

transportation. For a system moving on foot the area reachable in that daily routine is a circle of around 5 km diameter which makes about 20 km². Examining the size of village territories in Greece, not yet affected by modern technologies of transport we find a mean territorial size of about 22 km² (some of which inaccessible mountains) (Fig.20).

As we said, old cities, as measured by their external walls, never exceeded 5 km, The 5 km diameter can still be identified in modern Paris through a sharp bend in the fractal distribution of subway stations (Fig.21 and Fig.22).

For people having access to cars their territory for daily routines extends over a diameter of about 40 km or about 1200 km², about 60 times that of the greek villages (Fig.23).

Trips outside these territories are rare. Consequently, long-range transport systems pick only a relatively small fraction of the total movement and can be installed profitably only along certain *corridors* where these trips tend to concentrate. The corridors of intense traffic have an extraordinary historical stability. The main overland routes of the Middle Ages radiating across Europe from the Flemish port of Antwerp, have a familiar look in terms of present rail and autoroute trunk lines (Fig.24).

The number of trips outside the base territory are reported in Fig.5 for a number of European towns. The table of Fig.25 reports *one-way trips per year*. Looking at the numbers in the table we see the great stability of the system. The trips per person *per day* inside the base territory are usually 6 to 8 (one way!), and the trips outside the base territory are about the same, but *per year*.

The table of Fig.6 also gives the share between the purpose of the trips,

business, holidays, and short-term displacements for personal reasons. The numbers in the table are dated, as they refer to surveys done in 1970, but we could not find more recent figures with the same analytical detail and clarity. In any case, trip rates are more stable than distances traveled which depend on the speed of the transport modes. Just to give an example, the trips per head in Germany using airplanes are around one per year. I.e., Germans, on average, take an airplane for a journey once every two years. For Düsseldorf in this table the trip rate is 0.7, not far from the mean value for Germany as a whole today.

Looking at the shares of the trips between the three main modes of transport, car, train, and air, we can make some observations that can be of weight in the planning or in the operation of TGV trains. One is that the property of cars is not necessarily a disincentive for using trains. Toulouse with 70% of households having cars, has 0.8 trips on trains and Geneva with 65% of the families owning cars has 1.8 trips, while Valencia with 47% of the families with cars has only 0.3 trips on trains. The interpretation that come first to mind is the quality of the services that the railway system offers and certainly the Swiss Railways are way apart from the Spanish ones. Just to give a historical glimpse into the years of the past, when American railways reached their maximum penetration as a means of transport, *before* the appearance of the car, the trips per person per year were just one, as for airplanes today in Germany. The trips inside the base territory were again six or seven per day as at present.

We repeat here what has been said extensively before, that the fat market for a transport system offering a qualitatively new service is that

of the base territory, and the best way to compete is *to help extend it*, just as the car has very successfully done during the last 70 years. Taking a mean of the trips for the cities listed in Fig.25, we find that about 25% are for business, 25% for holidays, and 50% are short trips for personal purposes (shopping, visiting, medical, etc.). The procedure of mediating over a restricted number of cities may appear rudimentary, but as we have observed at various points in our analysis, traveling behavior appears extremely homogeneous over the world and is basically determined by the physical constraints of (TTB) (TMB). The key ratio is the cost of speed/income. Coming to our business travel, it is the peach of travel operators as it is well distributed over the year and wealthy. It is easy to observe on European airplanes, which charge a one-month worker's salary for any destination, that the larger part of the passengers are male and traveling for business. On the other hand, companies are usually well equipped with chauffeured, fast, comfortable, and representative cars. Consequently, the natural tendency is to move by car, as far as possible. Fig.26 reporting the modal split for business trips shows that the car is dominant up to a distance of about 500 km. Beyond that distance, airplanes dominate. Trains squeeze in between and at about 500 km they share one third of the traffic. This is remarkable as trains and cars do not offer much speed. The case of train speed is shown in Fig.27 for a system with a good image, at least technically, the Deutsche Bahnen (DB). It takes into account only intercity, i.e., long-distance trains. The center of the bar chart is at about 65 km/h, measured in terms of the geographical distance between terminal points. This means a 500 km trip takes between 5 and 10 hours, which implies an overnight stay at the end

point.

This is contrary to what we normally observe in company-related business travel where people normally try to conclude their trip the same day which makes airplanes so convenient.

The observation can be important for planning train schedules because it points to the existence of various classes of business travelers, some of which more adaptable to long hours of traveling (the ones going to stay) which will be in any case the prerogative of train transport. Airplanes can practically link any two points in Europe in less than a couple of hours. When available, they represent an unbeatable means of transport.

Let us now turn to the wildest side of transport demand, that for holidays. Every year western people are caught by a migratory impulse and move to another place for a while, as far away as possible. The stone age mechanisms behind this yearly *very long* journey may constitute a good subject for an anthropological study. (It must be the search for new grazing grounds as the *dancing bee* behavior of returning voyagers suggests.) But we will concentrate on its impact on the transportation system. Numerically the trips are in the same ballpark as business trips, and tendentially longer. The trip being the objective in itself and the return home displaced in time, speed may not be so important and trains have a strong appeal. On the other hand, train schedules are highly inflexible and vacationists schedules very strongly pulsed along the year, so there is here, a taxonomic mismatch.

Furthermore vacation trips tend to be family affair, better dealt with in a single package that the use of cars automatically provides. The property of a car being an essential watershed, let us look at the situation for *car*

owning families (Fig.28). Here the car dominates the scene for trips up to 1000 km, where it begins to yield to airplanes. Trains have a maximum share around 1000 km again, where they reach 30% of the passengers and buses have a maximum of around 800 km with a remarkable 20% share, probably because they provide a self-contained package, like cars.

Airlines and holiday operators have matched the pulsed character and low cost of the demand by separating their services from those of scheduled airlines through charter operations.

If the family does not own a car – a situation becoming more and more improbable in the west in general and in Europe in particular – then the picture is as shown in Fig.29. We see here trains dominating up to 1000 km and air transport beyond that.

We took personal short trips as the last item both because it carries the largest chunk of trips (50%) and because railways of improved characteristic can reclute here the largest number of clients.

Short-stay personal trips for car-owning households appear dominated by cars for distances up to 1500 km (Fig.30), even more than holiday trips. The phenomenon is very curious and a detailed investigation is worthwhile in order to see if faster trains could absorb at least part of this traffic, providing better services than the car itself. But in a region with a motor way network, a car can have a mean speed double that of an intercity train as shown in Fig.27. Above 1000 km the airplane starts picking shares, with 50% around 1500 km and dominating the rest. These plane trips are presumably on reduced fares, anyway higher than charter fares, not to speak about trains.

We end this review of travelers' behavior by looking at the case of

families not owning a car (Fig.31). Here trains have the upper hand all over, and airplanes are scarcely used, even for the longest trips. It seems natural that families without a car should also be short of money, statistically speaking.

If we come back to Fig.25 we can look again at trips in terms of means of locomotion. We find then by mediating between the cities that car trips take about 78% of the total, trains less than 10%, airplanes around 7% and buses 2%. This may appear contradictory with the previous charts, but it must be clear that these referred to *shares* of the trips, and that the car was dominating in short trips. The dominance of the car in the totals means that most trips are short-distance. This is shown in Fig.32 for the totality of the trips and for business, holidays, and personal short-term trips. *Not only people travel rarely outside the base territory, they also do not move very far away.* 90% of the total trips are *under* 200 km. It will be difficult for fast trains to find a juicy niche in this travel habit context.

Appendix:

The Mathematical Methodology

The mathematics used in this analysis is extremely simple. Because historians may not be familiar with it, we add this note for illustration. The basic concept that *action paradigms* diffuse epidemically, is condensed in the epidemic equation:



$$dN = aN(\bar{N} - N)dt$$

saying that the number of *new* adopters (dN) during time dt is proportional (a) to the number of actual adopters (N) multiplied by the number of potential adopters ($\bar{N} - N$), where \bar{N} is the final number of adopters.

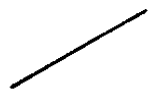
The integration of this equation gives



$$N = \bar{N}/[1 + \exp -(at + b)]$$

which is the expression of a logistic S-curve well known to epidemiologists and demographers. *We apply it to ideas.*

In the charts of the present paper the logistic equation is presented in an intuitively more pregnant form. N is measured in relative terms as fraction of \bar{N} ($F = N/\bar{N}$), and the S-curve is “straightened” by plotting $\log(F/1 - F)$ (Fisher-Pry transform).



$$\log(F/1 - F) = at + b .$$

The time constant ΔT is the time to go from $F \simeq 0.1$ to $F \simeq 0.9$. It takes the central part of the process (80%) and the relation between ΔT and the a in the equation is $\Delta T = 4.39/a$.

The central date T_0 is defined as b/a .

The final number of adopters \bar{N} is given as a number in parenthesis.

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Figure 1.
The dynamics of American transport infrastructure.

The evolution of a transportation system can be monitored in many ways, through its hardware in terms of infrastructures, or in terms of vehicles in operation. Through its productivity in terms of passenger kilometers transported per year, or the kilometers per person performed through the transportation system.

The time dynamics is usually treatable with a simple diffusion model (see *Appendix*). The advantage of the model as a descriptor is that it gives a crisp view of processes which evolved for long periods of time, even hundreds of years.

The *observed* stability of the dynamics of these processes has potential for *robust forecasting*, although there are many pitfalls in the use of the model for that purpose.

