Working Paper

Introducing TGV Trains in Europe Elements of Systems Analysis

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WP-93-29
June 1993

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Executive Summary

The problem of introducing faster modes of transportation has been analyzed in its generality using two methodological approaches.

The first one reduces traveling behavior to basic instincts, that of territorial animal and the cave dweller. They permit not only a generic illustration of the behavior of the traveler, but a quantitative and precise modeling. This line descends from the seminal work done by Zahavi at the World Bank.

The approach reduces technological evolution of travel machinery and infrastructures to a process of successive substitution which can be described using a simplified version of Volterra-Lotka equations of ecological competition. We dubbed it epidemic diffusion of action paradigms.

The results are crisp, quantitative, and predictive. Concerning the specific object around which all the analysis rotates – the introduction in Europe of higher speed trains – it comes out that trains moving at 200 to 300 kilometers per hour mean speed are welcome ameliorations to the rail transport system, but, in their long-range configuration they do not match the evolutionary constraints of the transportation system.

A constructive proposition is formulated, where 300 km/h mean speed could really become trump card. The counter-intuitive result is that these trains should be used to link large cities, point to point with smaller cities inside a radius of about 100 km. The rationale is that people usually do about three round trips per day, one long and two short ones. The long trip, however, is about 40 (20+20) minutes. Connecting two cities with a transit time of less than 20 minutes will practically fuse them transforming the intercity trip into intracity trips, which are almost two orders of magnitude more frequent.

Some examples of these possible connections are given with a total track length comparable to that of the projected European fast train network.

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Introduction

Schumpeter and Montroll, in very different contexts of modeling, noted that progress can be reduced to a spatio-temporal sequence of substitutions. In the case of transport, after the historical horse and buggy, starting from the XVIII century, we have witnessed a brisk (in secular terms) evolution of the means of transportation. The next one substituting the previous ones in 100 years or so.

The basic technologies for overland transportation can be reduced to their infrastructures: canals, railways, paved roads and motor ways and airports. What will be the next technology is everybody's guess, but Magnetically Levitated Trains (Maglevs) are a good candidate as they fit into the various constraints imposed by the quality of future *system demand.*

The substitution process has found its basic description into a *Logistic Substitution Model* (see Appendix) which was used first at IIASA to map primary energy substitution, but later found a very wide application in the description of all sorts of economic and social processes. For the case of transportation modes, we can measure their dynamic of substitution through that of their infrastructures, e.g., in the USA (*Figure 1*). On a shorter term we can also see the different modes operationally (passenger kilometer) through their substitution (see *Figure 2*). The process is of very general character and independent from the social or political context. The numerical parameters of the equations are, however, specific of the country (*Figures 3* and *4*).

Figures 1 to *4* show the substitution in relative terms but the exercise can be repeated also in absolute terms. The straight lines in our charts are logistic S curves and we see our infrastructures grow for one or two pulses (usually each of them embedded in a Kondratiev 55-year cycle), then they stay constant (one Kondratiev cycle), and finally start wearing down. From a functional point of view (e.g., passenger kilometers) they keep growing during the expansion pulses in absolute and relative terms. During the stationary phase they tend to lose in relative terms but to be stable in absolute terms. Passenger kilometers transported by European railways are more or less the same as they were in the thirties, at the end of the previous Kondratiev cycle. When the infrastructure starts losing pieces at the rim (*Figure 6a,b*), also in absolute terms, the functional indicators will start going down.

At this point, typically, the old technology tries to fight back by introducing new tricks and some reorganization of the system. The situation is very clearly described by what happened when steamships by their superior reliability (but inferior economics) started substituting sailships. The latter could not compete with the strict time tables for transporting precious mail and human flesh, but they could for bulk and in fact carried coal to the bunker points around the world to refuel the coal-guzzling steamers. The new technology, however, had much potential in store and kept explicitating it. The *Windjammer* replied with an all-out effort. The big merchant-man of 1850 was about 700 tons and had a crew of 25; by 1900 it was 6000 tons and had a crew of 16. In 1848 tea clippers sailed home from China *against* the monsoons in 129 to 146 days. In 1871 the spread was between 104 and 127 days. The times for the trips *with* the monsoons did not change. But finally they came to the end of the rope and the steamers kept improving. The situation is clearly depicted in *Figures 7* and *8*, showing the diffusion of the new steam technology for the UK and the functional substitution at the world level.

The penetration of railway infrastructure in Europe is given in *Figure 6a,b* in terms of kilometers of tracks. After two waves up and one steady it is clear that railways have to fight for their survival. And they do it following quite precisely the lines of the sailships. Collaborating with the competing mode, e.g., carrying road vehicles piggy-back over long stretches. Or competing by trying to conquer *speed* which is what all the competition is about. The sums earmarked for this last fight-back are very considerable, in the order if hundreds of billion ECU. *Our system analysis tries to identify the most profitable way to use them.*

Mobility Principles: The Travel Time Budget (TTB) and the Travel Money Budget (TMB)

Man is a territorial animal as our books of history clearly display. He is territorial in macro and micro with very strong parallels with the behavior of territorial animals. One of the tenets is that a large territory offers more resources than a small one. But it is harder to exploit and defend. So a compromise has to be found by optimizing between various constraints. Extensive field studies made originally by Zahavi under the spur of the World Bank and focusing on actual behavior more than on economic interpretations, have shown this behavior being contained into few very simple boundary conditions. *First* people move around *one hour a day* (mean over a population). *Second* people spend about *15% of their disposable income* to finance this movement. Inside these two boundary conditions they allocate this money and this time between different modes of transportation in such a way as to *maximize distances*, i.e., the size of their territory. With increasing income the distance covered with mechanical transportation increases quite regularly by about 4% per year as illustrated in *Figure 4* showing France since 1800.

Because Travel Time is Fixed They use their Money to Buy Speed

The boundary conditions given above are for a population, and there is obviously a large spread depending on age, sex, and profession, but if we want to analyze global response from the social system to changes in the structure of the means of transportation made available, then this level of aggregation may be sufficient. A *third* empirical observation of great importance is that the number of *round trips per day* oscillates between three for people living in cities to four or five for people living in villages or countryside.

Man is a shy animal spending about 75% of his time protected in his hole, the home. Another 15% is taken by work, nowadays mostly done indoors. This is true for Germany (*Table 1*) or for Greece showing

Table 1. Characteristic sizes of daily budget, (a) mean for all persons, (b) for the group of housewives without cars.

Characteristic size of time budget	Daily budget elements of activities (Minutes per person and day) (1)	(2)	(3)	(4)	(5)	(6)	(6a)	(6b)	(6c)	(7)
(a) Mean value for	German average person older than 10 years									
251 Work days	1046	182	14	49	31	65	19	30	16	53
50 Saturdays	1161	46	4	20	36	61	20	31	10	112
65 Sundays & holidays	1211	21	1	2	4	59	24	30	5	142
all 366 days 1976	1090	135	10	37	27	64	21	30	13	77
Maximum value	1314	232	29	89	66	90	45	50	31	211
Minimum value	975	0.5	0	0	0	36	9	16	0	24
Standard deviation	75	73	7	25	13	9	5	6	6	42
(b) Mean value for	German housewives without car									
251 Work days	1276	19	0	1	56	47	25	14	8	41
50 Saturdays	1255	10	0	1	48	50	23	21	6	76
65 Sundays & holidays	1260	4	0	0	5	57	27	26	4	114
all 366 days 1976	1270	15	0	1	46	49	25	17	7	59
Maximum value	1360	80	14	22	108	109	85	60	29	241
Minimum value	1097	0	0	0	0	22	10	2	0	5
Standard deviation	40	17	2	2	26	14	10	9	6	38

(1) At home.
(2) Work.
(3) Business.
(4) Education/training.
(5) Shopping.
(6) Traveling; (6a) on foot, by bicycle or motor cycle, (6b) in motorized individual traffic, (6c) with public transportation.
(7) Other.

that the quality of the climate and of the weather is of not primary importance. The time spent, unprotected, moving around has to be used at best, and in fact it is. Virirakis, analyzing the spacial structuring of the services in a "natural" city like Athens, found that by using or not using them, the customers imposed a spacial distribution that minimizes total travel. As they mostly move at constant speed on foot, this corresponds to minimizing travel time.

The three trips are of very different length. Usually the large one (~50 minutes per day) is used for moving to work and back. This is understandable as it permits the largest choice in order to optimize the two most important options in the life of a person, his workplace and his house. If we define a city as the conurbation inside which people move daily, we find that these constraints strictly define the maximum physical size a city can have. For a city on foot the maximum diameter is about 5 km (one hour on foot) and for a city on cars it is about 40 km. Checking historic walled cities shows that imperial Rome, Vienna (in 1700), Marrakech, or Beijing all had diameters of about 5 km. An analysis of the urban size of Berlin from 1800 to present (*Figure 9*) shows a neat matching between the speed of the fastest transport in operation and the size of the city.

That the *barrier is time and not space* is easily shown taking the case of cities having a very large river or sea strait inside them and looking at what happens when we move from a slow link (ferries) to a fast one (bridges or tunnels). The cases we will look briefly at are Lisbon and Istanbul. The analysis will show results very pertinent to our question of introducing fast trains, because it gives not only an idea of the effect of the increased speed, but also of the time necessary to assimilate it into reorganization of the community and of its behavior.

We take first the example of Lisbon, a city built on the northern side of the broad outlet of the Tago River. The river is so large at this point that only ferries could be used to cross it until 1966 when a bridge was opened. This bridge was not really intended for the city, well connected with the southern conurbations of Almaide and Seixal by the ferries, at least in the mind of city planners. The bridge, a feat of engineering and of good aesthetics was built where it is in order to be seen from the city as a monument to the constructivity of Salazar's regime. But the propinquity had a snag, not foreseen by the planners, that it reduced transit time between Lisbon and the southern conurbations to a level where the trip could be incorporated into the daily long one. In other words, it transformed *intercity* trips by ferry into *intracity* trips by cars and buses. The difference in frequency is almost two orders of magnitude and we can analyze in detail the process and its dynamics.

Vehicle transported by ferries between 1950 and 1987 are reported in *Figure 10*. The line starts around 1940 because activities usually grow in pulses starting with the beginning of a Kondratiev-wave (the present one started around 1940). We see a saturation point of 2 million vehicles for this wave, plus 0.4 million from the previous one ending in 1940. The opening of the bridge is marked on the figure and brings a drastic fall in traffic (with some pick-up in the following years). The second face of the medal is reported in *Figure 11* showing vehicular traffic over the bridge. It starts with almost three million during the first years, growing logistically to a saturation point of 26 million cars per year. This is also the maximum technical capability of the bridge with 2 × 3 lanes. The original width of 2 × 2 lanes was already saturated in 1977 when the 2 × 3 was put into place.

The cleanness of the example is paradigmatic. Lisbon and the southern conurbations existed before the bridge, and the connection with the ferries was most probably largely sufficient in terms of capacity. Although we do not have data about the capacity offered by Lisbon's ferries, these machines tend to run with low utilization factors. In Hongkong, where we have precise statistics, this factor is about 30%. What happens with ferries, however, is that even when the transit proper takes 20÷25 minutes, as in this case, loading and unloading plus some waiting brings the trip length into the area of one hour. The bridge proper can be crossed in five minutes, although accesses take certainly time, especially because the bridge is apart from the city since it was built for other purposes. What has been observed, in fact, is a *reorganization of residence, jobs, and shopping procedures* to take advantage of the new spaces which were made available to the city inside the *city's time walls.*

We are not going to report on similar examples coming from Istanbul where a highway bridge was constructed on the Bosphorus in a place where the strait is narrow and the banks appropriate for a bridge. As in the case of Lisbon, the bridge *happened to be* in sight of the town of Istanbul and was consequently used as a fast link to the eastern side of the strait where large conurbations were present. It must be clear that the strait was and is equipped with a frequent service of ferries for vehicles and people, so that formally the two sides were well connected (*Figure 12*). The bridge was invaded by local traffic as is shown in *Figure 13*. The saturation point of 29 million vehicles per year is the technical capacity. In fact a second bridge has been constructed in the meantime and opened in 1988. The Tago bridge had a saturation of 26 million vehicles. The difference is in the time constants: 20 years for the Tago bridge and 5 years for the Bosphorus bridge. Although we did not search in depth, a possible explanation is that a large conurbation of perhaps 1 million people already existed on the eastern banks of Istanbul providing a ready source for city organization reshuffling.

We did a similar study for Hongkong, where three tunnels were opened under a 2 km wide strait with the express decision of facilitating traffic (again for trucks in the road tunnels). Things went well and traffic is moving to a saturation point of *800 million* transits per year or about 2.2 million per day. A curious fact is that trucks still prefer ferries in Istanbul and in Hongkong, their timetables being not as sensitive as those of human passengers, but the tolls cheaper.

A very important *rule of thumb* gained from these analyses is that when two conurbations are meshed into one by a fast connection, the traffic changes from intercity to intracity and the *number of transits* (both ways) *closely matches the population of the smaller conurbation.* In other words, if the smaller conurbation has 10^5 inhabitants, the transits per day will be around 10^5. If it is a public service (like train and metro in two of the tunnels in Hongkong), this permits rapid amortization on one side, but requires peak quality in organization to face peak loads of 10^4 passengers per hour, or so.

Where to best located fast trains?

