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MOBILITY: ON THE POTENTIAL AND THE EFFECTS OF INTRODUCING MAGLEVS IN THE EUROPEAN TRANSPORT SYSTEM

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PLAN OF WORK

Our system analysis searches for the implications of Maglevs as a new technology for the transportation of people and goods.

The conceptual framework and the operational conclusions are condensed in the executive summary. In a nutshell Maglevs appear to have a revolutionary *potential* capable of satisfying the mobility demand for the next century.

The second part of the text is devoted to various technological and operational aspects. Part of the text is actually transferred into the legends of the figures that should be read in parallel. Due to severe limitations in financing it has not been possible to go into special applications in Europe.

The appendix contains the basics about the deep seated instincts of the traveling man, which severely constrain the characteristics of a successful transport system.

EXECUTIVE SUMMARY

Maglev is a new ground transport technology that has a potential for speed. Consequently, it also has the potential to revive public ground transport which is now ailing to death.

Our analysis has two prongs; the first one deals with an overview of the *technology* with the objective of *identifying the problems* and *the potential*, short– and long–term, of the various mutants. It is a little early to enter into the problem of economics, but it is safe to say that the mutant with more technological potential for operative performance has also more configurations available to escape economic pitfalls.

The second prong deals with the *ways of using this technology,* i.e., to build a conceptual interface between the social system and the technology. Misuse can finally rob the citizen of the power of speed, and empirical tatonnement rob him of his money.

Maglevs are magnificently suited for urban, suburban, intercity, and continental traffic.

To arrive at these conclusions, I have filtered almost all the literature on Maglevs, and discussed the issue with experts. I have also made extensive use of a conceptually very illuminating vision of the *anthropological* drives and constraints for travel demand. The subject has been touched upon in various reports on mobility prepared for PROMPT. One such report, forthcoming in the journal *Technological Forecasting and Social Change* is attached here as an appendix for easy reference.

In a nutshell: man tidily preserves his instincts of a *territorial cave man,* using speed to enlarge his territory in order to profit from the opportunities contained there, and comes back at night to his cave. He is scared of the big aggressive world and carefully doses his *sorties* to about one hour per day. *All traveling is cave–centered and space is homothetical to speed available.*

Consequently, the configuration I finally propose for Maglev systems as a long–term attractor for ground transport, is substantially independent of the spatial hierarchical level except for speed. It calls for *small vehicles* (20 to 50 people maximum) rushing from *point to point* under the complete control of a computer system. It very strongly resembles, conceptually, the architecture of an Integrated Service Digital Network (ISDN) system for the transport of information where addressed packages of digits are switched at nodes to final destination. The physical embodiment of the Maglev machinery strongly resembles, conceptually, that of particle accelerators where "buckets" of potential fields carry bunches of charged particles.

As explained in the Appendix, the parameters through which a transport system is evaluated by the consumer is its *inclusive speed* (in the same spirit of the inclusive fitness of Darwinian biologists). To clarify with an example, the great success of cars is due to the fact that their inclusive speed is high (if one can find a parking space) in spite of the fact that their operational speed is mediocre (40 km/hr mean, since Ford's time!). The good inclusive speed comes from the fact that one can go from A to Z without waiting time and mode change. It is interesting to note that 80 years of technological development were mainly devoted to insure a constant level of inclusive speed for cars (the said 40 km/hr since Ford's time). Appendix – Figures 12 and 13.

To have a high inclusive speed in a public service like the Maglev necessitates consideration of not only the actual distance between stations but also of any waiting time and intermode changes, which should be minimized. This calls for a peculiar set–up whereby stations are numerous and trips should be "personalized" as far as possible. This entails no intermediate stops, especially for urban and suburban travel where time is really critical.

Technical Conclusions

1. Various technical proposals for the realization of a Maglev have been analyzed. From a systems analysis point of view the *side–wall suspension* with null flux centering appears the more promising (Figures 4 and 5). It has the potential of simplicity, easy access for repairs and compactness. *It allows vertical displacements* and, consequently, switches with no moving parts can be utilized. As the technical situation is still evolving, Europe should help keep the options open. Incidentally, the Japanese, who were first in Maglev experiments, do keep their basic choices evolving: they are now working on the side–wall. The Americans are also converging towards this sytem.

2. As mentioned above the quintessence of a new transport technology is to provide inclusive speed. Maglevs can have the speed characteristic of airplanes, with the possibility of "landing" next door, i.e., at a Metro station. High speed has many problems: aerodynamic, acoustic and energetic. In tunnels it requires large cross-sections. The neat solution is that of the Swiss Metro which operates Maglev trains into *partially evacuated tubes*. This technology should be given priority in long–term R&D plans. Furthermore, realization with other concepts, such as the German Transrapid, should be planned in such a way as to permit a retrofit with the technology of evacuated tubes and side-wall suspension. It must always be kept in mind that transport infrastructures have a life time of centuries. *Compatibility* does not mean only the possibility of accommodating evacuated tubes, but also *straightness* to accommodate higher speeds.

3. Electromagnetic linear motors have peculiar characteristics that should be exploited for a superior performance of the Maglev. The salient one, in my opinion, is the capacity to exert a *pull on the train independent of speed.* This means that the *power delivered is proportional to speed*, something an electric or internal combustion engine cannot do. From the point of view of minimizing transit times, this allows operating the trains under the best conditions, i.e., accelerating during the first half of the trip and braking for the second half (CAM mode, or Constant Acceleration Maglev). Such a mode of operation can produce very smooth rides, in addition to the potential of very high

speeds with accelerations below those of a sports car (typically, 0.5 G or 5 m/sec^2).

4. Linear motors operated in a CAM mode can absorb very high power levels when speeds become high. In a Gedankenexperiement, I have linked Bonn to Berlin (500 km apart) in ten minutes with a 0.5 G (5 m/sec^2) CAM train. The power absorbed in the center of the track would be in the order of Gigawatts for a 100 tons train. Because power demand constantly goes from these levels to zero in a matter of minutes, this would put a heavy strain on the electric grid feeding the Maglev system. A solution, however, is in sight. Constant pull force means *constant energy per unit distance.* If we had an *energy storage system distributed* along the line, the problem of power would be solved. The system could store locally the energy recovered from braking trains (recovery can be quite good with linear motors) and re–deliver it to accelerating trains. The external grid would only provide, on a quasi continuous basis, the make up for the losses due to trains, motors and storage. Present day trains, like the Transrapid, may not really need this, and they use the external electric network as a buffer. But following the principle expressed above for retrofitting, some *research* should be done to define at least the possible size and spatial arrangements of these storage systems.

5. Coming to operational considerations, Maglevs have the potential of extreme flexibility in mechanical terms. To use that in an appropriate way, and to provide an efficient feedback with

the demand, the whole system has to be *computer controlled.* Incidentally, a Maglev train has no engine on board and consequently it is fully passive to the forces generated by the electric equipment on the line.

To make the system most compatible with a computer every subset has to be *digitalized.* To give an example, step motors or synchronous motors are preferable to asynchronous ones, just for the sake of control.

Operational Conclusions

As mentioned above, Maglev has the potential to take over, or at least take a large share of, present public transport for short–, medium and long–range (continental) travel, including air transport. Taking a large share means more than substituting present transport infrastructures and present passenger flows. Because of its special characteristics, basically *high inclusive speed* and *very high intrinsic speed*, Maglevs will open *new passenger flows* on a grand scale. It must be clear that this effect is not due to Maglevs per se. When the car entered the game, people in France had a travel length of about 5 km/day on transport vehicles. Now they have about 35 km/day (Figure 16 – Appendix). The extra 30 km came from the car which increased passenger flows (pass km and km/pass) five times in only 50 years.

The scheme proposed here for intercity transport keeps the Metro stations as they are (spaced perhaps 500 m apart as in the 6 km radius around central Paris) but should provide more direct access to the train.

The possibility of vertical train displacement, (e.g. with the side–wall suspension), permits having a single network with trains crossing stations above, below or at level using the same line. The architecture of the flow of vehicles and passengers must be conceived to require minimum walking displacement. For example, interchanges should be possible between trains stacked vertically, so that passengers only go a few meters of stairs. On present Metros, think of Paris or London, rivers of passengers have to flow in interminable corridors.

A completely interconnected network would make it possible to link any couple of points with a direct train (no intermediate stop, or perhaps an extremely limited number). This should pose no problem if passenger flows are sufficient. If they are not, a hub and spokes arrangement should be adopted such as many airlines already have, e.g. in the United States. This would then mean making one change for any destination except the spoke itself. The two architectures can run in parallel, and change over time according to the fluxes of passengers, if passengers feed back the computer by signalling the final destination (via magnetic tickets or buttons) when they enter a station or stand for departure.

Wagons must be small (e.g., 50 seats or less), and perhaps come in different sizes, as the service must be frequent even if passengers are few. This is because to be competitive with cars, the system must minimize access and waiting times, both detrimental to *inclusive speed.*

Substituting a Metro with a better, i.e. faster one, does not mean only making things better for the inhabitants of the city concerned. Rather, it also means *expanding the functional area of the city itself.* The increase will be proportional (in linear distances) to the increase in inclusive speed going from present wheel Metros to Maglev Metros. This means conurbations now sitting around a city will be functionally incorporated.

Maglevs with linear motors permit high acceleration (and braking) e.g., of 0.5G or 5 m/sec^2; (present designs for Maglevs have up to 3 m/sec^2). One may assume that in the relatively long distances between the center of a city and the "suburban" conurbation the Maglev will run at sustained speeds of e.g., 500 km/h. With 0.5G this speed can therefore be reached in about 30 seconds. A 100 km radius for "intercity-intracity commuting" then appears feasible. This corresponds to an area of about 30,000 km^2. With the population density of Hadrian's Rome (one million people packed inside 5 km diameter walls or 50,000 persons/km^2), 3 10^4 km^2 could accommodate 1.5 *billion* (10^9) people. One can say these population densities are unthinkable nowadays. But, they can be found in the luxurious City of Monaco and are coming into the Mexico City sprawl, which is logistically growing to 50 million people (in about 1,000 km^2 corresponding to an inclusive speed of cars of 40 km/h and a similar diameter for the city). (Figure 4 – Appendix)

I certainly do not propose a 10^9 city, but the potential is there; and in the last 200 years those potentials created by new modes of transport have always found a final exploiter (see the case of Berlin,

Figure 2 – Appendix). Naturally, the potential for high speed can be told the other way around: to give a bucolic setting to a 10^7 people city (with 1% the density of Hadrian's Rome). To make a transport system manageable however this population should coagulate in centers of 10,000 people or so, where the great commuters live in the center, near the station, and the local staff more on the periphery. Megacities of this kind are already delineated in the area of London, Amsterdam, Ruhr and Paris.

The densifications of human settlements illustrated by Doxiadis using the subjacent secular drives are reported in Figure 1a for Europe and Figures 1b, 1c and 1d for the rest of the world. They show the long term hot beds for installing Maglevs.

1. TRAVELING WITH MAGLEVS

1.1. On Sequences of Innovation in Transport

Man strives for speed which is obtained by the progressive penetration in the market of faster and faster means of transport. The whole process is reported for France for the last two hundred years (Figure 16 – Appendix). The chart only reports facts, however, without an attempt at quantifying them. Because new modes of transport can be classified as basic innovations, we can look how their introduction can be positioned in the innovation waves which are tuned to the Kondratiev waves (Figure 2).

As a first approximation we found a key of interpretation by looking at the development of transport infrastructures in the USA. The beginning of the penetration of an infrastructure can be seen as the start of penetration of the corresponding mode of transport. Now there is a coincidence between the centerpoint of a given mode (Figure 3) and the start of the next one. These centerpoints are located almost exactly 6 years after the low of the Kondratiev cycle which is *now* located around 1995. According to this clock, a new mode of transport should be introduced a little after the year 2000.

This systemic signal neatly matches the opening of the first Maglev line in Germany, the connection Berlin-Hamburg, which is expected in the first years of the next century. The basic innovation in Mensch's sense, when the first object becomes commercial, should come around the middle of the innovation wave which is 1992.

This is in fact the case, as commercial demonstrations have been operating for a few years, e.g., the Maglev *metro* in Berlin.

If we look at the mode of transport in terms of the propulsive technology, we find the steam locomotive commercial in 1824 (Kondratiev minimum 1830), the gasoline engine commercial in 1886 (Kondratiev minimum in 1885) and the jet engine commercial in 1941 (Kondratiev minimum 1940). We can agree on a commercial magnetic levitation system (Berlin Metro) around 1991 (Kondratiev minimum 1995).

These considerations may appear a little formal and abstract, but the same analysis applied to primary energy sources gave consistent coincidences for *the start* of innovation waves with the market introduction of new primary energies. Extending this coincidence into the future predicts a new primary energy source for 2025 as a reference date. This coincides with the plans of development of fusion, as done by the engineers on different occasions. It also marks exactly 1972 as the beginning of commercial nuclear energy using an innovation wave that can be calculated, but not yet tested empirically (it ends around 2005).

In terms of speed a Maglev can be visualized as a low flying airplane but cannot offer more than a jet airplane (mean speed around 600 km/h) for aerodynamic reasons. But if one imagines Constant Acceleration Maglevs (CAM) operating in a depressurized tube, and capable of 3000 km/h on relatively short stretches (500 km distance with 0.5G acceleration-deceleration) they would offer supersonic speed where supersonic airplanes could never operate.

The Maglev can also operate with superior efficiency in a Metro-mode, providing speed and frequency far beyond what is attainable with current techniques.

In our vision of the cave man trying to get new territories, what is really important is not so much the technical speed, but the speed which is functionally available (inclusive speed). The superiority of the car with respect to the train is not so much in the technical speed, they are in fact very similar, but the instant availability (infinite frequency) and the short access time at both ends of the trip if parking is available. As an easy reference, cars permit a speed of about 40 km/h from point to point inside a conurbation. This speed did not change since Ford's times, all advances in car dynamics having exactly compensated the viscosity created by the increasing number of cars in circulation. From 1950 to the present cars multiplied by about three times the speed of the European population, and consequently, by about 10 times the area of personal territories, with all the possible choices incorporated in this process of territorial expansion.

Contrary to current opinion, traveling is home-centered and defined by the characteristics (and prices) of the modes of transport available to the individual (see Appendix for details). Unless our individual lives in a small and far away island, the scale of the country is actually not so important. Americans travel by air four times as much as Europeans in terms of km/person/year, but the mean length of their trips is about 1000 km. Just as for the Europeans for trips bound in Europe. Incidentally air travel is much cheaper (x4!) in the USA. On the other hand, train trips are 100 km in the mean both in the USA and in Europe. Incidentally, the ratio of the mean speed of an airplane (600 km/h) and that of an intercity train (60 km/h) are equal to the ratios of the length of trips.

1.2. The Maglev's Principles and Appropriate Exploitation

The invention of the wheel is considered as the first breakthrough in the technology of transportation. It reduced by an order of magnitude the force necessary to pull a load, if we take as a reference the best technique still used in primitive countries, that of elastic long poles, dragged over the back end. This with a reasonable level and solid ground. However, the wheel slushed for millenia into mud and dust, impeding the explicitation of its full potential. Roads paved with stones in the Roman style greatly improved the situation, although the strong irregularities of their surfaces still did not permit the full explicitation of the potential. This came by providing very smooth surfaces, first in wood as already quoted by Agricola for mines, then in iron, and finally in steel. Wheels could roll freely on these smooth surfaces and trains had been invented.

Trains were the breakthrough in land transportation both because of the low force and consequently low energy required to pull them and because the rails were soon capable of carrying great loads. Low friction also meant relatively high speed, even with the reduced power (in modern terms) that the first locomotives were able to deliver. High speed meant efficient unification of countries through the long range movement of people. High loads meant efficient transport of goods over long distances unifying nations economically.

Just to give a feeling of the previous situation, in spite of the fact that the stones necessary to construct a Gothic cathedral were all quarried in the same region, their *transport* cost about 80% to 90% of the total cost of the building.

The next step was to smooth the earth itself, her mountains and valleys, through the invention of a flying machine. Flying is in principle energetically cheaper than running, as the analysis of energy spent by animals has shown. But flying animals are aerodynamically much more sophisticated machines than airplanes. In any case, flying has a high "fixed cost" in the fact that the support is dynamic, i.e., one has to push air down to stay up. The energy cost depends on the time in flight and consequently low speed machines (e.g., helicopters) are heavily penalized.

Maglevs are a compromise that tries to get the best of two worlds by using magnetic forces to obtain the hovering effect. If the magnets are static, the energy cost of hovering is zero. This situation is actually not so favorable: to obtain the strong forces to support a train electromagnets are necessary for the time being, and superconducting magnets are very useful. Both consume quite limited amounts of power, however, for energizing or for cooling. In any case, the hovering energy cost is actually much lower than that of an airplane.

A further advantage lies in the propulsion. An airplane gets the propulsive force through the same mechanism as the hovering forces: by pushing air backward. The force depends on the momentum of this air. Momentum means speed of the air pushed back, i.e., energy lost. Maglevs do not push air, but the earth, which has a large mass and can provide momentum at negligible energy cost. Having magnetic forces for suspension is natural to have magnetic forces for propulsion. Maglevs have then great potential for low travel energy cost. Conceptual designs promise *a two order of magnitude reduction in energy consumption* in respect to airplanes, for similar performances.

The third point is that Maglevs *do not carry fuel nor engines.* There is, then the potential for very low vehicle weight, meaning a low total mass paying load. At present an airplane at takeoff, a car or a train, weighs about one ton per passenger transported. The cost of transport then is mainly due to the transport of the vehicle itself. For Maglevs, vehicles weighing 200 kg/pass or less are envisaged.

Maglevs can be operated in a *reduced air pressure tunnel* simulating high altitude flight. When moving at high speed, beyond 100 km/h, the main energy expense to propel a vehicle is due to air resistance. Low pressure helps reduce it. It can go to almost nil in almost perfect vacuum. This opens the door to very high speeds with limited resistance forces, and finally limited energy consumption.

As a final and ideal configuration, the development of *high temperature superconductors* would permit hovering at zero energy cost and presumably have a almost complete energy recovery in deceleration. *There is potential then for traveling at very high speeds and at almost zero energy cost. In time this great potential will help Maglevs displace competitors and reign supreme in most transport niches.*

Historically, when a new basic technology starts competing with an established one, the advantages are limited and the old one starts improving to stay in the race. But the new one wins because of its larger potential for development. The most important drawback of Maglevs is that fixed costs in the infrastructures are very high – in the same order of magnitude as the TGV. This means they must operate on connections where traffic is very intense. This high traffic may not exist to start with. The short connecting time Maglevs realize over mean distances can create huge currents of traffic even where there is almost none today. This effect has been clearly shown in my studies of Lisbon, Istanbul and Hong Kong, when bridges and tunnels substituted ferries.

Maglevs were invented in 1930 by the German engineer Kemper. He had a house near a railway line and was thoroughly disturbed by the rattling of the passing trains. He then devised means to eliminate the wheels by a magnetic suspension he patented in 1934. The idea was a bit early in terms of context. Cars did not present a challenge to trains for short distances as there were so few, and air traffic was a non-entity at that time. So there was no pressure for trains to innovate.

The Maglev idea popped up again in the mid-1960s (Powell and Danby, 1966) with the first serious engineering and constructive studies. They saw Maglevs as a variant of a train, sticking to the systemic image of actual trains. This haunting of the previous technology is the rule more than the exception. The first trains were conceived as a sequence of horse carriages, and the first steam cars had wooden horses sticking out in front. Actually a very light envelope, suspended on moving magnetic fields, modeled by a computer has systemic characteristics that lead to an operational system completely different from that of a classic train, even in the fast version of a TGV.

But this cultural hangover still looms in the mind of Maglev designers and we should propagate the suggestions that come from a "back-to-basics" vision of how people use the transport system. This anthropological context, which comes in various forms in my previous reports on mobility, is reported here in an augmented form in the appendix. *I consider this back to basics a necessary reading before starting any planning.* The current reasoning that because we have so much traffic using such and such transport mode so let us use a more convenient mode and part of the traffic will be switched to it, is limiting at best and can lead to serious mistakes. Travel is generated, *i.e, created,* by the *speed, costs and availability* (frequency) of the means of transport. By changing these parameters people change their mental maps and traveling habits.