In this example we took the total length of the transport infrastructures as the reference at any time for the relative weight of a given infrastructure. Airways network length is measured in terms of the sum of distances between airports when there is a scheduled connection. The numbers give the time constants, i.e., the number of years (85) for railways to go from 50% (in 1915) to 1% (in 2000) of the total transportation infrastructure length.

USA - SUBSTITUTION OF TRANSPORT INFRASTRUCTURES

Figure 1.

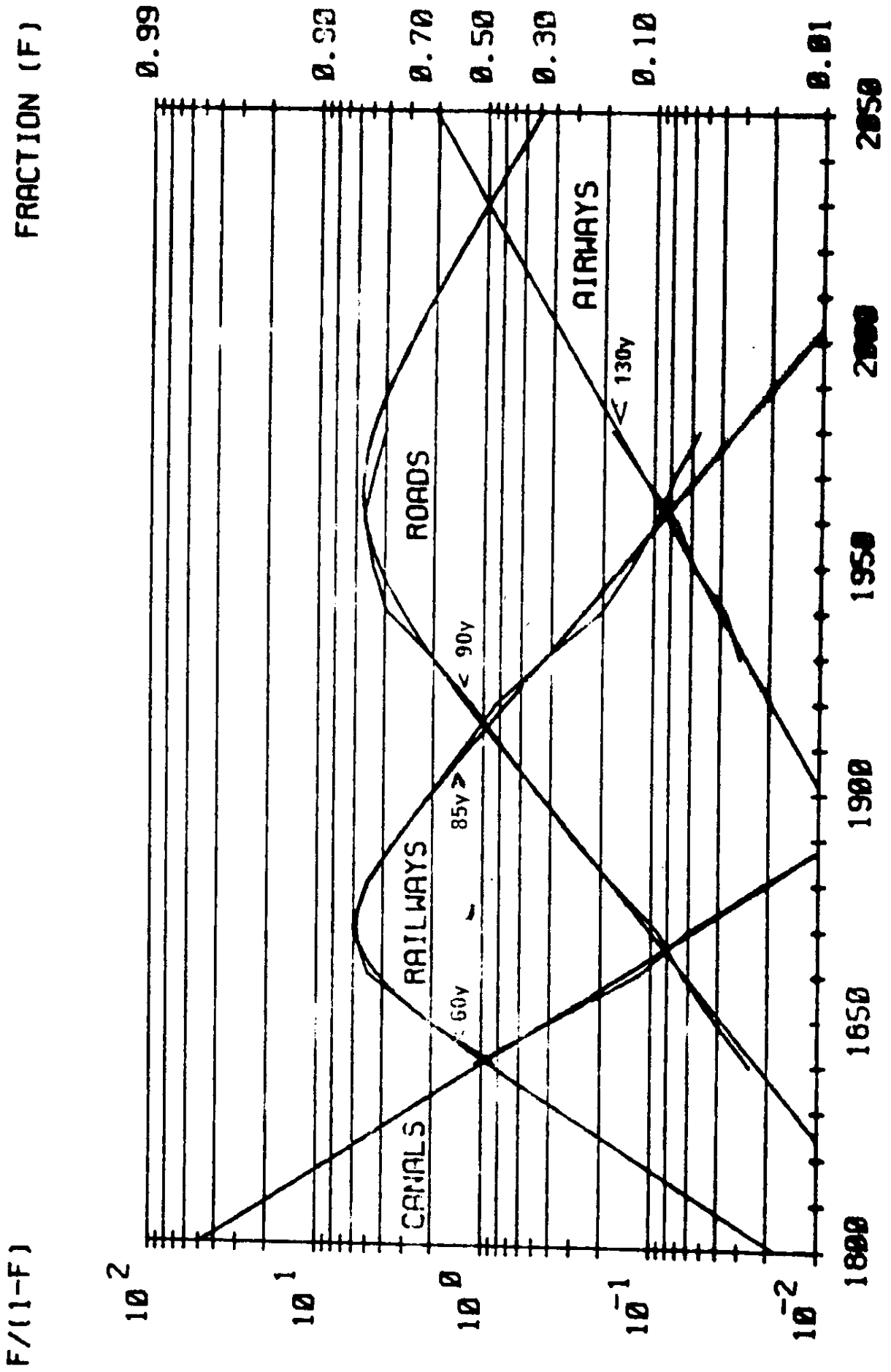


Figure 2.
Modal split for passenger kilometers in the USA.

The analysis takes here again the problem of transportation using the functional indicator, passenger kilometer per year, to establish the level of functional substitution between modes. Usually the last mode, which is the fastest, and the last but one, take all the new traffic as it appears. Another way of looking at the facts is that people allocate more and more of the Travel Time Budget to the fastest mode, and consequently bag more mileage altogether. The importance of this effect can be seen, e.g., in the USA where people travel about 50 seconds per person per day on planes and this makes 15% of the intercity mileage they perform.

The time spent on planes in Europe is about 15 seconds per person per day. The increase in travel distance is about 4% per person per year. This has been verified in detail for France since 1800 (see *Figure 5*).

In the present example of modal split for intercity passenger traffic in the USA, we see that cars reached their maximum share of passenger kilometer around 1960 at the level of 90% to progressively lose ground to airplanes which have already eaten the shares of railways and buses.

Projections to 2050 are a little daring because with the next Kondratiev cycle to begin in 1995 a new mode of transportation can be introduced (e.g., Maglev) eating shares from the airplane.

Figure 2.

USA - INTERCITY PASSENGER TRAFFIC SUBSTITUTION

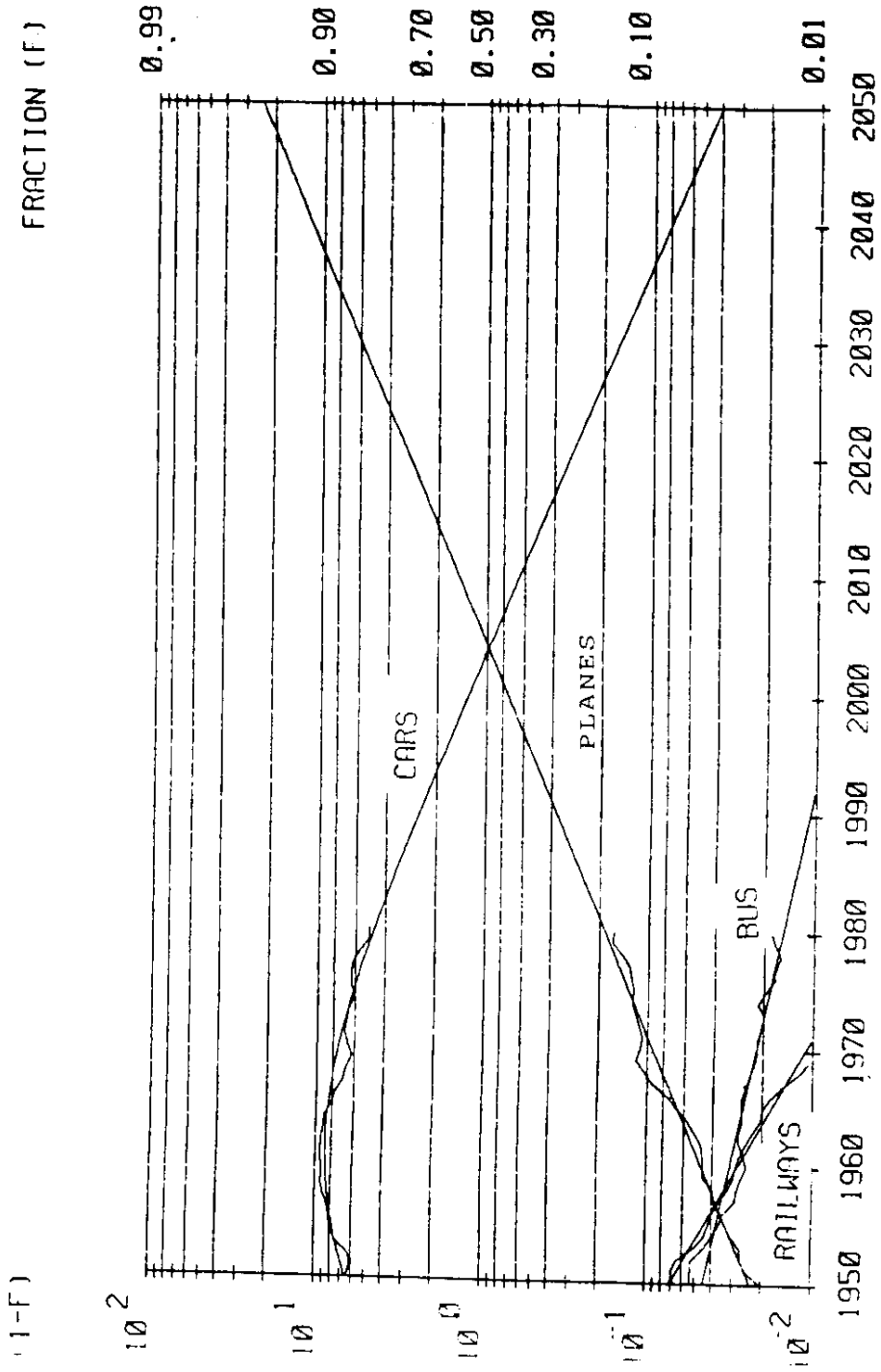


Figure 3.

Evolution of passenger kilometers and modal distribution in the Soviet Union.

The process of diffusion of technologies operates through mechanisms of social interaction that are deeper than the political structure of a community. Although numerical parameters for the substitution equation depend on the particular society, the basic processes are always the same.