Let us now come to the central point of our discussion: *how to best use the increased performance of trains.* Japan led the way in fast trains with the Shinkansen opening the first line in 1969. The technology had at least 10 years. So we should expect, 30 years later, something more exciting on the market. Put it in a blunt quantitative way, Shinkansen technology can make 300 km/h top speed and the new SNF (or BB) trains *500 km/h.*

Daily trips provide the largest market in terms of number of trips, as we said, but also in terms of passenger kilometers. Just to give a figure, 90% of the *passenger kilometers* on *railways* in Germany is concentrated in the 0–50 km range. In the case of cars and road transport, 60% of the passenger kilometers are again concentrated in the 0–50 km slice. So the short range is the really fat market and the problem is how to use the best technology in road transport for that segment. The answer is very simple and derives from the *20-minute one-way trip length* that fixes the discontinuity between daily trips and the rest.

The analysis leads then to use very fast trains in their best performance for 20-minutes trips or so, to connect centers having at least 10^5 inhabitants providing the basis for a number of trips per day of the same order of magnitude. A 500 km top speed train can make about *100 km in 20 minutes* if one takes into account acceleration–deceleration procedures. Because stops consume more or less ten minutes in stop proper (5 minutes) plus decelerations–acceleration, *stops are by necessity to be avoided.* These trains *run from point to point only, as in the case of airplanes.* As airways have already discovered and experimented, the best practical configuration is that of *hub and spokes*, meaning a large center (hub) connected radially (spokes) to a number of smaller centers. We have tried a few big cities in Europe (hubs) to see where the spokes would end (< 100 km away) and the results are reported in *Table 2*. The search is occasional and should only serve to start looking around. However, even at this extremely rudimentary stage, the result gives some quantitative hints on the market. The nine hubs list 80 spokes. If the mean length of each spoke were only 50 km, that *would give 4000 km of TGV lines*, capable of absorbing all the present level of goodwill and money available in the direction of Very Fast Trains of conventional design planned for Europe.

Table 2. Some possible hub and spoke connections.

Paris (12)	Reims	Beauvais	Rouen	
	Troyes	Compiegne	Amiens	
	Fontainbleau	Orleans	Beauvais	
	Chartres	Evreux	St. Quentin	
Milano (10)	Piacenza	Bergamo	Lecco	Torino
	Parma	Como	Novara	Alessandrio
	Brescia	Varese	Vercelli	Genova
	Cremona			
Frankfurt (13)	Ludwigshafen	Kaiserslautern	Kassel	Pforzheim
	Karlsruhe	Koblenz	Würzburg	Wiesbaden
	Heidelberg	Siegen	Hellabron	Mainz
	Bonn			
Berlin (9)	Leipzig	Magdeburg	Frankfurt/Oder	
	Dessau	Wittenberge	Cottbus	
	Halle	(Stettin)	Stendal	
Hamburg (10)	Kiel	Braunschweig	Bremen	
	Lübeck	Hannover	Bremerhaven	
	Rostock	Wolfsburg	Flensburg	
	Schwerin			
Manchester (9)	Sheffield	Bradford	Blackburn	
	Liverpool	Leeds	Nottingham	
	Stoke	Blackpool	Birmingham	
London (11)	Ipswich	Portsmouth	Reading	
	Southend	Southampton	Oxford	
	Brighton	Bournemouth	Luton	
	Cambridge	Northampton		
Bruxelles (6)	Liège	Gent	(Eindhoven)	
	Maastrich	Brugge	(Breda)	
	Antwerpen	Mons		

The meshing of the activity of medium cities into large ones has very important consequences. In a study I did some years ago on the distribution of cities at world level, by the usual rank–size analysis (Zipf), see *Figure 14*, I found a curious "shortage" of very large cities, as demanded by a functional (fractal) hierarchy of tasks, but obviously difficult to run as urban conglomerates. By putting "corridors" in the list, the problem appears to be neatly solved (*Figure 15*). A corridor is a chain of cities served by fast connections, typically air-shuttles with frequencies in the order of a fraction of an hour and transit times below one hour. It seems that such mobility provided to the elites is sufficient to integrate the cities, and position them into higher hierarchical slots. European cities seem to be in a saturation stage and so is urbanization in Europe (*Figure 14*). Because positions in the rank of nations is related to availability of *centers* large enough to sit in a high rank, *coagulation through hubs and spokes* could create fairly large centers. These could later be connected by shuttles into larger ones.

The precise example is that of Japan which somehow through the Shinkansen, but in particular through air shuttles, is coalescing about 80 million people in the Tokyo–Osaka strip, the largest conurbation in the world. In 1900, when long-range travel was too slow for this kind of synthesis, the rank–size of cities at world level showed London at the top, a counterproof of an evident economic and political situation (*Figure 14*). The connecting technology were trains.

One of the questions that comes to mind is what happens to the smaller cities when connected to a large one. Will they become dormitories losing their present character? The question is not easy to answer as some examples move in one direction and others in the contrary direction. The British examples, when trains were introduced, lead to specialization in the sense of luxury residences outside the large towns; the Italian examples tend to show a swamping by lower social segments attracted by lower rents. Or they can specialize in quality (or price) services, in terms of, e.g., marketing textiles, apparel, food and restaurants, etc. So perhaps knowing some of the future, local authorities may well take channeling measures.

There will be some time available. As the sample of Lisbon shows, if interaction requires development, the transient can well last for 20 years. If there is a pent up demand as in the case of Istanbul, where only some reorganization was necessary, then five years were sufficient to saturate *the first* bridge. I think ten years is a good rule of thumb for local decision makers to provide the proper umbrella for the changes.

Let us now move to the next step, that of trips longer than 20 minutes. As said in the beginning, man is a territorial animal centered into his cave, where he likes to come back at night to find reassuring familiar patterns and protection. Most of these 1-day trips are of business character, and most of them are short range ($<$ 50 km). But we are now interested in analyzing the long-range connections. Doxiadis in his path-opening book *Ecumenopolis*, had clearly identified the habit and classified the area reached by these occasional commuters as *Eperopolis*. An example taken from that book is reported in *Figure 19*.

Because one working day can be up to 12 hours long, and at least 4 or 5 hours have to be dedicated to the business proper, total transportation time cannot be more than 3 hours ($\times$ 2) door to door. This means that the long-distance part cannot be much longer than 1.5 hours. In fact field analysis shows a high sensitivity in switching from plane to train or vice versa when this "seuil" is crossed.

This very simple logic rules out many proposed fast train links whose rationale is to compete with airplanes especially for the rich business travel. A school-book case is that of the Italian "Pendolino" which takes "only" 3.5 hours to go from Milan to Rome and failed to attract business travel except when Milano airport is fogged out. Or of the Shinkansen which did not inhibit an extremely active "air bridge" between Tokyo and Osaka where fleets of long-range 747s are loaded with up to 750 passengers in extremely packed configurations.

On the other hand, in spite of the flourishing little niche of *air transport*, the numbers are small. In Germany, air trips for all purposes, inland and outland, are 0.5 per person per year, or about 35 million. Of these about *half are business* and the other half mostly vacation trips. Business trips ($>$ 50 km) account for 1% of train trips or 0.25 trips per person per year in Germany. For car trips beyond 50 km they account for one trip per person per year. These are one-way trips and this means 60 million business trips per year for the whole of Germany (beyond the 50 km limit).

If we compare this market with that of 20-minutes daily trips, we are clearly off by more than two orders of magnitude. Consequently, we have to look at the few channels where this flow is concentrated. One of them is through "twin" centers, like Milano–Rome, Barcelona–Madrid, Amsterdam–London, etc. These twin centers are easily revealed by air shuttle service, formal or informal (one plane every hour). As an analysis done at IIASA shows, the problem here is that in the medium future the size of planes will not be sufficient to satisfy such level of demand with a reasonable number (e.g., 50) of flights per day. This is already the case for the Tokyo–Osaka and other connections in Japan. Here a train with different characteristics from the plane, e.g., the potential for launching *one train per minute*, may come to rescue. The train should, however, have a speed similar to that of a plane, around 600 km/hr *mean*. Maglevs seem more adaptable to this task as they are completely passive, with external drive (like San Francisco cable cars) and under computer control.

The other possibility is to look for the "connection core" inside an economic area. I will take some results from a study done by Erlandson at the Geographic Institute of Lund (1991). He looks at the number of air connections (5-day work week) between all cities in Europe, selecting the group where each city has > 25 connections per week with all the other cities in the group. The connections with more than 25 flights per week (5 days) are reported in *Figure 7*. The core connections are reported in *Figures 18* and *19* with a zoom on the time dynamics. The first core (full lines) is made by the cities that interconnect with all others in that group (with > 25 flights per week). The cities at the end of the dashed lines connect with the central core minus one. They can spring in and out with the opening of a new flight. Milano, with the air schedules of 1991, springs into the central core.

This central core is the natural candidate for TGVs, provided transit times do not exceed the *Eperopolis Paradigm*. Again they should be considered as point to point connections, just like airplanes. The very high speed explicitated will almost inevitably require new tracks. *Being* *point to point connections, each track may have different characteristics in terms of power source and gauge. The Shinkansen which shares some of the thinking presented above, is different from the other Japanese trains both in terms of power source and track gauge.*

The discussion about creating a high-speed rail network in Europe is very heated and many interests of financial character and of political prestige are stretching the problem outside its rational and economic basis. Our first round of reflections shows that the network planned, basically an international and relatively long-range one *does not* look like a *first choice for a rational investment.* First, long-range travel is thin, even if the magic one hour time connection is kept in mind. Second, there are political and cultural barriers that separate *different countries* and communities speaking different languages inside a given country. This entails a *reduction in traffic by about an order of magnitude, coeteris paribus.*

Long-range fast connection is now safely provided by airplanes. The number of air passengers and *their evolution in time* is the best indicator for the intensity of the link (*Table 3*). Because city underground transportation systems (i.e., fast intracity transportation) are or will be linked to airports, the best location for fast intercity end stations will be at the airport themselves so that incoming traffic can be added to local traffic. This configuration has already been adopted, e.g., by Lufthansa in Germany on short stretches where present railway speed permits connections more or less respecting travel time constraints. These trains are formally treated as planes and tend to move only point to point with no intermediate stops. Higher speeds will permit a larger area coverage, up

Table 3. Number of air links per working week for selected European couples of cities.

Link	Non-stop flights per week
Paris–London	243
London–Paris	242
London–Amsterdam	211
Amsterdam–London	211
London–Dublin	158
Dublin–London	157
Barcelona–Madrid	153
Madrid–Barcelona	151
Bruxelles–London	135
London–Bruxelles	130
Milano–Rome	132
Rome–Milano	131
London–Glasgow	130
Glasgow–London	130
Väst–Berlin–Frankfurt	120
Frankfurt	
Väst–Berlin	120
Edinburgh–London	115
London–Edinburgh	110
Munich–Frankfurt	105
Frankfurt–Munich	105
Zürich–Genève	103
Genève–Zürich	102
Stockholm–Göteborg	100
Göteborg–Stockholm	100

to including some of the links proposed for the TGV network.

The general problem of providing speed and mileage to people appears much simpler and clearer if looked at in historical perspective. *Figure 5* reports the case of France since 1800 giving the distance traveled per person and per year, using mechanical means of transport (including bicycles!). This distance was a very low 20 meters per day in 1800 showing an extremely static society where only the top elites were mobile. The value for 1985 is still relatively low, about 25 km per day per person. As I belong to the elites who do 250 km per day (thanks to airplanes) and do not feel tired, this means there is still much space to go before reaching saturation. With the historical rate of growth of 4% per year (dashed line fitting *all transport modes*), to cross two orders of magnitude will take about 120 years. This increase in total traffic of 4% will be picked up by the faster means of transport: the car until everybody permitted to drive will have one. In Europe we are not far from that level of ownership. So finally the airplane, in the present and hypersonic version, will take all the increase.

This means large figures. Airplanes take now 10% of intercity passenger kilometers in Europe. At 4% per year the passenger kilometers will double in less than 20 years. If all the new traffic were absorbed by airplanes this would mean an increase in air traffic by a factor of ten in 20 years. Our hubs and spokes may well take a share of this traffic, but it is clear that some connection will be too overloaded to be served by airplanes. This is the area where chances are open for very fast trains (400 km/hr mean speed point to point) and superfast trains (700 km/hr mean speed point to point). As investments decided during the next 10 years will become operational during the following 10 years, this look into the future may be of great interest for fixing a rational policy.

A More Detailed Analysis on How People Move in the Medium Distances

As we have seen, people tend to stay mostly home and move mostly short range, *inside* the city and the village or the nearest territory. The size of the area covered by all this leaving the nest and coming back to the nest is quintessentially determined by the speed of the means of 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 km^2. 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 km^2 (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 km^2, 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 couples 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:

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

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 ($\overline{N} - N$), where $\overline{N}$ is the final number of adopters.

The integration of this equation gives

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

which is the expression of a logistic S-curve well known to epidemologists 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 $\overline{N}(F = N/\overline{N})$, 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 $\overline{N}$ is given as a number in parenthesis.

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Picture Credit

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Figures: 3, 5, 7

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Figures: 1, 2

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Figures: 17, 18a, 18b

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Figure: 14

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Figure: 19, 23

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.

Figure 1.