If a development is done as a public service, speed should connect resources. If a development is done to reap a company profit, speed should provide access to resources – typically to a place of work from a place of residence. Speed makes the choice wider in space and consequently in number and quality for jobs and residence places.

Back to the history of Maglevs, the later sixties and the beginning of the seventies saw a great theoretical activity. The numerous problems that the machine was posing attracted the attention of electrical engineers in academia and industry. More or less at that time the various configurations for suspension propulsion and stabilization were developed. We will now discuss them in more detail.

1.3. The Levitation Systems

Maglevs have the common characteristic of being magnetically levitated, but this can be performed in various ways. A short analysis is presented here because the model chosen can not only influence the cost but, more importantly, the *potential* of the system.

At the moment the most developed Maglev is the German one. This design uses a system of suspension requiring great precision in setting out the lines, and presumably a limitation in speed to perhaps 800 km/h or so. The general *strategy* for the development of Maglevs at European or world level should leave a *door open* for new entries, thus avoiding the usual blockage generated by the generalized application of the technology that first reached commercial maturity.

A classical example can be given by using the case of light water nuclear plants. The possibility of market entry of other reactor models, e.g., high temperature ones, endowed with much more potential in terms of efficiency and penetration into the universal market, has been severely stifled.

Analyzing the numerous proposals of Maglev suspension, I would classify them into three groups:

1. *Attractive* placed on the ground or the ceiling.

2. *Repulsive* placed on the ground or the ceiling.

3. *Hanging on the sides* (side-wall system). (See Figures 4 and 5).

Group 1 systems have no equilibrium point whatsoever, and consequently stability can be obtained only through a *precise and fast* feedback control of the magnets mounted on the train.

In the case of Group 2, the equilibrium is one way only because going downward gravity is equilibrated at some point by the repulsive field which works when the resistance is reduced. There are no recalling forces however, so that in a sense the train sits on a spring.

Hanging on the sides, Group 3, is a variant of the attractive system where the forces are generated when the axes of attractive magnets are displaced. The shear forces that appear then are symmetric, meaning that the train is contained between two springs, one pushing upward and the other downward. The horizontal alignment is in principle unstable, but can be passively stabilized using null–flux coils.

The Europlan prototype developed by the Germans adopts a system of Group 1 type with normal iron cored magnets on the line and on the train. The gaps are in the centimeter range and the alignment of the lines must then be very precise, e.g., milimeters over ten meters. The German system is the most developed and practically ready for a large demonstration (Berlin – Hannover).

The Japanese, who came first in large scale experimentation with Maglevs, originally adopted a scheme of Group 2 in a formulation that strongly simplifies the rail structure reducing it to a conducting (aluminum) plate. With very strong (superconducting) magnets mounted on the train, the current induced in this plate when the train is moving produces the suspension repulsive field. Like an airplane, however, the train needs wheels to start running, and this vestigial limb from the previous technology is very embarrassing. It originated a bad accident in Japan when a tire was flat and the magnesium wheel caught fire finally destroying the train.

The Japanese are now moving away from the dynamic repulsion system. At first they considered static repulsion with magnetic windings in the line itself. Recently, however, they have shifted the suspension system onto side–walls so that the train is supported "by the armpits" so to say. Also the magnetic fields that provide the pull and the braking of the train are incorporated into this band. The whole becomes intricated, but compact, as present day large electric generators are. One of the great advantages of this configuration is that there is no more problem of vertical clearance, only the less critical one of lateral clearance. The corrective actions needed to keep the train centered are taken through a third set of magnetic coils embedded in the same band, the *null–flux* coils, which provide automatically, i.e., without computer control, the restraining forces when the train is out of axis with the side walls.

The Americans, who were the first to rediscover the idea of the Maglev in the 1960s, but never financed a real research effort, have now started a vigorous initiative at the *Argonne National Center*, both from the point of view of technology and systems analysis and they have called the industry to provide fairly elaborated conceptual designs. A list of these concepts and their characteristic are reported in Figures 6 and 7. Noteworthy, in my opinion, is the design presented by Foster–Miller.

The system to which the Argonne group is directing their efforts belongs to Group 3, with all the external coils concentrated in a band on the side walls. Just the same as the Japanese. This design looks to me as having the most potential because: it solves the problem of clearance to the ground; the restraining forces operate both ways; and an engineering simplification is obtained by incorporating all the magnetics in a single block. One point not very clear, however, is how to provide lift when the vehicle is stationary. Although a last resort, skids might be admissible; but a magnetic solution must be found.

1.4. The Maglev's Maximum Impact: The Daily Trip

Home–centered *daily trips* absorb about 90% of the traveling time. In western countries these trips are mostly traveled by car, as cars have an unbeatable inclusive speed of about 40 km/h. The increase in mean speed for the population as a whole, as shown in Figure 16 of the Appendix, has to come mainly by improving the performance in this segment of travel demand. Subways may beat cars in speed, if access time is reasonable and surface roads congested. In central Paris (6km diameter core) with Metro stations spaced about 500 m apart, mean access times are in the order of 5 minutes, leaving about 15 minutes for the actual train trip, including waiting time. The technology of Maglevs could greatly increase the distance traveled during these 15 minutes, by automatically operating small vehicles (e.g., 50 places) at high frequencies (1 minute) to reduce waiting time, and serving *point to point connections* without intermediate stops. This requires that the whole system be under computer control, with some feedback from the travelers. A magnetic imprint of the destination on their ticket would give the computer the information on travel demand, when they cross the gates or change at hubs.

Such sophisticated technology is easy to implement in a new subway system, but finds many impediments if one thinks of refitting existing networks. One of the elements of rigidity is that the different lines usually do not interchange, so that a given vehicle can only move along a single line. However, a retrofit of the system (keeping tunnels and stations only), could greatly increase speed, and also capacity and comfort.

The next step would be to use this new technology to extend the existing lines *in proportion* to the higher speeds attainable. As said in the appendix people travel in a time context, and speed is the price for space, consequently ranges will expand proportional to speed.

Thinking of a wagon navigating in a magnetic bucket created by the computer opens new avenues as accelerations can be independent of speed. As said before, the magnetic field in the bucket can apply a *constant force* to the vehicle and can be regulated very finely as the currents in the winding are under electronic control.

To give a very theoretical, but palpable example, with an acceleration of 0.5 G, and operating in a CAM mode (Constant Acceleration Maglev) *one could cover 10 km in 1.5 minutes* at a mean speed of 400 km/h. This is certainly not directly a proposal, but an identification of the physical potential. The Swiss Metro design takes benefit of this potential and shows how the application of the Maglev can extend the Metro concept to a set of cities, the largest in Switzerland, *fusing them into a functional city.*

From a *systems logic* point of view, such a system with "addressed" cars appropriately switched at the nodes of the network, strongly resembles the ISDN (Integrated Services Digital Network) where information packets are sent into a common carrier starting from various sources, and switched at the network nodes, according to addresses incorporated into the packets themselves, until they reach the final destination inscribed in the address code.

These considerations may look as meandering in the maze of possible configurations. They have already been examined and proposed for experimentation (see the PRT 200 project of Raytheon). They are an attempt to match the potential of the new technologies to the anthropological context of the traveling cavemen, endowed with tools and money.

1.5. Where Maglev's May Solve an Insoluble Problem: Serving the Demand of Fast 1,000 km Trips

Maglevs are very flexible machines and may compete with other forms of transport at all speeds. The infrastructures they need, however, tend to be expensive, at least at the present stage of their technology, and consequently high traffic levels are necessary for an economic exploitation. On the other hand, they are well adapted to carry very large levels of traffic.

As explained in the Appendix, total traffic generated in a population is determined by the speed available in the system, because traveled time is constant. Maglevs are capable of very high speeds even on short stretches because they can have high accelerations. Consequently their introduction will increase pass-km performed on city and suburbs (becoming city!) as said. This point must be kept clear in mind when dealing with their potential.

On the other hand, we may ask ourselves: why more speed? The answer is again in the instincts of the territorial animal as said in the Appendix. But in social and economic terms, territory is the key to opportunity and it is natural to try to extend it as far as possible. Analyzing the evolution of mean speed using vehicles in France over the last 200 years, we can observe a regular growth at around 3% per year (Figure 16 – Appendix). This means a doubling every 20 years or so, meaning about 30 times in *a century, the rational time horizon in conceiving a transport system* because infrastructures (e.g., tunnels) are so longeve and expensive (think of the Channel tunnel), and because for cultural reasons connecting routes too stay the same for centuries.

Doubling in 20 years brings problems to planners, as they are "so near". Present mean speed of Europeans is about 35 km/h (or per day!). Most of it is related to the use of *cars* which are now more or less *saturated.* The logic is that one should gain mean speed by transferring *travel time* from slower modes to faster modes. Airplanes are now the mode faster than cars and Europeans spend about 15 seconds/day, as a mean, on them. With a mean speed of 600 km/h, this means a non-negligible 2.5 km/day. With rough arithmetics one could say that for adding an extra 35 km/day one should travel more than three minutes per day, as a mean, on airplanes.

This is not terrible seen from the passenger side, as it would mean one round trip per month roughly. From the air transport side, however, the passengers would increase by more than an order of magnitude (14 times) in 20 years or 14% per year in the mean.

From a technical point of view the most serious bottleneck is the size of the airplanes. Up to 1980 IATA airplanes were constant in number (about 4,000), mating to traffic via proportional increase in productivity (pass-km/h). At present the situation has been altered due to a very fast extra growth of pass-km in the eighties, too fast for the plane manufacturers and the air companies to take the appropriate measures they had taken before. Consequently, the air system is now saddled with an "excessive" number (5400) of airplanes, "too small and often too old".

According to my previous projections, the plane of the nineties should have had about 1,000 places (with the usual speed around Mach 0.75). Increasing traffic by a factor of 10 would require, in this conceptual scheme, planes with ten times the productivity of the Jumbo-1000. This may be possible by increasing the speed to Mach 7.5, a concept under development, but the real problem lies in the second level of airplanes that should have about 6,000 passenger flying at Mach 0.75. These airplanes should link heavily connected airports. These connections can carry today 10^6 pass/yr per direction. A factor of 10 would make about 30,000 pass/day, an interesting figure for a Maglev line: *London–Amsterdam, London–Dublin, London–Zurich, are already in the* 10^6 *ballpark.* The other obvious parameter is distance. According to the analysis in the Swiss Metro project this Maglev has infrastructural costs comparable to those of a fast train of the TGV kind. If the cost of the ticket were proportional to distance only traffic would count and distance would have no effect. But in fact distance has other deterrent effects. The decision to construct refers to a given connection and the consequent financial burden is proportional to distance. And ticket price is usually nonlinear with distance.

A factor of 10 may look large, but in the USA people travel on planes approximately 4 times more than Europeans. The usual explanation is that America is a large country. However, the mean distance traveled in Europe and in the USA is the same, about 1,000 km. Traveling is traveler centered, as our anthropological appendix explains, and the size of the territory is basically shaped by the speed of the mover. Airplanes have the same speed in the USA and Europe and that explains the 1,000 km. The reason why US people travel more, i.e., *make more air trips,* is most probably to be found in the cost of air travel, which "by chance" is about 4 times cheaper in the USA than in Europe. The disposable income is more or less the same, as is the percentage of income spent for traveling (about 12%). (See Appendix for details).

Deregulation in the CEE is coming in, even if in a very viscous way, and in 10 years it may be expected to be completed. On the other hand, Maglev lines will require some years to complete. Ten years is an optimistic time horizon. So the two systems will converge: *reducing fares through competition will raise traffic above capacity on certain connections and the Maglev will be there ready to solve the problem.*

To give a face to the situation, I have identified a number of connections where Maglevs could supplement or substitute planes. As mentioned the basic tool of search is to look at air traffic. It turns out that connections from a given starting point, e.g., Frankfurt, can be ranked in intensity and show a fractal structure, i.e., the ratio of passengers on a connection and the next one in intensity. For Frankfurt the ratio is about 1.5. See e.g., Frankfurt–London (693), Frankfurt–New York (457), Frankfurt–Paris (315), Frankfurt–Milan (220). As these numbers tend to grow homothetically, if the reference point and the largest connection are OK now, a factor of 10 increase in traffic would bring the following 5 in the OK range ($1.5^5 \simeq 8$).

Due to the very limited funds available for this research, we could not develop this line of analysis in detail. However, it does deserves attention as a possible template, produced independently, for gauging the numerous proposals, not totally independent formulated today.

Some proposed lines for Germany, the USA and Japan are reported in Figures 8, 9, and 10.

2. MAGLEVS FOR THE TRANSPORT OF GOODS

Most of the considerations relative to the use of Maglevs and found in the literature are related to the transport of people. Transport of goods is quoted occasionally but to my knowledge has never really been studied in detail.

As we have said, in the succession of competing means of transport, the last one must provide extra speed. Maglevs may substitute car transport over medium distances and air transport over long ones. For various reasons, technical and organizational, railways are substantially out of the game, having lost already to the road. Most of the technical cause is in the low inclusive speed of rail transport. For the transport of goods the road in fact is now dominant both in Europe and America.

Maglevs are an ideal technology for Metro transport. Metros now penetrate cities in depth and detail. Cities become larger and larger and consequently impenetrable by surface transport. As in the case of Imperial Rome, where goods traffic was prohibited during the day, the city accepts this traffic only out of sheer necessity. And, as a last point, containers are progressively penetrating into the transport of goods.

The proposition is then to provide *container handling systems at the Metro stations,* possibly completely automatic, so that an addressed container deposited in station 'A' or, let us say Rotterdam, is "switched" to station 'Z' and deposited there. Consequently, the surface movements would be limited to less than half the distance between Metro stations, which in the dense core of a city (e.g., the inner 6 km diameter of Paris) is about 500 meters.

As mentioned above, Maglev lines must be conceived for very intense traffic. Consequently, except for a few peak hours, "goods trains" can intermingle with passenger ones and in any case run at night. Unloading and storing is automatic. If traffic is intense enough, e.g., that interconnecting Mexico City (which is moving toward 50 million inhabitants), and a sea port, Maglev lines

Fig. 1a, b, c, and d.

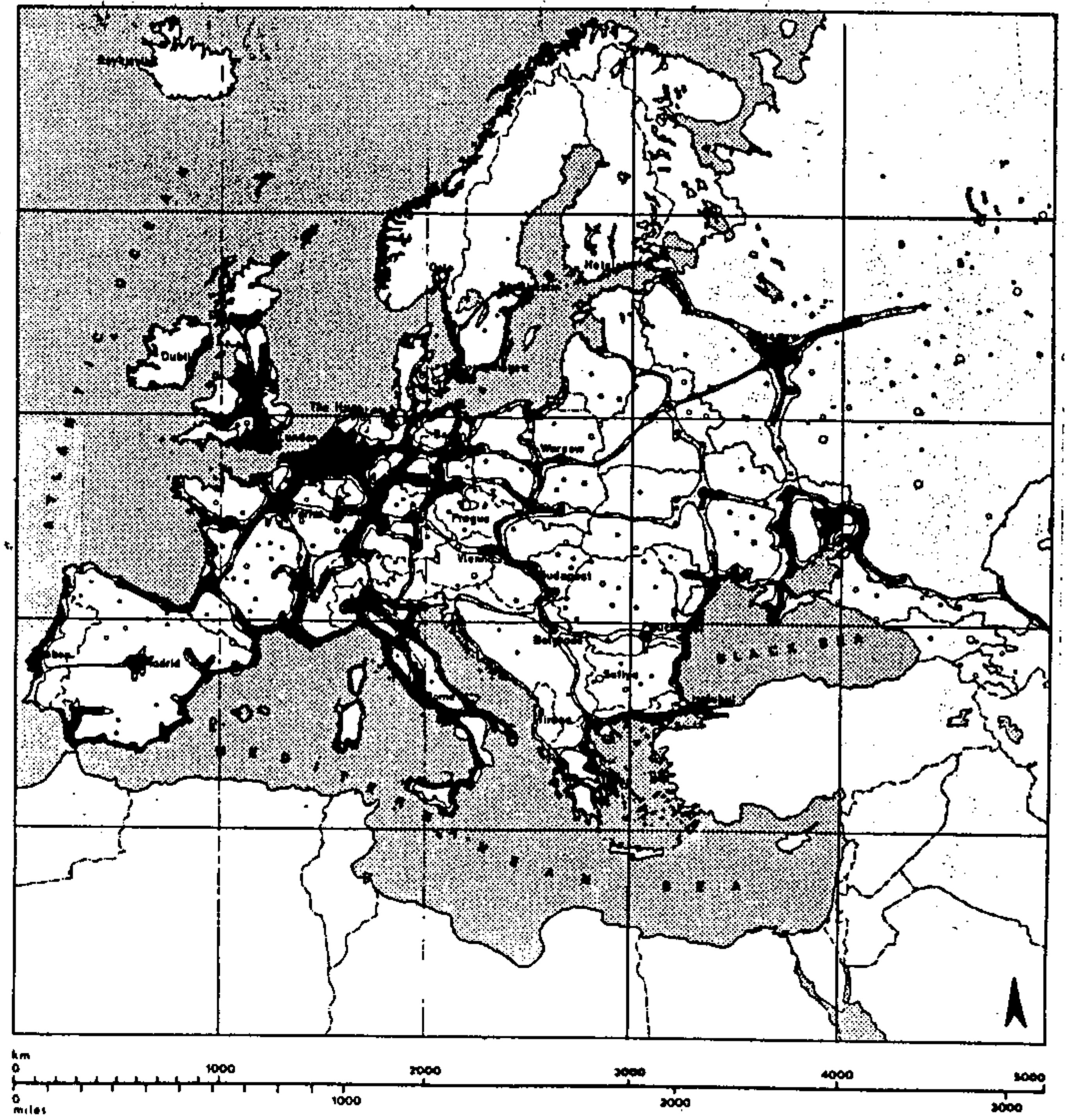
In 1974 Doxiadis published a seminal book on the structure and dynamics of cities in particular and human settlements in general. Based on the historical time change of a number of parameters, he set up a method to forecast probable developments in population distribution worldwide. The result for year 2100 is reported in these illustrations.