The case of passenger kilometers by mode of transportation in the Soviet Union is reported here. The curves have much resemblance with the American ones, except for buses taking, in a way, the role of cars. The introduction of new technologies appears to be delayed and even buses, or road transport, reach their maximum level 30 years after the USA.

Figure 3.

USSR: PASSENGER TRANSPORT

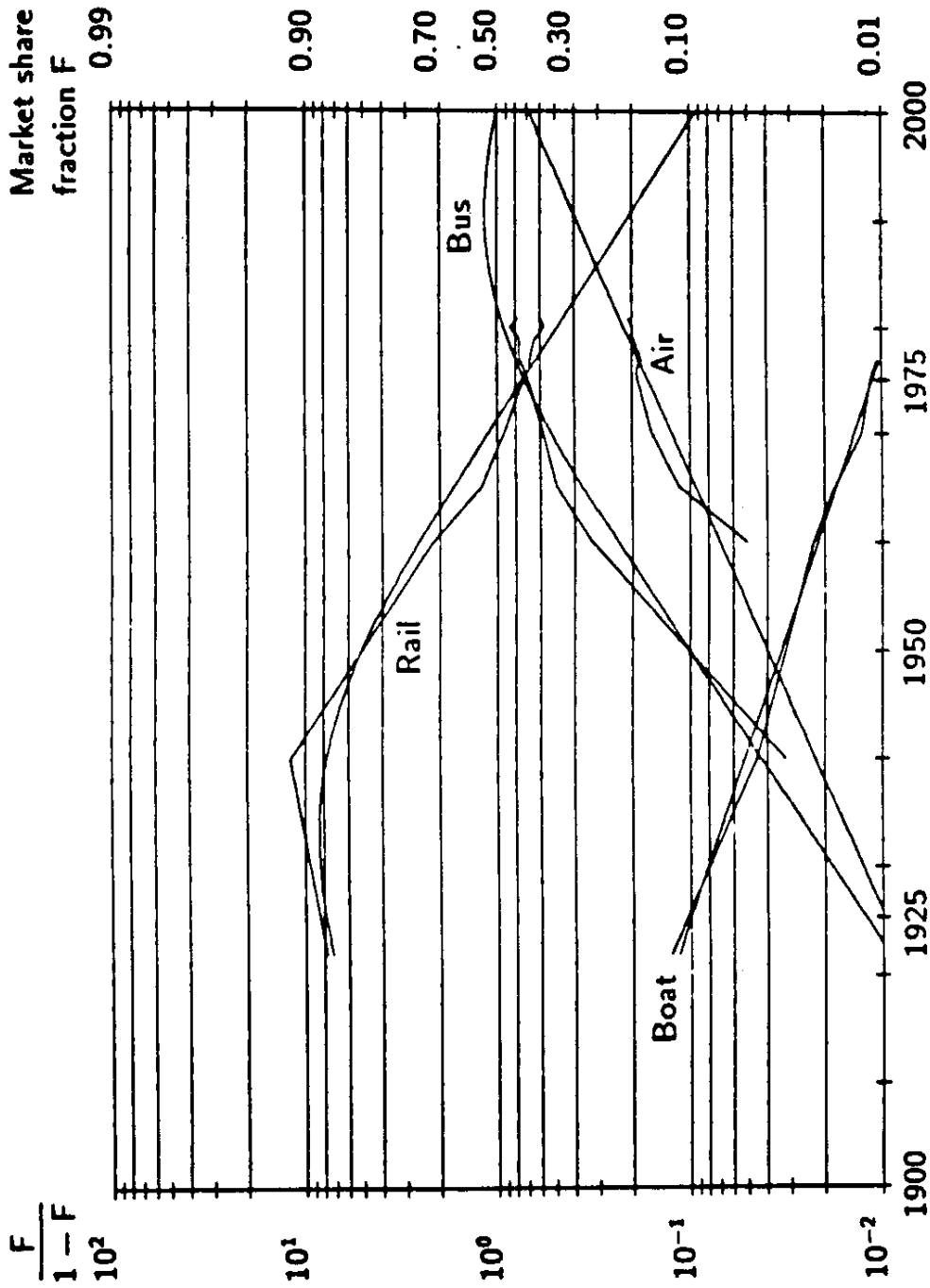


Figure 4.
Evolution of intercity traffic in Europe (9) by modal split.

As we have seen in *Figure 3*, a new mode of transportation provides extra speed for the traveler. If we examine modal split for intercity traveling in Europe, we find cars saturating at around two thirds of surface transport. With ownership approximating the level of one car per one able person, as in the USA, and mean speeds basically stable (since Ford times) at ~ 40 km/hr, there is not much speed to be gained from the use of cars in the future. So the extra speed will come from an *increased travel time allocation to airplanes*, possibly from an improvement of speed of trains, and perhaps from the introduction of new technologies, such as Maglevs and hypersonic airplanes.

Figure 4.
 W. EUROPE - INTERCITY TRAFFIC (Pass-km) MODAL SPLIT

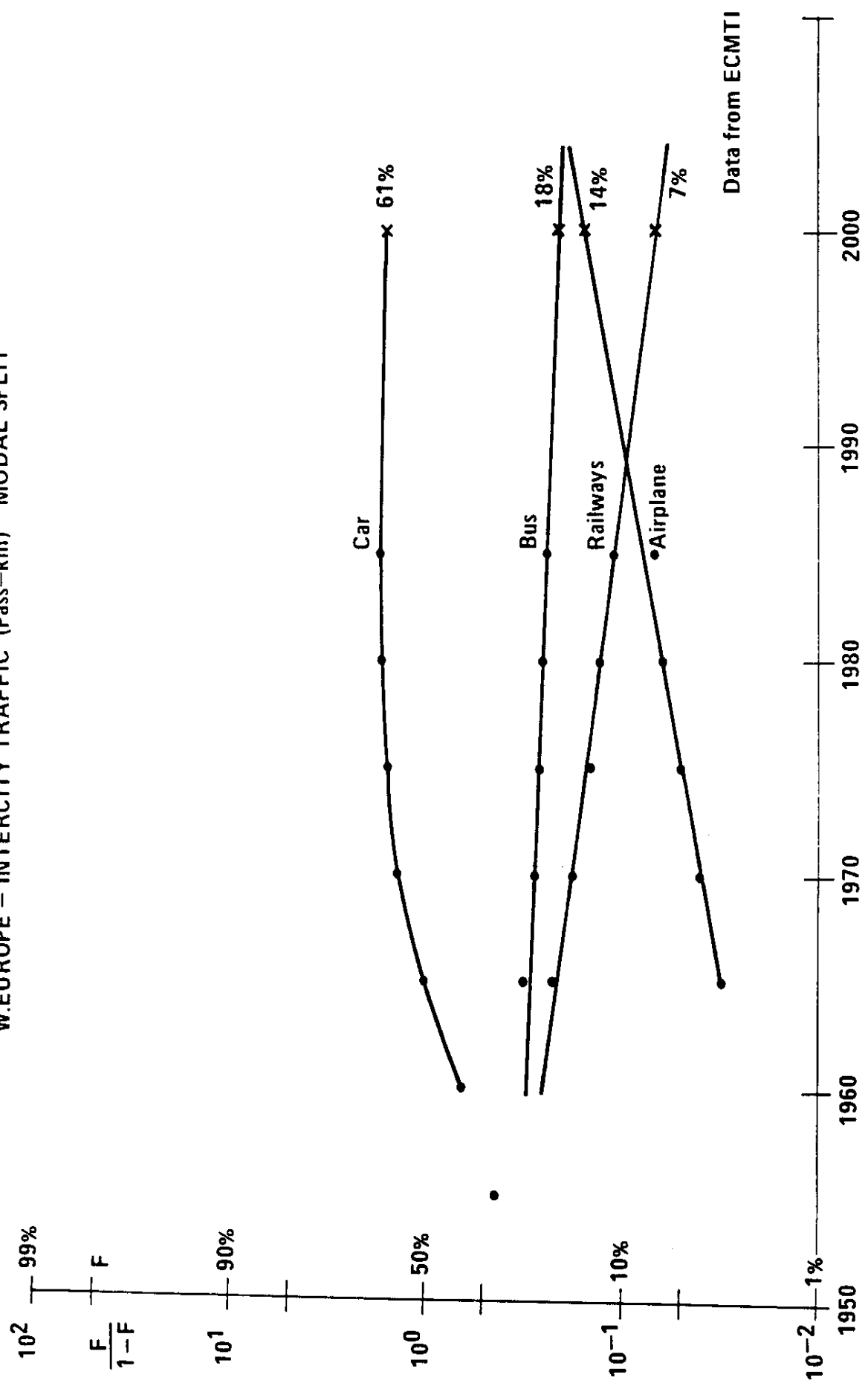


Figure 5.
Evolution of passenger traffic in France since 1800.

This chart reconstructs in detail the evolution of mobility of French people since 1800. This mobility is measured in terms of mean distance covered *with vehicles* per day and per person. It goes from about 20 meters in 1800 showing a very static society moving only on foot except for very restricted elites. It developed into a relatively mobile society with about 25 kilometers per person per day today.

The smooth growth of mobility shows that no means of transport was individually the cause of quantum jumps in mobility, but their progressive phase-in and phase-out were the smooth internal mechanism.

Another information that can be extracted from the chart is that a given technology (e.g., horses) first grows (logistically), then holds a constant mileage (typically for ~ 50 years), and then creeps down (logistically). Railways had two logistics up, a constant level (since World War II), and one may expect a phase-out during the next Kondratiev cycle (starting formally in 1995), see *Figure 6a*.