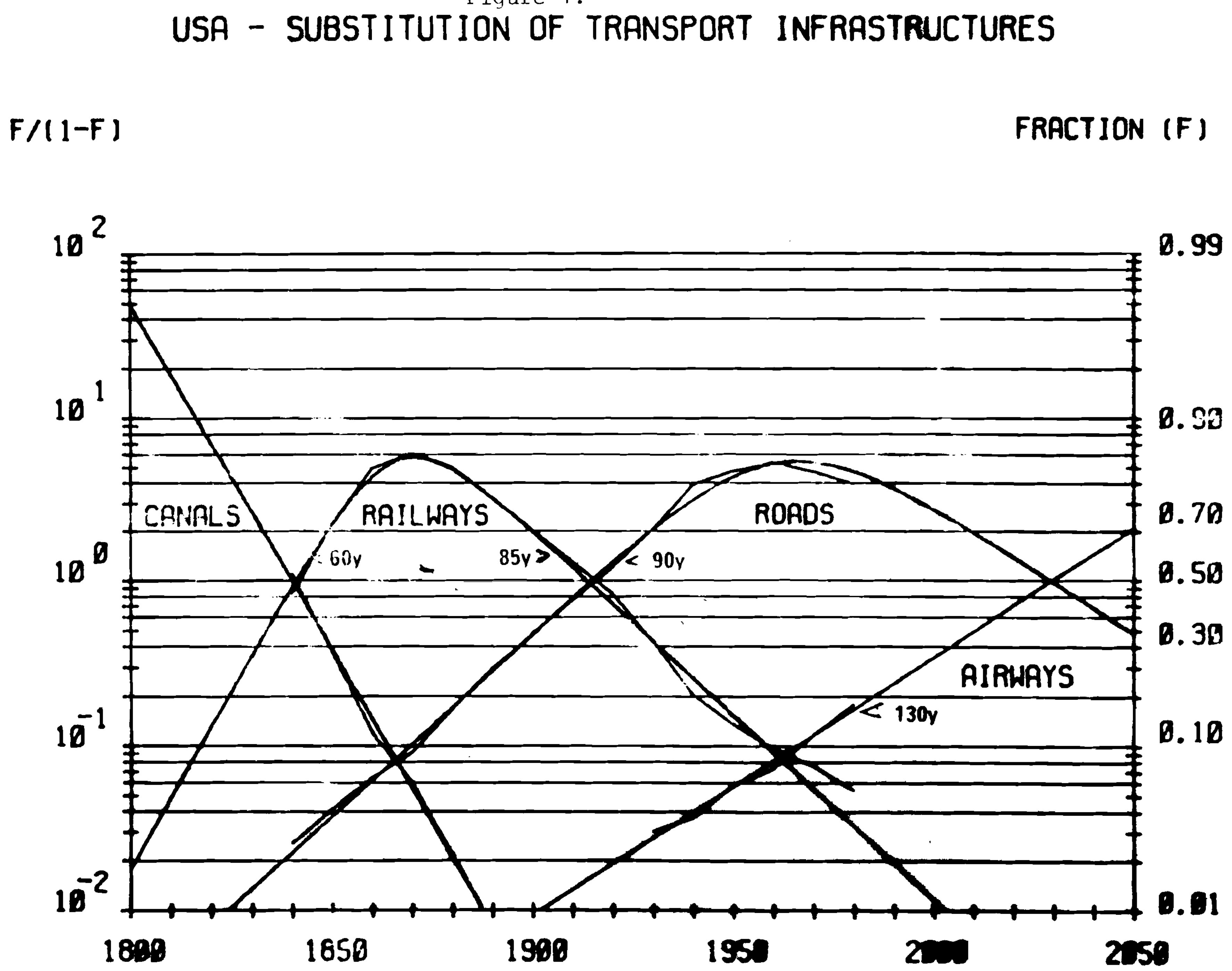
USA - SUBSTITUTION OF TRANSPORT INFRASTRUCTURES
F/(1-F)
FRACTION (F)
10^2
10^1
10^0
10^-1
10^-2
0.99
0.90
0.70
0.50
0.30
0.10
0.01
1800
1850
1900
1950
2000
2050
CANALS
RAILWAYS
ROADS
AIRWAYS
60y
85y
90y
130y

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

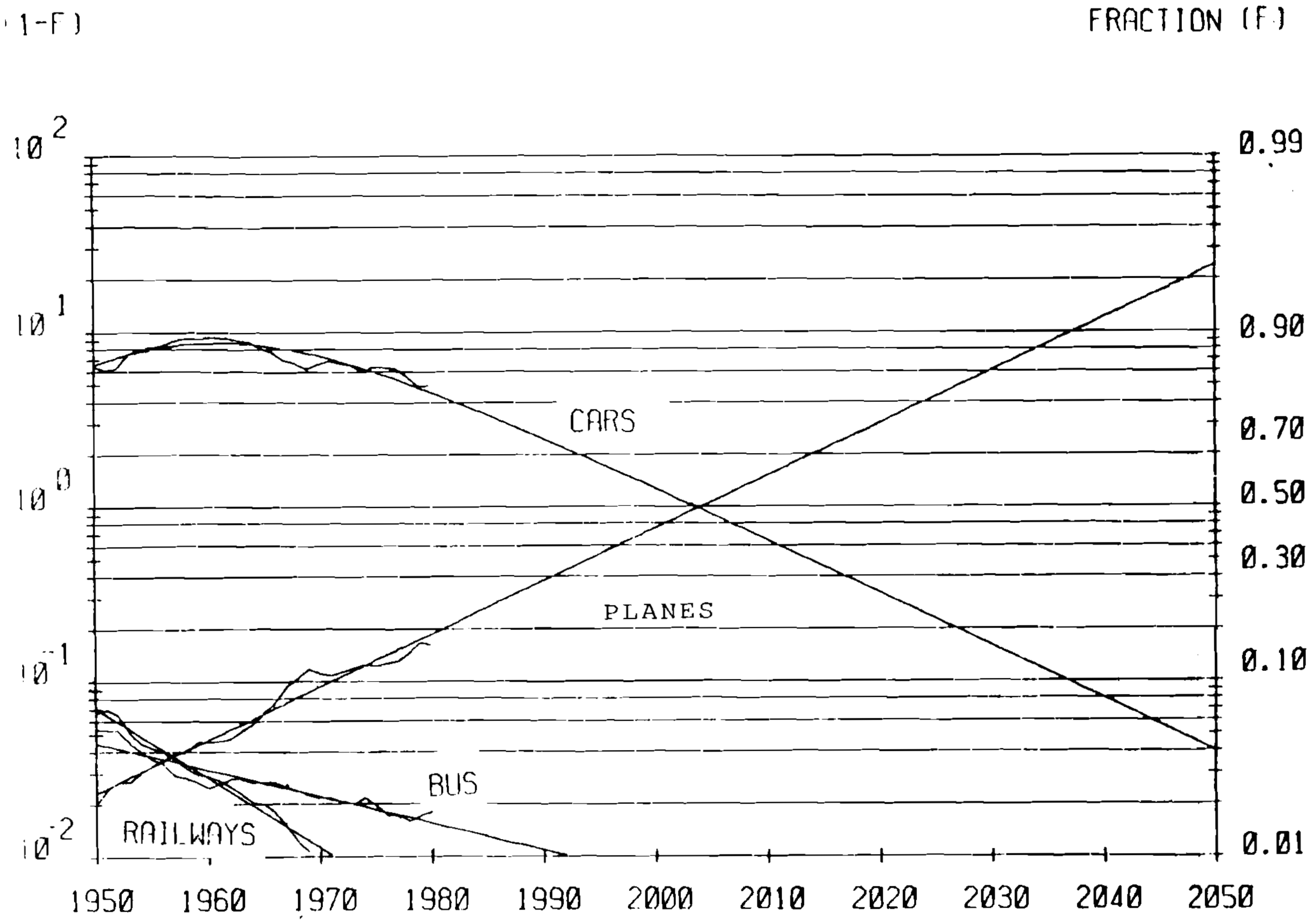

Figure 3.
Evolution of passenger kilometers and modal distribution in the Soviet Union.

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.

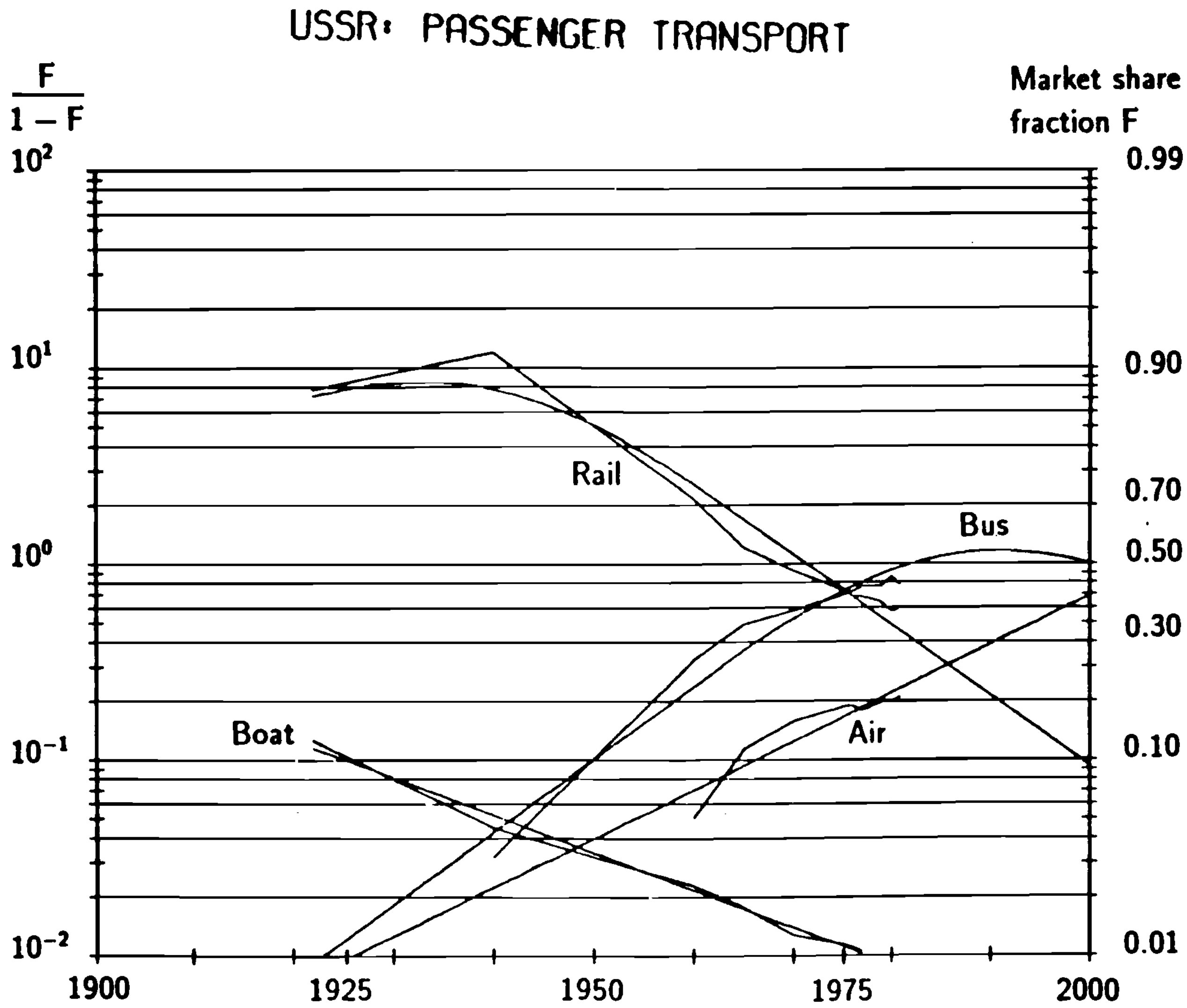
USSR: PASSENGER TRANSPORT
F / 1 – F
Market share fraction F
10^2
10^1
10^0
10^{-1}
10^{-2}
0.99
0.90
0.70
0.50
0.30
0.10
0.01
1900
1925
1950
1975
2000
Rail
Bus
Boat
Air

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 $\sim$ 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

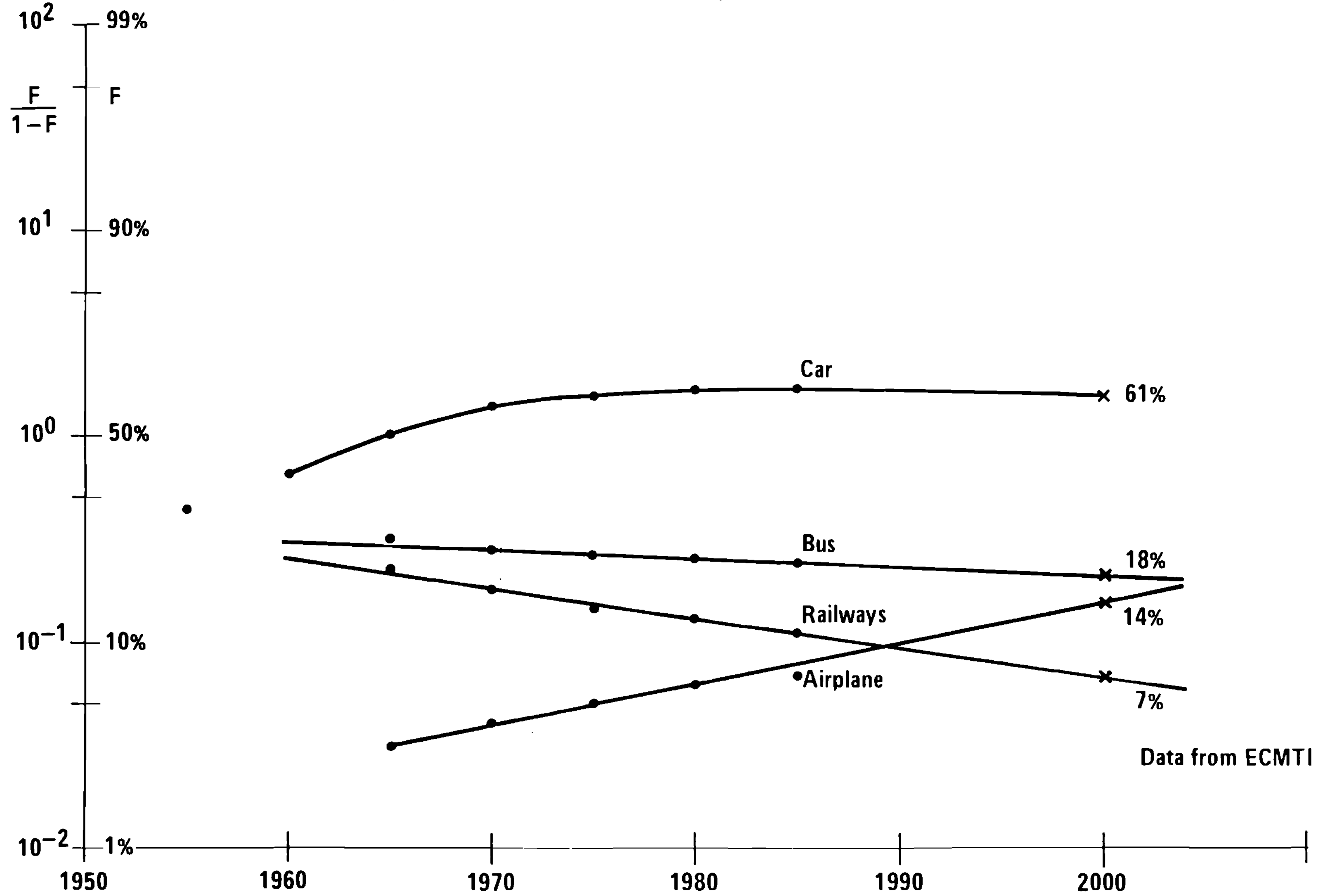

Figure 5.
Evolution of passenger traffic in France since 1800.

