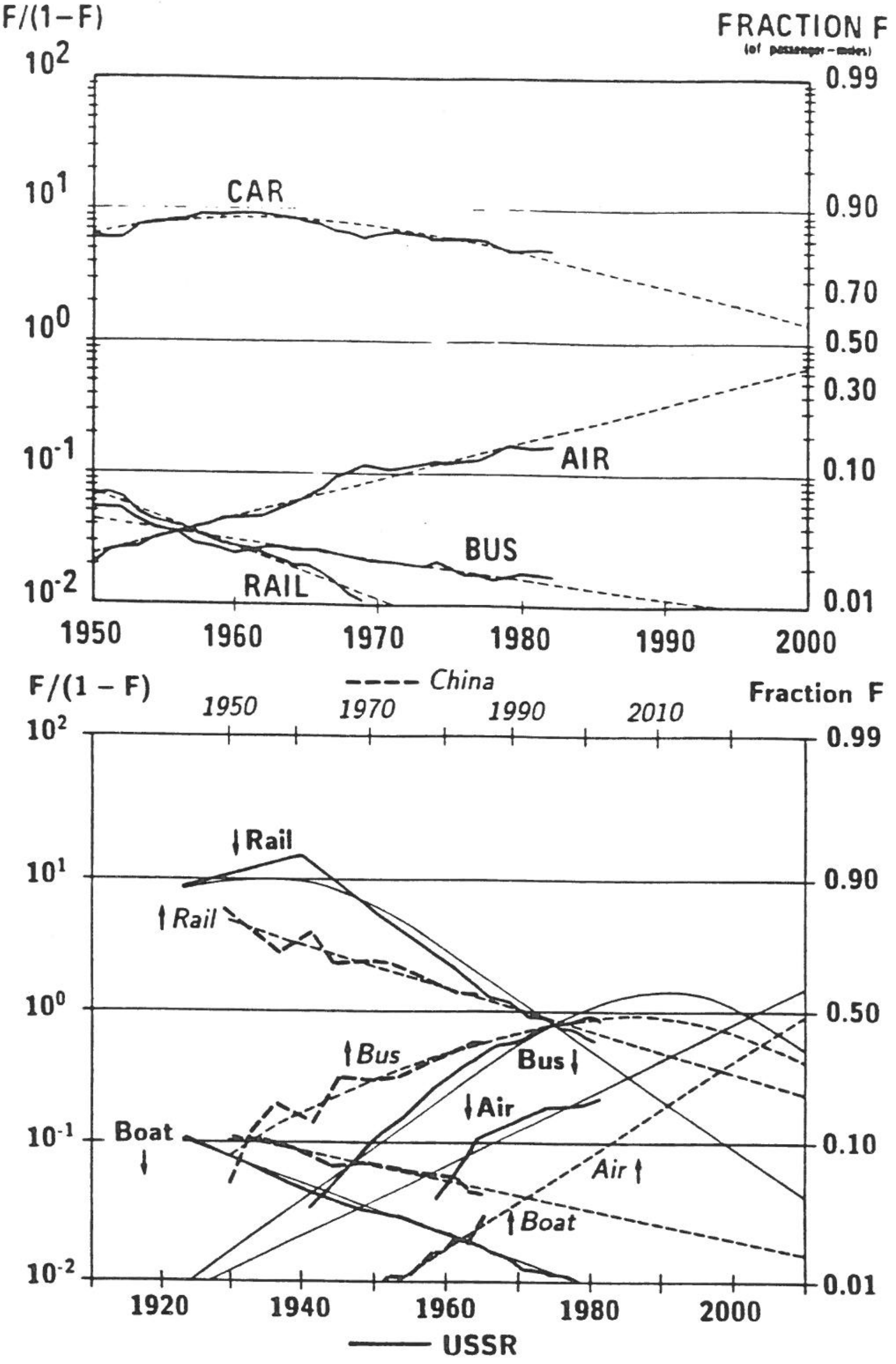

Figure 6. Substitution of Intercity Passenger Transport Modes in the United States (top) and the Former Soviet Union and China (bottom, with shifted time axes), Fractional Shares in Intercity Pass-km.

Zahavi (1979) has shown that traveling and commuting is optimized under the constraints of individual time budgets and family income. On average roughly 15 percent of disposable family income is allocated to travel so as to *maximize distance*. Szalai (1972) analyzed time budgets of the inhabitants of 12 cities throughout the world including industrialized and developing countries. His work indicates that the time spent for traveling and commuting (work and pleasure) is roughly 1.5 hours a day. In a given situation, each individual will make different choices, but on average the modal split will change as income increases, despite the assumed invariance of travel-time budgets. Incomes have increased and the cost of travel has decreased in real terms, leading to an increase in the volume of travel (passenger-kilometers) and the range in a given unit of time.

Over time, larger shares of travel are thus allocated to faster modes. The slower modes recede to serve fewer people over shorter distances (fewer passenger-kilometers) and low-value segments of transport. Their shares in passenger transport decline, resulting in the rationalization of the respective infrastructures. The least productive links are decommissioned, and the infrastructure declines. The diffusion of more productive and faster means of transport leads to increased range and connects ever larger areas into single functional entities. During the last two centuries villages merged into towns, towns into cities, and cities into metropolitan areas. Large urban corridors have evolved throughout the world, some approaching a hundred million inhabitants requiring high productivity transport systems.

4. Spatial Diffusion

The spatial dimension of diffusion processes is a well-recognized feature established in geography ever since the seminal contribution of Hägerstrand (1952 and 1967). *Figure 7* illustrates the spatial diffusion of railways in Europe (Godlund, 1952; Grübler, 1990) and shows the two characteristic features of spatial diffusion phenomena: the neighborhood effect and the hierarchy effect. Four spatial hierarchy levels can be identified in *Figure 7*. The spatial diffusion of railways originated in the United Kingdom starting in 1826. The years later railway networks extended over much of England and reached a second spatial hierarchy level: Belgium, Lyon in France, and Bohemia in the Austro-Hungarian Empire. From these second hierarchy levels railways extended over much of central Europe by 1846, and by that time the third spatial hierarchy level was reached including Napoli in Italy and St. Petersburg in Russia. The fourth spatial level was reached some 30 years later when railway networks started to be constructed in Greece.

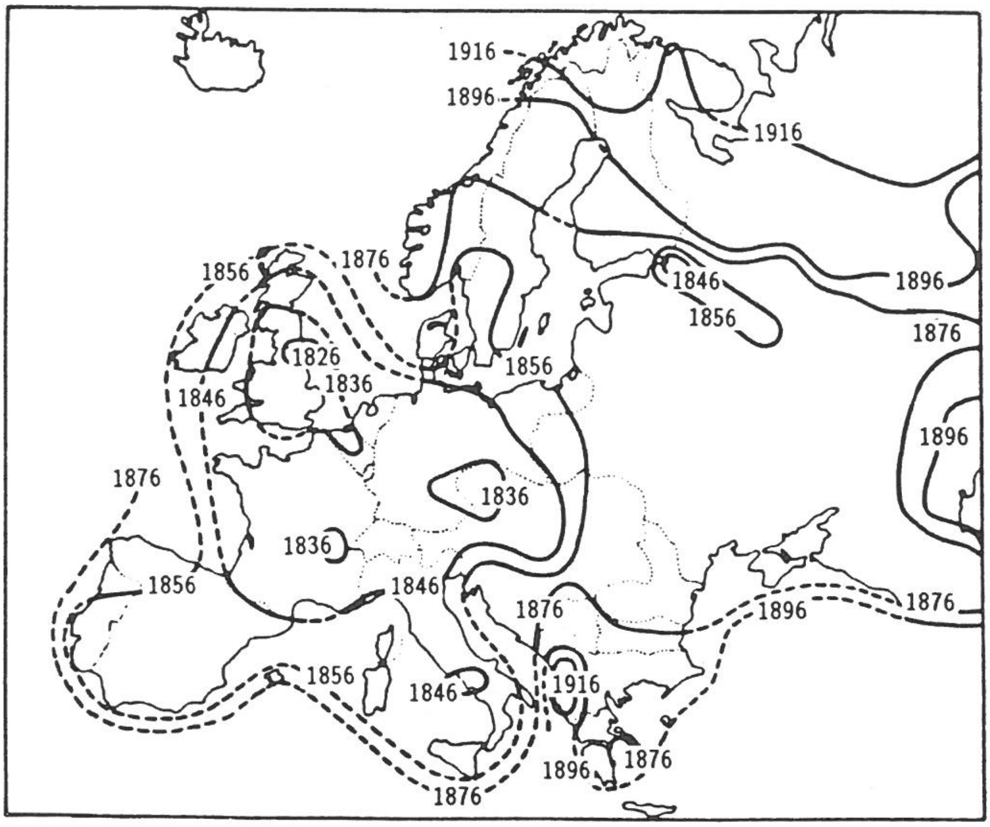

Figure 7. Spatial Diffusion of Railways in Europe, Isolines Indicate Introduction Date Date (Grübler, 1990).