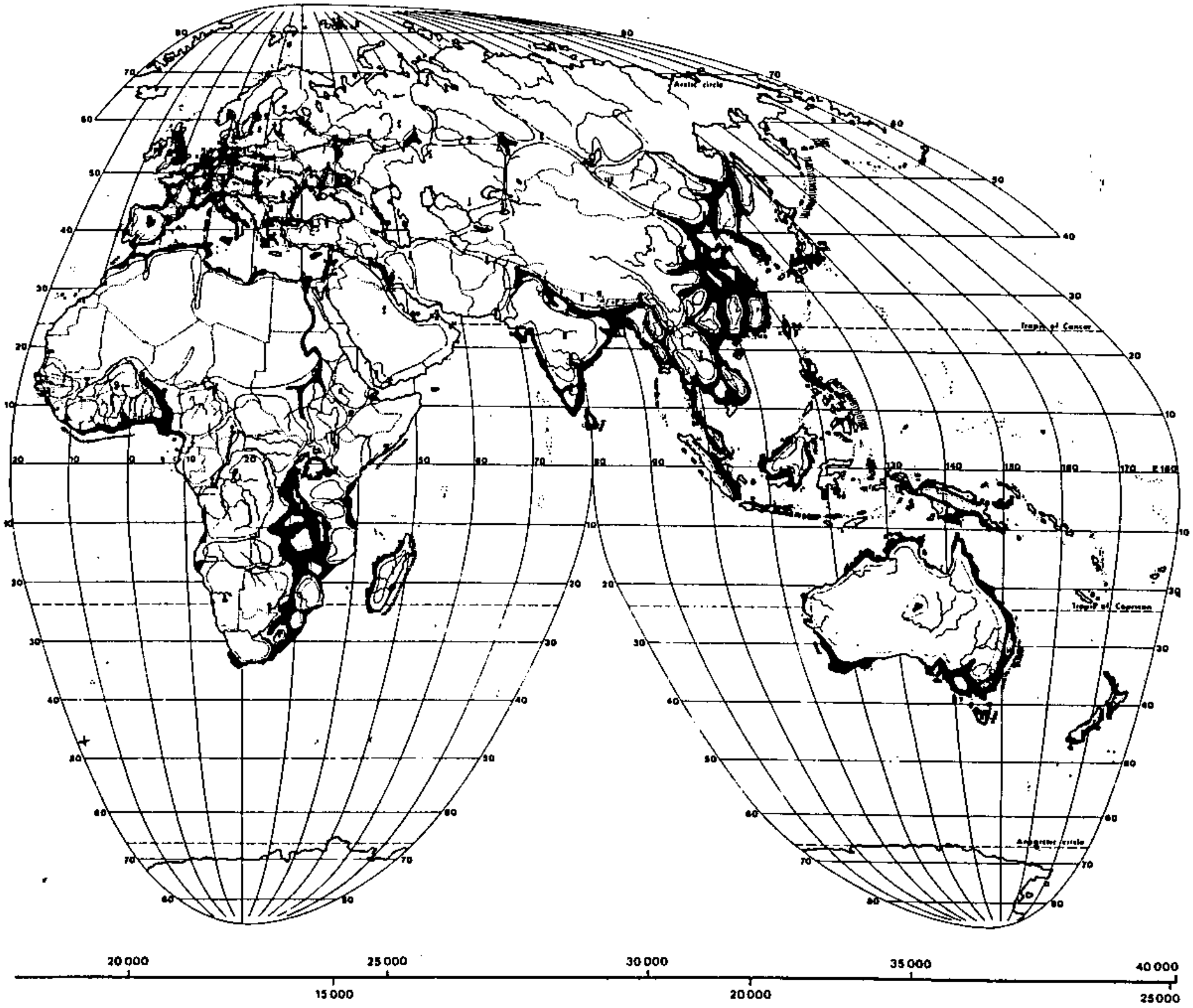
Year 2100 may appear far away, but a new transport system affirms itself in about 50 years (a Kondratiev cycle), diffuses to saturation in another 50 years, resists competition without losing pass-km for another 50 (but drastically shrinks in relative terms) and then in another 50 years it disappears. This reasoning can be the *logo* applied to the history of railways, who face the final go.

The importance of having at least a mental map of things to come helps realizations with highest lasting benefits. After all, tunnels, very expensive to construct, may well last for 200 years. It is best to construct them where they will be very useful for all the 200 years.

The maps show a progressive organization of world people settlements in filamentary configuration, a boon, and perhaps a feedback cause, for fast public transport.

ECUMENOPOLIS 2100




Arctic circle
Tropic of Cancer
Tropic of Capricorn
Antarctic circle
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20 000
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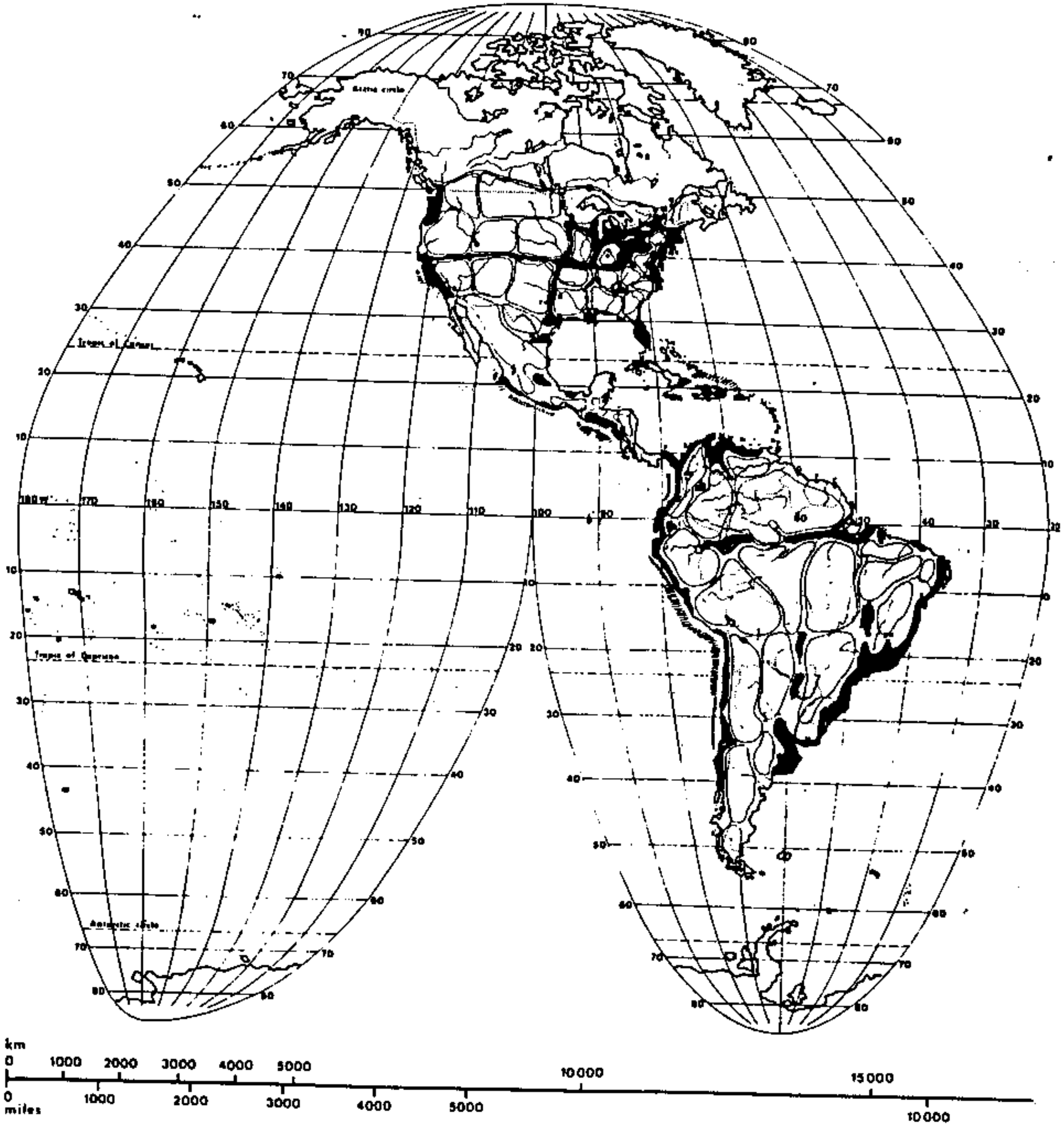
Arctic circle
Tropic of Cancer
Tropic of Capricorn
Antarctic circle
180°W
170
160
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130
120
110
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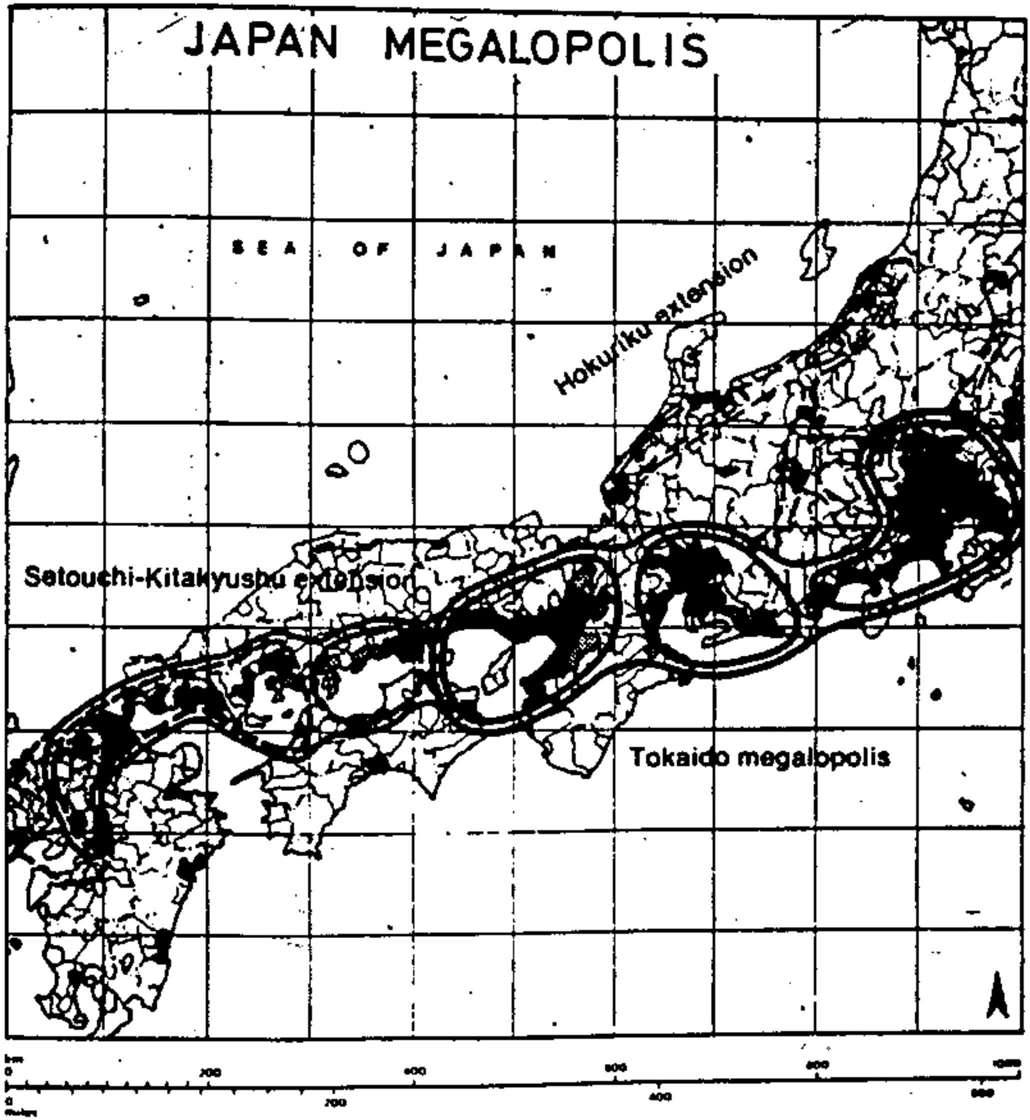

JAPAN MEGALOPOLIS

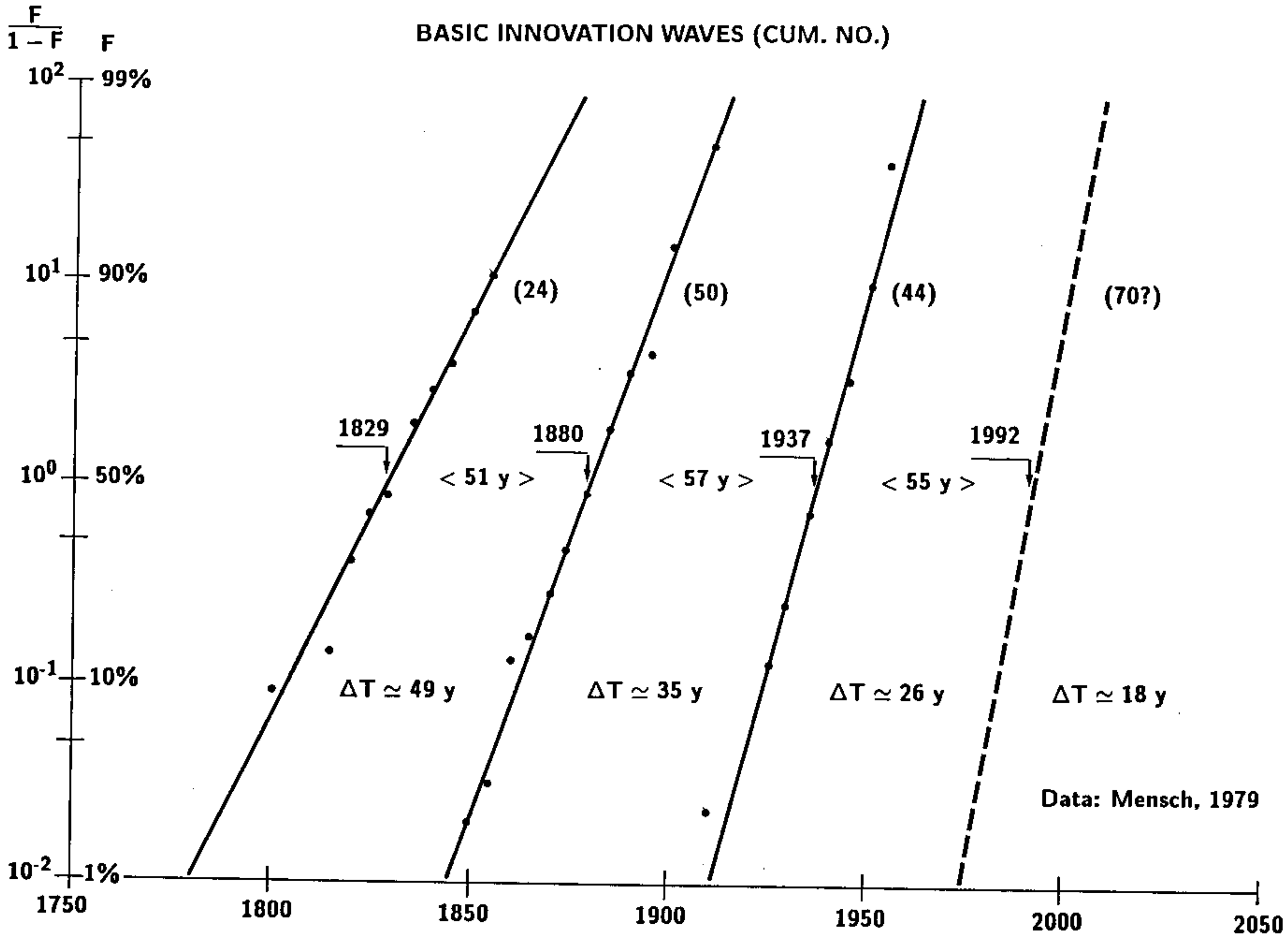
Fig. 2. Basic Innovations

Maglevs can be considered a basic innovation and consequently fall into the rules of introduction of basic innovations reported here. These innovations come in waves, here plotted in integral form.

New primary energies come into the market at the beginning of the waves, when they cross the 1% level in this chart.

The centerpoints of these waves are spaced about 55 years, the length of the Kondratiev economic cycle.

BASIC INNOVATION WAVES (CUM. NO.)



Data: Mensch, 1979

C. Marchetti, IIASA,

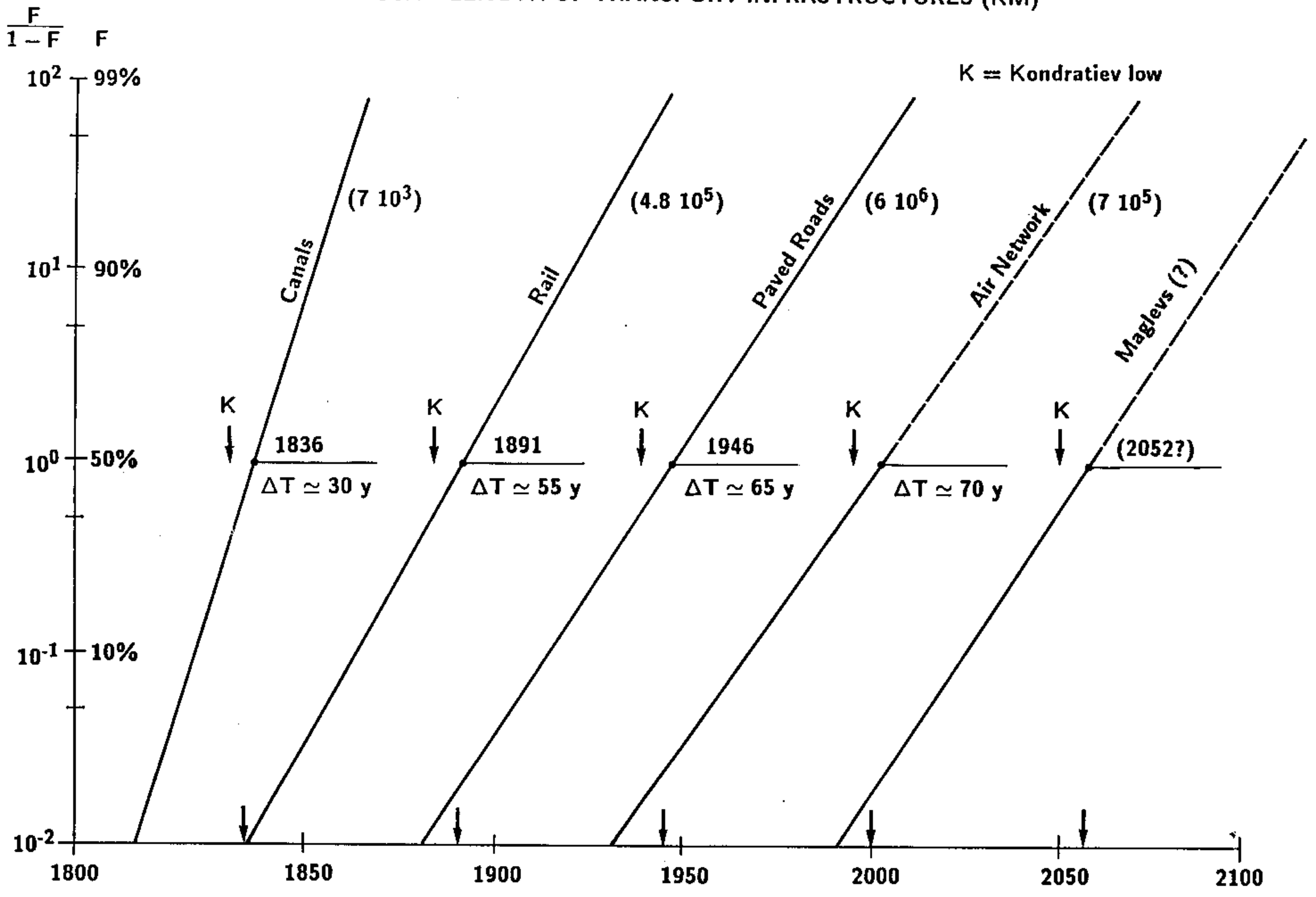
Fig. 3. Length of transport infrastructure in the USA

The length of the various transport infrastructures in the US is here reported in normalized form, i.e., as percentage of the saturation length (in brackets). We also use the Fisher-Pry transform for the presentation in the chart.

As said in the text, one can establish a relationship between key dates in Fig.2 and Fig. 3 that permit to forecast the opportunity window for the next transport mode.

We have here actually traced a possible trajectory for the penetration of Maglevs in America. It should be substantially similar to the penetration curve for Maglevs in Europe.

USA – LENGTH OF TRANSPORT INFRASTRUCTURES (KM)



C. Marchetti, IIASA, 1992

Fig. 4.

A very important principle in magnetic suspension is shown here. It is based on aligned magnets where strong shear forces appear when they are disaligned. The force have the form of an elastic restoring force toward a central point. The axial distances have to be kept by control coils and a feedback system.

The principle is incorporated into what I consider the winning system of Fig. 5.