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 $\sim$ 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.

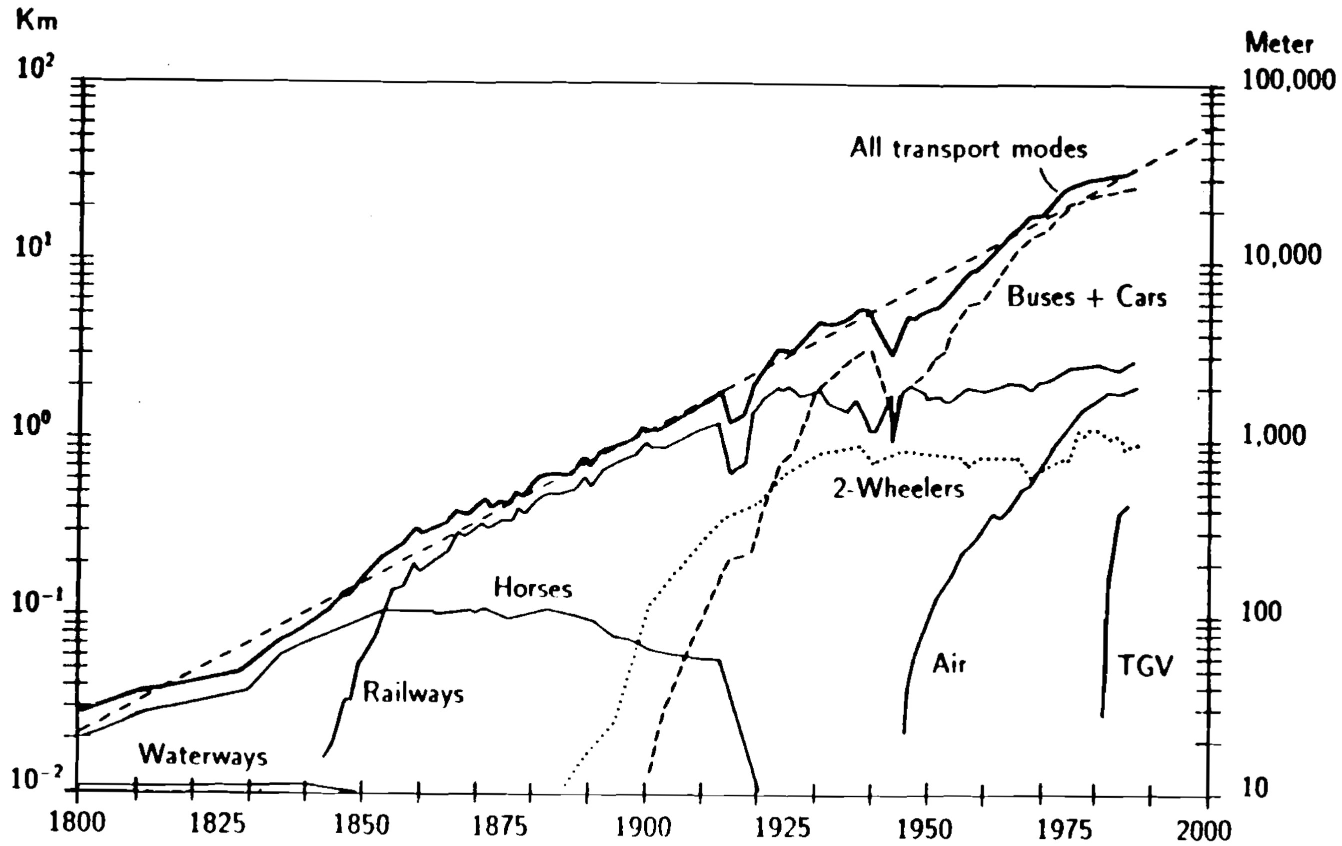
Km
10^2
10^1
10^0
10^{-1}
10^{-2}
Meter
100,000
10,000
1,000
100
10
1800
1825
1850
1875
1900
1925
1950
1975
2000
All transport modes
Buses + Cars
2-Wheelers
Horses
Railways
Waterways
Air
TGV

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.

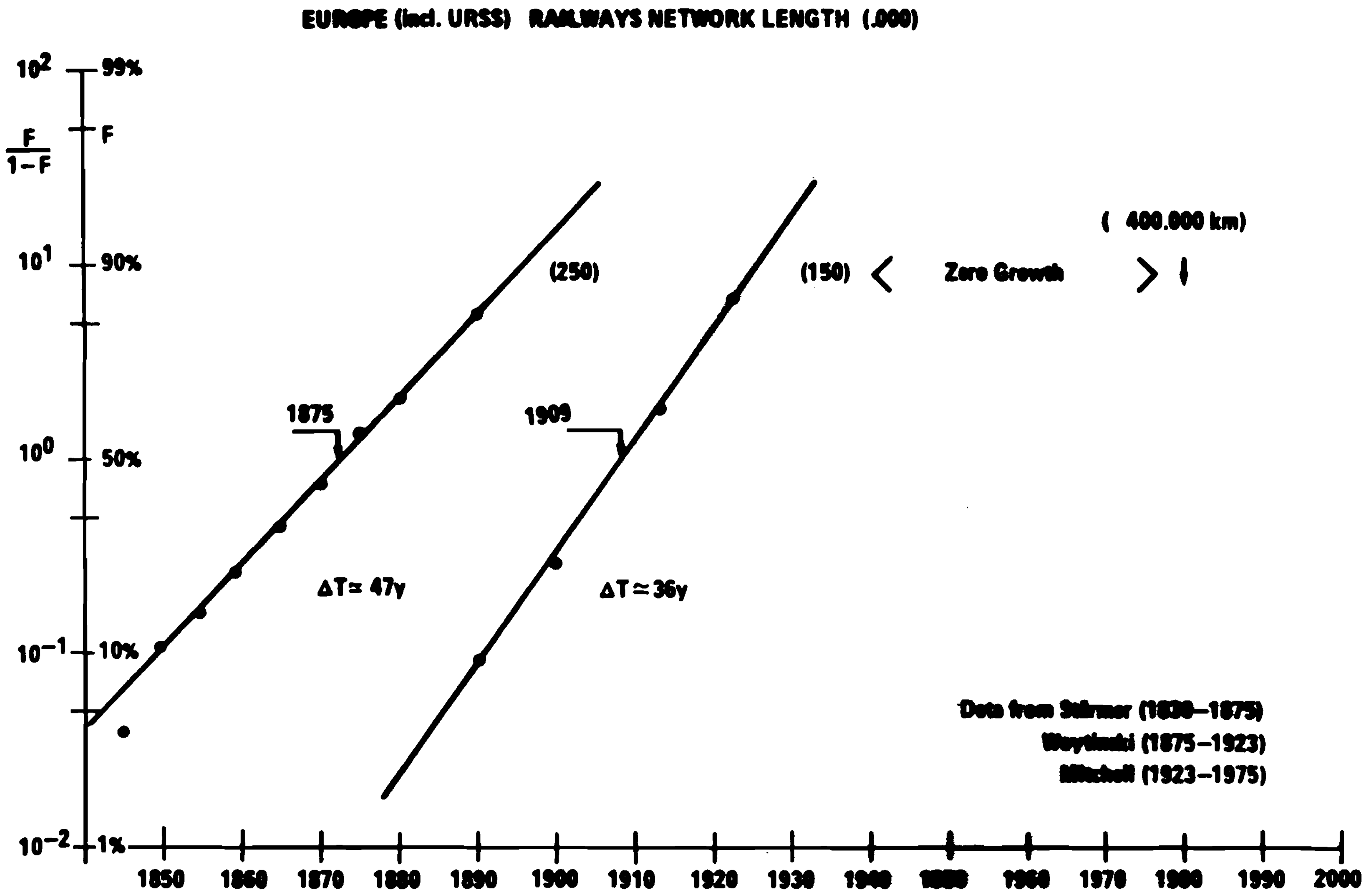
EUROPE (incl. URSS) RAILWAYS NETWORK LENGTH (.000)
$\frac{F}{1-F}$
10^2
10^1
10^0
10^{-1}
10^{-2}
99%
F
90%
50%
10%
1%
1875
1909
ΔT ≃ 47y
ΔT ≃ 36y
(250)
(150)
Zero Growth
(400.000 km)
(1875–1923)
(1923–1975)
1850
1860
1870
1880
1890
1900
1910
1920
1930
1960
1970
1980
1990
2000

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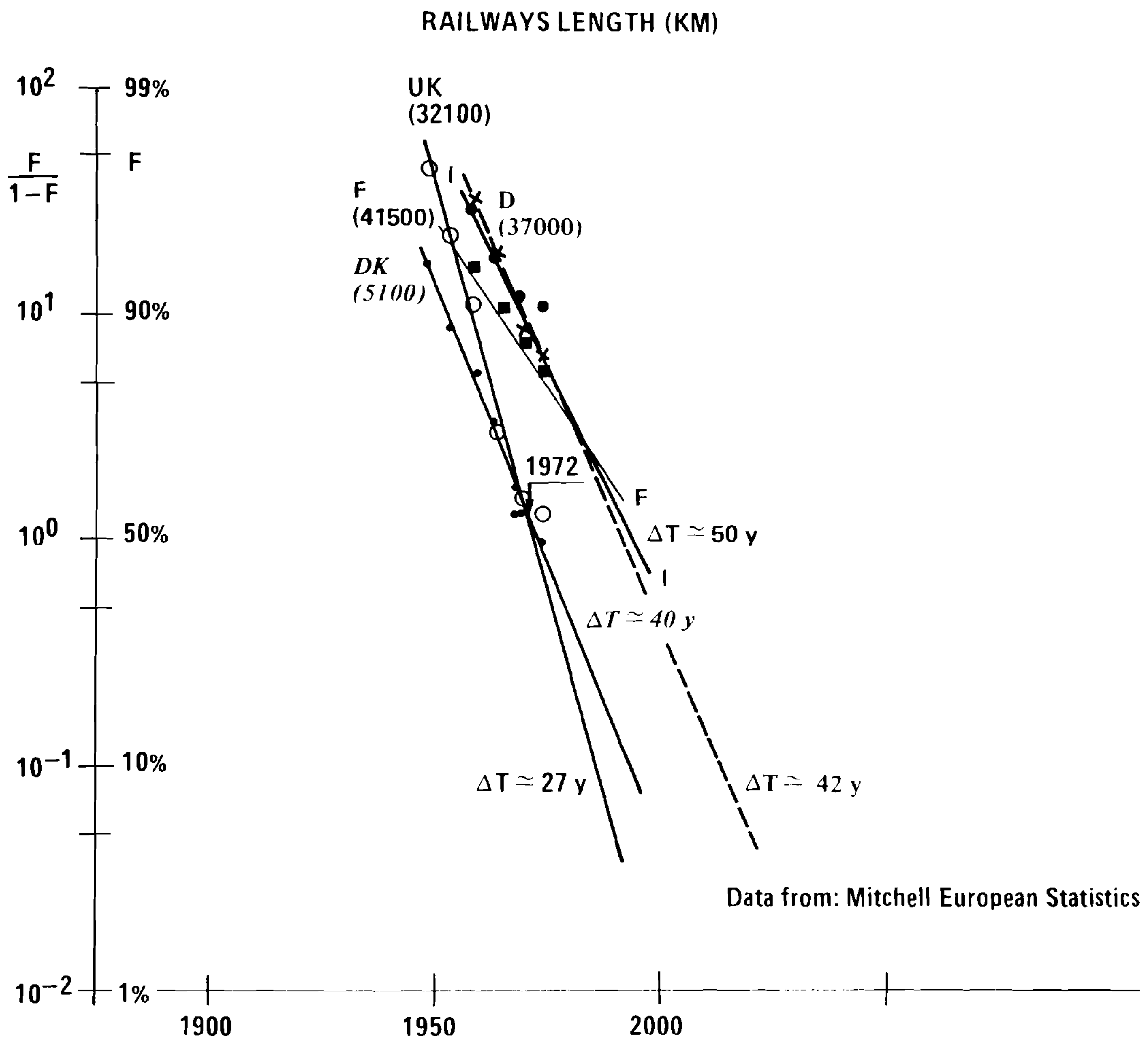
Figure 6b.