Figure 5.

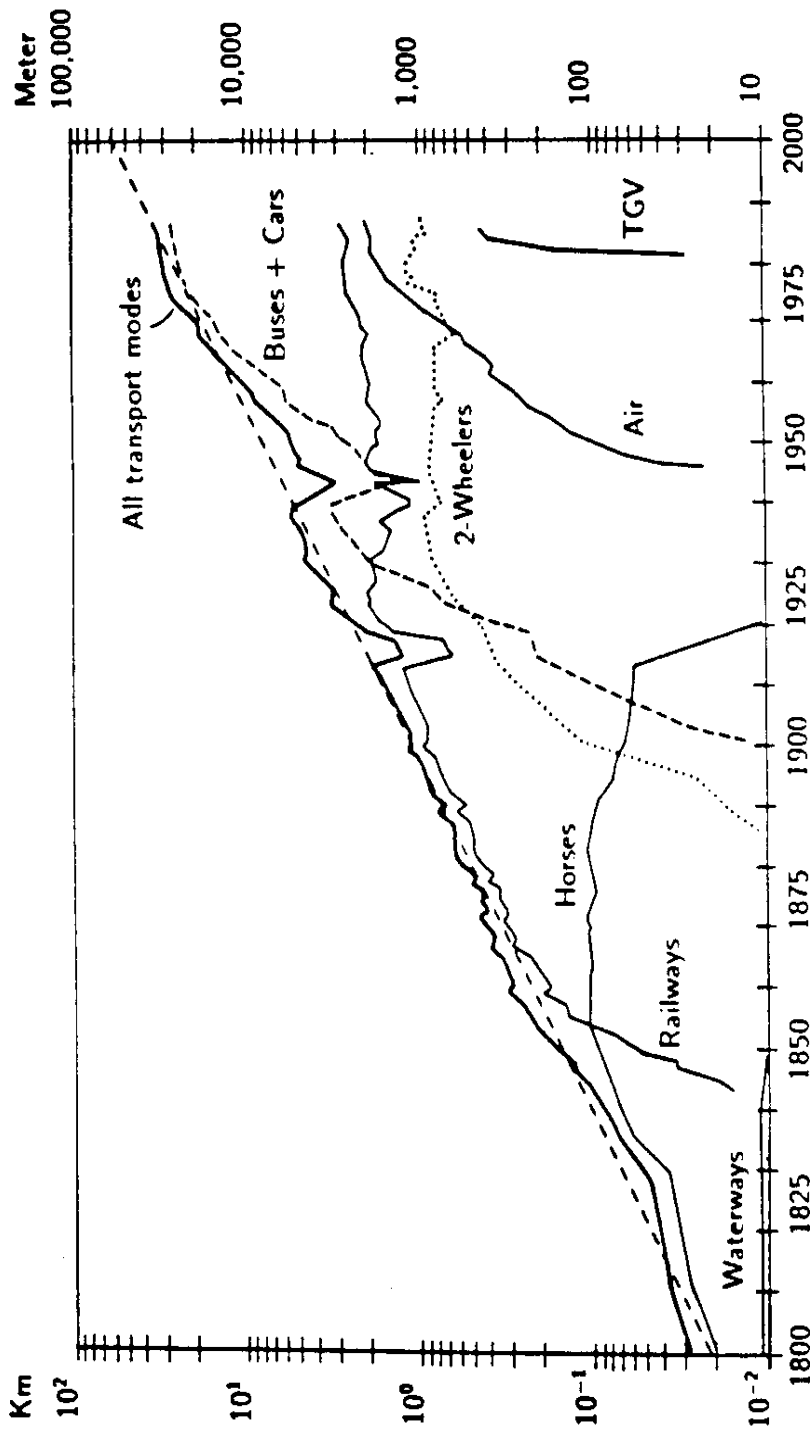


Figure 6a,b.
Railways network length.

The construction of the European railway network was a major feat in engineering and financing between 1850 and 1940. It led to the creation of a network of 400,000 km substantially improving transport in speed and quantity for goods and people. The first pulse of construction is centered in 1875 and the second one in 1909. There is basically no growth altogether until 1980. Reductions of track length in Western Europe have been compensated by some construction in Eastern Europe.

However, during the last years a process of "chopping dead branches" has started, together with substantial reductions in personnel, showing that the system starts shrinking. The passenger traffic is basically that of 1930. Normally these are signals of an industry ready for collapse (presumably during the next Kondratiev cycle starting formally in 1995). The TGVs, if they introduce saleable speed, may be taken as an independent breed and start a new penetration line for them. They are already moving on a different track system.

Figure 6a.

EUROPE (incl. URSS) RAILWAYS NETWORK LENGTH (.000)