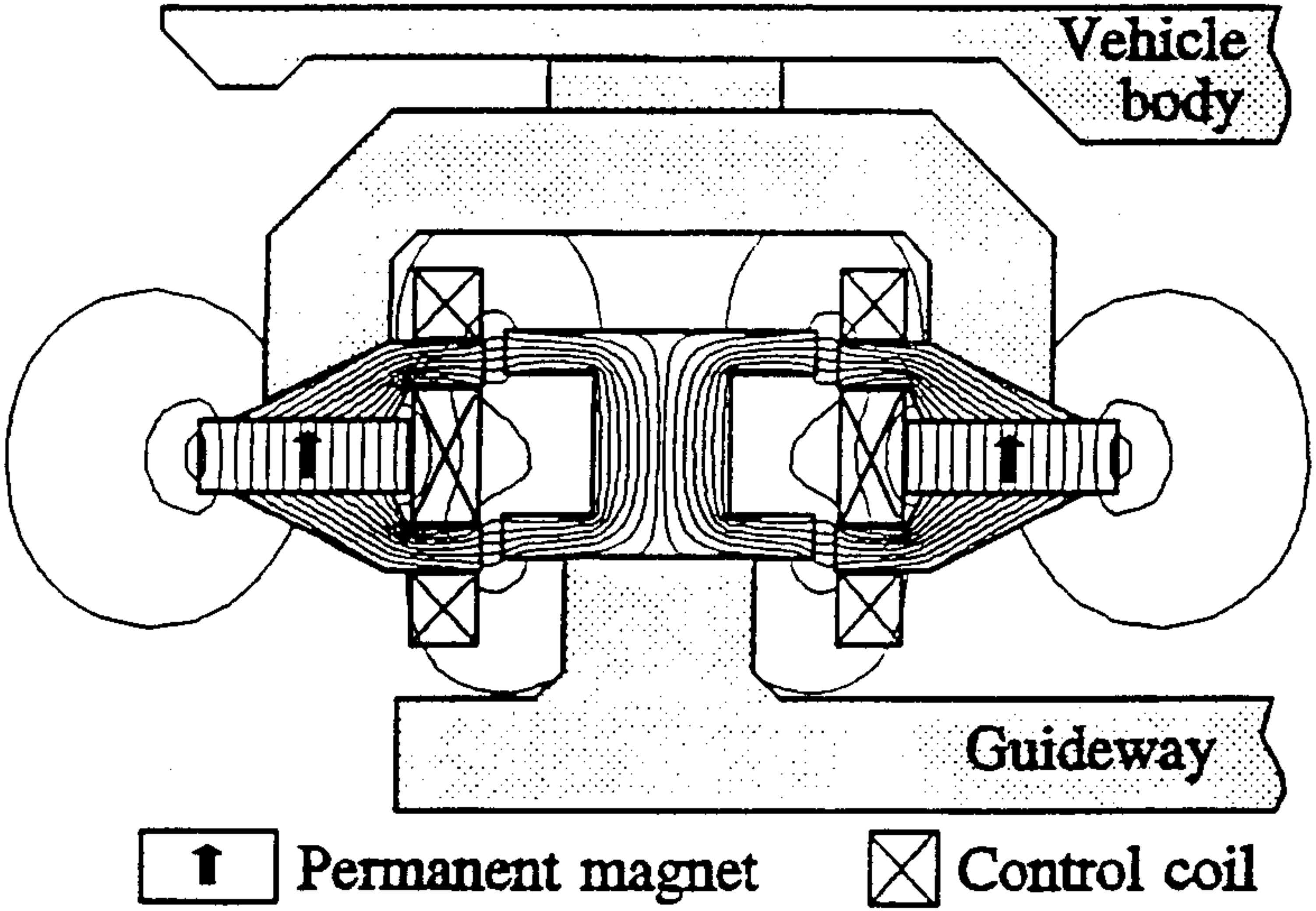

Vehicle body
Guideway
Permanent magnet
Control coil

Fig. 5.

The suspension scheme for a Maglev having most chance of success in my opinion, is reported here. Japanese and American designs evolutionarily converge to it. Levitation is obtained by shear magnetic forces (Fig.4). Superconducting magnets mounted on the train interact with magnetic coils in the drive band which contains also the propulsion coils and the lateral control coils (null flux).

A train suspended this way has no problems of vertical clearance. On top of that *it can be displaced vertically by* a staggered set of levitation coils, permitting *line switching* of a train *without moving parts.* The concept has been adopted in the design by Foster-Miller.

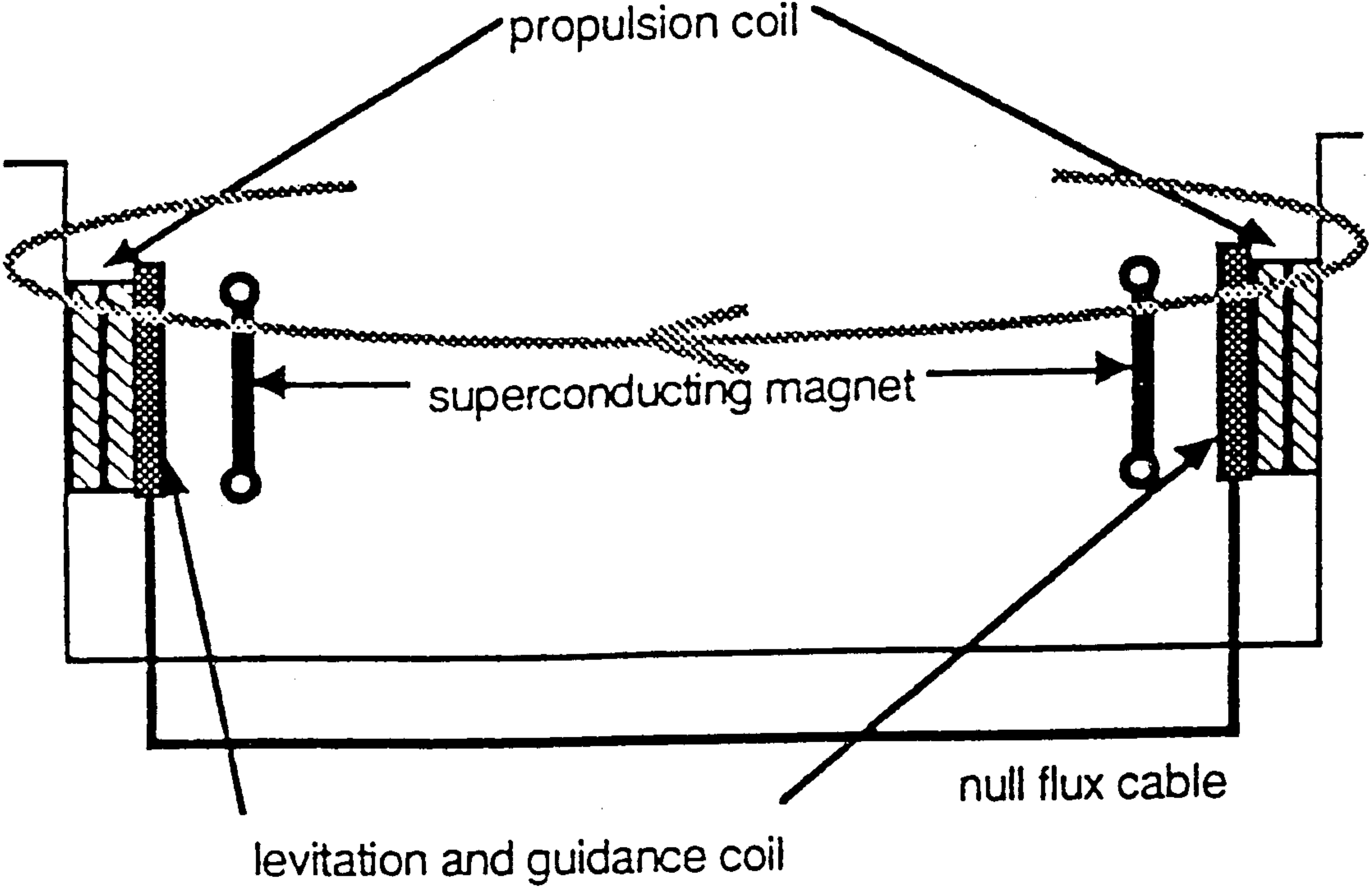

propulsion coil
superconducting magnet
null flux cable
levitation and guidance coil

Fig. 6.

Coming to actual performance we see again the results of an overall analysis made for the USA on the Maglev concepts proposed for further study. No prototype exists. Perhaps the most important feature is the relatively low vehicle weight/pass of around 500 kg (Foster-Miller). The Swiss Metro project brings this weight to 250 kg/pass. It is clear that for energy economy and general economy, the ballast mass should be reduced to a minimum as its transport costs just the same as that of passengers and goods. A weight of 250 kg/pass very favorably compares with that of an airplane that has to carry the fuel and the engines. Just to give a definite example, an MD-81 weighs about 500 km/seat at take off.

Parameter	**TGV-A**	**TR07**	**Bechtel**	**Foster-Miller**	**Grumman**	**Magne-plane**
Standard Passengers/Consist (SP)	700	160	110	140	120	100
Gross Mass/SP (kg)	700	650	600	520	530	470
Max. Low-Speed Accel. (g)	0.05	0.096	0.14	0.15	0.097	0.17
Reserve Accel. @ 134 m/s (g)	N/A	0.01	0.12	0.05	0.05	0.04
3.5% Grade Speed (m/s)	30	120	140	140	140	140
10% Grade Speed (m/s)	N/A	10	140	110	5	90
0-134 m/s Time (s)	N/A	320	75	120	180	99
Minimum Radius (m)	*6,000*	5,800	2,600	2,800	3,300	2,200
Prop. Efficiency @ 134 m/s *[83 m/s]*	*[0.78]*	0.83	0.87	0.91	0.78	0.84
Power Factor @ 134 m/s *[83 m/s]*	*[0.94]*	0.74	0.98	0.97	0.98	0.99
Aero. Drag/SP @ 134 m/s (N)	220	360	430	280	240	170
Total Drag/SP @ 134 m/s (N)	240	390	500	320	270	380
Energy Intensity @ 134 m/s (J/SP-m)	310	450	590	340	360	450
SST Energy Intensity (J/SP-m)	N/A	690	620	440	420	650
SST Trip Time (min.)	N/A	150	120	120	130	130
Guideway Tolerances: Safety (mm)		5	6	25	30	50
: Ride-Comfort (mm)	1-3	2	3	12	5	20
Consist Cost /SP ($k)	41	58	39	93	71	200
Dual Elevated Cost: SCD ($M/km)		9.7	17	9.3	7.8	13
: GMSA ($M/km)	14	12	14	20	9.9	15

Fig. 7.

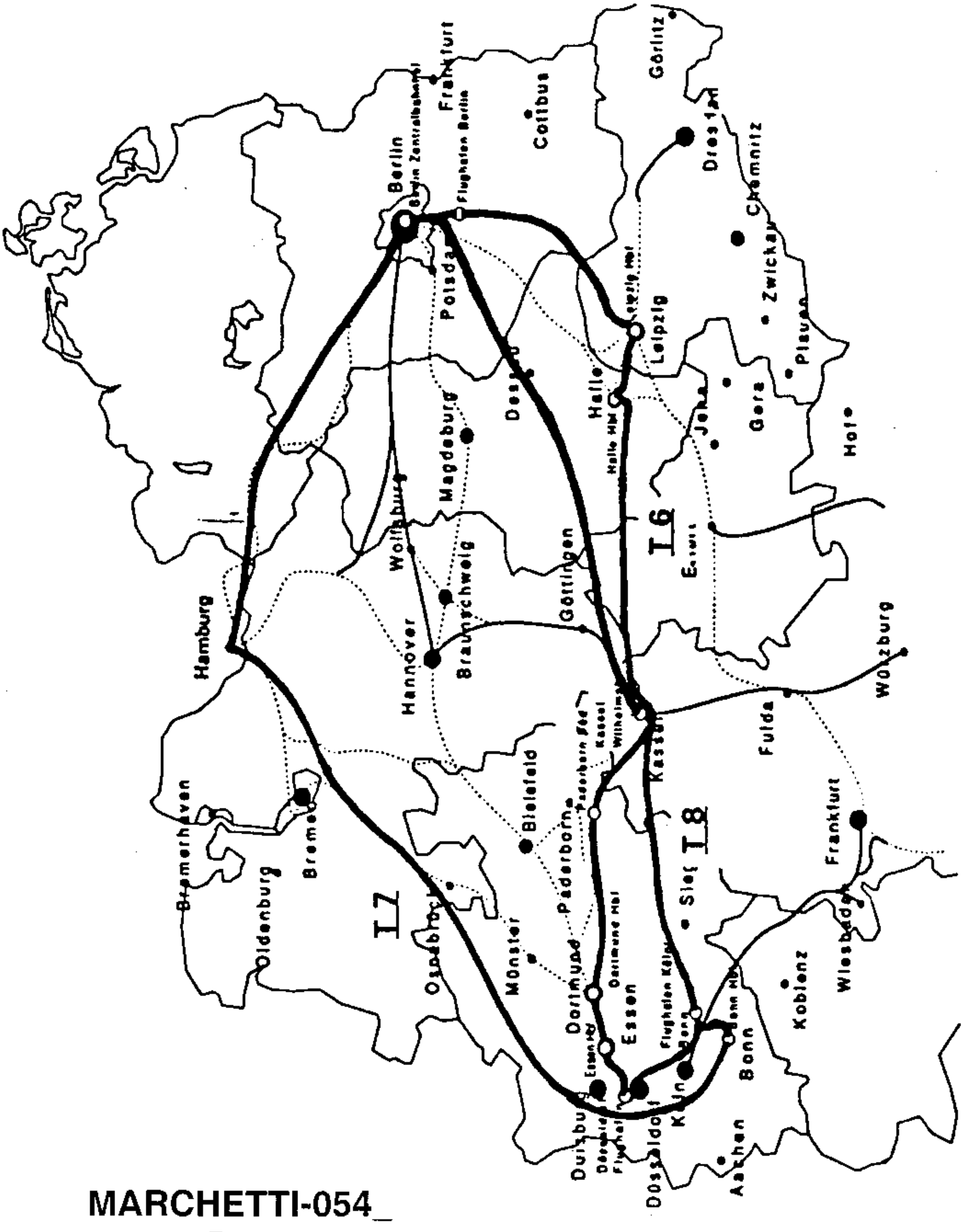
As usual when a new technology starts, many variants will be tested to explore their implication potential. Historical analysis of basic innovations like the electric motor or the typewriter, shows that these variants are in the order of 100. *One will emerge* and penetrate the market. Curiously the winning versions appear fairly soon and their design is not very different from the final one that will conquer the market.

We have a fairly detailed analysis of American Maglev proposals compiled by J. H. Lever (1993) as an abstract to a Government System Assessment. The model incorporating the most promising features, including a *vertical switching system with no moving parts,* which will have a great selective value for its potential for switching a high velocity and for lift and over/underpass at stations, with low velocity manoeuvring. To make things perfect Maglev designers should eliminate wheels. The trains listed have a standard cruise speed of 500 km/hr (134 m/sec). In comparison TGVs appear to have fairly "antiquated" characteristics.

Parameter	TGV-Atlantique	TR07	Bechtel	Foster-Miller	Grumman	Magne-plane
Basic Concept	steel wheel-on-rail	EMS, separate lift & guidance	EDS, ladder levitation	EDS, sidewall null-flux	EMS, common lift & guidance	EDS, sheet levitation
Vehicles/Consist	1-10-1	2	1	2	2	1
Seats/Consist	485	156	106	150	100	140
Gross Mass (10^3 kg)	490	106	63	73	61	48
Floor Area/Seat (m^2)	1.2	0.83	0.80	0.74	0.93	0.58
Cruise Speed (m/s)	83	134	134	134	134	134
Total Bank Angle (°)	7	12	30	28	24	35
Primary Suspension	passive	active	passive	passive	active	semi-active
Secondary Suspension	passive	passive	active	passive	none	none
Critical Air Gap (mm)	N/A	8	50	75	40	150
Low-Speed Support	N/A	maglev	air bearings	wheels	maglev	air bearings
Normal Braking (g)	0.045	0.12	0.20	0.16	0.16	0.16
Emergency Braking (g)	0.10	0.30	0.25	0.25	0.20	0.50
Cryogenic System	N/A	none	isochoric	recompress.	recompress.	refrigerator
Onboard Power (kW)	9,000	460	190	220	170	190
Guideway Type	ballasted rail	T-shaped	box beam	sidewall	Y-shaped	trough
Switch Concept	swing-nose rails	bendable steel beam	bendable FRP beam	vertical elect.-mag.	bendable steel beam	horizontal elect.-mag.

Fig. 8.

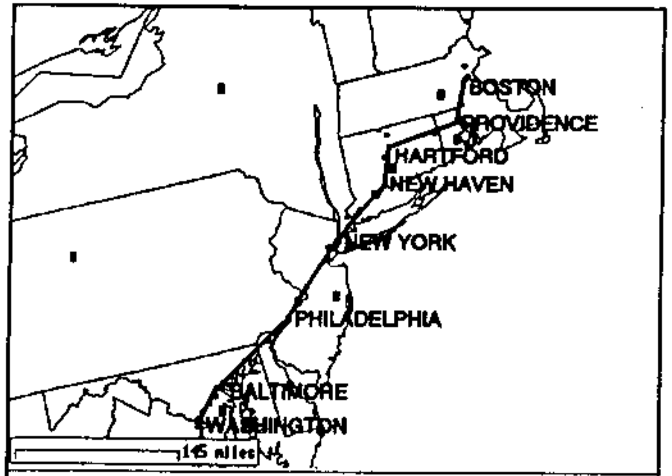
A possible set of Maglev lines to be implemented in Germany. Berlin-Hamburg is almost decided. Also here we find the historical relic of transport networks. Maglev systems may finally appear networked, but their best use is connecting nodes. Functional networking may come as in air transport, according to the principle of hub and spokes.



MARCHETTI-054_
Pt.2

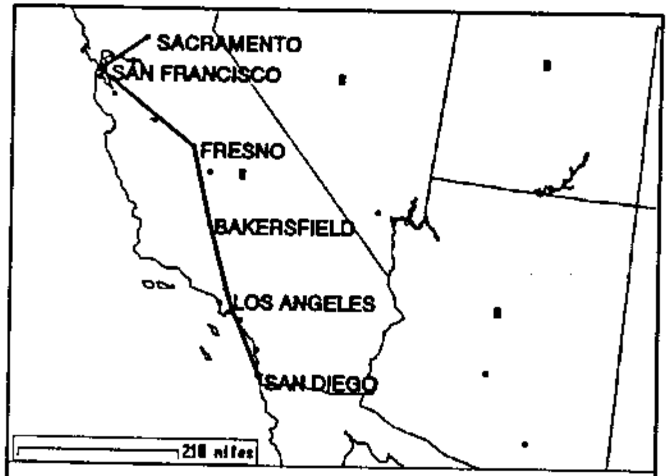
Fig. 9.

Two possible Maglev lines in the Bos-Wash and Sacramento-San Diego corridors may fuse blocks of settlements amounting to 10-15 million inhabitants. In my opinion one should connect the farthest points in a direct way, adding the rest afterwards as meshing lines. Because connections should always be point to point this does not affect dispatching. It may somehow increase the length of the lines (and of the tunnels) but it will shorten total travel time. A balance between plus and minus has to be struck case by case. The lines should have or be easily adaptable to very high capacities (e.g., 10^5 pass/hr) because this is the kind of fluxes to be expected of equilibrium. (Normal ways of calculating these fluxes, e.g., through cost-benefit, never give the right orders of magnitude.)