The railway network in all European countries was basically completed (i.e., achieved its maximum network size) by the end of the 1930s. Ever since, the railway network has undergone rationalization and decommissioning of links. The completion of railway expansion throughout Europe by the 1930s, along with the later start of railway construction in peripheral areas of Europe is shown in *Figure 7.* There is a noticeable catch-up effect in the development of railway networks in Europe. Thus, while some 100 years passed in the United Kingdom between the start-up of railway construction and completion of the railway network, this development process proceeds much faster in the fringe countries of the European continent, such as Scandinavia, where the process took only about 50 years. The start-up dates of railway construction are thus spaced rather widely over time.

Another observation on the spatial diffusion of railway networks is that the ultimate railway density between the core countries (i.e., the first hierarchical levels of the spatial diffusion of railways) and their hinterlands was in fact very different. The railway network density (either per capita or per unit country area) decreases with the distance to the innovation and the spatial hierarchy centers of diffusion. The absolute level of adoption is however much lower for the late adopters compared to the early adopters. The ultimately achieved railroad density is in general higher the earlier the railroads are introduced; leaders achieve the highest diffusion levels. *Figure 8* shows this phenomenon. The density of the railway networks is measured as a ratio of the peak of national railway length over land area. Both countries where the networks were completed by the 1940s are included and those countries that built railways later and thus did not belong to the original railway bandwagon. It demonstrates that the railway densities can be grouped within a declining "density envelope" as a function of the introduction date. This result shows that whereas the diffusion rate accelerates (i.e., the "catch-up" effect) for late adopters, the intensity of final adoption levels decreases. The intensity falls even further for those countries that introduced railways after the completion of the expansion pulse in the core countries. This identifies an "opportunity window" for the diffusion of pervasive systems like railways, which were the dominant transport system during the second half of the last century.

The adoption level of the automobile in different countries follows the same pattern as the observed saturation levels of railroads. Of the industrialized countries, the diffusion rate was slowest in the United States and Canada, faster in most of the European countries, and fastest in Japan. The adoption of the automobile was even faster in developing countries, albeit that it started only recently and has led, at least for the time being, to relatively low levels of car ownership.

Figure 9 reports these results by showing the diffusion rate (Δt, given on the lower curve and labeled on the left vertical axis) as a function of the beginning of the innovation diffusion on the horizontal axis. The band at the top of the figure gives the estimated automobile adoption levels (plotted on the right vertical axis in number of cars per 1,000 capita with the associated statistical uncertainty bands), again as the function of the automobile introduction date. Thus, a pronounced *acceleration* of the diffusion rates can be observed that is proportional to the time lag in innovation adoption. Again, the ultimate adoption

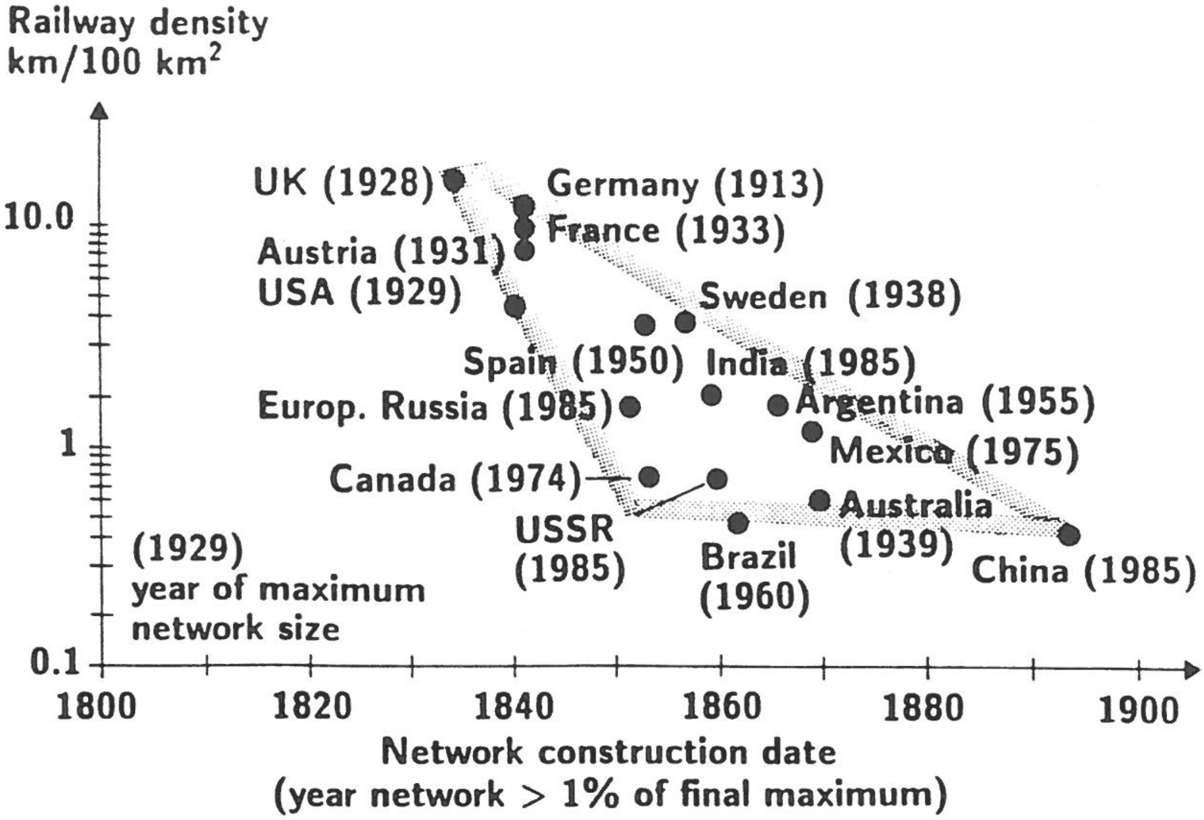

Figure 8. Railway Network Density as a Function of Introduction Date, World (Grübler and Nakićenović, 1991).

levels *decrease* with shorter diffusion time.

This result is consistent with spatial patterns of innovation diffusion. Originating from innovation centers that reach the highest adoption levels, the innovation generates additional gravity centers in space; however, the adoption levels remain lower in the peripheral regions compared with innovation centers. Our result confirms this finding at an international level in both time and space. Early innovators achieve higher adoption levels and have the longest diffusion or "learning" times. Peripheral regions catch-up so that the diffusion process focuses toward the saturation period, but the adoption level in the periphery remains much lower than in the leading centers. This acceleration tendency in the global diffusion process indicates that a country that started adopting private automobiles now would have a diffusion rate (Δt) of less than a decade. Such a rapid diffusion of car ownership appears quite infeasible from a practical point of view. Should it actually occur, it certainly will not result in a significant