RAILWAYS LENGTH (KM)
10^2
10^1
10^0
10^-1
10^-2
F
1−F
99%
F
90%
50%
10%
1%
1900
1950
2000
UK
(32100)
F
(41500)
DK
(5100)
D
(37000)
I
1972
F
ΔT ≃ 50 y
I
ΔT ≃ 40 y
ΔT ≃ 27 y
ΔT ≃ 42 y
Data from: Mitchell European Statistics

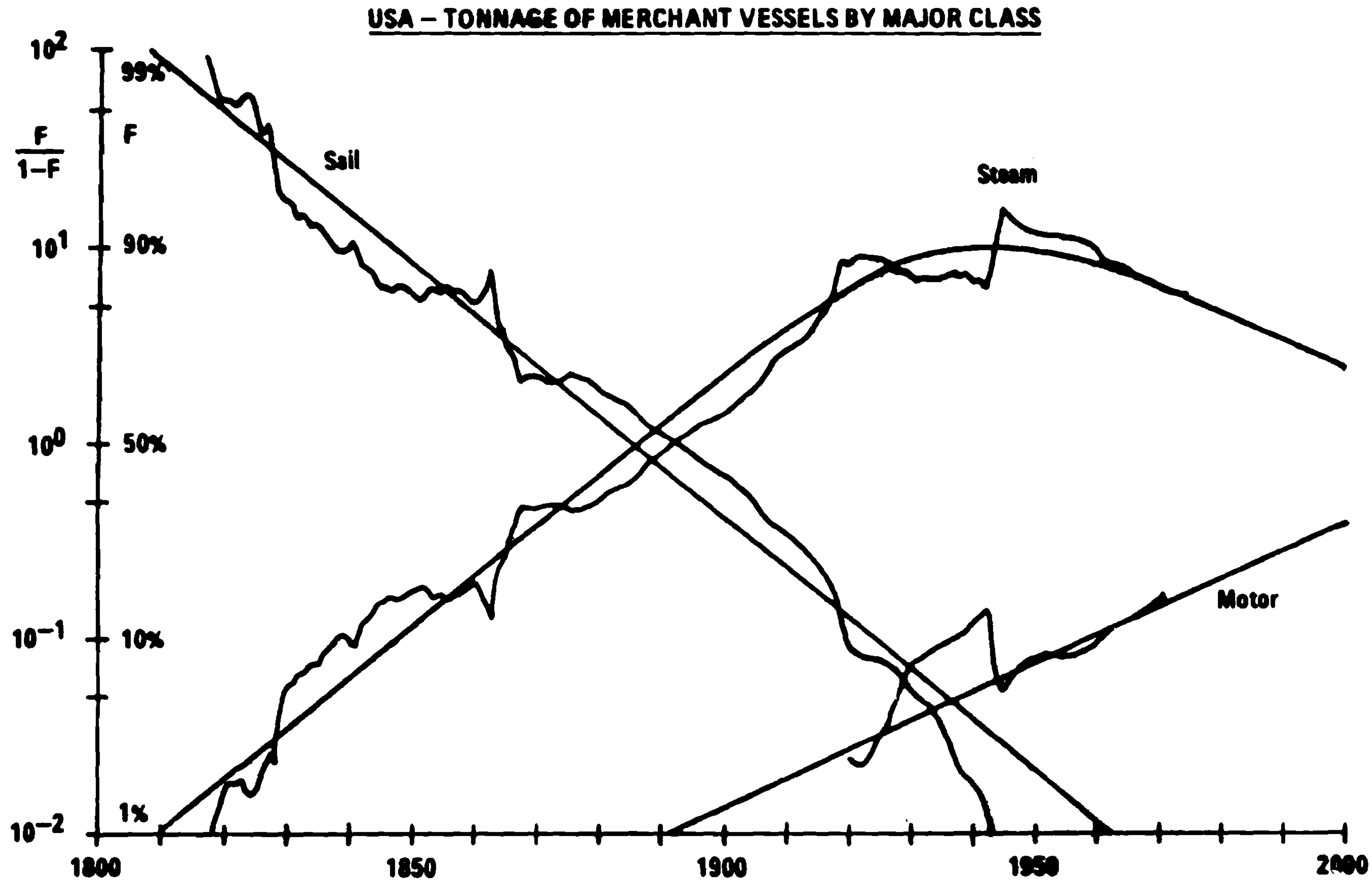
Figures 7 and 8.
Dynamics of substitution in ship propulsion.

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.

Figure 7.



USA – TONNAGE OF MERCHANT VESSELS BY MAJOR CLASS
10^2
$\frac{F}{1-F}$
10^1
10^0
10^{-1}
10^{-2}
99%
F
90%
50%
10%
1%
Sail
Steam
Motor
1800
1850
1900
1950
2000

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

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Figure 8.

WORLD – STEAM vs. SAIL IN TONNAGE AND PRODUCTIVITY

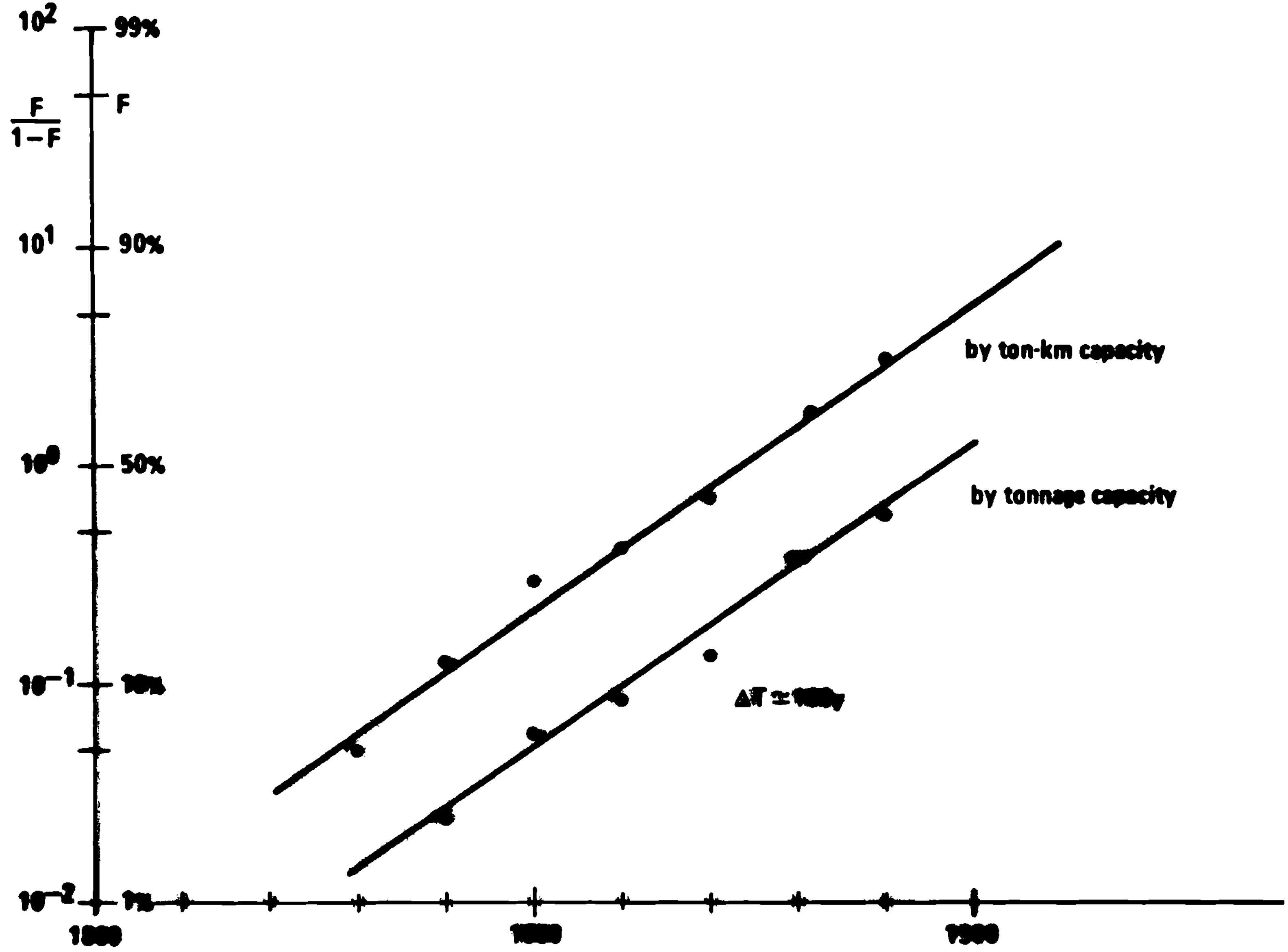


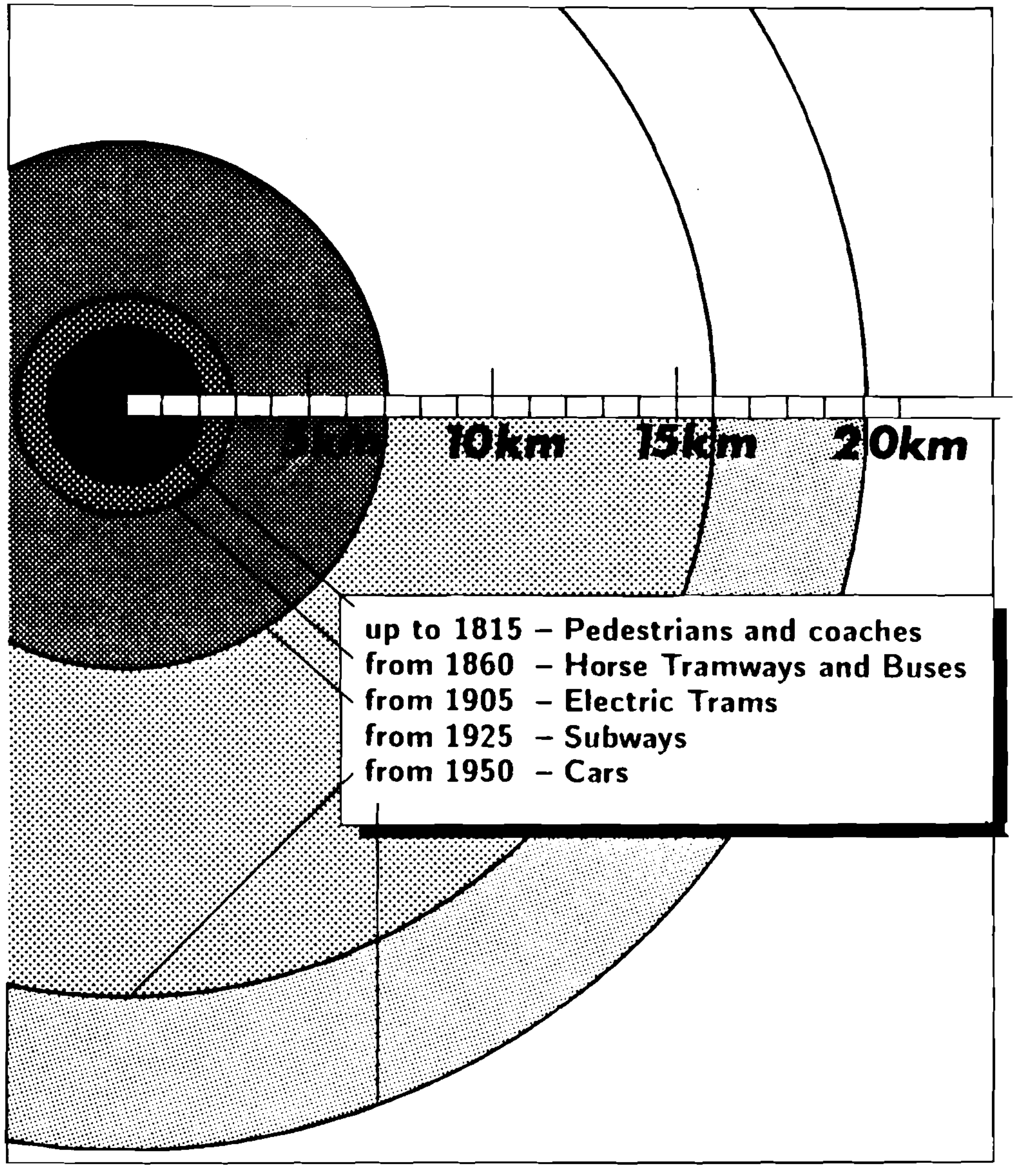
Figure 9.
On the size of cities and the transport infrastructure.

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.


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

Figures 10 and 11.
Lisbon vehicular traffic on ferries.