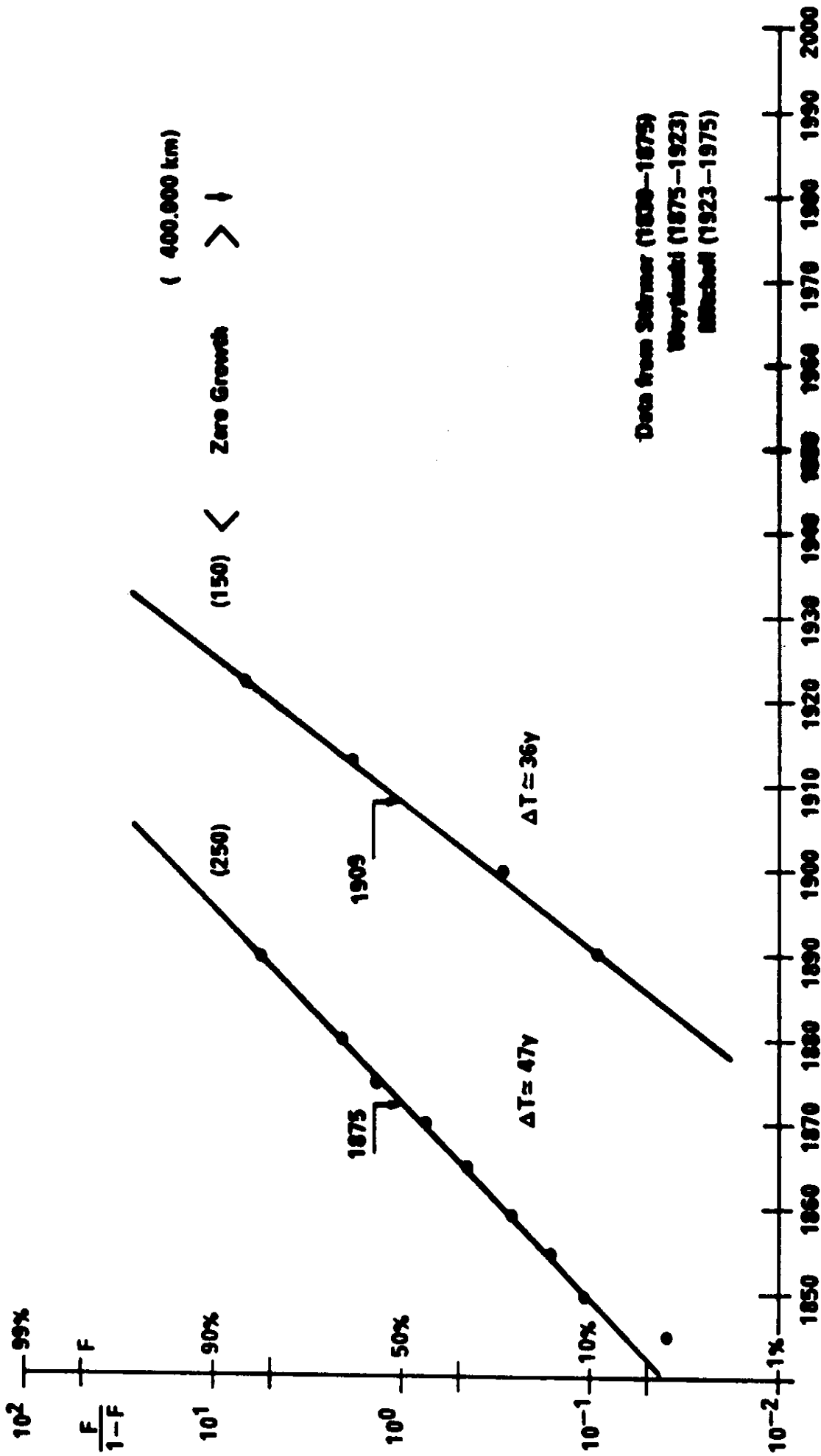


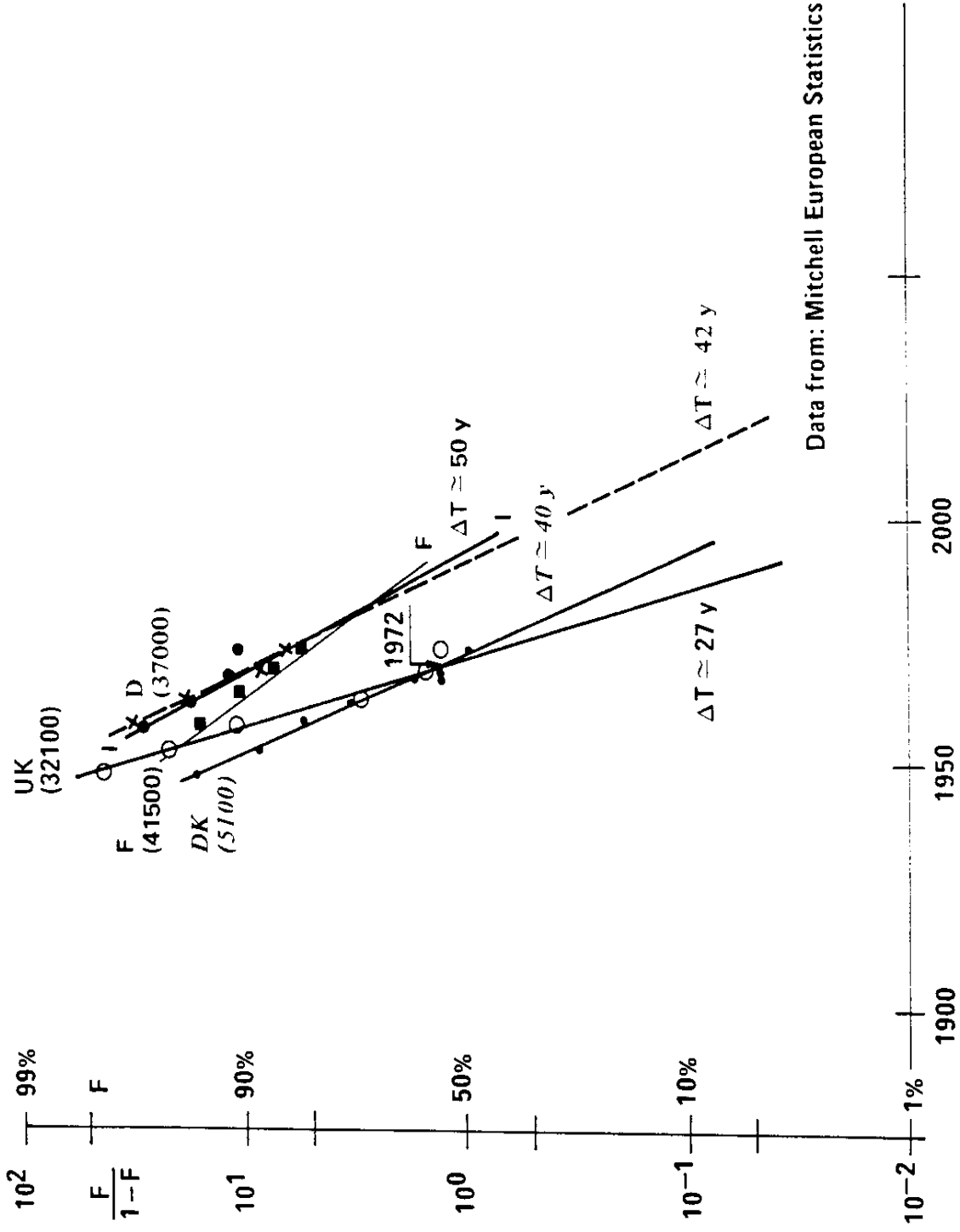
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Figure 6b.

RAILWAYS LENGTH (KM)



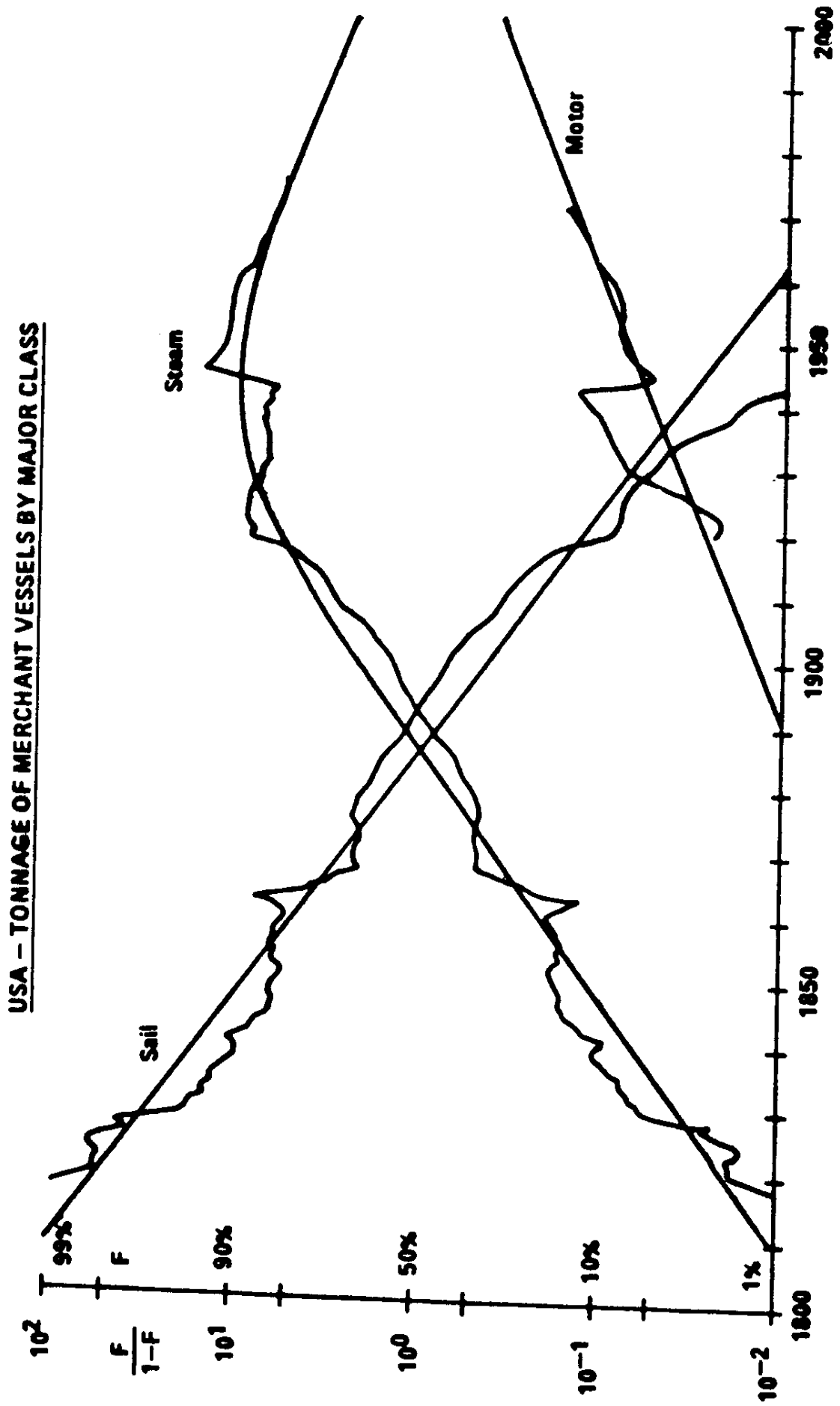
Figures 7 and 8.
Dynamics of substitution in ship propulsion.

The sail (with some help from rowers) has been the prime mover for ships since antiquity. Steam-powered ships were introduced at the beginning of the last century. Once teething troubles were reabsorbed, *steamers* showed their winning card: *the capacity to hold schedules*. As they were very expensive to buy and to run, they were used for what airplanes are used today, transporting mail and passengers.

Sailships were basically cheaper almost till the end of the last century, and one of the tasks on which they made a lot of profit, was to carry coal at the bunker points of steamships. The evolution of steamship technology finally led to the complete elimination of sailships toward World War II, the end of the previous Kondratiev cycle (1940).

The process of substitution for the USA is reported in *Figure 7*, that of the world level in *Figure 8*. For the world the substitution is reported in terms of tonnage and in terms of ton-km transported. The time constant in both cases is a neat 100 years.

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Figure 8.