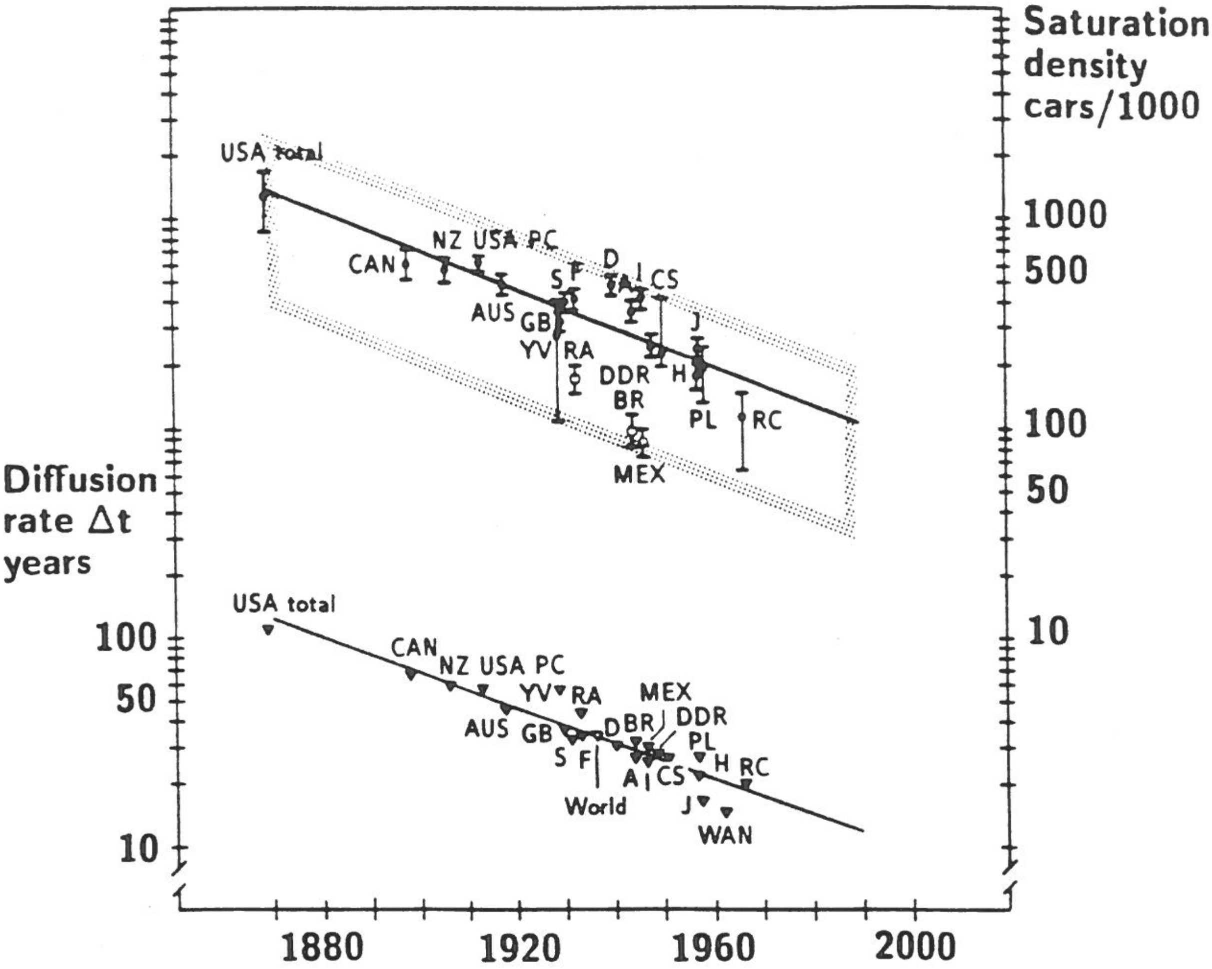

Figure 9. Diffusion Rates and Ultimate Ownership Densities of Passenger Cars as a Function of Introduction Date, World (Grübler, 1990).

growth of both absolute and relative car adoption levels. In other words, very few cars would be adopted.

From such a perspective, the current "opportunity window" of pervasive car diffusion to developing countries may be closing. An open question is whether a similar "diffusion bandwagon" as that in the industrialized countries might re-emerge in the longer-term future. To a large extent this is also a function of the development strategies taken by these countries. Unfortunately, the present development prospects in the reforming economies of Eastern Europe and in many developing countries are rather bleak. Therefore whereas it is likely that road transport will continue to increase in the developing countries, any massive diffusion of car ownership, especially to levels anyway close to those of industrialized market economies, cannot happen "overnight". It is more likely to take several decades and extend well beyond the time horizon of the illustrative energy scenarios adopted here. In the meantime, additional growth in mobility outside the OECD region will have to rely to a large extent – as in the past – on buses, railways and aircraft.

5. Scenario of Car Diffusion

Given that the replacement of transport and energy technologies follows broadly similar patterns both in space and time, our scenario of global mobility development assumes a similar co-evolution of transport systems and infrastructures in the future. A new generation of automobiles and aircraft is assumed to be associated with a new generation of vehicle fuels, namely electricity and hydrogen, new generation of infrastructures, such as smart roads, and new institutional arrangements. The scenario also assumes that the absolute diffusion level of these new technologies would be lower in the lagging regions of the world than in those that lead the innovation process.

The scenario of the future growth in automobile diffusion is based on two main assumptions. First, it portrays a S-shaped diffusion pattern that leads to a saturation after the end of this century. This is estimated from the historical growth of the world automobile fleet up to the present number of about 425 million passenger cars. Second, the diffusion process is separated into two phases, each corresponding to different market niches and driving forces of the growth of the automobile (see *Figure 4*, Nakićenović, 1986, and Grübler and Nakićenović, 1991). During the first phase, the automobile diffused rapidly into the market niches previously held by horse-drawn carriages, where its comparative advantage was particularly high and led to average growth rates of about 30 percent per year. The second phase, which started after the 1930s and is still in progress, is characterized by substantially lower growth rates: The number of cars registered worldwide increased typically by five percent annually.

The two phases of automobile diffusion are shown in *Figure 10*. They are especially visible on the logarithmic scale (left side) with the inflection point occurring around 1930. The scenario extends to the year 2010 and is shown on the linear scale (right) of *Figure 9*. Since the actual diffusion of the automobile in the world is still decades away from the estimated saturation level, the scenario is based on two alternative cases derived from the historical data - the "best fit" and "high" estimate. The two cases correspond to an increase in the global passenger car fleets of 21 to 38 percent by the year 2010.

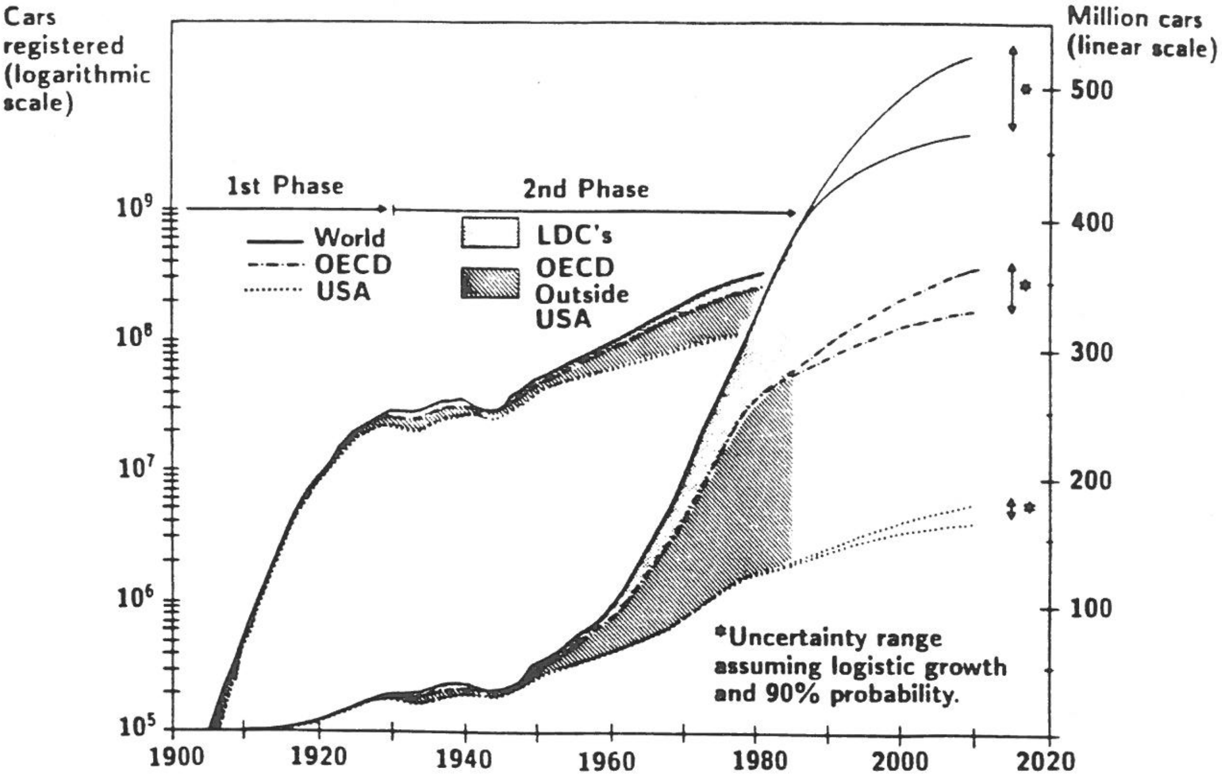

Figure 10. Passenger Car Diffusion and Scenario, World.