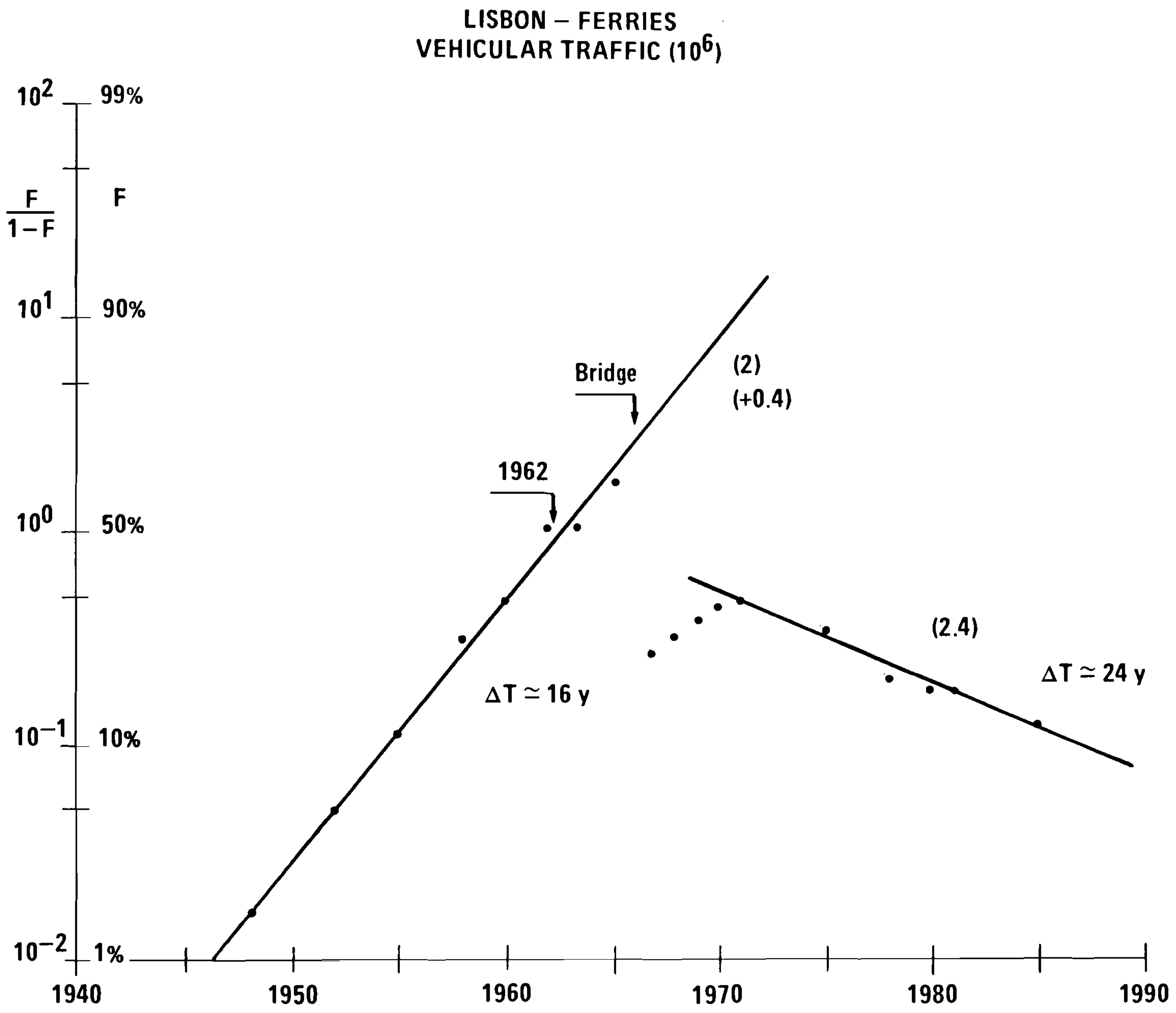
Before the construction of the 25 April bridge across the Tago, traffic with the southern bank of Lisbon was done with ferries. The evolution of vehicular traffic carried by the ferries is reported in *Figure 10.* As many other things, traffic grows in pulses of 55 years, synchronous to the Kondratiev-pulses 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 (10^6)
$\frac{F}{1-F}$
F
10^2
99%
10^1
90%
10^0
50%
10^{-1}
10%
10^{-2}
1%
Bridge
1962
(2)
(+0.4)
(2.4)
ΔT ≃ 16 y
ΔT ≃ 24 y
1940
1950
1960
1970
1980
1990

Figures 10 and 11.
Lisbon vehicular traffic on ferries.

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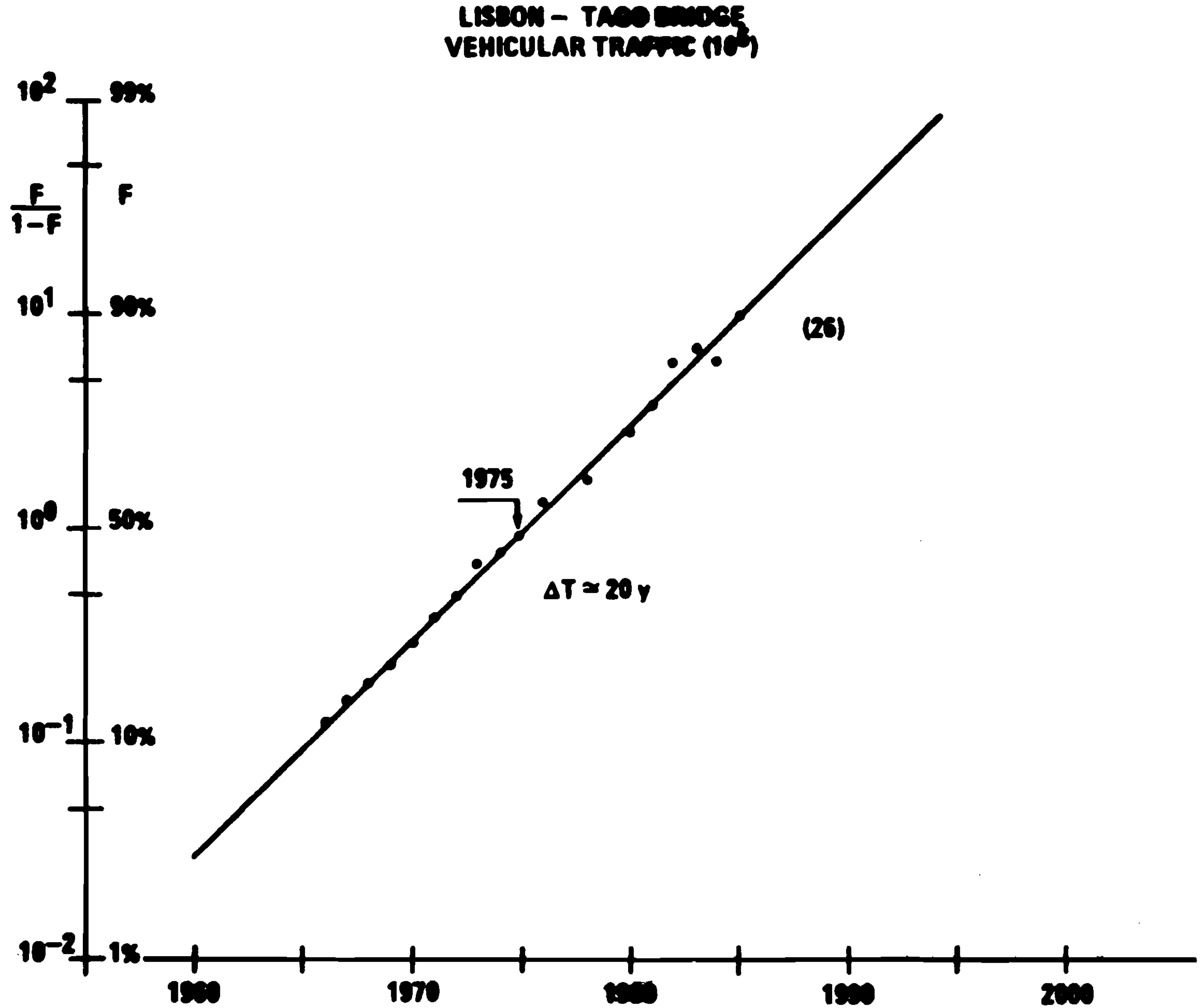
This is a very clear example of how traffic is generated by the reduction of transit times between two preexisting conurbations.

Figure 11.


LISBON – TAGO BRIDGE
VEHICULAR TRAFFIC
F/1−F
F
99%
90%
50%
10%
1%
1975
ΔT ≃ 20 y
(26)
1970
2000

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 chronical 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 (10^6)