WORLD - STEAM vs. SAIL IN TONNAGE AND PRODUCTIVITY

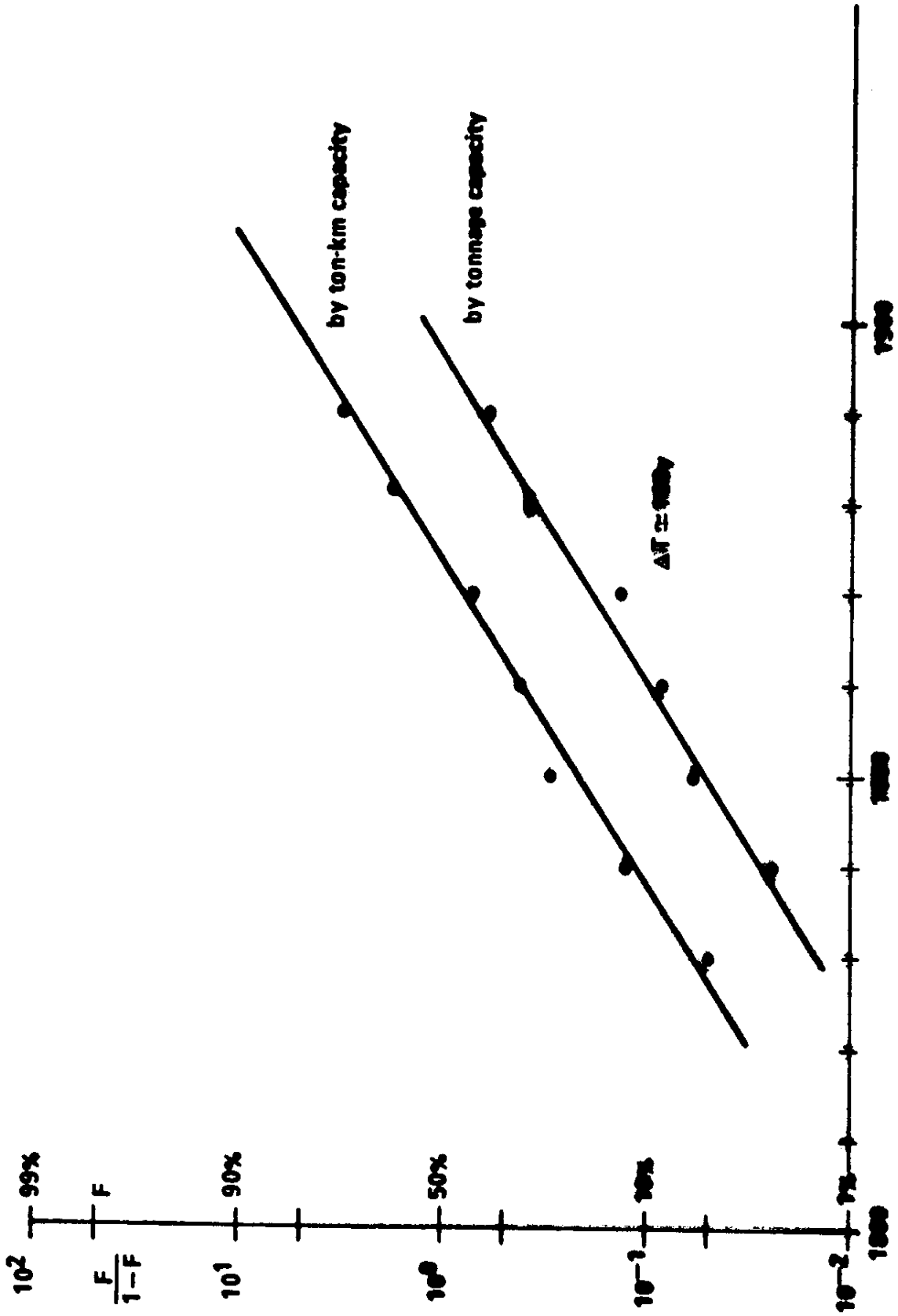


Figure 9.

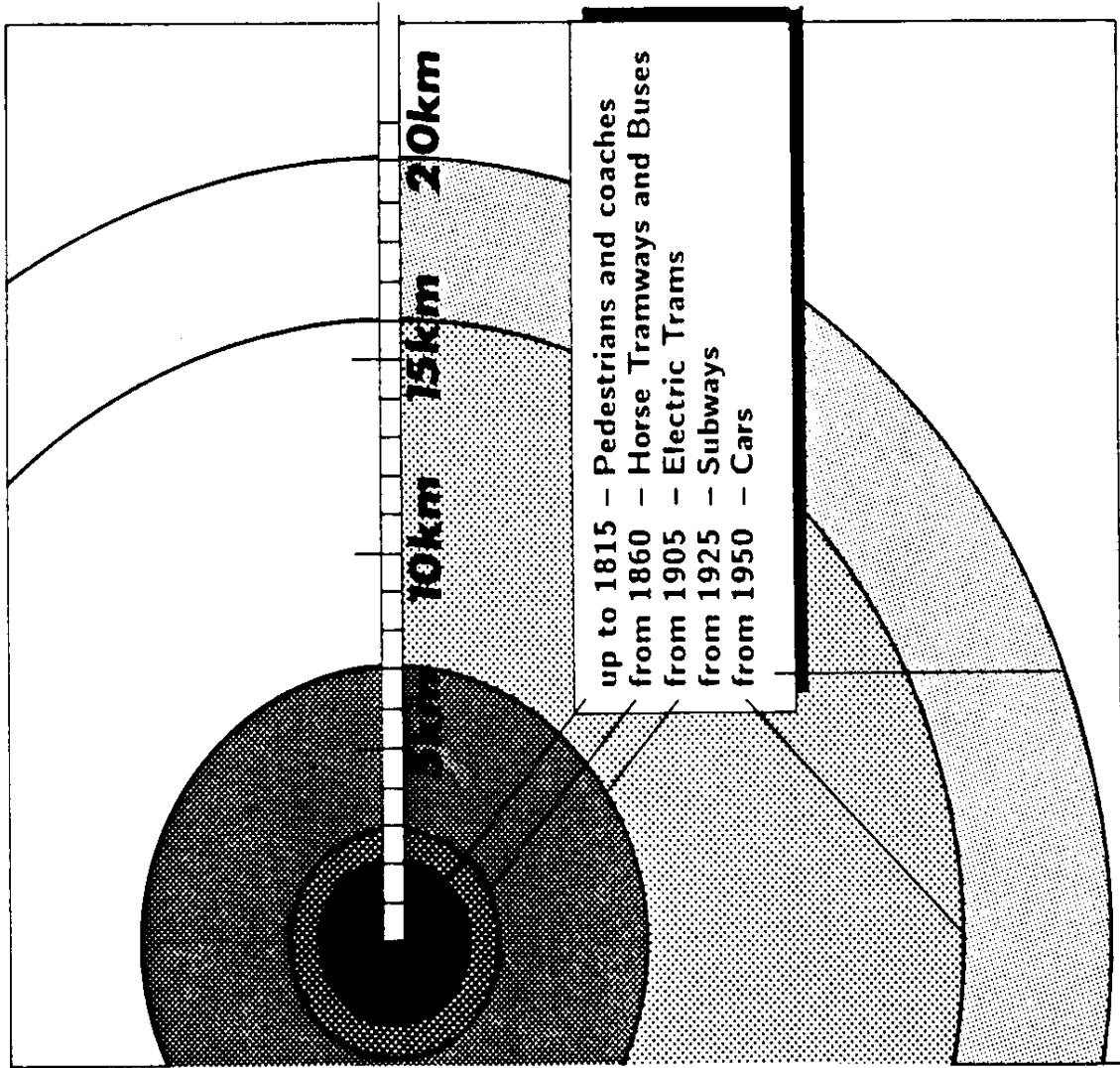
On the size of cities and the transport infrastructure.

The constraint of about one hour per day total travel time introduces strong constraints into the structure of a city. A *city* can be defined as *a conurbation inside which people move daily*. The size is then determined by the longest trip done with the fastest means of transport in about half an hour. In other words, the diameter of a city will be about one hour transit time by the fast mode.

It is easy to verify that the largest cities in antiquity and the Middle Ages never became larger than 5 km across, which is one hour walking. They can be easily measured by their wall. One can cite Rome (Aurelian walls), Persepolis, Beijing, Marrakech, Vienna (1700); or connected Venice today.

If we come to modern cities, we can look at the growth, e.g., of Berlin, from a 1800 Berlin moving on foot to a modern Berlin moving by car, with a diameter progressively growing from 5 km to 40 km, following the increasing speeds of the means of transport: horse tram, electric tram, Metro-Schnellbahn, and car.

Figure 9.



Figures 10 and 11.
Lisbon vehicular traffic on ferries.

Before the construction of the 25 April bridge across the Tago, traffic with the southern bank of Lisbon was done with ferries. The evolution of vehicular traffic carried by the ferries is reported in *Figure 10*. As many other things, traffic grows in pulses of 55 years, synchronous to the Kondratiev-pulses of economic development.

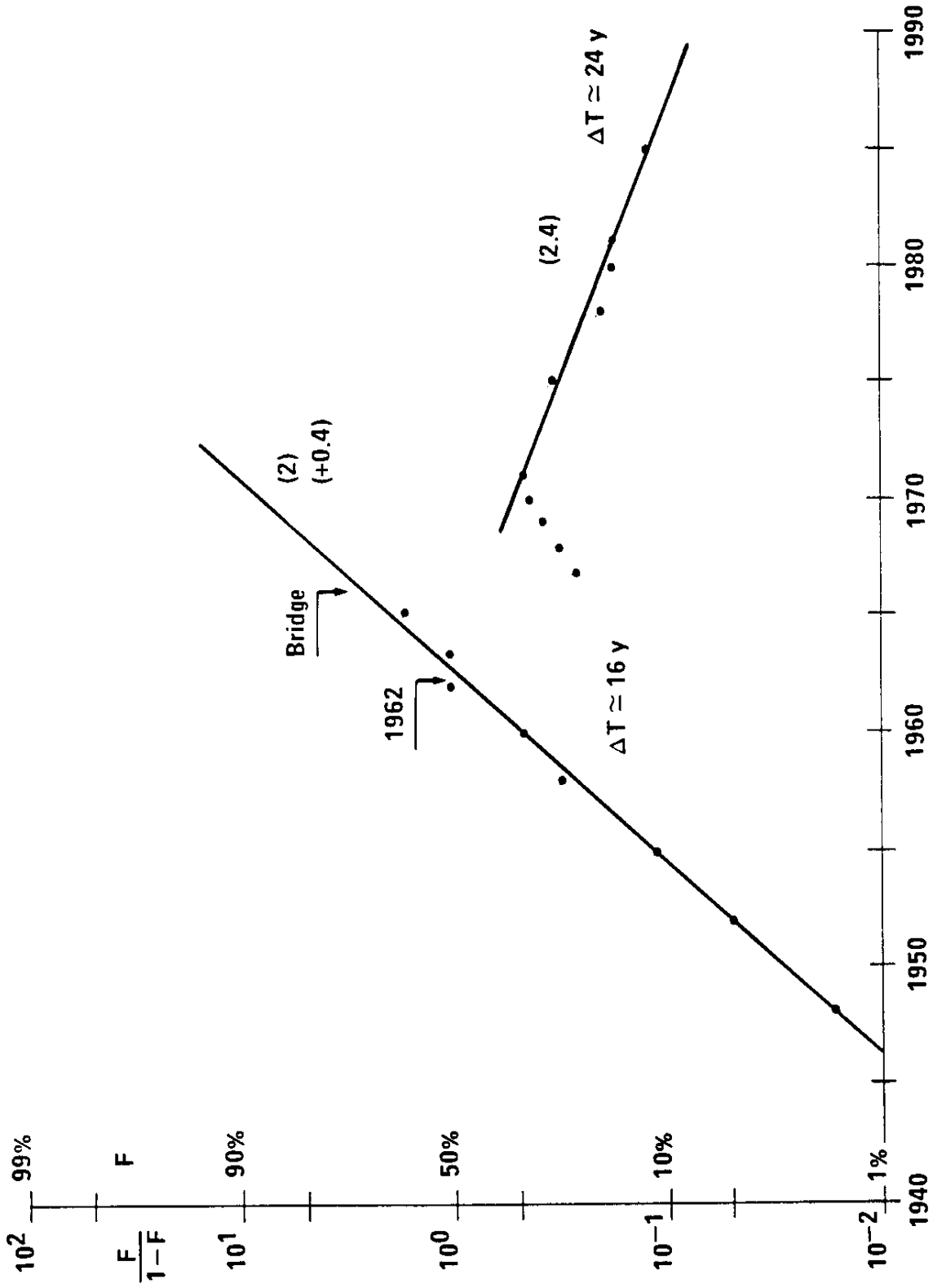
The analysis starts in 1940 giving a saturation level of 2 million cars per year. To this, one has to add 0.4 million cars per year from the previous Kondratiev-pulse ending formally in 1940. The opening of the bridge in 1966 brought a sudden fall in the number of vehicles transported (with some later recovery!), but at the same time – the year of the opening – the bridge absorbed 2.7 million transits. The shortening of the transit time created “instantly” about 1.5 million transits. After a short reprise the traffic on the ferries kept decreasing and it will go to vanishing level in a period corresponding to the time constant (24 years), but the service may be eliminated before that for economic reasons.