Table 1 summarizes the results by regrouping the 1985 values and scenario ranges (the best fit and high cases) for the year 2010 by broad geographical regions based on the selected sample of 21 countries. For a better comparison with other projections we have also aggregated 12 of the OECD countries (representing 98 percent of all passenger cars registered in the OECD) as a proxy for more developed countries, and the residual to the world total as a proxy for the sum of less developed (LDC) and (former) centrally planned economies (CPE). *Table 1* shows the high degree of heterogeneity in the ultimate adoption levels among different regions of the world. The differences are generally a function of the diffusion time. *Figure 10* illustrated that this is indeed the case and the scenario demonstrates the possible consequences of such a development in the future. The early adoption leads to higher diffusion levels and thus to higher and more pervasive automobile ownership. The scenario suggests an increase in the global passenger car fleets of between 21 and 38 percent compared with 1985 levels. The growth is higher in the developing regions both in absolute and in relative terms, and in the high case the car fleet actually doubles until the year 2010 outside the OECD region to a level of about 150 million cars.

Table 1. Scenario of Passenger Car Registration for the Year 2010.

	1985			2010		
Region	10^6 cars	10^6 pop.	Cars/ 1000	10^6 cars[a]	10^6 pop.	Cars/ 1000[a]
North America[b]	147.2	264.7	556	169.4–187.4	303.1	559–618
10 OECD Countries[c]	141.9	427.0	332	153.7–169.1	458.6	335–369
4 CPE[d]	11.7	80.5	145	16.5–21.5	85.7	193–251
5 NICs[e]	22.6	291.5	78	39.0–69.8	397.6	98–176
World	364.8	4838.5	75	439.5–501.6	7015.9	63–71
12 OECD Countries	289.1	691.7	418	323.1–356.5	761.7	424–468
% of world	79%	14%	–	71–73%	11%	–
LDCs and CPEs	75.7	4146.8	18	116.4–145.1	6254.2	19–23
% of world	21%	86%	–	27–29%	89%	–

[a] Range corresponds to best fit and high case respectively.

[b] USA and Canada.

[c] Australia, Austria, France, FRG, Italy, Japan, Spain, Sweden, New Zealand, and the UK.

[d] Czechoslovakia, former GDR, Hungary, and Poland.

[e] Argentina, Brazil, Mexico, Taiwan, and Venezuela.

This scenario is lower than other projections in the literature, especially for developing countries. Often, pervasive adoption of the automobile is thought to lead to similar ownership densities throughout the world. In contrast, the scenario does not rely on the motorization trends of the industrialized countries as a guide of what might occur in the developing regions. Instead, the rationale for the relatively low levels of automobile adoption in the world is based on the possible saturation of car densities in urban areas, an increase in air transport for longer journeys, the availability of new high-speed ground transportation systems, and perhaps also the increasing environmental problems associated with the further expansion of automobiles. The high urban population growth rates in developing countries calls for the construction of efficient mass transit systems for short-range travel. For long-distance travel, the growth potential for air transportation appears to be more consistent with the likely future developments in these countries than a linear extrapolation of the transportation trends of industrialized countries.

Today, different automobile ownership rates coexist at similar per capita income levels due to different initial conditions, diverse economic structures, varying degree of infrastructural development, etc. Countries like Argentina, Brazil, Mexico or South Korea have similar GNP per capita (of about 2,000 1982 US$ per capita in the Latin American Countries to about 2,500 1982 US$ per capita in South Korea) whereas in 1986 their car densities ranged between between 64 and 124 cars/1,000 inhabitants in the Latin American countries and 16 cars/1,000 in South Korea. According to the scenario, the diversity in automobile ownership would continue to be a characteristic feature of both developing and more developed countries.

6. Spatial Integration Patterns in Europe

Europe is often referred to as a single entity. In comparison to the new world and other parts of the globe this indeed may be appropriate. It is, however, a definition that is far removed from the actual demographic, cultural, social or economic conditions that prevail. Europe is very heterogeneous. The spatial distribution with respect to economic development levels is almost unimodal: the highest density of activities being in the "core" and tapering off towards the rim. Moving outwards towards the more distant peripheries in the South and East, this decreases even further. The core almost coincides with the Community countries, but also includes other developed regions in (Southern) Scandinavia and Central Europe (Switzerland and Austria). This representation reveals densely concentrated flows in the European core that thin out towards the periphery. Most of the interaction mass is centered in the pentagon London–Paris–Milan–Frankfurt–Amsterdam. This is the inner core of Europe. The gradient between the core, its rim and the more peripheral regions can be represented as a three-tiered structure, providing a conceptual taxonomy of European countries. This spatial classification of Europe into three regions is mirrored in almost all indicators of economic activity and spatial interaction, as reflected in the flows of people, information and goods. In terms of economic, human or spatial interaction indicators, the "functional distance" (i.e., the friction of distance intervening in the interaction) defines whether a particular region or country can be considered as part of the core's rim or periphery.

The only sharp delineation in a European context was represented by the iron curtain. For some 40 years the iron curtain separated

Eastern Europe both spatially and functionally from the rest of Europe. Politically and economically Eastern European countries have been so decoupled that apart from a few exceptions (most notably for the export of primary commodities), they could not even be considered as an integral part of Europe. Instead, Eastern Europe's level of integration with the rest of Europe was more representative of continents like Africa, Asia or Latin America. With the removal of political and institutional barriers this "apartheid" of the two Europes is on the verge of disappearing. The principal question therefore is what are the likely scenarios for the future integration and interaction of Eastern Europe with the rest of the continent.

Spatial interaction in Europe is represented by large metropolitan areas that act as gravity centers and are interconnected by flows. The flux of people and goods is the outcome of the mutually attractive force of the gravity centers and an expression of their degree of integration. This high density of interaction is an expression of the high level of economic activity, integration and resulting interdependence of inner Europe.

The dominance of interaction within the inner European core compared to the rim and periphery is most vividly illustrated by the flow of passengers between the three regions based on the actual number of city to city trips in 1982 (Grübler and Nakićenović, 1990).

Out of an estimated 2.2 billion interregional trips performed in 11 European countries in 1982, some 78 percent were domestic, 18 percent international to the inner core, and some 4 percent to the outer core and the rim. The inner European core accounts for two-thirds of all interregional trips performed in 1982 and also accounts for over 80 percent of all international interregional trips (either as source or as destination) of the 11 European countries covered in *Table 2*. The absolute dominance of road transportation (mostly by private car) also becomes evident: 84 percent of the domestic interregional trips and over 88 percent of all international trips rely on road transport. The share of railways is particularly low for international trips (less than 7 percent), whereas the share of air transport, whilst being rather modest for domestic interregional trips in Europe (less than 3 percent, compared to a market share value of up to 20 percent in large countries like the United States or the Soviet Union) rises to over 5 percent for international interregional trips and increases rapidly in both absolute and relative market share terms.

Table 2. Interregional European Passenger Traffic in 1982 (million).

Area From/To	Domestic	International Core	 Rim[1]	 Total	Total
Core	1,627	301	85	386	2,013
Rim[1]	49	90	4	94	143
Total	1,676	391	89	480	2,156
In % of all passengers	77.7	18.2	4.1	22.3	100.0
By rail	226	24	8	32	258
By road	1,405	346	77	423	1,828
By air	44	21	4	25	69
Rail %	13.5	6.2	8.8	6.7	12.0
Road %	83.9	88.5	86.4	88.1	84.8
Air %	2.6	5.3	4.8	5.2	3.2

[1] Austria, Denmark, Ireland and Switzerland.

This kind of analysis demonstrates that the interconnections in Europe, measured in terms of their intensity, do not necessarily follow the current political alliances and divisions within Europe. Austria and Switzerland portray a higher degree of interconnection (measured both in absolute number of trips as well as in per capita trip intensity) with the European core than, for example, the UK or Italy. By analogy, although the data are not available, we speculate that the other countries belonging to the periphery and especially the Eastern European countries, must have levels of integration that are a large factor lower than those of Italy and the UK. Even major rates of annual increases in these flows would have to be sustained for many years to reach the international passenger travel intensities of the European rim or core countries.

Thus, international passenger travel intensity of one to two trips per year per capita is typical for the interconnections of large countries with their European neighbors. Smaller countries have generally a much higher degree of international interconnections, with Switzerland showing the highest total international trip density of above 7 trips per capita, whereas the UK with 0.3 trips per capita remains relatively isolated from the European core.