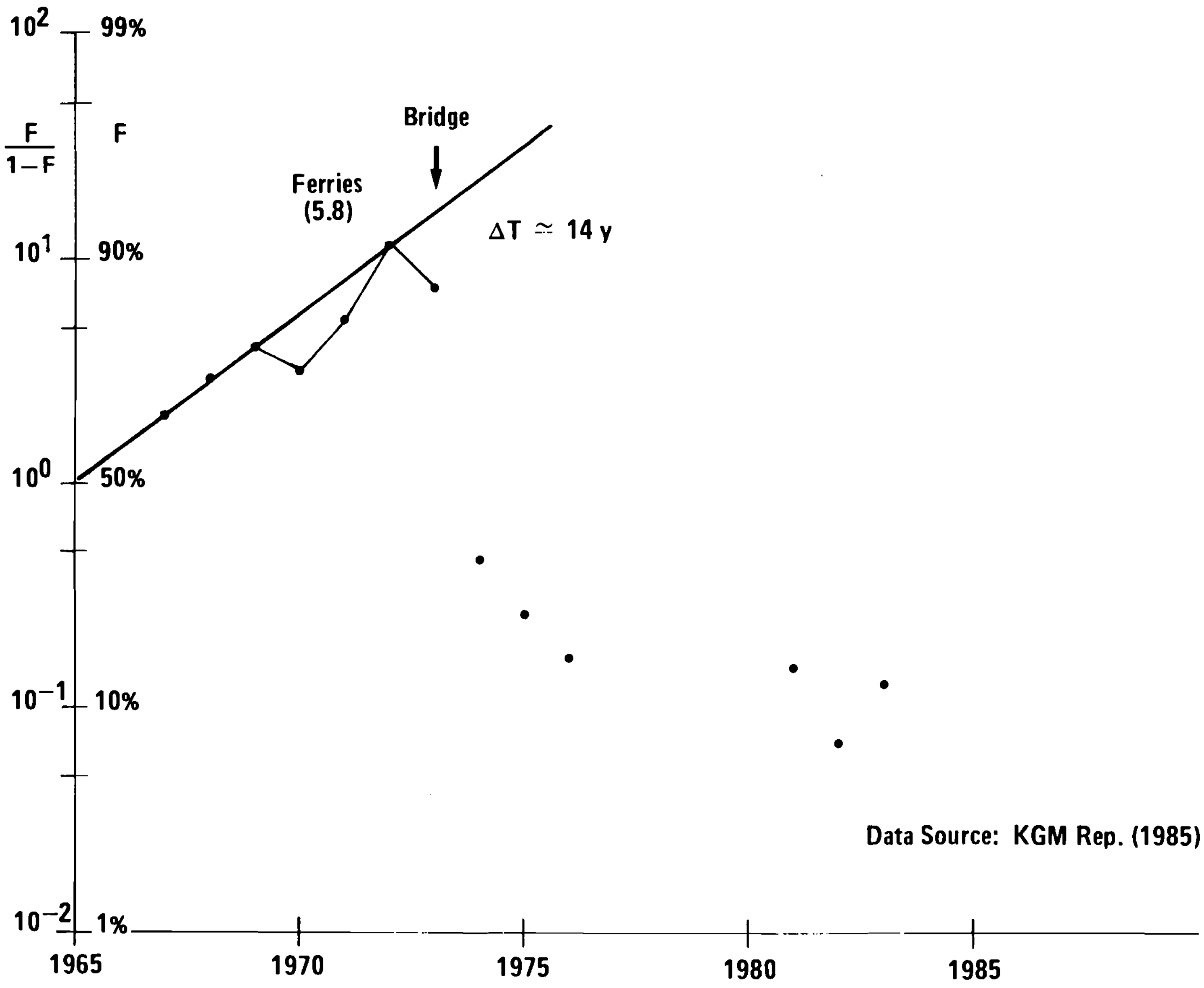


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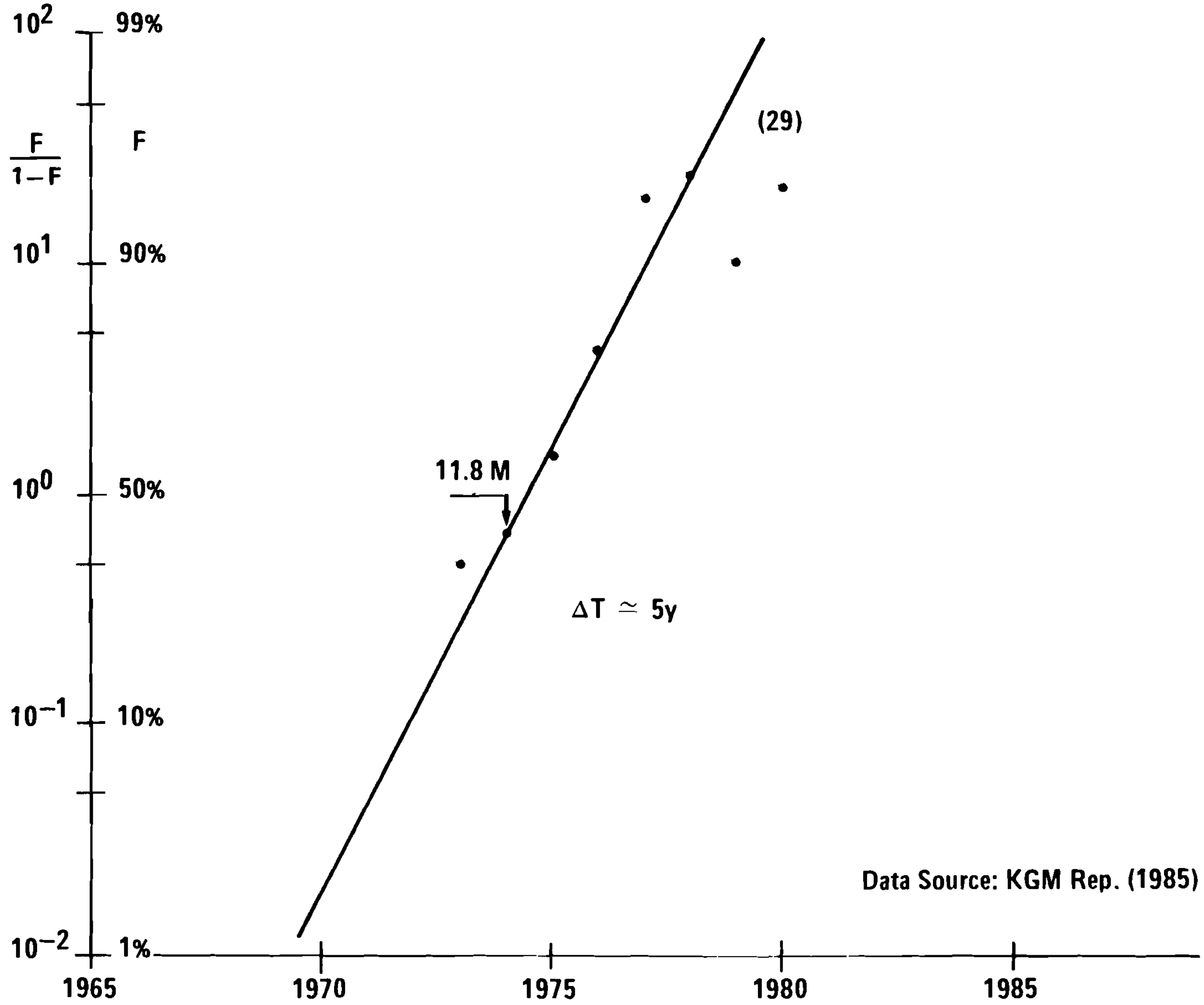
Figure 13.

BOSPHORUS BRIDGE – VEHICLE TRAFFIC (10^6)



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

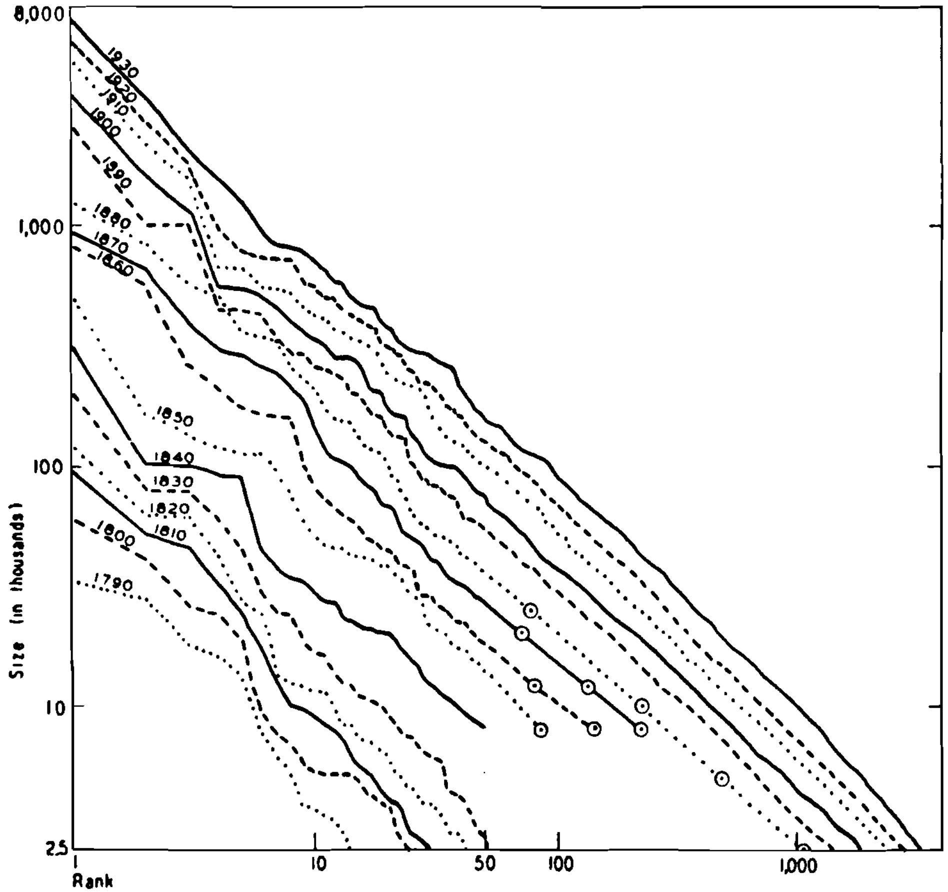
Ranking cities by their size (the largest one has rank 1, and so on) Zipf constructed very self-consistent maps of city size distribution. There is also something more in the charts. The workings of the social system have a hierarchical fractal structure which is mirrored in the size distribution of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

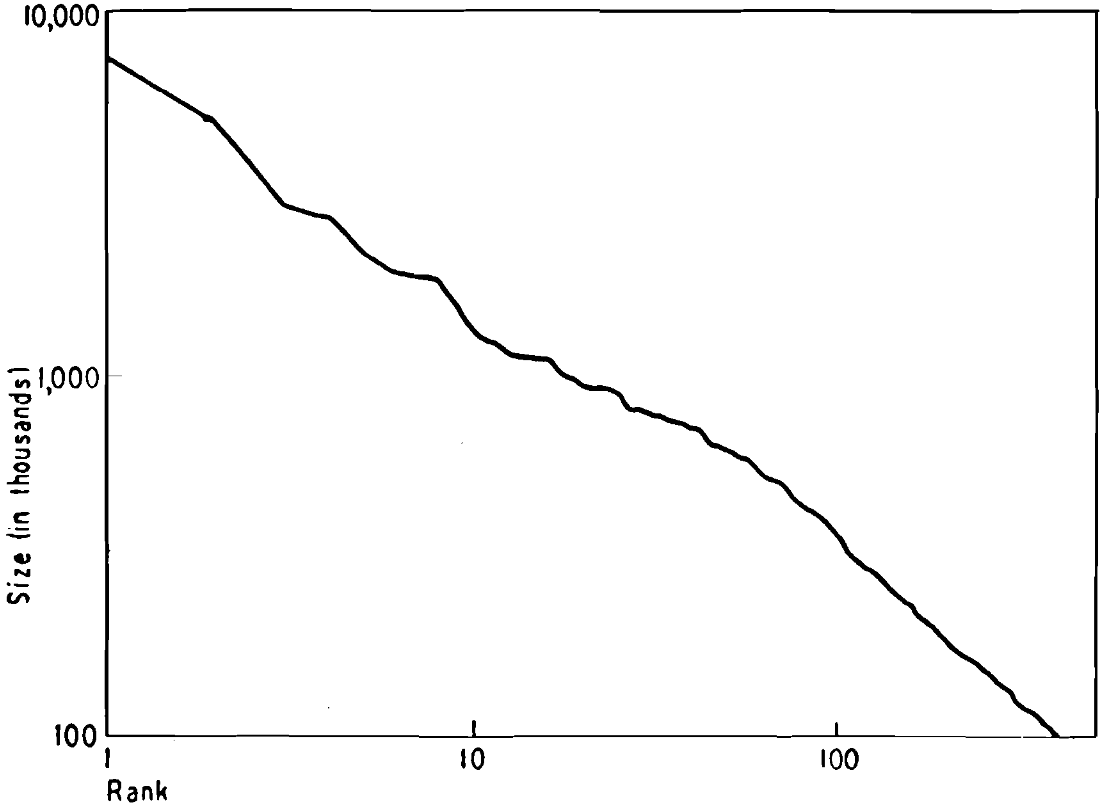
Repeating the exercise for modern cities (1975 data), one gets the rank-size structure of *Figure 15.* The knee in the distribution points to a scarcity of very large cities if we take Zipf's paradigm as significant. From estimates (1975) by Doxiadis in his book *Ecumenopolis* I then ranked the size 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.
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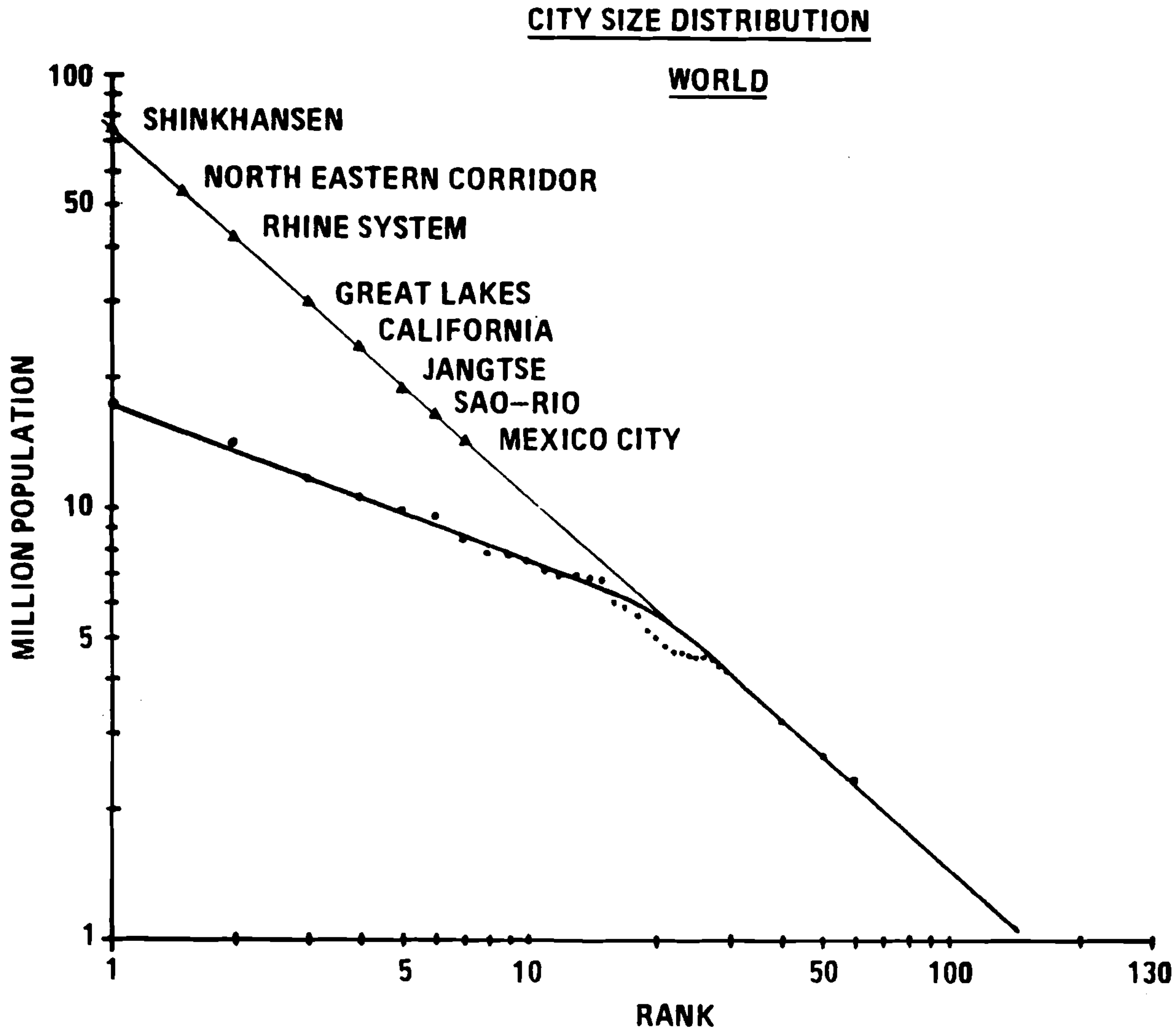
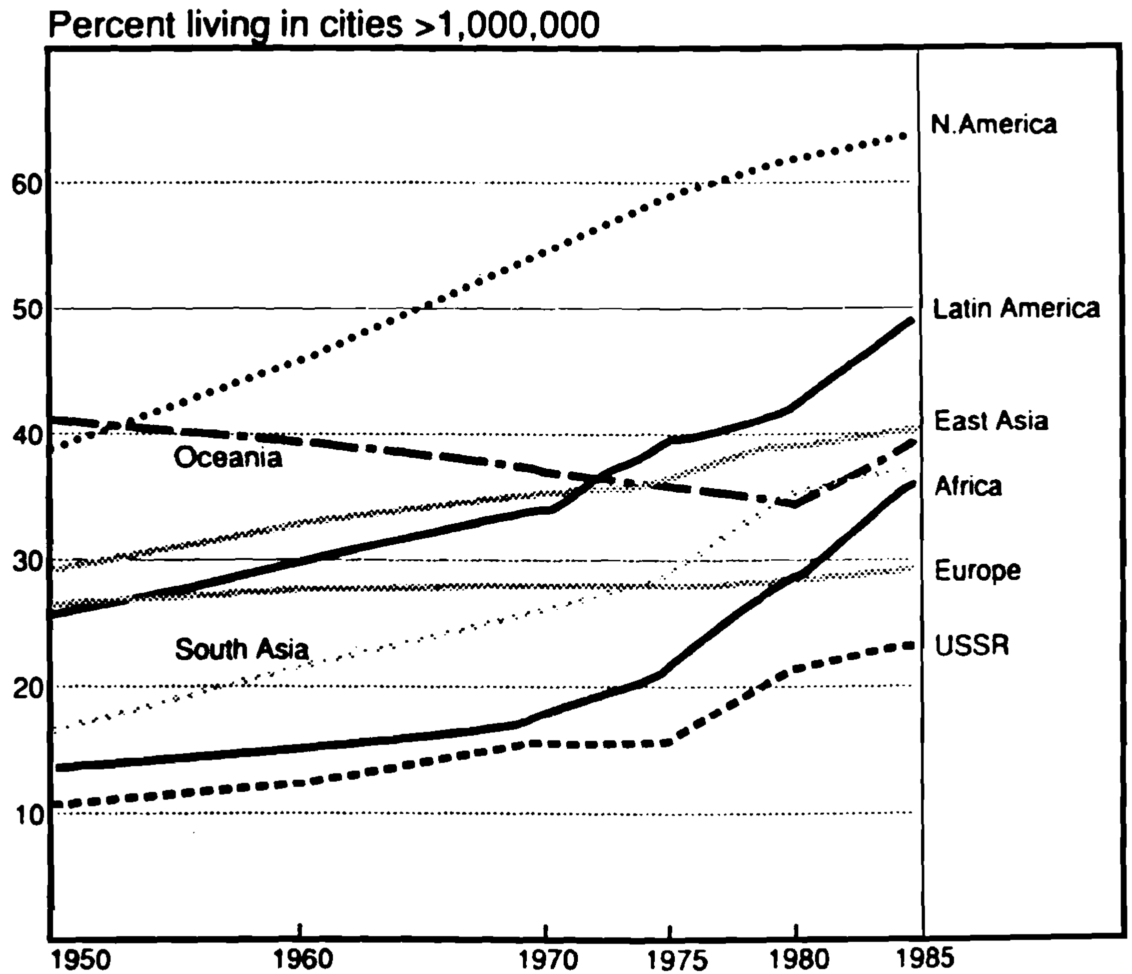