On the other side we see the bridge absorbing more and more traffic with a saturation point of 26 million transits per year, an order of magnitude larger than the 2.4 million transits with the ferries. The time constant is 20 years and the bridge is now technically saturated, in spite of a broadening from 2×2 to 2×3 lanes in 1977.

This is a very clear example of how traffic is generated by the reduction of transit times between two preexisting conurbations.

Figure 10.

LISBON - FERRIES VEHICULAR TRAFFIC (10⁶)



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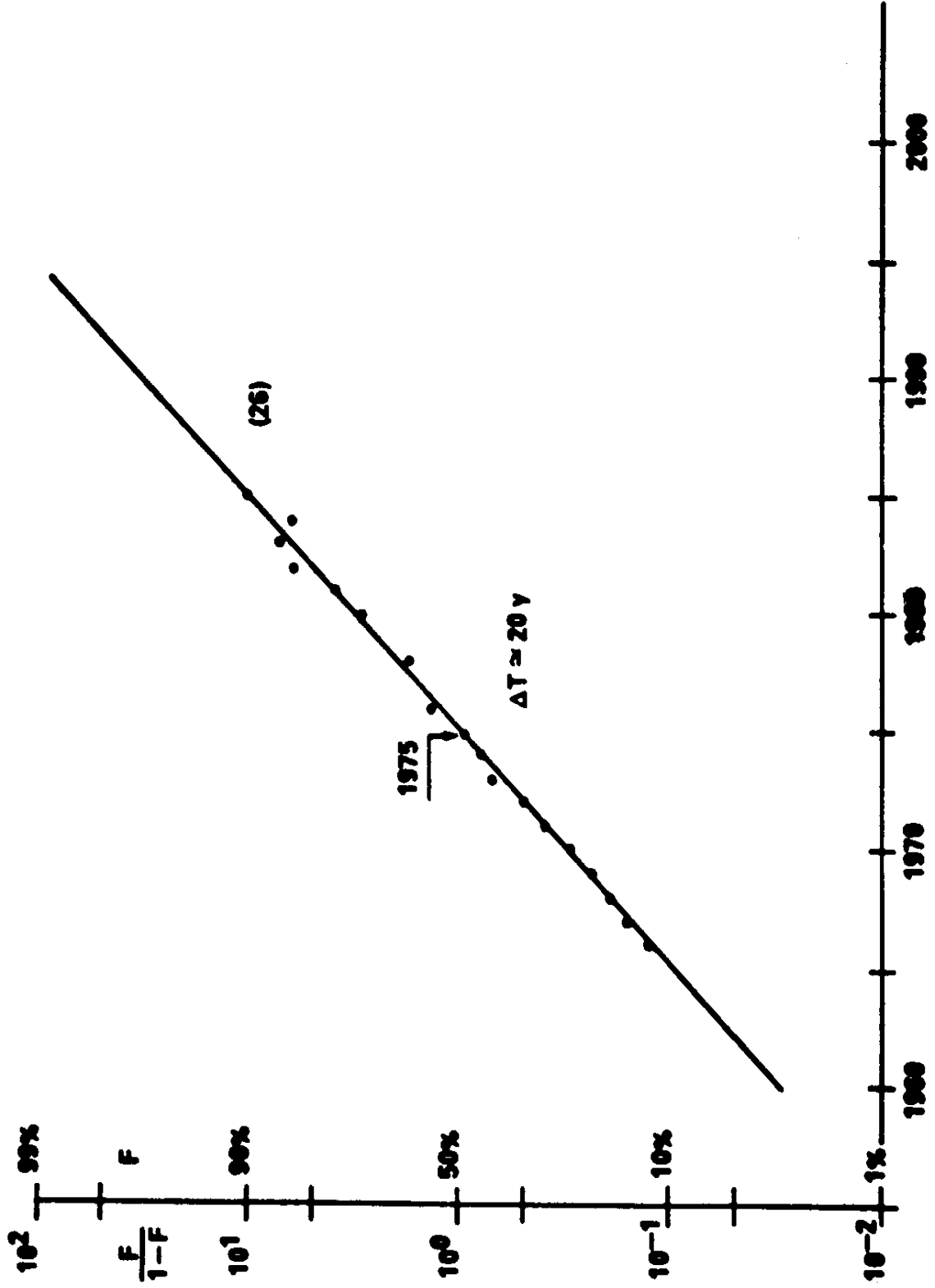
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Figure 11,

**LISBON - TAGO BRIDGE
VEHICULAR TRAFFIC (10³)**



Figures 12 and 13. The case of Istanbul.

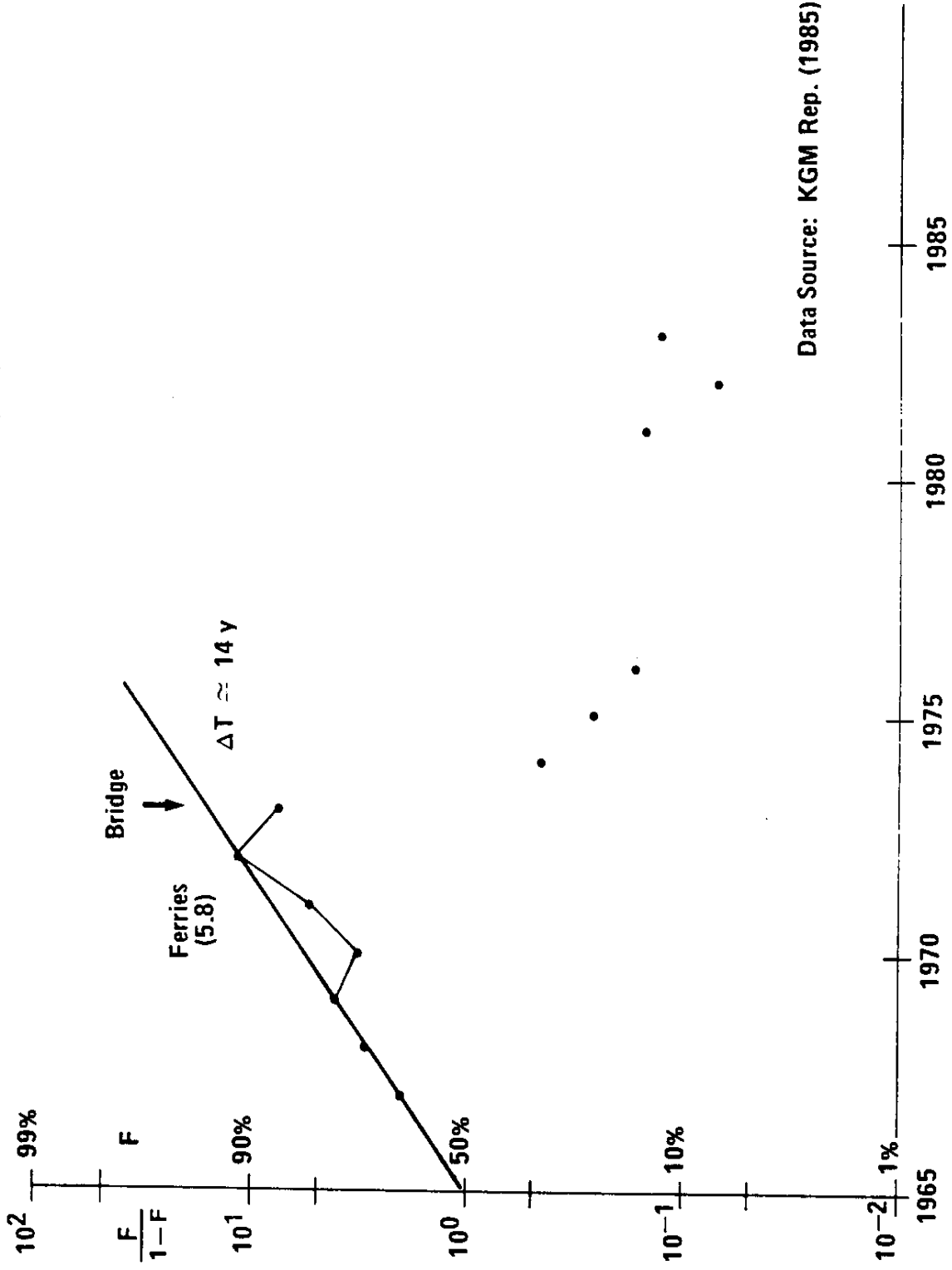
A bridge across the Bosphorus was built in 1974. The original intention was to close a gap in the Middle-East-Europe highway, plagued by chronic queues at the embarcaderos of the ferries. The bridge was built at a point where the Bosphorus is narrow and the banks appropriate. *By chance* this point is relatively near to the city and this completely changed its fate. The toll bridge in fact was absorbed by local traffic with the long-range trucks, for which it was constructed, still using the (cheaper) ferries.