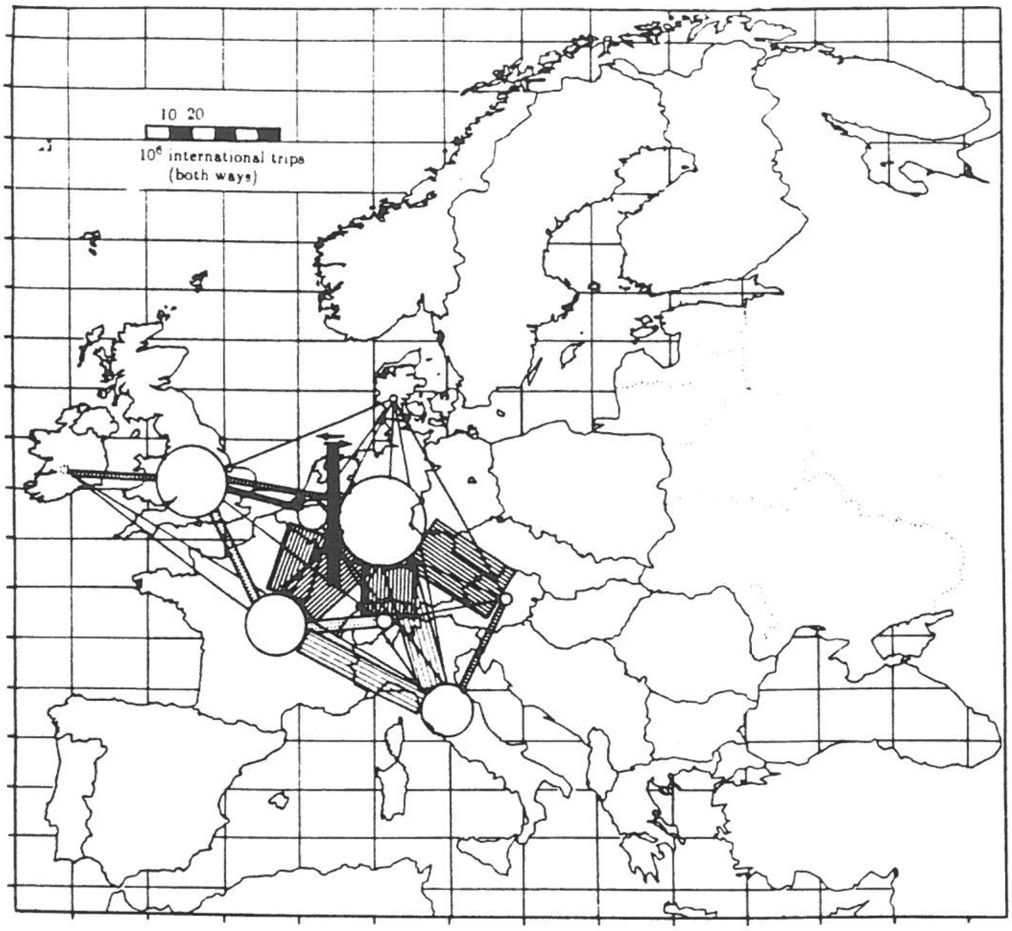

Figure 11. European Interregional Passenger Traffic, Domestic and International in 1982 (in million passengers, domestic proportional to circle area, international trips proportional to thickness of connecting bars).

Using the above metaphor of gravity centers and their interconnecting flows as expressed in the domestic and international interregional passenger traffic, *Figure 11* shows that the pentagon of the European core undergoes a salient transformation. With the very large flux of interchange between Austria and the Federal Republic of Germany, the outer delimitator of the European core is moved East. Most of the interaction though is focussed in the triangle between France, the Benelux countries and the FRG. Compared to the European pentagon, as shown by air passenger flows, the importance of London diminishes as a manifestation of the persistent barrier effect of the Channel and, possibly, also illustrating that even modern transport infrastructures cannot completely overcome the separation of the British Isles from

Continental Europe.

Thus the flows between the European gravity centers appear to follow closely a hierarchical structure. This is in fact not surprising considering that urban agglomerations show generally a rank-size distribution pattern. This is illustrated in *Figure 12* for the FRG. The rank-size classification shows that there is a mathematical relationship between the magnitude (i.e., the size, usually measured by the resident population) of a given city and its rank within a hierarchy of central places. For example, if the coefficients of this rank-size relationship are known, one can determine immediately the size of, for instance, the 100 largest cities based on the size of the largest city of a country. It is interesting to note that compared to other European countries, the top rank cities of the FRG are below the size expected based on the rank-size distribution, pointing to a polycentric structure of the major cities of the FRG and also to a lack of a national capital comparable to Paris or London. Possibly the greater Berlin with over 5 million inhabitants could emerge as the city with the highest rank in the system of central places of the unified Germany. In such a case a new significant "attraction potential" with resulting dense travel and communication flows is to be expected.

The flows between the gravity centers in the same way as the rank-size relationship orders the gravity centers by their relative importance; however, the relative positioning of cities and their source-destination traffic flows can be different, as exemplified by the example of West-Berlin, which is population-wise the 6th largest city of the FRG, whereas in terms of its traffic flows to and from the city it ranks only 67. *Figure 12* also shows that the relationship between the largest and the smallest passenger flows is the same between the largest and the smallest gravity centers. In other words, once the rank-size distribution of the cities of a given country and the traffic flow between any pair of cities are known, it would be easy to determine the rank-size distribution of the intra-city connections and also by integrating the total traffic flow of a country, based on above finding.

The formal relationship in the rank-size distribution of the intra-regional passenger flows allows also the determination of a rule of thumb distribution of the traffic flows. In the above example for the FRG, the top 25 percent of the intra-regional relations account for 50 percent of the total long-distance trips of the FRG. Seventy-five percent of all traffic is accounted for by 50 percent of intra-city connections based on the above distribution function.

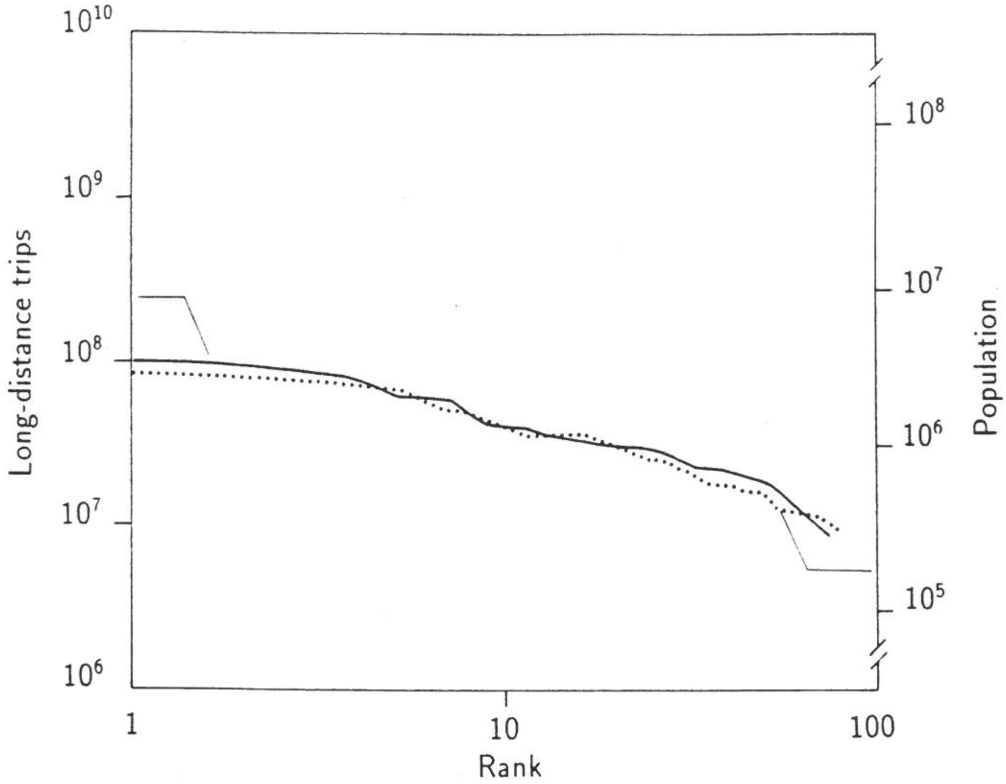

Figure 12. Rank Size Relation of 79 Metropolitan Areas and Their Interregional Passenger Traffic Flows in FRG in 1985.

The spatial pattern of goods transport in Europe a similar and even more drastic structure: the bulk of the exchange is concentrated in the core, with low interaction intensity towards the periphery, particularly in South-western and South-eastern Europe. Out of a total of 14 billion tons transported in and between 19 West European countries in 1986, 95 percent was national (domestic) traffic and only some 5 percent was international traffic. In international goods traffic the dominance of the European core countries is particularly noticeable, receiving 87 percent of all international goods tonnage. Also, 75 percent of all international goods transport flow between the core countries indicating that the economy of Europe is basically confined to the central core area. The modal split in domestic goods transport shows the absolute dominance of road transport, accounting for 90 percent of all tonnage transported nationally in the 19 Western European countries aggregated in *Table 3* (excluding sea and pipeline transportation; air freight is negligible). The dominance of road transport decreases in international goods transport, where trucks account for close to 47 percent of the tonnage transported, with inland waterways taking an important share of over 30 percent. The high share of inland waterways in West European international goods traffic is the result of the dense waterway traffic between

Table 3. Western Europe Goods[1] Traffic in 1986 (million tons).