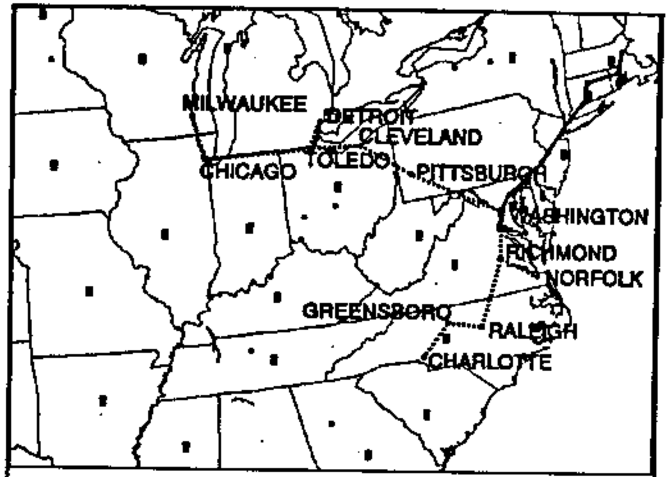
LEVEL I CORRIDOR

Boston/Washington Corridor 415 Miles 8/Top 75 Merit 48,680



. LEVEL II CORRIDOR

Sacramento/San Diego Corridor 549 Miles 6/Top 75 Merit 13,395



LEVEL II EXTENSIONS

←

Washington/Detroit Extension	455 Miles	+4/Top 75	Merit 16,572
Washington/Norfolk Extension	176 Miles	+2/Top 75	Merit 15,914
Toledo/Chicago Extension	212 Miles	+1/Top 75	Merit 12,251
Richmond/Charlotte Extension	290 Miles	+3/Top 75	Merit 11,076
Chicago/Milwaukee Extension	82 Miles	+1/Top 75	Merit 10,324

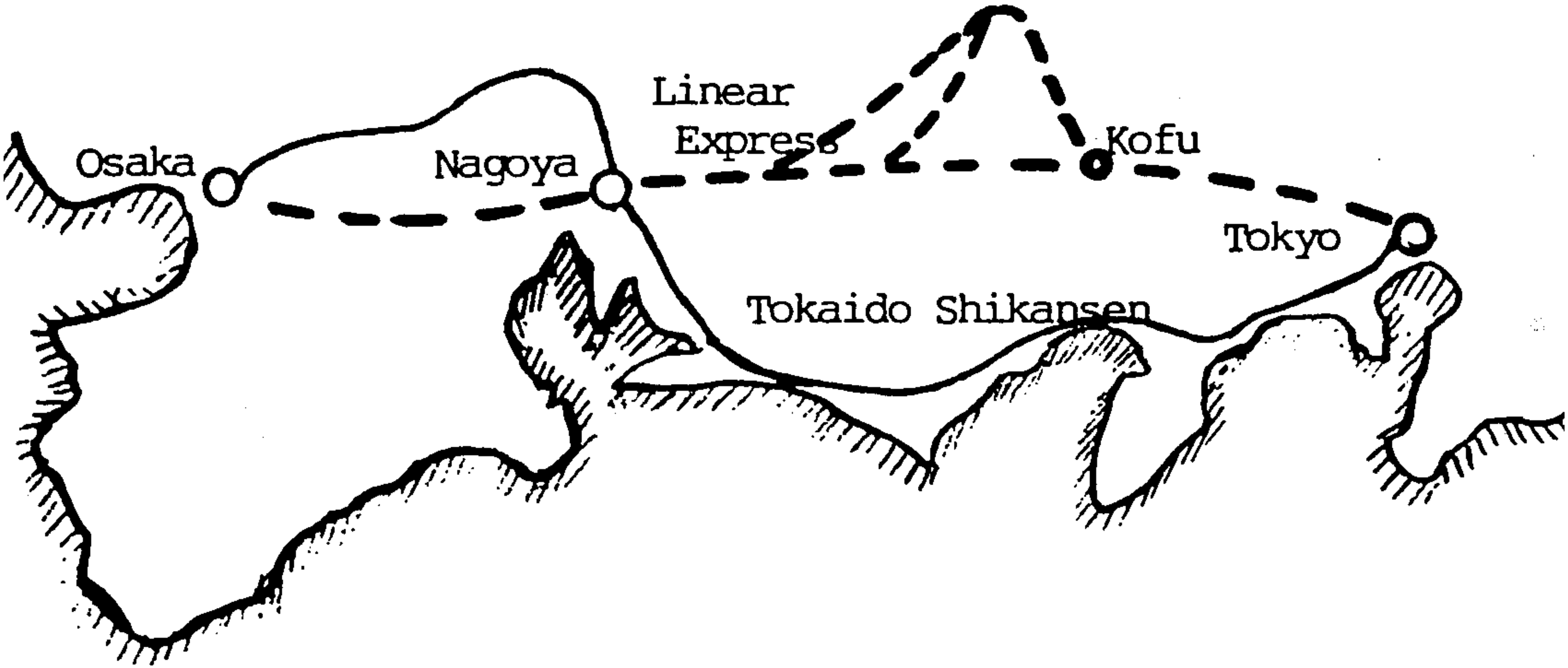
Fig. 10.

A possible trace for the Tokyo-Osaka connection with a Maglev. Using current technology the distance of about 500 km could be covered in about one hour. However, more than 70% of the line will be in tunnels, which creates entrance problems where the shock wave of the train interacts with the mountain's surface and reflects back on the train (which has to be airtight to protect the eardrums of the passengers).

High speed requires tunnels to be large (cross-section ratio between tunnel and train of at least 10) and consequently expensive. The Swiss Metro solution seems to be an unavoidable attraction point, as the cross section of the tunnel matches that of the train.

With CAM technology which appears possible in a Swiss Metro type context, the distance Tokyo-Osaka could be covered in a mere 10 minutes instead of the 60 minutes of the planned Maglev connection.

With appropriate feed lines the Tokyo-Osaka system could nurture a composite city of 30-40 million inhabitants operating as a single unit.


Osaka
Nagoya
Linear
Express
Kofu
Tokyo
Tokaido Shikansen

Anthropological Invariants in Travel Behavior

C. Marchetti
International Institute for Applied Systems Analysis
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Abstract

Personal travel appears to be much more under the control of basic instincts than of economic drives. This may be the reason for the systematic mismatch between the results of cost benefit analysis and the actual behavior of travelers.

In this paper we put together a list of the basic instincts that drive and contain travelers' behavior, showing how they mesh with technological progress and economic constraints.

Introduction

That man is a territorial animal is a statement that does not need demonstration. History is a collection of squabbles between human groups competing for territories: But also brothers sharing the same room squabble for its division in areas of influence. Now the *basic instinct* of a territorial animal is to *expand its territory*. A larger territory means larger resources and opportunities and the rationale for accretion is obvious. Exploiting a large territory is also expensive, however, both because it requires the physical exertion of moving over large distances, and because moving means to be in the open, under the possible threat from enemies and predators.

For an animal, and for a pretechnological man, a balance can be struck by *adjusting* one single parameter: *mean traveling time per day*. Strictly speaking this fixes only the "*exposure time*", but, in fact, multiplied by the mean speed of movement of a certain animal, it fixes a distance, or a *range*, that is, a territory.

The second point is that *man has a cave instinct*. The protection of the high tree with dense foliage in the tropical rain forest has found a good substitute in the hiding shade of the cavern, where man spent most of the time not devoted to gathering and hunting. This relic is important as the big business of air transport pivots on this instinct, as we shall see in a moment.

The field work of Zahavi [6,7], who was at the World Bank when he did it, is in my opinion most remarkable because it shows the *quintessential unity of traveling instincts around the world*, above culture, race, and religion, so to speak, which gives unity to the considerations relative to the history and future of traveling, and provides a robust basis for forecasts in time and geography.

The empirical conclusion reached by Zahavi is that all over the world the *mean exposure time* for man is around *one hour per day.* This is a mean over the year and over a population, but the tails of the distribution are not spread much around the central value. The effects of the instinct are pervasive. Even people in prison for a life sentence, having nothing to do and nowhere to go, walk around for one hour a day, in the open. Walking about 5 km/hr, and coming back to the cave for the night, gives a territory radius of about 2.5 km and an area of about 20 km^2. This is the definition of the territory of a village, and, as Figure 1 shows, this is *precisely* the mean area associated with Greek villages today, sedimented through centuries of history. The same principle operates when a city, through its importance, political or economic, expands its population and, as a consequence, its physical size. There are no city walls of large, ancient cities (up to 1800), be it Rome or Persepolis, which have a diameter greater than 5 km or a 2.5 km radius. Even Venice *today*, still a pedestrian city, has exactly 5 km as the maximum dimension of the *connected core.*

When introducing mechanical transportation with speeds higher than 5 km/hr, the physical size of the city can grow in proportion, as the historical analysis applied to the city of Berlin clearly shows (Figure 2). The commuting fields, based on cars, of a dozen American cities are reported in Figure 3. On the same chart and to the same scale, the Greek villages of Figure 1 are shown in schematic form. *Cars make all the difference.* As they have a speed 6 or 7 times greater than a pedestrian, they expand daily connected space 6 or 7 times in linear terms, or about 50 times in area. Ancient cities typically had a maximum population of about 1 million people. Today the population may tend to reach 50 million people in conurbations like Mexico City (Figure 4), with a population density equal to that of Hadrian's Rome. If the Japanese complete a *Shinkansen Maglev* (a magnetically levitated train) connecting Tokyo to Osaka in less than one hour with a large transportation capacity, then we may witness a city of 100 million people. If we expand the reasoning, we can muse about a city of 1 billion people, which would require an efficient transportation system with a *mean speed* of only 150 km/hr. This could happen in China, as *these aggregations tend to stop at cultural and political barriers as we shall see.*

The accent can be set, then, on *transportation as the unifying principle of the world, and not communication* as the current wisdom indicates. On one side the so-called explosion in communication during the last 20 years did not dent transportation expansion; on the other hand, they tend to move together (Figure 5) as Grübler has shown, pointing to a synergistic more than a competitive situation [4]. As communication and transportation move together, one can be used as a proxy for the other for measuring the effect of the political–cultural barriers we cited before. We can look, for example, at interactions between communities of different languages (e.g., culture), or between communities with the same language but different political denomination. The results of the analysis are obtained by looking, for example, at telephone calls between cities in Quebec (French speaking) and Ontario (English speaking) and the nearby United States. As we can see in Figure 6, *cultural barriers or political barriers bring a reduction by an order of magnitude in communication,* *and supposedly in personal movement.*

The reduction can be seen by applying a gravitational model to communication and transportation, which works well in both cases and differ in the numerical coefficient as explained in the legend of Figure 6. This means that a superfast Maglev connection system for the European core may link it without really unifying it in the sense of the Shinkansen area, at least in the short term — 50 years, for example. Mixing people may favor cultural compatibility — as history shows. Cultural traits are slow to modify and fast transportation may finally raise the central problem of *how to realize a viable multicultural society*, however. This is not only an inevitable political and religious problem, but also an *ecological* one, so to speak, as it seems like a good idea to *preserve the cultural diversity* of human populations in parallel with the *biodiversity* of living species.

In one of my *Gedankenexperimente* I explored the possibility of using transport technology in such a way as to leave the possibility of saving cultural roots, allowing intense interaction at the same time. Such problems can be solved only by going back to basic principles and I tried to go in that direction. Man, as I said before, is a cave animal and *spends much of his time in his cave, actually more than two thirds* (Table 1). His family, his furniture, and his cultural roots are there. In order to preserve all that it seems almost necessary to permit a person to come back to the cave, wherever his work and business takes him during the day.

My *Gedankenexperiment,* which I presented at Marrakech in a congress related to the problem of linking Africa (or better the Magreb) to Europe with a bridge or a tunnel across the Gibraltar Strait, was based on the exploitation of the maximum potential of the *Maglev*, the magnetically levitated and driven train. At the Polytechnic of Lausanne a Maglev transportation system about 700 km long linking the major Swiss cities with transit times of 10 minutes has been proposed (Figure 8), with the characteristic of running in an evacuated pipe (air pressure equivalent to a height of 15,000 meters) [3]. The rationale is to have a *small tunnel*, almost fitting the size of the train. Due to the mountainous conformation of Switzerland, such connections have to be made in tunnels for the most part, and the cost of tunneling is dominant over every other component of the system.

Operating in a partial vacuum, however, removes the most important constraint to vehicle speed, as Maglevs move more or less in a frictionless manner on a magnetic cushion. We still have a limitation on the acceleration that humans can take. I assumed 0.5 G or 5m/sec^2 as an acceptable one. It is the acceleration (for a few precious seconds) of extremely expensive cars, like Ferraris and Porsches.

Operating a Maglev between Casablanca and Paris at constant acceleration (CAM), that is, by accelerating halfway and braking the other half at 0.5 G, the train would cover the distance in about 20 minutes. In other words a woman in Casablanca could go to work in Paris, and cook dinner for her children in the evening. Vice versa for shopping for special items in a special cultural atmosphere. With appropriate interfaces, such trains could carry hundreds of thousands of people per day. *The idea behind this is to save cultural roots without impeding work and business in the most suitable places.* Incidentally, businessmen who can afford the extraordinary cost of air travel in Europe do exactly that. They take the plane because it permits them to come back at night to sleep in their beloved cave, with family, cultural, and status symbols in place.

Speaking of a European core, I must say that functional integration at a high hierarchical level (e.g., having a common foreign policy) may not require full integration at a lower level, which would be an integration hitting against cultural and linguistic barriers. A suggestion in that sense comes from an analysis I did on the rank–size of world cities. This rank–size images the *distribution of tasks* between the largest cities of the world (or of a nation) in running the system and filling a territory fractally. As shown by Zipf in his seminal work in the 1940s, a well-developed system shows a fractal structure in the size of the population of cities (Figure 9). In 1920 London was the world's largest city and her number one ranking was obvious in terms of politics and finance. The ranking of the world's cities sat on a nice straight line *as it should* according to Zipf. If we repeat the exercise now, we find that the world cities line has a big knee (Figure 10). In a sense, either the world is short of large cities or in some way it is not at equilibrium.

Air transportation has made it possible to commute between cities, however, if not every day, at least for the necessary number of times, for the "elites" in functional terms — managers, politicians, professionals of a high rank. The sets of cities where air shuttles work, showing high density of this kind of exchange, have been dubbed by Doxiadis as *corridors.* They often have a linear structure like Boston-New York-Washington, or Tokyo-Nagoya-Osaka. *Assimilating corridors to cities* and repeating the exercise we find a fit according to Zipf's paradigm. This is certainly not a proof, but a strong suggestion that the movement of the elite is sufficient for a *functional integration at the highest level.* Most corridors are between cities that are culturally and politically homogeneous, a generalization is then not advisable. Some strong interconnections between cities like London and Amsterdam may be testbeds for studying the effect of cultural and political barriers at the level of the elite.

If these effects are not so strong as for the bulk of the population, in the sense that they can be digested in a relatively short time, then *hypersonic planes* operating shuttles at world level, with the elite coming back to their cave at night wherever they have to go, could become the *backbone of a single world. Speed is a unifying principle*, as the case of the evolution of "on foot empires" and "horseback empires" in China shows (Figure 11). They eventually reached the same final dimension *measured in time* of about *one month* for a return trip from the periphery to the capital. If it takes longer, as happened when Rome lost control of the sea, then the periphery splits, building an independent political unit (the Eastern Roman Empire). This one month maximum time lag in the dominant-to-subject feedback cycle has never been studied to my knowledge but the evidence that comes from the evolution of Roman, Persian, Chinese, and Inca empires points to another subjacent, basic instinct. The splendid transport networks empire builders were forced to put in place appear to be a necessary consequence.

Trips of longer periods are the ones made by tourists (historically preceded by pilgrims) about once a year. Coming from a tourist attractor (Florence), I have always been curious about the driving forces behind tourist wanderings, and being familiar with the species I am very skeptical about their rationalizations. My hypothesis is that there is again a basic drive behind this. If I can describe the behavior of a tourist, perhaps a little sarcastically: he chases a target as far away as possible, hopefully unexplored (unpolluted means he is the first to go there). Once the place is reached, he collects material for tales and physical souvenirs. Then he comes back and fills the heads of colleagues, friends, and parents with the tales of the magnificent land he has just discovered. The behavior is very much reminiscent of the *dancing bee* telling where the blossoming tree is located and the mass and kind of flower (she carries the souvenirs, pollen and the perfume, on herself). Souvenirs then become a tangible testimony that the tales are veridical (man is a born lier). When Moses sent scouts to Palestine, they traveled back loaded with specimens, in particular, a bunch of grapes so large that two men with a pole were needed to carry it. Seen from this systemic point of view, we can perhaps study the tourist phenomenon through a fresh and objective approach.

There is another fundamental observation made by Zahavi that links instincts and money. Because of its generality it could be dubbed as a money instinct. People spend about 13% of their disposable income on traveling. The percentage is the same in Germany or Canada, now or in 1930. Within this budget, time and money are allocated between the various modes of transport available to the traveller in such a way as to *maximize mean speed.* The very poor man walks and makes 5 km/day, the very rich man flies and makes 500 km/day. The rest sit in between. People owning a car use it for about one hour a day (Figure 12) and travel about 50 km/day (Figure 13). People who do not have a car spend less than 13% of their disposable income, however, presumably because public services are underrated and consequently there is no possibility of spending that share of income traveling one hour per day (Table 2.) The number of people killed by road traffic, on the other hand, seems to be invariant to the number vehicles.

Technology introduces faster and faster means of transportation, which also are more expensive in terms of time of use. These new technologies are introduced roughly every 55 years in tune with the Kondratiev cycle. Their complete adoption takes about 100 years (Figure 16). We are now in the second Kondratiev for cars and most mobility comes from them. It was about 10 km/day earlier, and is now 40 km/day. Airplanes are making inroads into this situation and they promise to bring the next leap forward in mobility, presumably with the help of Maglev trains. Hypersonic airplanes promise to glue the world into a single territory.

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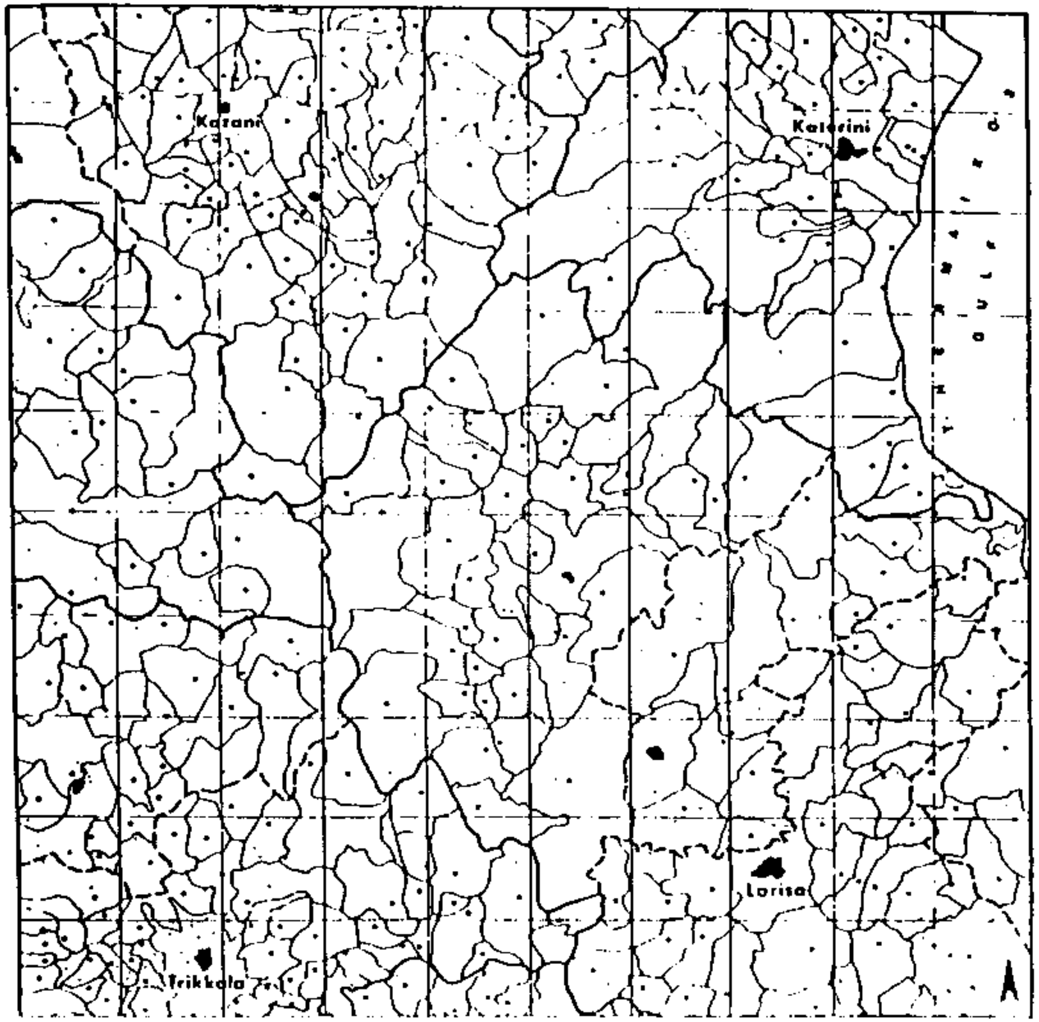
Fig. 1. Territory around villages in Greece.