The situation before the bridge is given in *Figure 12*. The chart is not really satisfactory because the lack of data before 1965 makes the fitting difficult. However, the ferries were carrying about five million vehicles per year when the bridge was built. They decreased to 0.5 million after a couple of years. The bridge, on the other hand, absorbed about 10 million transits in the year of the opening, saturating to about 28 million only five years later. A comparison with the Tago bridge in Lisbon shows that it had reached technical saturation.

The bridge has 2×3 lanes for vehicular traffic. (A second bridge has been constructed in the meantime and opened in 1988, but it is farther away from the city and it had a mediocre success.) The shortening of the transit time (not microeconomic reasons, as the toll price is higher than the ticket price of the ferry) generated about 23 million new transits in just five years. Obviously the economies of the two agglomerations on the two banks of the Strait had started mixing thoroughly.

Figure 12.

BOSPHORUS – VEHICLES ON FERRIES (10⁶)



Data Source: KGM Rep. (1985)

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Figures 14 and 15.
On the rank size distribution of world cities and their possible meaning.

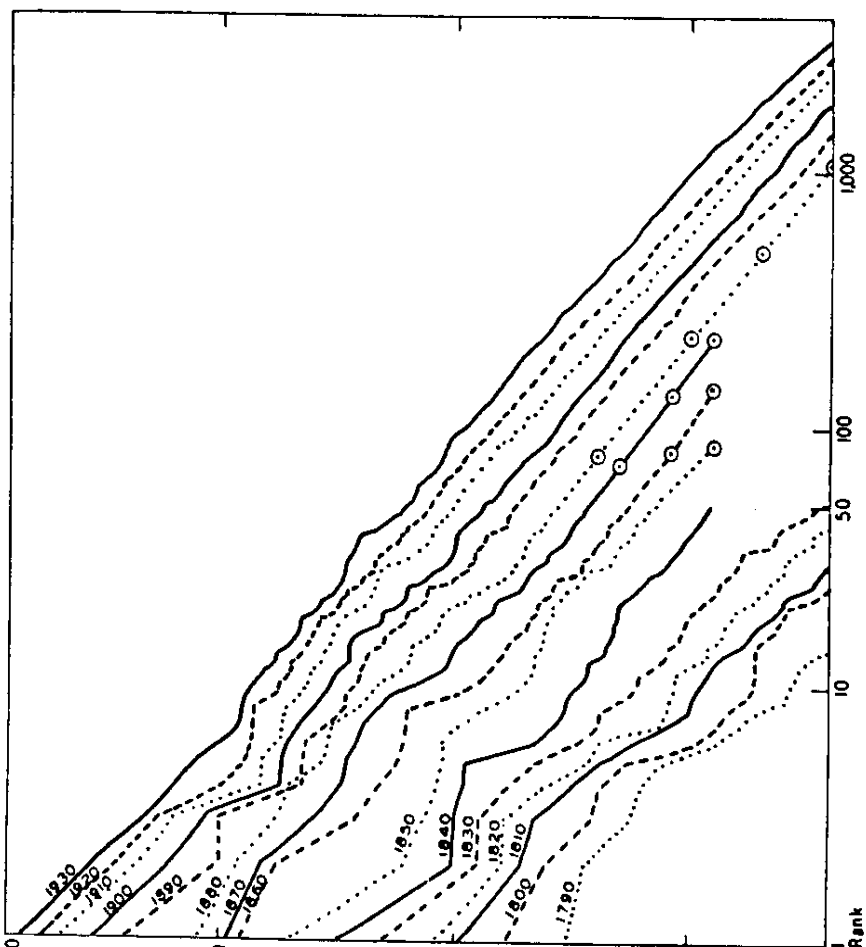
Ranking cities by their size (the largest one has rank 1, and so on) Zipf constructed very self-consistent maps of city size distribution. There is also something more in the charts. The workings of the social system have a hierarchical fractal structure which is mirrored in the size distribution of the cities.

The highest functional services are provided by the city of Rank 1. In this chart by Zipf in 1920 that place is taken by London, the obvious world center for finance and politics. Incidentally, a rank size analysis of the cities of the British Empire left London too high in the chart. In other words, London was perfectly positioned only at the world level.

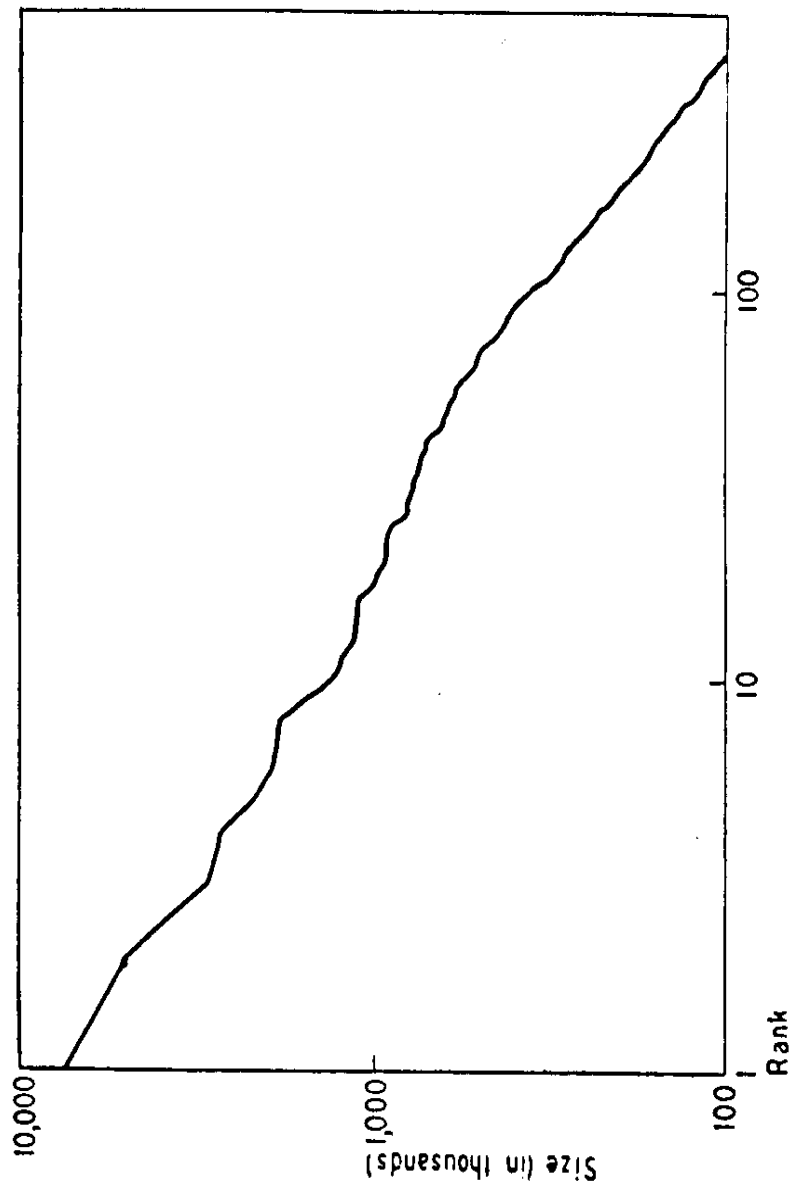
Repeating the exercise for modern cities (1975 data), one gets the rank-size structure of *Figure 15*. The knee in the distribution points to a scarcity of very large cities if we take Zipf's paradigm as significant. From estimates (1975) by Doxiadis in his book *Ecumenopolis I* then ranked the size of "corridors" around the world, a corridor being defined as a set of cities linked by a very fast transportation system, typically an air shuttle. The result is astonishing, as the Zipf single line of 1920 is neatly reproduced. At the top of the line we have the Shinkansen corridor with about 80 million people, presumably the next world center for finance (and politics?). The construction of a Maglev line between Tokyo and Osaka already started for a demonstration track (50 km) will make the bind much stronger with connection times for these trains in the order of the magic one hour. Air shuttles already do that, but their capacity is very limited, even with overpacked 747s as currently used.

The interesting point for a policy is that the mobility of the elites can be sufficient for the functional union of two different conurbations, at least from the point of view of the world distribution of tasks.

Figure 14.



U. S. A. 1790-1930. Communities of 2500 or more inhabitants ranked in the decreasing order of population size.



Cities of the world (about 1920) with at least 100,000 inhabitants, ranked in the decreasing order of population size.

Figures 14 and 15.

On the rank size distribution of world cities and their possible meaning.

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