Area		International				
From/To	Domestic	Core	Rim	Periphery	Total	Total
Core	9,429	505	12	2	519	9,948
Rim	2,399	33	21	1	55	2,454
Periphery	1,432	7	3	2	12	1,444
Unaccounted	0	43	28	18	89	89
Total	13,260	588	64	23	675	13,935
In % of all tonnage	95.2	4.2	0.4	0.2	4.8	100.0
By waterway	230	205	5	2	212	442
By rail	1,086	110	27	10	147	1,233
By road	11,944	273	273	33	10	316
Waterway %	1.7	34.9	7.7	9.0	31.4	3.2
Rail %	8.2	18.7	41.5	45.5	21.8	8.9
Road %	90.1	46.4	50.8	45.5	46.8	87.9

[1] Excluding sea, pipeline and air transport.

the Benelux countries, France and the FRG (primarily on the Rhine river).

The share of waterways in goods transport decreases drastically from the core to the rim and periphery. Symmetrical to this, the importance of railways in international goods transport increases further out to the periphery, reaching 45 percent, compared to 19 percent in international goods transport in the European core. The share of road transport in international goods traffic remains, on the other hand, rather constant at 46 to 51 percent between the core and the periphery.

Thus, the European core dominates international goods transport as illustrated graphically in *Figure 13*, whereas the European periphery is only marginally connected via intensive goods flows to the core.

7. Two Scenarios of Maglev Diffusion in Europe

The analysis of the spatial distribution of economic activities and the spatial interaction patterns as reflected in travel and freight clearly showed the large disparities between the European core and the low

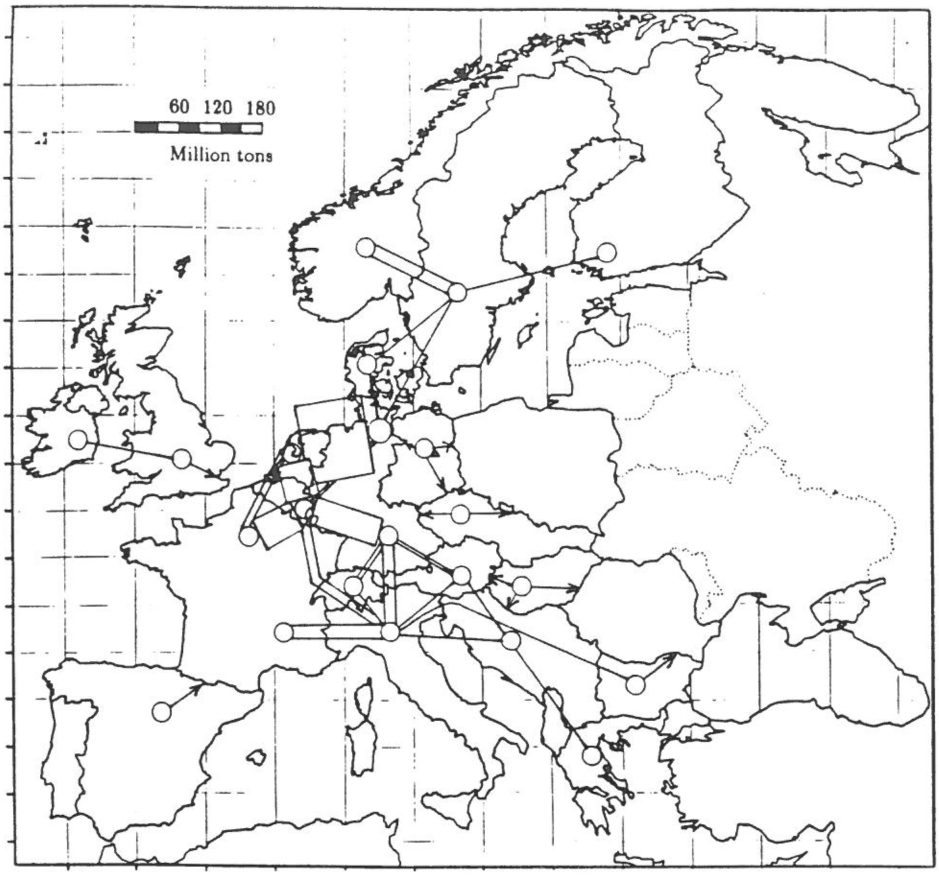

Figure 13. Major International Goods Transport Flows Between 19 European Countries (million tons).

levels towards the periphery (Grübler and Nakićenović, 1990). Any scenario of possible future development has to reflect the increasing "gravitational pull" of the core, and therefore a further increase in the gradient to the periphery. Such development would be very likely according to the gravity model of spatial interactions. Taking this analogy a step further from the Newtonian physics to present day cosmology, one could speculate about a possible mass collapse of the core and the effects of resulting shock waves on the periphery. "Mass collapse" could be imagined as a situation in which the core develops into a functional entity that can be characterized as a European ecumenopolis. This should *not* be confused with a single high density central European city. The European ecumenopolis would instead consist of a network of interacting centers connected by highly efficient infrastructures. Between these components of the ecumenopolis large "empty" spaces would exist, much like the green belts of 19th century garden cities. Frequently the empty space would take the form of untouched natural parks built on the recultivated industrial areas of the 19th century.

The salient feature of the ecumenopolis would be that the current long-distance travel within the European core would become local commuting, and long-distance communication would be replaced by local communication. It is in this sense that we speculate about the possible collapse of the European core. It would imply international travel densities equal to those of the largest metro stations of London, Paris and New York, and frequency of communication at the rates of present day Paris and London intercity phone calls.

Assuming that one out of two inhabitants commutes every day, as in Hongkong, Paris or London, the population of the European ecumenopolis would make about 200 million "local" trips per day. Most of these trips would extend over distances more typical for present international and long-distance trips. This would correspond to about 70 billion passenger trips per year or about a factor 30 increase over present (1982) international travel densities. Considering that it may take between 50 to 100 years to implement such a new "Eurometro" infrastructure one could assume that by 2010, ten percent of the ultimate potential could be achieved, or about 7 billion trips per year (corresponding to an annual growth rate of 5 percent per year over the next 20 years).

Although such a scenario may appear unrealistic with the current technologies and institutions, and in any case infeasible with a further intensification of traditional transport modes such as car or rail travel, it would be consistent with the historical trend towards greater spatial range. *Figure 1* illustrated the increase in the daily travel range in France ever since 1800. The daily travel increased with the process of development throughout the world. These increases in mobility were primarily achieved by the introduction and growth of new transport modes, railways in the 19th century and buses and cars in the 20th century. Although the increases in mobility may be sustained over several decades by increases in the performance of the dominant transport system, there are obvious limits to the further expansion of traditional transport systems.

Taking the long-term secular trend from *Figure 1* as a guide, mobility could increase to some 100 km per day per capita by the year 2010 and to about 300 km by the year 2040. A three-fold increase in passenger travel by the year 2010 would cause serious obstacles from a logistic and also from an environmental viewpoint if based on the growth of car travel. Furthermore, the time budget constraint may even be a more stringent limitation considering that the average travel speed by car does not exceed some 30 km/h. Even larger travel ranges would in any case be infeasible with present day transport systems. Ranges in the order of 300 km per day or more are however, plausible considering a transformation of present local commuting to long-distance commuting within an European ecumenopolis based on a maglev "Eurometro" with speeds over 600 km/h connected to more conventional high speed infrastructures like the TGV running at 300 to 400 km/h. Such a "Eurometro" could also provide the necessary feeder functions and integration to transcontinental travel. Hypersonic air transport connecting the world cities in as little as two hours would, for of obvious environmental reasons, have to be removed from the densely populated areas of the European core. A more likely scenario would consider a hypersonic hub located off-shore, building on the considerable engineering expertise available in Europe as a result for example of offshore platform technologies developed for North Sea oil production.

It has to be emphasized however, that the above outlined scenario is not merely a question of technological developments and investments into new infrastructures. Present institutional rigidities impeding a harmonization of European infrastructures (such as the conflict on compatible design parameters between the French TGV and the West German ICE new rapid rail systems) will have to be overcome. New regulations, organizations and institutions would be required to further "just-in-time" integration and communication within the "gravity strings" of a European ecumenopolis. Finally the question of social adjustments and shifts in employment away from traditional economic activities to new opportunities opened-up by long-term investments into new infrastructure should also be considered. From such a perspective, coal miners could build the tunnels of the "Eurometro" maglev, and North Sea oil workers the new offshore hypersonic hub, once their services in their traditional fields are no longer required due to changing societal and economic preferences in the energy system.