The agricultural area referring to a village has been settled by trial and error during the centuries. This figure shows a part of Greece, with villages marked as points on the map. The mean area belonging to each village is a little above 20 km^2, pointing to a radius of about 2.5 km. This is also the *largest* radius of the walls of ancient cities, like Rome, Persepolis, Marrakech, or Vienna. The connected core of Venice has the same dimensions today [2].

Village Patterns in Greece



Mean area 22 km^2

Fig. 2. City dimension and speed of transport: The case of Berlin.

The fact that the “daily radius” depends on the speed of transportation is clearly manifested by the evolution of the size of the city of Berlin. The Berlin of 1800 was very compact with a radius of 2.5 km, pointing to a speed of 5 km/hr, the speed of a man walking. With the introduction of faster and faster means of transportation the radius of the city grew *in proportion* to their speed, and is now about 20 km, pointing to a mean speed for cars of about 40 km/hr. The center of the city can be defined, then, as the point that the largest number of people can reach in less than 30 minutes. Reducing the access to the geometric center, for example, through zoning, can displace the functional center elsewhere, for example, outside the city. Shopping centers are a typical consequence of poor transportation toward the center of the city.

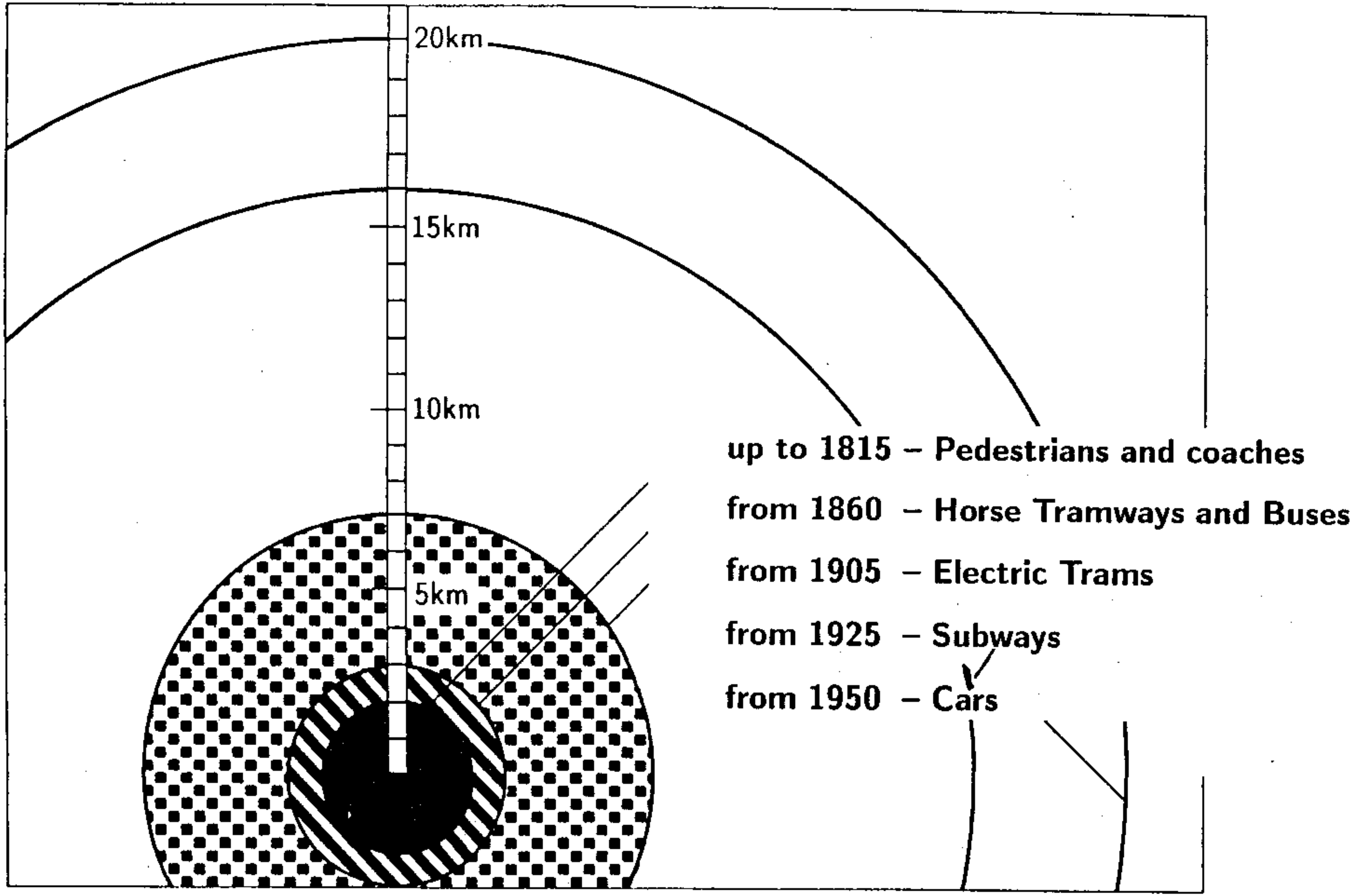

20km
15km
10km
5km
up to 1815 – Pedestrians and coaches
from 1860 – Horse Tramways and Buses
from 1905 – Electric Trams
from 1925 – Subways
from 1950 – Cars

Fig. 3. Commuting fields in 11 American cities.

The geography of the “walking man” is shown here on the same scale as that of the “driving man” commuting in a number of American cities. As cars have a mean speed of about eight times that of a pedestrian, the commuting distances are about eight times as great. The areas accessible — *the territory* — however, grow as the square of the distance, so the driving man has a territory which is about 60 times larger than the walking one [2].

Commuting Fields of Eleven American Cities

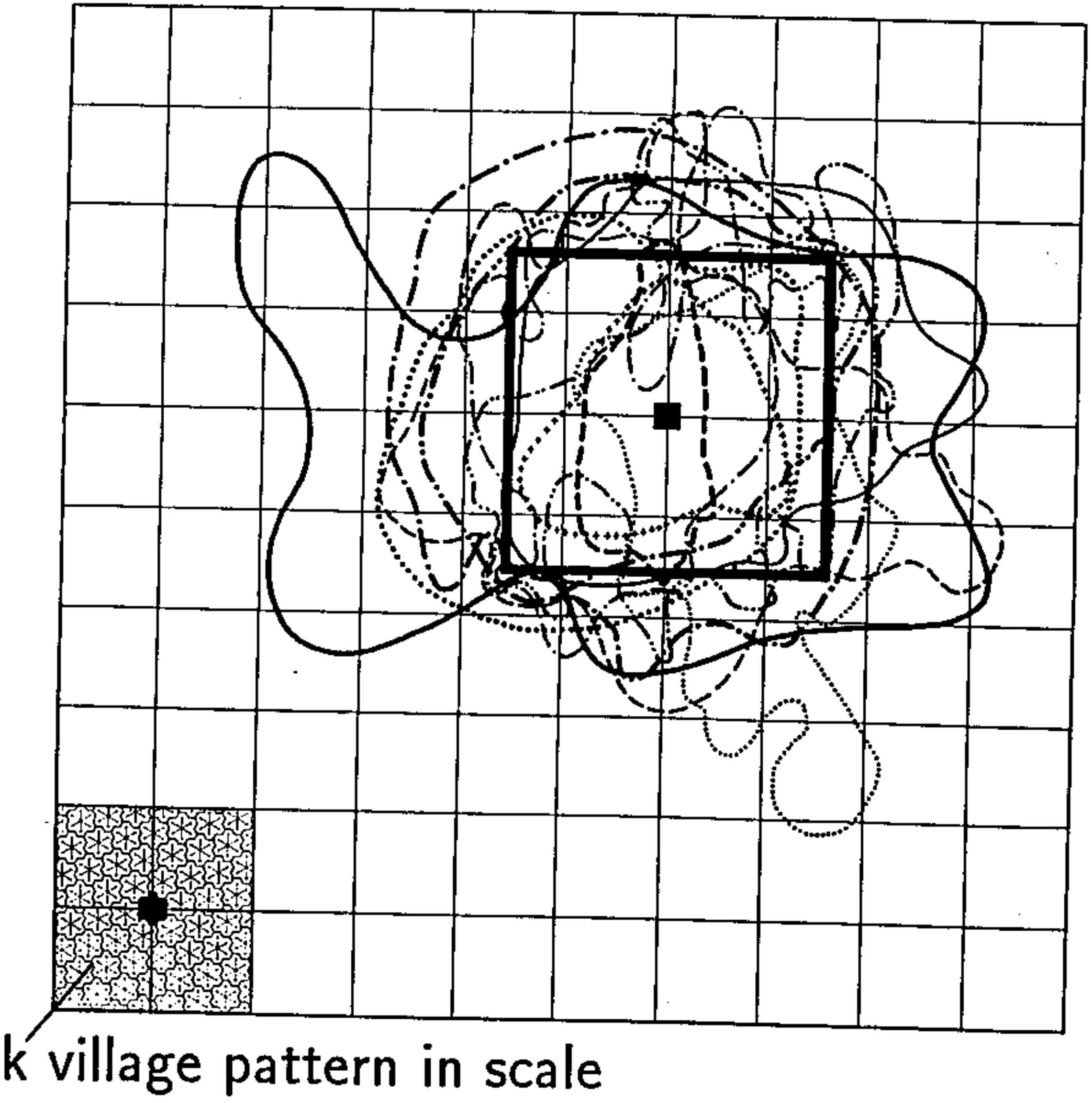
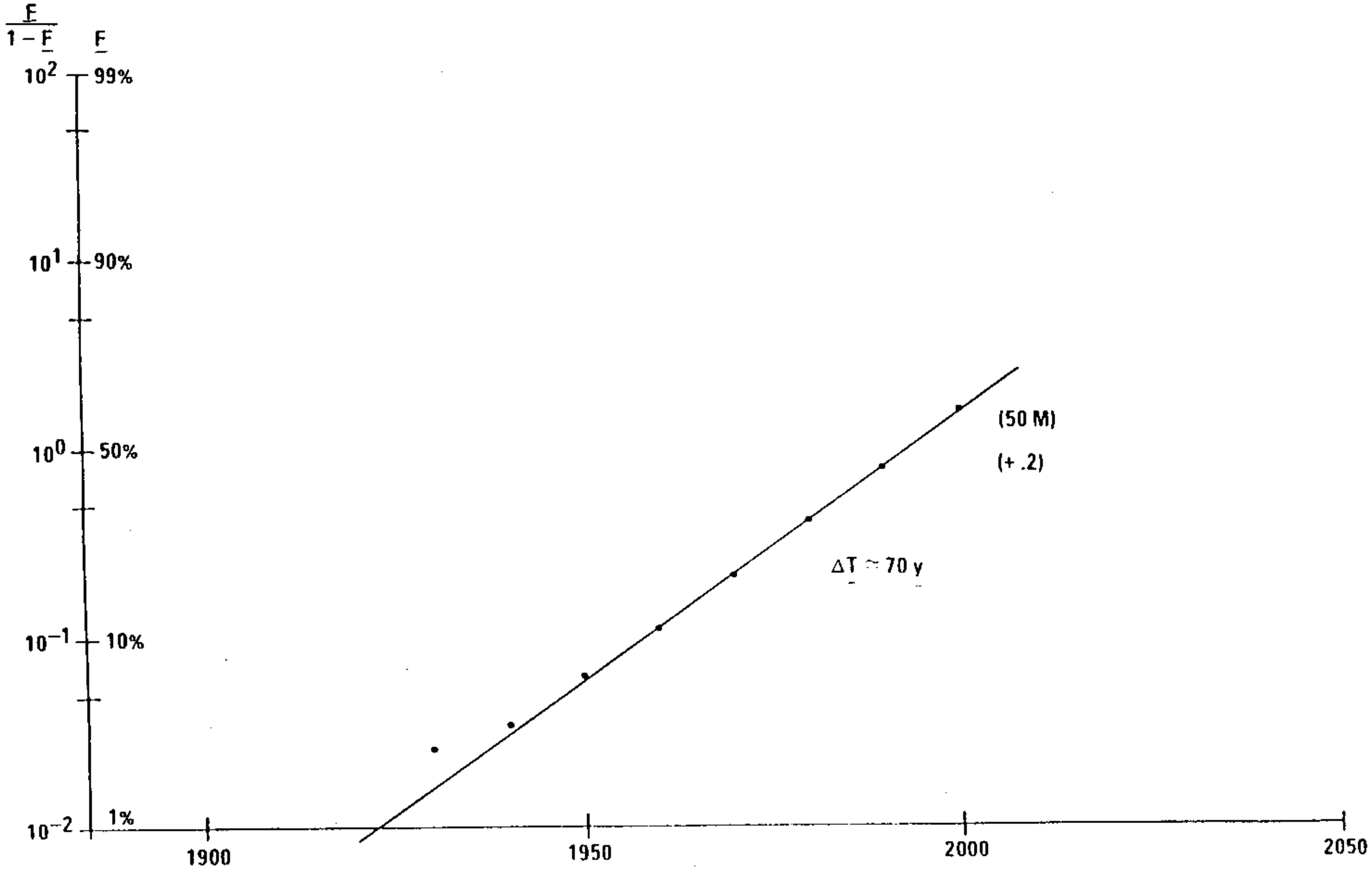


Fig. 4. City size and transport speed: The case of Mexico City.

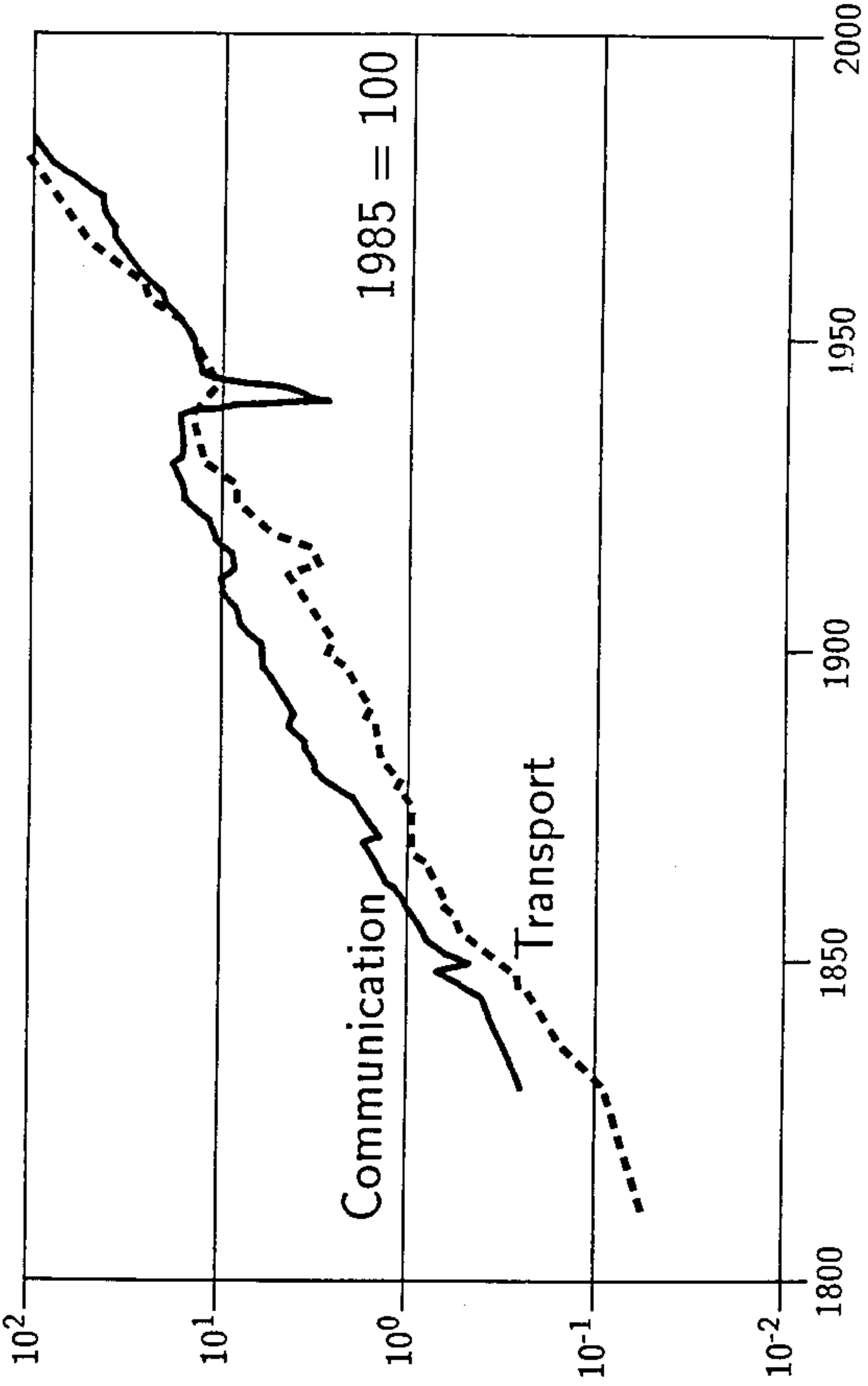
At the density of Hadrian's Rome (1 million people over 20 km^2), we could pack 60 million people in a city where the speed of transportation gives access to an area 60 times larger, meaning an eight-fold increase in speed of transportation. The logistic analysis of the growth of Mexico City points to a saturation level of about 50 million, well in tune with these top-down estimates. We took a transportation speed of 5 km/hr for Rome and 40 km/hr for Mexico City.



$\frac{F}{1-F}$
F
10^2
99%
10^1
90%
10^0
50%
10^{-1}
10%
10^{-2}
1%
1900
1950
2000
2050
(50 M)
(+ .2)
$\Delta T \simeq 70$ y

Fig. 5. Transport and communication: A historical survey for France.

There is much talk about the communication explosion and the possibility of it substituting the physical transport of persons (the "wired city"). Up to now, communication in terms of messages exchanged and transportation in terms of pass-km, seem to move together as the indexes show for France. The increase in personal territories increases the number of information exchange points accessible only by telecommunication. In a village all exchanges are carried out face to face without any need for mechanical devices to communicate [4].



1985 = 100
Communication
Transport
10^2
10^1
10^0
10^{-1}
10^{-2}
1800
1850
1900
1950
2000

Fig. 6. Messages as measure of interconnection: The case of Canada.

Due to parallelism between message exchange by telephone and traveling, we may use the first as a proxy for the second, at least in an approximation where we look for ballpark figures. Here, we are trying to assess the barrier effect of political and cultural differences. The base model is gravitational [8], meaning that in a homogeneous system telephone calls between two cities are proportional to the product of their population divided by some power of their distance KP_1P_2/d.

The model works also for systems with different languages (here Ontario and Quebec) but equal political systems, and for systems of the same language (Ontario and nearby USA) but different political systems. The *proportionality coefficient K is an order of magnitude smaller, showing that cultural and political differences are very powerful interchange barriers*, however, similar results are obtained by looking at travel inside Europe, where real unification may take longer than the abolition of frontiers or the construction of a fast connection grid with Maglevs[1].