Assuming that the core would undergo such a gravitational collapse the key question is what would happen with Eastern Europe. Of the many possibilities two contrasting alternatives are of special interest in this context. The first describes a future in which the core becomes self-contained through the collapse and closed to the periphery. Such a closure could include a mixture of institutional and physical barriers such as the lack of efficient and compatible transport and communication systems in Eastern Europe. A second more optimistic future would result if the attractive force of the core is not blocked by the existence of various barriers thus enhancing integration and interchange. This would further increase the activities both within the core and periphery, and provide a positive feedback to the intensity of interaction within a wider Europe. In both scenarios, however, there is a stronger increase in density of activities within the core, so that the major difference between the two scenarios is in the steepness of the gradient toward the core.

The metaphor of the "golden curtain" describes the image of the first scenario (Grübler and Nakićenović, 1990). This kind of scenario implies a reversal in the polarity of the segmentation barrier between two Europes. Whereas before people could not leave, now they are denied entry. The "golden curtain" has both technical and institutional dimensions. Technically, barrier effects may stem simply from the incompatibility between the new infrastructures in the core and traditional systems in the periphery. For instance the barrier effect could operate very selectively. Second kind of barriers could be institutional in nature, i.e., visa requirements, residence permits, "entrance fees" and infrastructure usage tolls based on lump sum (e.g., annual) payments. All of these institutional barriers could be classified under "equal rights for all" in a sense that everyone would have to fulfill the same conditions for access. In practice, this would of course mean that the residents of the periphery could be denied access.

The second scenario would envisage either some extension of infrastructures from the core into the periphery or an effective interface between the traditional modes predominating in the periphery with the advanced systems of the core. This kind of more optimistic scenario would imply a modest degree of integration and thus also higher standards of living, mobility and communication in the periphery. Nevertheless, spatial and social heterogeneity will also continue to prevail in this scenario. This will be especially true with respect to the relatively high access costs to the core for the residents of the periphery. Consequently a two-tiered society could emerge in the East, with the elite having a similar lifestyle to people in the core. For instance the elite may travel by air and use telefax machines, whereas the rest of the society would continue to share telephones and continue to travel by bus and conventional rail. The crucial difference between this and the "golden curtain" scenario is that the degree of integration would be higher, and at least the possibility exists for a part of the society of the European periphery to catch up with the core.

In the "golden curtain" scenario, the large gradient between the core and periphery (and especially Eastern Europe) that has prevailed over the last 40 years is basically perpetuated. This means that, while economic exchange relations exist, the periphery is decoupled from emerging development trends of the core. In the transport area, this scenario could imply that electricity based maglevs and electricity or hydrogen based cars could emerge in the core in order to improve both the effectiveness of the systems as well as to alleviate environmental concerns. In contrast, the periphery will continue more in the direction of increasing car and bus utilization, for instance by importing used equipment from the core.

In the second scenario the number of interchanges between the core and the periphery would improve to such an extent that one could speak of one Europe, however with different degrees of development: a "two speed Europe" instead of "decoupled Europe". With respect to transport systems the periphery would not develop an *interconnected* maglev network, but instead may develop stand alone segments with some connections to the core. For example maglev links could be developed between Leningrad and Moscow or between Berlin–Prague–Munich, or Budapest–Vienna–Munich. The infrastructure development pattern in the European periphery would look like a mosaic with fragmented resemblance to the core, much like the present day isolated highway links throughout Southern and Eastern Europe.

Even in the more optimistic "two speed Europe" scenario, this would imply that growth in passenger travel and goods transport from the periphery to the core would not increase more than the interchanges within the European core itself. In the "golden curtain" scenario, the gradient in economic activity and integration between the core and the periphery would become larger. In the "two speed Europe" scenario, the periphery would achieve a higher level of integration to the core, furthering its autonomous economic development potential.

In conclusion we will briefly describe an important infrastructural component as a prerequisite of this development, i.e., the emergence of new high-speed rail based transport systems in Europe. The high-speed connections illustrate most vividly the nature of the "gravitational compression" within the European core. *Figure 14* shows the space-time geography of Europe, giving distances in kilometers and travel time in hours by conventional and high-speed rail. In comparison to the conventional rail system, the high-speed trains generate substantial

European Distances: Travel Time by Rail
Present Network (1982 data)
High-speed Network (incl. Maglev)

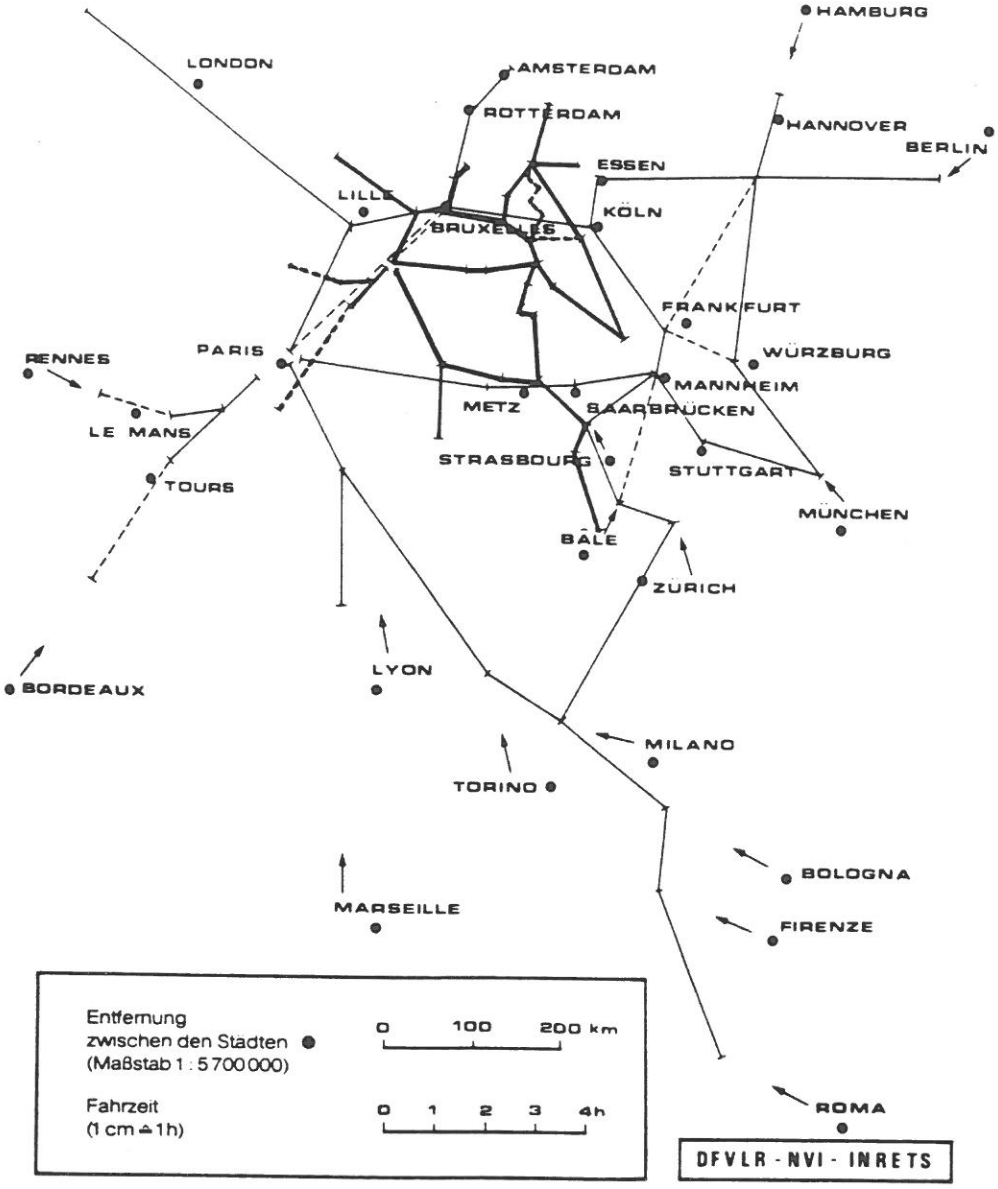

Figure 14. Space-Time Geography of Europe in Kilometers and Travel-Time by Conventional and High-Speed Train.

travel-time reductions that result in a "space-time contraction" shown in *Figure 14*. The speed of the advanced train links illustrated in *Figure 14* are assumed to be about 300 km per hour. This may be considered as modest compared to the proposed maglev designs for the next millenium capable of speeds up to 1000 km per hour which would result in a "gravitational collapse" by comparison. The figure illustrates that the most modest high speed rail networks proposed to date would reduce the effective frictional distance between European cities, but would not collapse into an agglomeration traversable by commuting (i.e., less than one hour time distance). Nevertheless the proposed infrastructure can achieve a higher degree of integration by reducing travel time to a few hours and thereby increasing the travel flux and interchange characteristic for an "ecumenopolis". It does not allow, however, the emergence of a single functional European metropolis. Maglev infrastructure would create such a gravitational center in Europe, but the time-scale is longer placing the concept of a "single" Europe well into the next century.