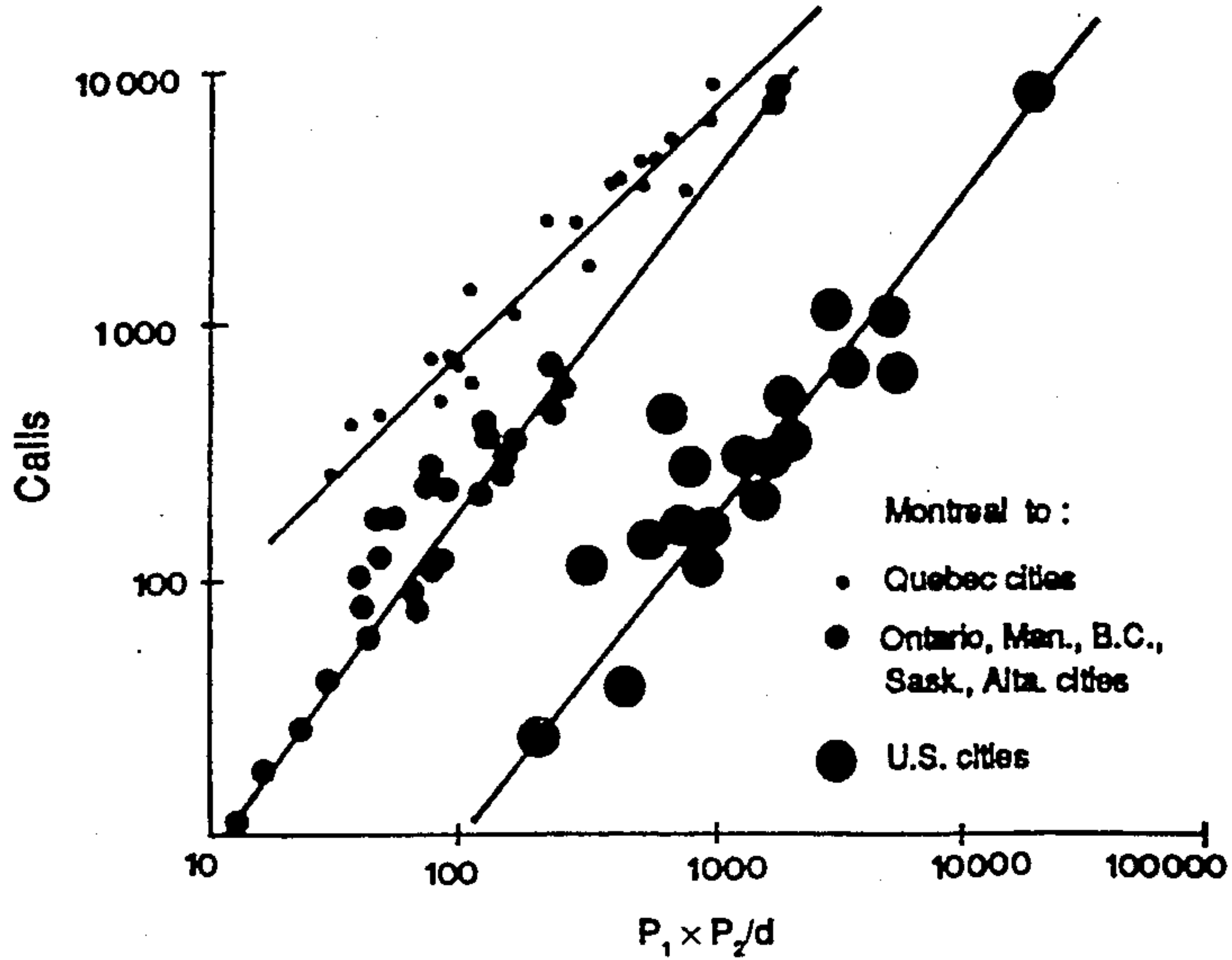

10 000
1000
100
Calls
10
100
1000
10000
100000
$P_1 \times P_2/d$
Montreal to :
• Quebec cities
● Ontario, Man., B.C., Sask., Alta. cities
⬤ U.S. cities

Fig. 7. Time spent at home by adults in various countries [2].

Time Spent at Home by Adults

City and Country	Percent
Athens	75*
Belgium (65 urban areas)	75
Bulgaria (Kazanlik)	61
France (6 cities)	71
West Germany	70
Poland (Torun)	76
USSR (Pskov)	61
USA (44 cities)	68

Fig. 8. Proposal for a “Swiss Metro” made by the Federal Polytechnic School of Lausanne, Switzerland.

A Maglev train would run in a partially evacuated tube to save on tunneling costs. The time taken to connect two adjacent cities is kept constant at about 10 minutes. The consequence of such an arrangement would be the fusion of these cities at all levels of operation. The pivot city, Bern, could become the “city center” of the system.

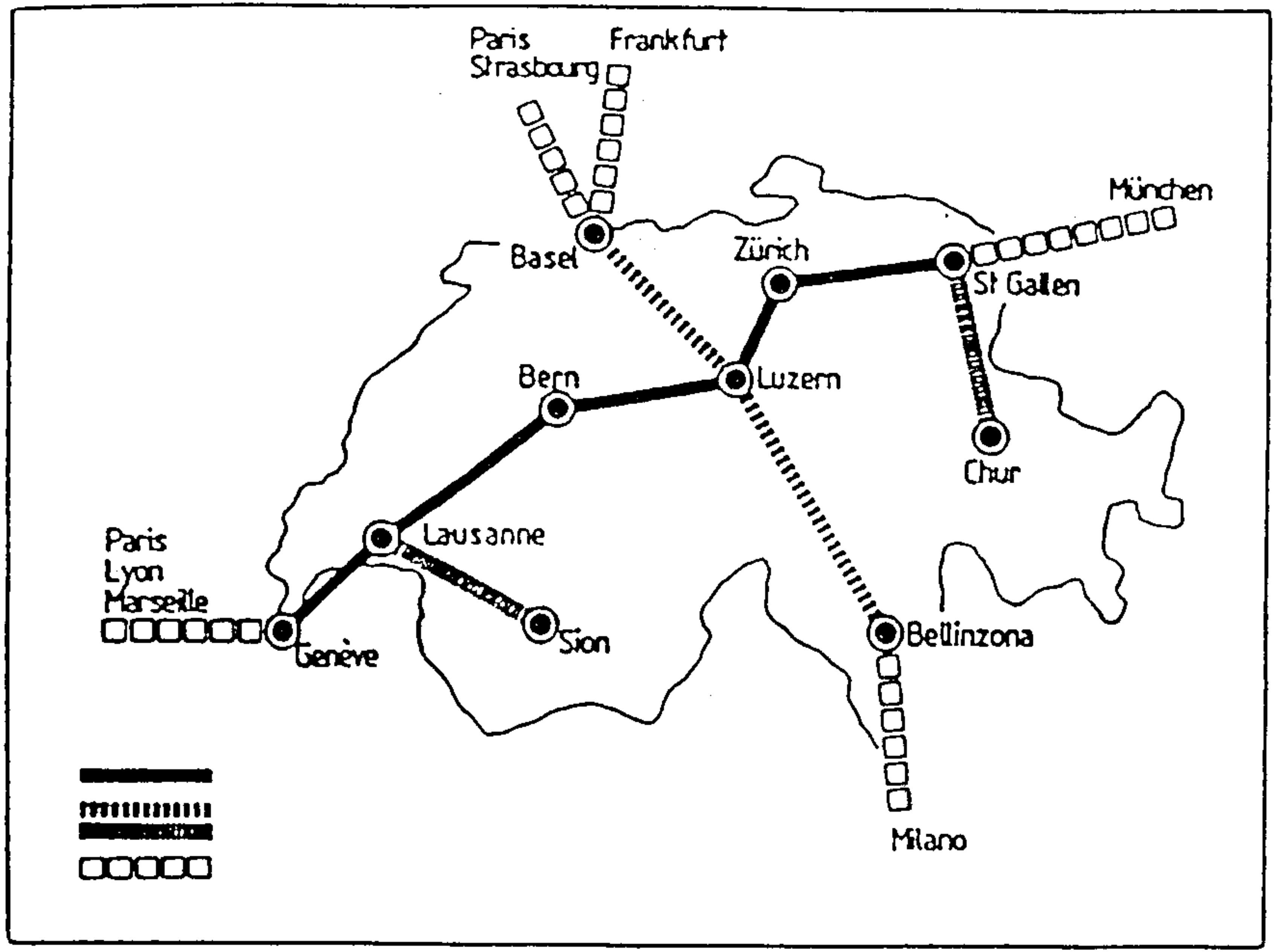

Paris
Strasbourg
Frankfurt
Basel
Zürich
St Gallen
München
Bern
Luzern
Chur
Paris
Lyon
Marseille
Lausanne
Genève
Sion
Bellinzona
Milano

Fig.9. The rank-size distribution of the world's largest cities in 1920

Zipf showed that in an interconnected system the population size of cities tends to have a constant ratio when ordered in a decreasing size sequence (rank). According to Zipf, who ordered these sequences in a log-log "rank-size," matching a straight line is the manifestation of some sort of equilibrium in the distribution of tasks. Rank number one belongs to the city with the highest rank functions in world politics and finance. At world level, London fitted well into that position in 1920. The distribution can also be interpreted as a fractal set that fills a space [8].

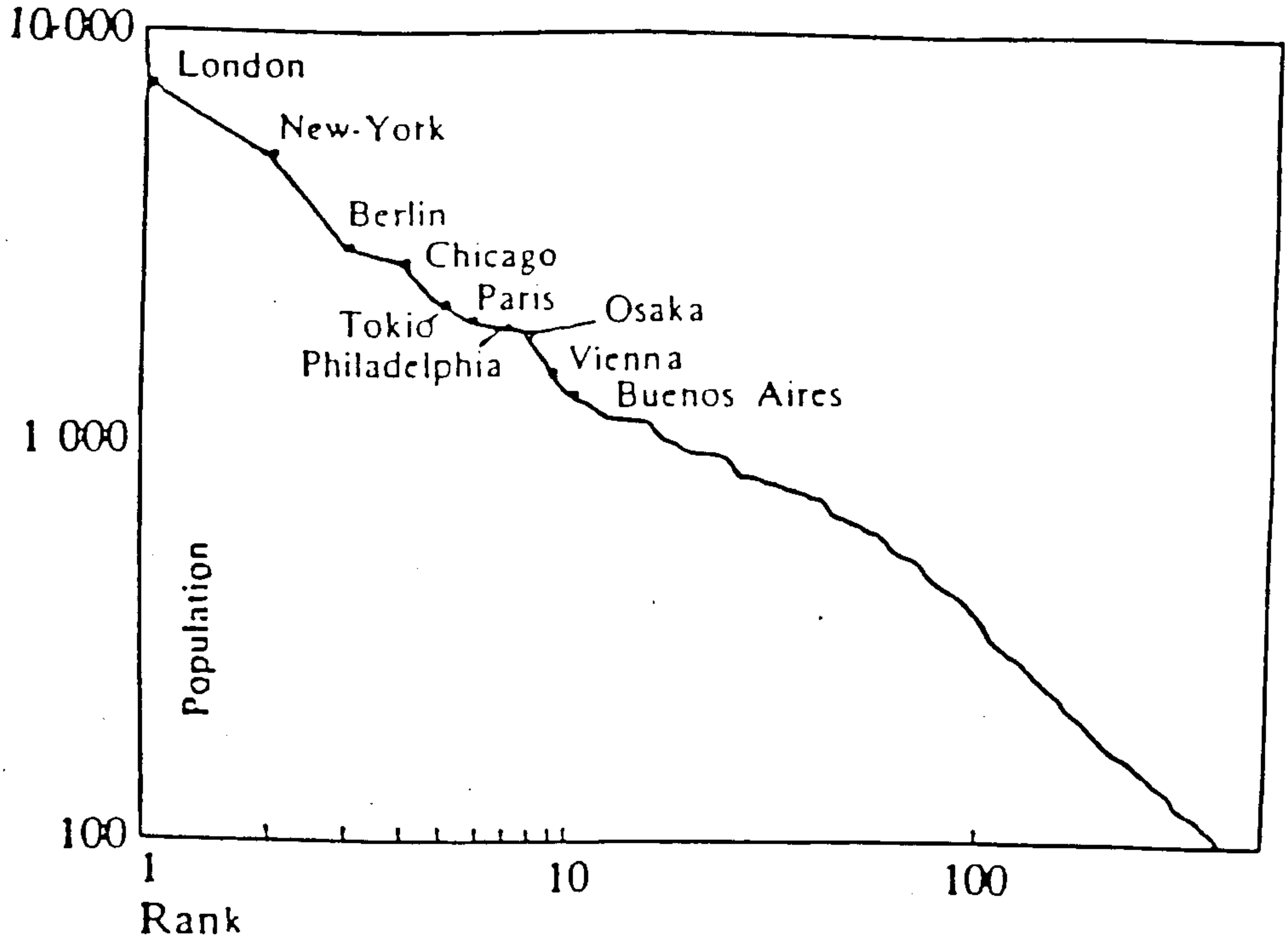

10 000
1 000
100
1
10
100
Rank
Population
London
New-York
Berlin
Chicago
Paris
Tokio
Philadelphia
Osaka
Vienna
Buenos Aires

Fig. 10. “Corridors” as functional units.

If we repeat the Zipf chart of 1920 today, we find that the rank-size of world cities line bends sharply at around a population of 7 million. Projecting from the smaller cities upward, one could say that, in the Zipf logic, we are short of very large cities. However, counting “corridors”, that is, sets of cities connected with air shuttles and very fast trains, as single units, we find Zipf’s order again. This may mean that the daily movement of the “elite” is sufficient to ensure the highest rank functions, with corresponding sizes equal to the sum of the connected cities.

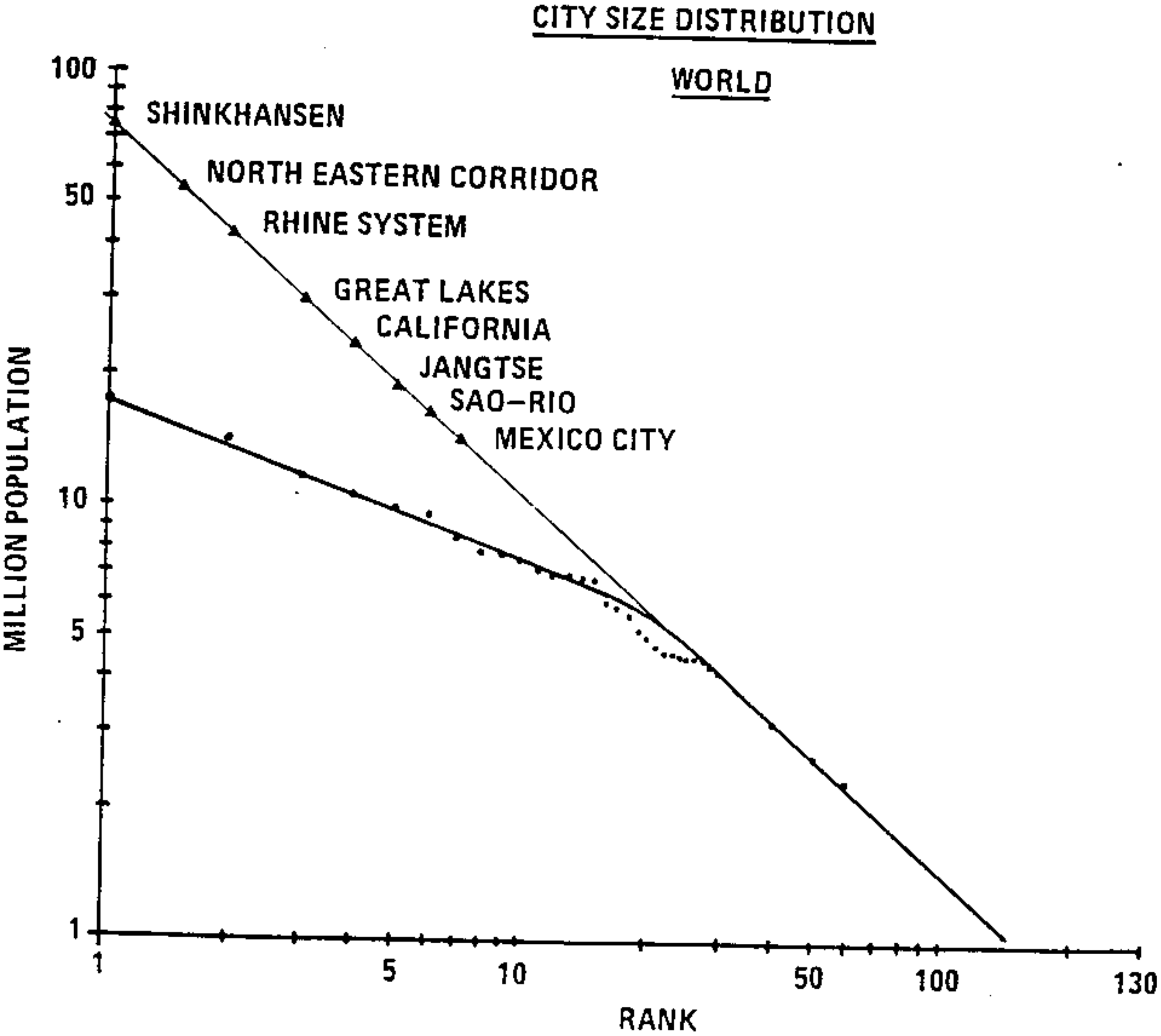
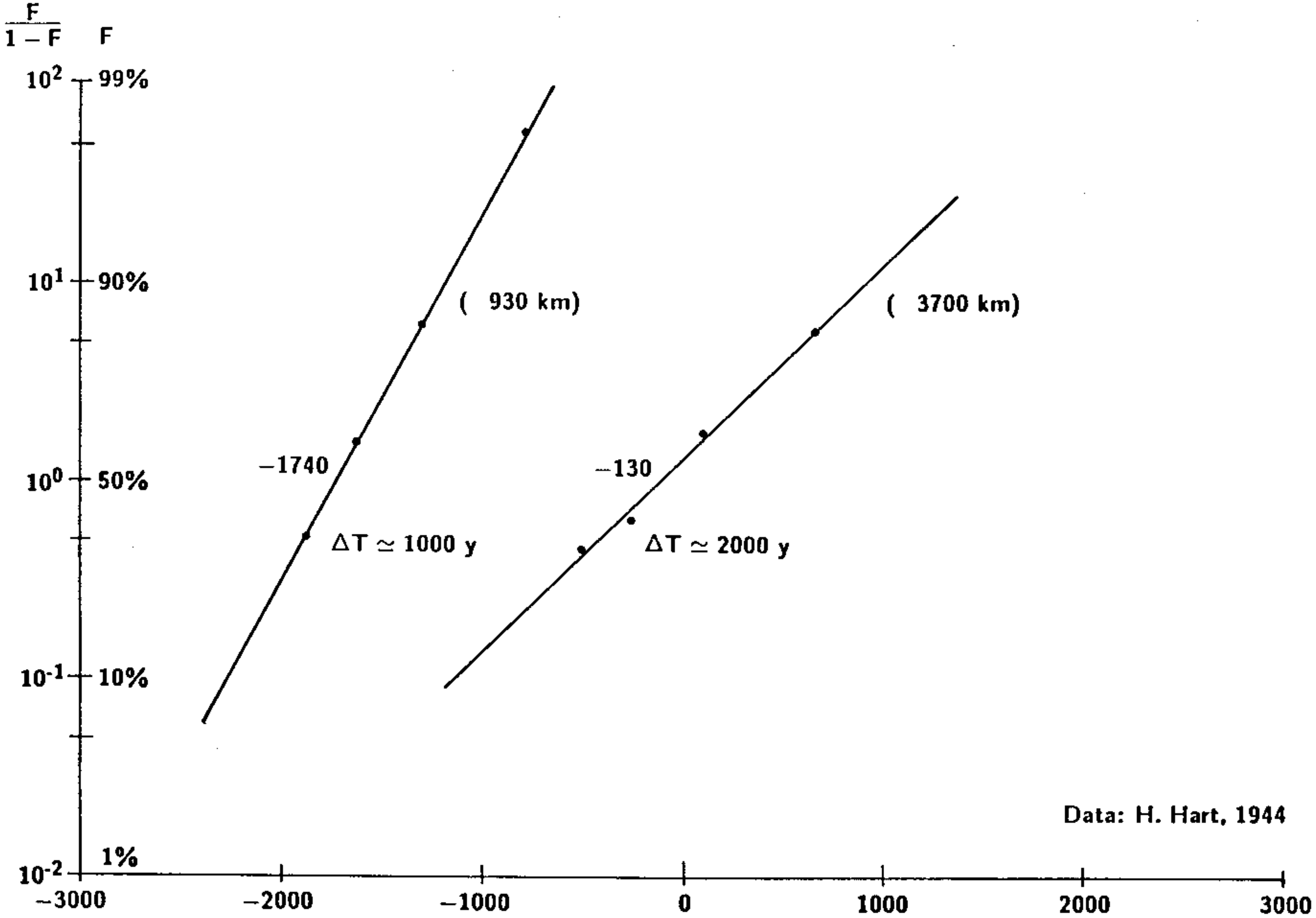

CITY SIZE DISTRIBUTION
WORLD
SHINKHANSEN
NORTH EASTERN CORRIDOR
RHINE SYSTEM
GREAT LAKES
CALIFORNIA
JANGTSE
SAO–RIO
MEXICO CITY
MILLION POPULATION
100
50
10
5
1
RANK
1
5
10
50
100
130

Fig. 11. Travel speed and the maximum size of an empire.