8. A Possible Global Outlook

There is a consistent global analogue of this differentiated European development into a core and periphery. The core was characterized as an ecumenopolis with a network of interacting centers connected by highly efficient infrastructures such as a maglev system while the periphery would resemble more the current structure although it may develop stand-alone segments of a high interaction links.

A global analogue of this development was called "the polyanter and the periphery" by Berry (1990). The heart of the argument is the fact that the share of global population living in urban areas has been increasing ever since the beginning of industrial revolution to reach almost 50 percent at present. This development can be expected to continue and is illustrated in *Figure 15.* At the end of the Great Depression, the world's more developed regions were barely 40 percent urbanized, while today more than 70 percent of inhabitants in these areas live in urban areas (Berry, 1990). Today, the world's developing regions are approaching 40 percent urbanization levels and their urban growth is still accelerating so that in 50 years the world as a whole could be more than 70 percent urbanized. For example, between 1975 and 2000, the number of cities larger than million inhabitants is expected to more than double, from 190 to 440 (Berry, 1990).

Thus, during the next five decades and beyond, the share of people living in urban areas can be expected to double while the global population doubles itself to some 10 billion. As a result the urban population might increase up to four times leading to unprecedented levels of population concentration. In turn, this would cause further

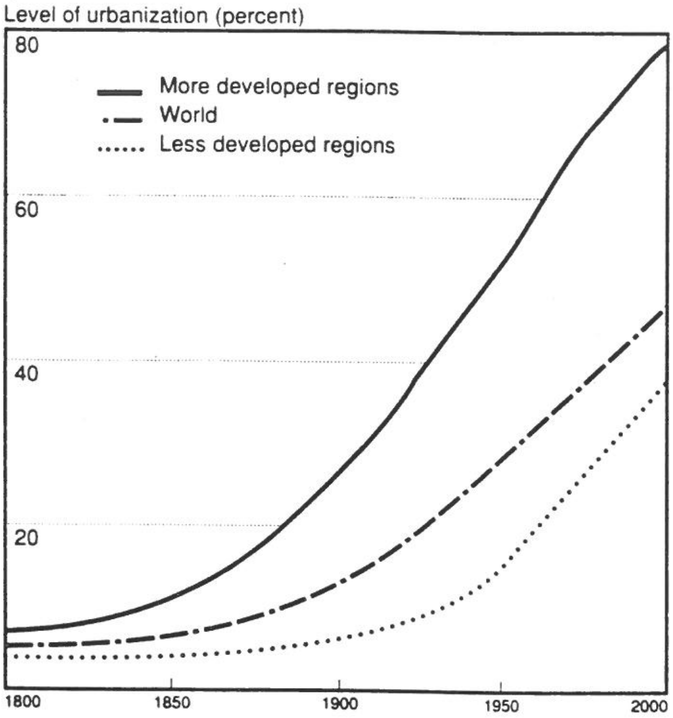

Figure 15. Increases in the Level of Urbanization in the World's More-and-Less Developed Regions, 1800–2000 (Berry, 1990).

compression of "time and space" in the world as new technologies are introduced and diffused that are capable of handling the enormous flows of people, goods and information. According to Berry (1990), one way to characterize the resulting urban systems is as dynamic networks. This structure suggests that traditional vertical hierarchies arranged into heartlands and hinterlands are to yield to a global structure where the regional "cores" are centers of creativity and entrepreneurial activities wherever they may be located and are linked into transnational (and intercontinental) networks (Berry, 1990). The tightly interlinked polycenter of the global urban network is illustrated in *Figure 16* as it appears today.

It spans three continents and connects Japan, the European core and urban centrs in the North America. During the next half century, the polycenter can be expected to integrate further and grow to include some, new peripheral regions. As was speculated in the preceding section, the European core might become interlinked by high-productivity maglev or super-fast rail network. The Tokyo–Osaka corridor has already the first such rail system as do parts of Europe including France, Germany, Benelux countries and, in the near future, also

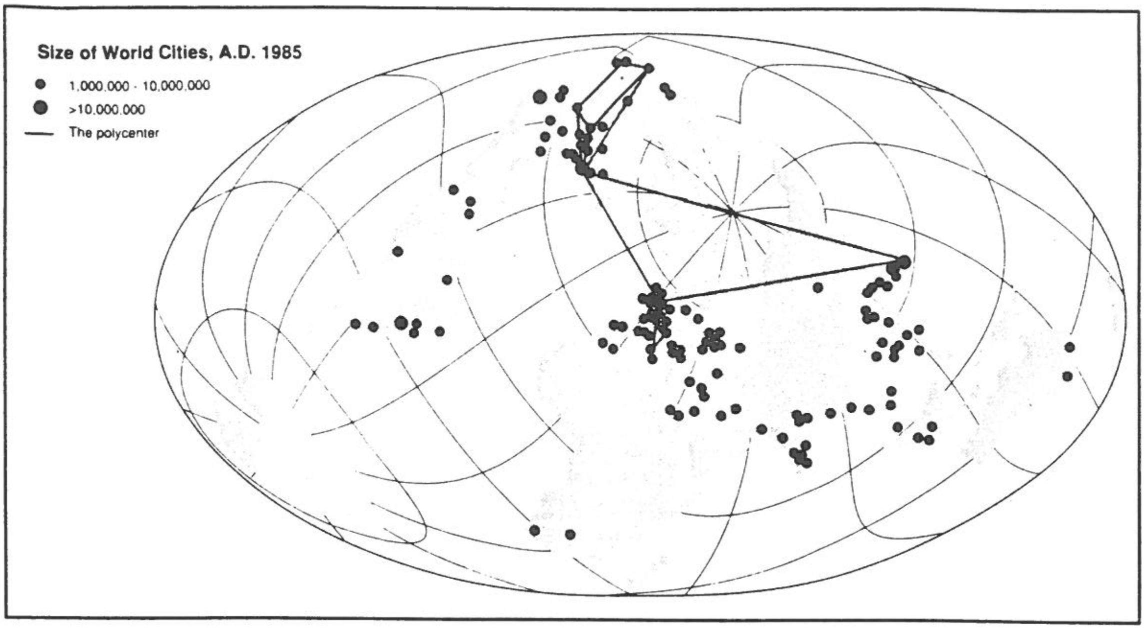

Figure 16. The Polycenter and the Periphery, 1985 (Berry, 1990).

Spain. A similar system is planned for Dallas–Fort Worth concurbation in the USA and a number of similar systems are being discussed in many countries including, for example, a fast rail system for South Korea. First, maglev systems are planned as well including a firm decision to build a link between Orlando airport to Disney World in Florida. The German Transrapid design was chosen for this first commercial maglev connection.

According to the proposed scenario, each continental sectors of the global polycenter would become interconnected by maglev and/or super-fast rail systems such as the French TGV design. Each of these grids would in turn have a few global-scale hub airports connected by super-jumbo aircraft such as the recently announced 1000 passenger Boeing aircraft (Baker, 1992) or by high-productivity supersonic and hypersonic transports in the more distant future for Far East to Europe and North America links. Shorter over-the-water links such as those between the Tokyo–Osaka corridor and Seoul in Korea might be difficult to connect by maglev and too impractical and environmentally hazardous to connect by super-jumbo air transports. A possible future alternative might be the recently announced transoceanic wing-in-the-ground effect air transports designed in Russia that could be as large as ocean liners carrying 2000 passengers with fuel economy much better than conventional aircraft and with almost the same speed (Aviation Week, 1992). They would connect harbor terminals of the maglev grid.

In sum, this scenario envisages a global metro system consisting of continental and subcontinental maglev networks within the polycenter allowing transit times of up to at most a few hours. These maglev networks would in turn be connected by advanced generation of large air transports over global distances and by large ground effect air transports within "coastal areas". These air transports would also connect the large urban centers in the world periphery with the polycenter. This scenario also envisages a growing number of very large cities and urban concentrations in peripheral regions beyond the polycenter but with much lower levels of interaction compared to those within the polycenter.

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