As the Chinese say, past history contains all useful precedents to interpret the present. It may be interesting to muse about how transportation speed shapes the empires. Here, the size of the largest empires in Chinese Asia are reported. They can be ordered in two logistics having saturation points of 0.7×10^6 km^2 and $\sim 10 \times 10^6$ km^2, or *mean diameters* of $\sim$ 930 km and $\sim$ 3700 km. In both cases, this corresponds to about a 15-day return trip from the center on *foot*, and on *horseback*, respectively. Apparently, empires where the periphery is more than 15 days away from the capital split, showing that *fidelity to the central power has a holding time of one moon.* Rome's empire had to split when Rome lost control of the seas. An overland trip to the Black Sea took one month. The good news is that with current airplanes a world government is possible. With mach-7 airplanes and matching Maglevs, a world city is also possible. The assimilation of the technologies in political terms, however, will take some time.



Data: H. Hart, 1944

C. Marchetti, IIASA, 1992

Fig. 12. **How long do car owners use their mobility prosthesis.**

The owner of a car clings to it for most of his “exposure time” of one hour a day. Cars provide high mobility today at costs accessible to most. Low income has a small effect on car use.

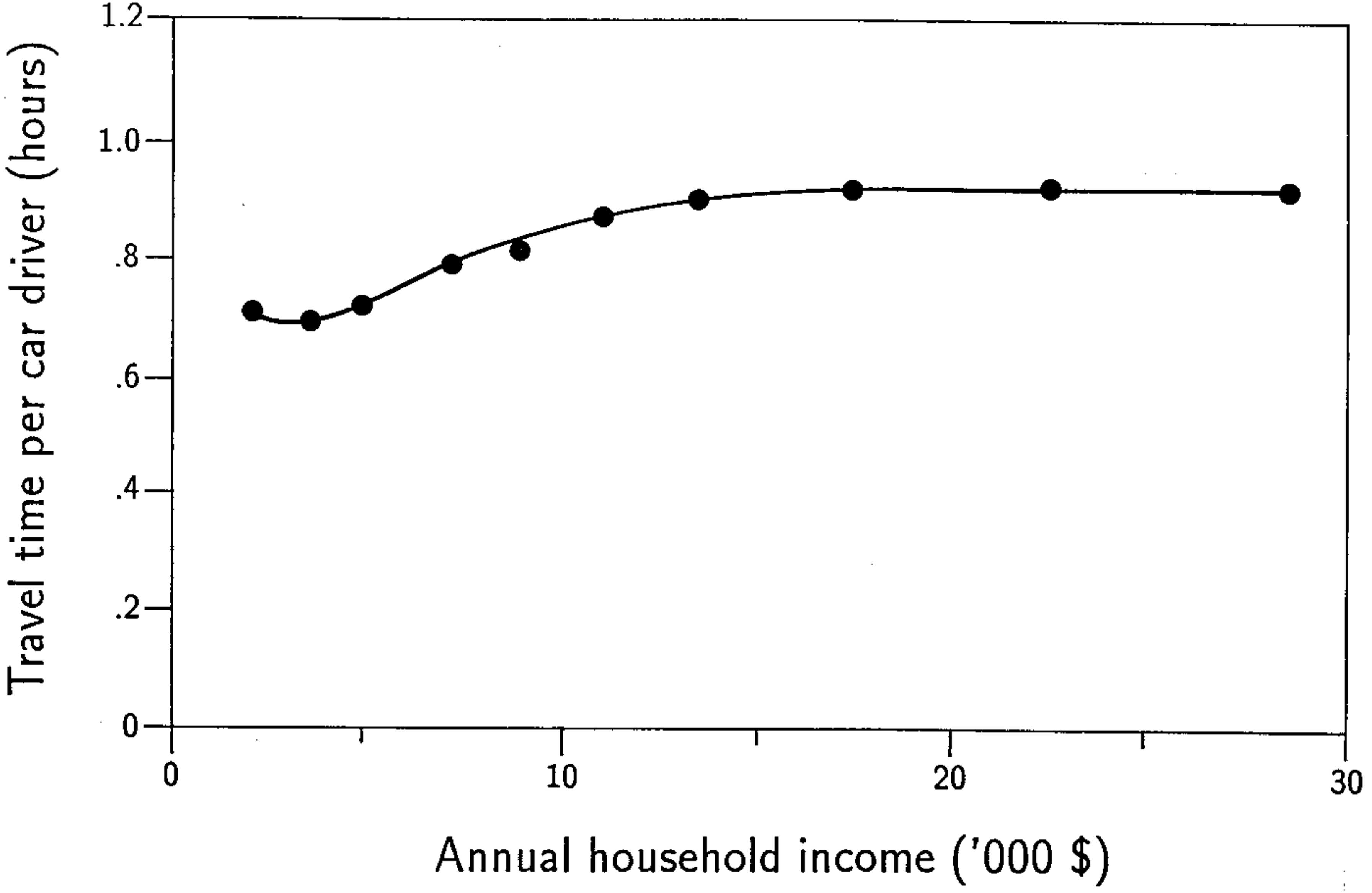

Travel time per car driver (hours)
1.2
1.0
.8
.6
.4
.2
0
0
10
20
30
Annual household income ('000 $)

Fig. 13. A historical overview of car mileage in the USA (miles/year).

The regularity in the use of cars (about one hour per day) is mirrored in the stability of mileage per year, reported here for the USA. This implies a curious stability in the mean speed, about 30 miles/h — since Henry Ford's times. Data from [5].

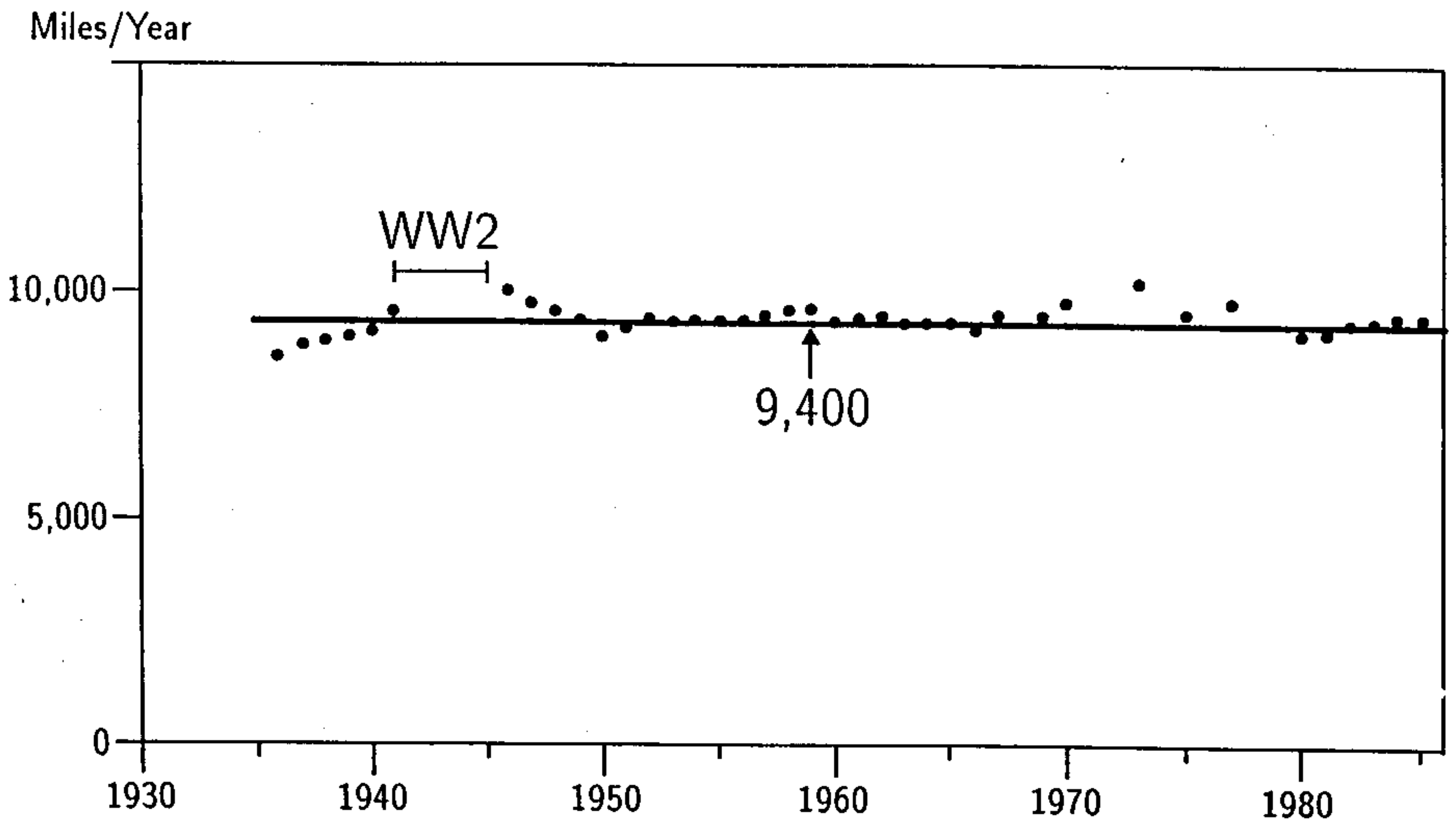
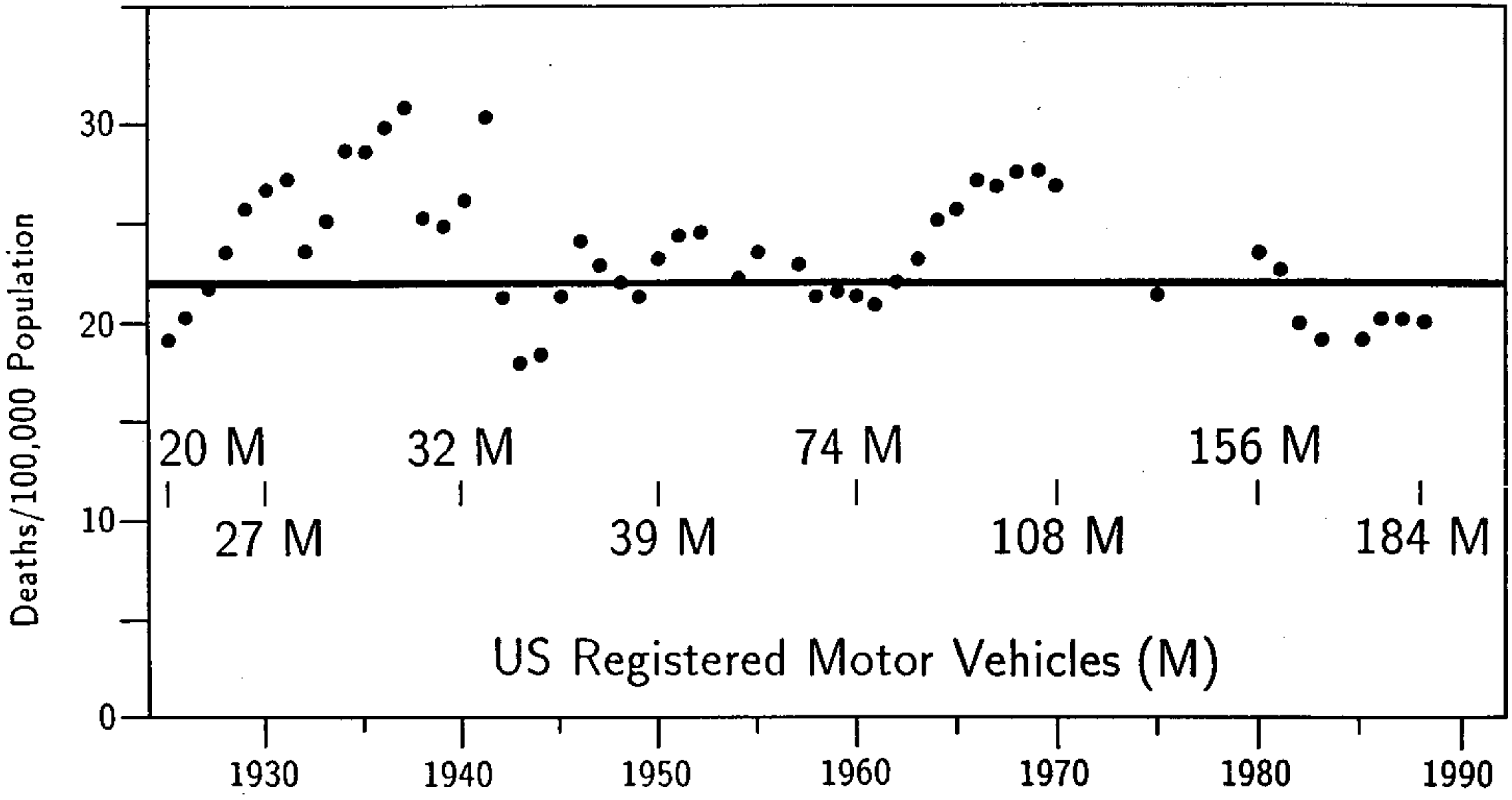

Miles/Year
10,000
5,000
0
1930
1940
1950
1960
1970
1980
WW2
9,400

Fig. 14. Death rates due to road traffic and circulating vehicles

Death rates due to motor vehicle traffic appear to be largely independent of the number of vehicles in circulation and stable around 22 per 100,000 per year since Henry Ford's times. We seem to be facing here another basic instinct in risk management. Data from [5].

USA – Motor Vehicles Traffic – Death Rates (per 100,000 Population)



Data: US Historical Statistics & US Statistics

Fig. 15. Rates of travel expenditure in various countries.

Expenditure on travel appears to add up to quite a stable mean value of about 13% of *personal disposable income.* This budget is allocated between transport modes in a way that realizes maximum mean speed (i.e., territory). People who do not have a car use public services, which are usually underpriced, and in the available hour for travel appear unable to spend the whole budget.

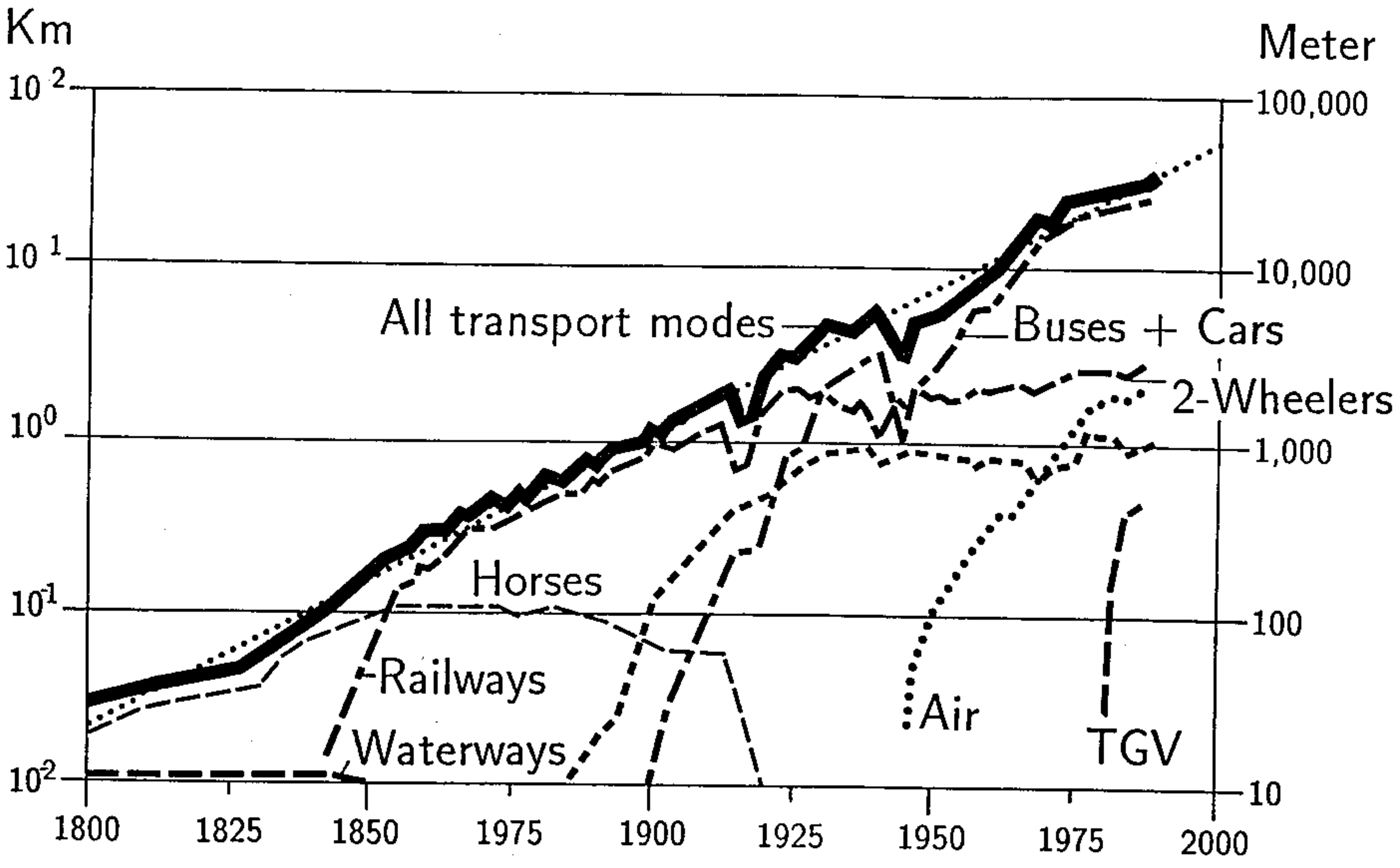
Travel Money Expenditures

NATIONWIDE vs. Total Household Expenditures, %		
US	1963–1975	13.18 ± 0.38
Canada	1963–1974	13.14 ± 0.43
UK	1972	11.7
West Germany	1971–1974	11.28 ± 0.54

URBAN vs. Household Income, %			
		With Cars	*Carless*
Washington, DC	1968	11.0	4.2
Twin Cities	1970	10.1	3.4
Nuremberg Region	1975	11.8	3.5

Fig. 16. Technical innovation in transport and the increase in mobility for France.

During the last two hundred years transport technology has been in search of speed at accessible costs. About every Kondratiev cycle a new basic mode of transportation is introduced. The last one was the airplane; the next one will most probably be the Maglev. The share of the fastest mode of transport in the time budget of the traveler keep increasing, with the costs decreasing and his disposable income increasing. The increase in mean speed for the last two hundred years for France appears to be a fairly stable 3% per year taking into account all mixes of transport modes. The basic drive of man's territorial instinct is behind this technological evolution. The chart reports distance traveled per day on vehicles [4].


Km
Meter
10 2
10 1
10^0
10^-1
10^-2
100,000
10,000
1,000
100
10
1800
1825
1850
1975
1900
1925
1950
1975
2000
All transport modes
Buses + Cars
2-Wheelers
Horses
Railways
Waterways
Air
TGV