CITY SIZE DISTRIBUTION
WORLD
SHINKHANSEN
NORTH EASTERN CORRIDOR
RHINE SYSTEM
GREAT LAKES
CALIFORNIA
JANGTSE
SAO–RIO
MEXICO CITY
MILLION POPULATION
100
50
10
5
1
1
5
10
50
100
130
RANK

Figure 16a,b,c,d,e,f.
World urbanization trends.

In the evolution of the structure of human settlements in the world, the general tendency has been to concentrate populations into larger and larger cities, with the exclusion of Europe where the population in centers larger than one million inhabitants has been more or less stable during the last 30 years. This may lead to a weakening of the world hierarchical positioning of Europe, *unless* a number of these centers are sufficiently interconnected, in the short-time mode ($\sim$ 20 minutes) so as to integrate them completely, or in the medium-time mode ($\sim$ one hour) in order to integrate them at the highest functional level.

To give an idea of the historical trend in the localization of the world's largest cities, a set of four snapshots is reported, showing the situation in 1700, 1800, 1900, and 1985.

Figure 16a.


Percent living in cities >1,000,000
60
50
40
30
20
10
1950
1960
1970
1975
1980
1985
N.America
Latin America
East Asia
Africa
Europe
USSR
Oceania
South Asia

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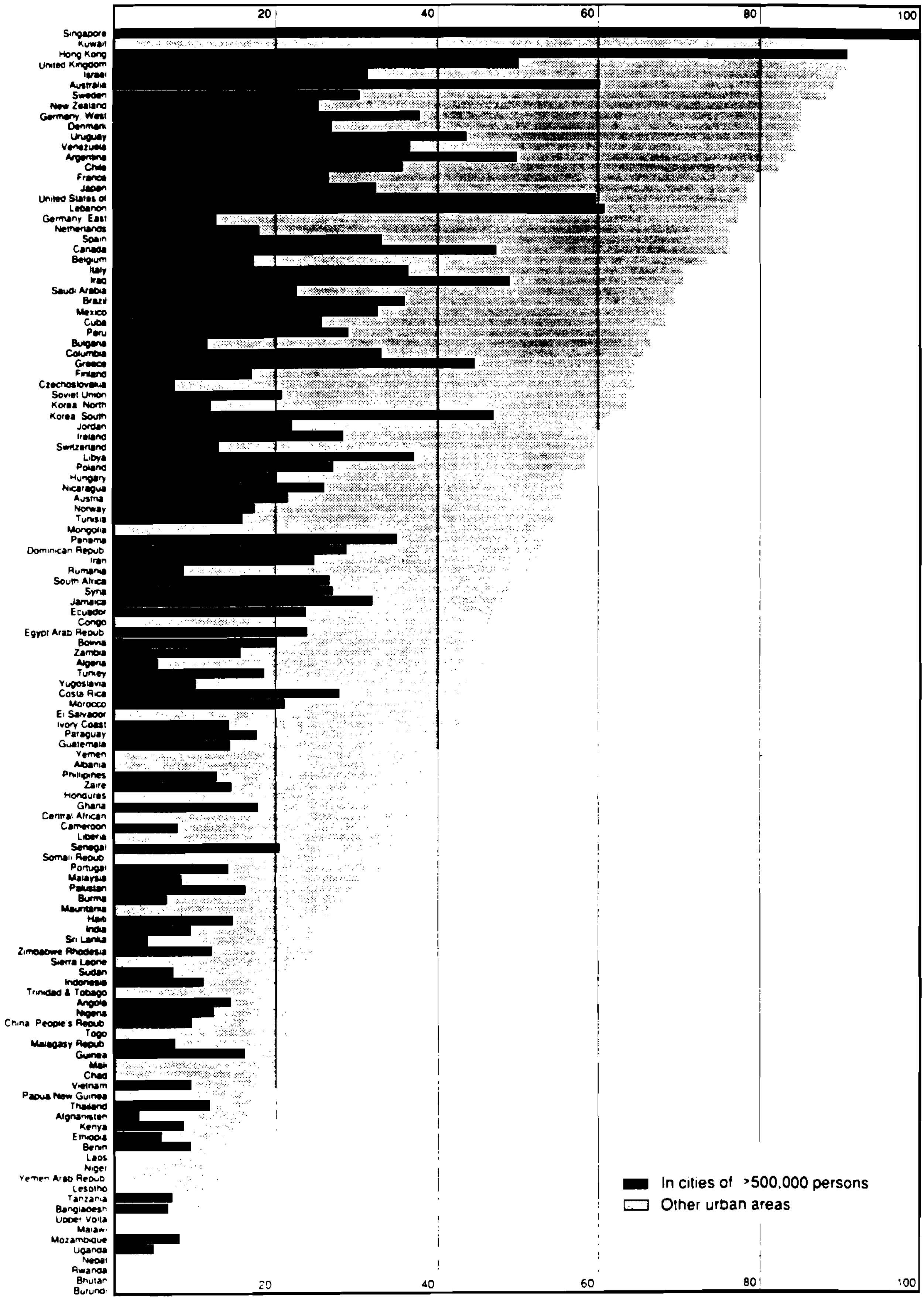
20
40
60
80
100
Singapore
Kuwait
Hong Kong
United Kingdom
Israel
Australia
Sweden
New Zealand
Germany West
Denmark
Uruguay
Venezuela
Argentina
Chile
France
Japan
United States of
Lebanon
Germany East
Netherlands
Spain
Canada
Belgium
Italy
Iraq
Saudi Arabia
Brazil
Mexico
Cuba
Peru
Bulgaria
Colombia
Greece
Finland
Czechoslovakia
Soviet Union
Korea North
Korea South
Jordan
Ireland
Switzerland
Libya
Poland
Hungary
Nicaragua
Austria
Norway
Tunisia
Mongolia
Panama
Dominican Repub
Iran
Rumania
South Africa
Syria
Jamaica
Ecuador
Congo
Egypt Arab Repub
Bolivia
Zambia
Algeria
Turkey
Yugoslavia
Costa Rica
Morocco
El Salvador
Ivory Coast
Paraguay
Guatemala
Yemen
Albania
Philippines
Zaire
Honduras
Ghana
Central African
Cameroon
Liberia
Senegal
Somali Repub
Portugal
Malaysia
Pakistan
Burma
Mauritania
Haiti
India
Sri Lanka
Zimbabwe Rhodesia
Sierra Leone
Sudan
Indonesia
Trinidad & Tobago
Angola
Nigeria
China People's Repub
Togo
Malagasy Repub
Guinea
Mali
Chad
Vietnam
Papua New Guinea
Thailand
Afghanistan
Kenya
Ethiopia
Benin
Laos
Niger
Yemen Arab Repub
Lesotho
Tanzania
Bangladesh
Upper Volta
Malawi
Mozambique
Uganda
Nepal
Rwanda
Bhutan
Burundi
In cities of >500,000 persons
Other urban areas

Figure 16b.

Figure 16a,b,c,d,e,f.
World urbanization trends.

In the evolution of the structure of human settlements in the world, the general tendency has been to concentrate populations into larger and larger cities, with the exclusion of Europe where the population in centers larger than one million inhabitants has been more or less stable during the last 30 years. This may lead to a weakening of the world hierarchical positioning of Europe, *unless* a number of these centers are sufficiently interconnected, in the short-time mode ($\sim$ 20 minutes) so as to integrate them completely, or in the medium-time mode ($\sim$ one hour) in order to integrate them at the highest functional level.

To give an idea of the historical trend in the localization of the world's largest cities, a set of four snapshots is reported, showing the situation in 1700, 1800, 1900, and 1985.

Figure 16c.

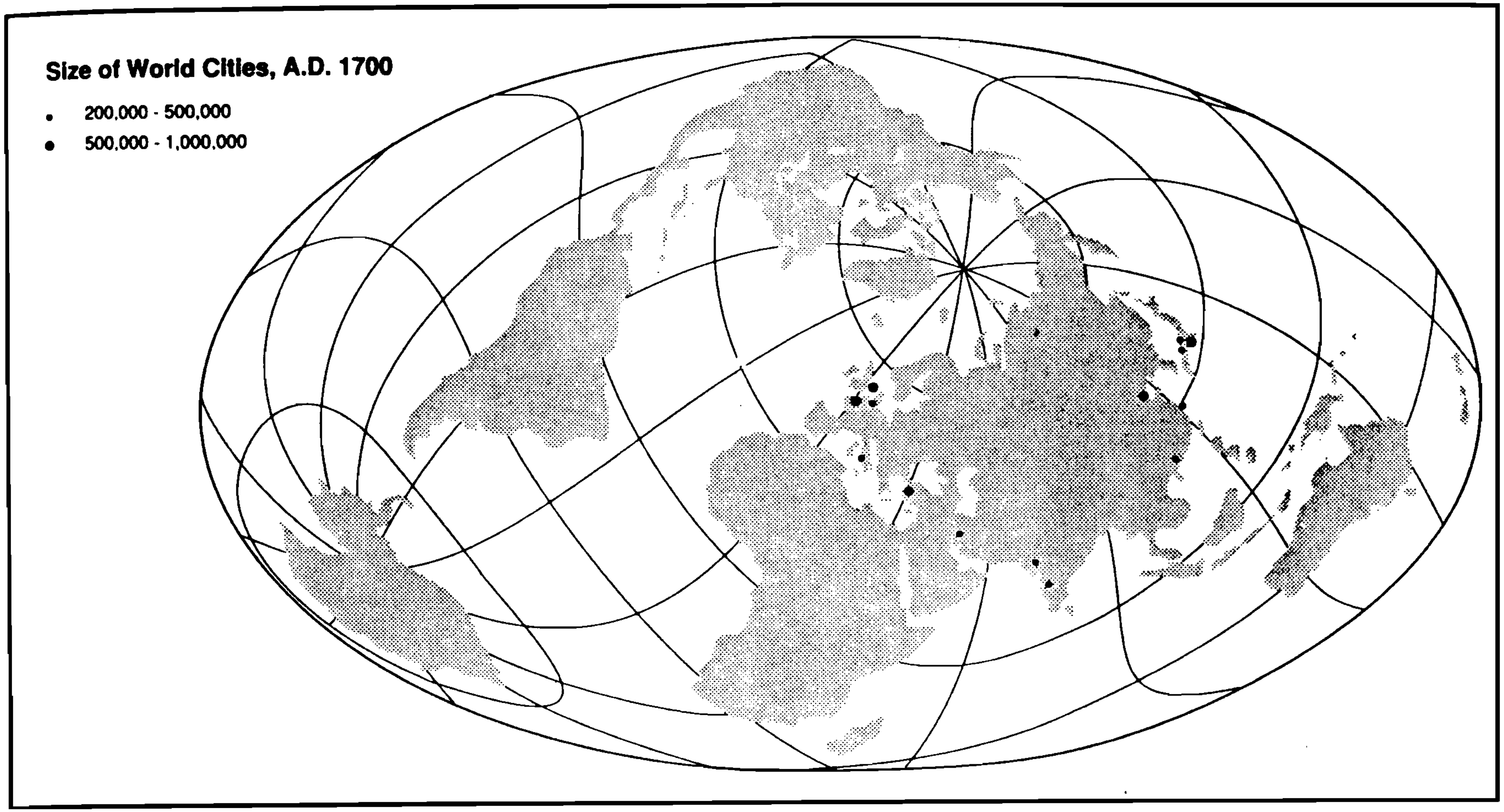

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Figure 16d.

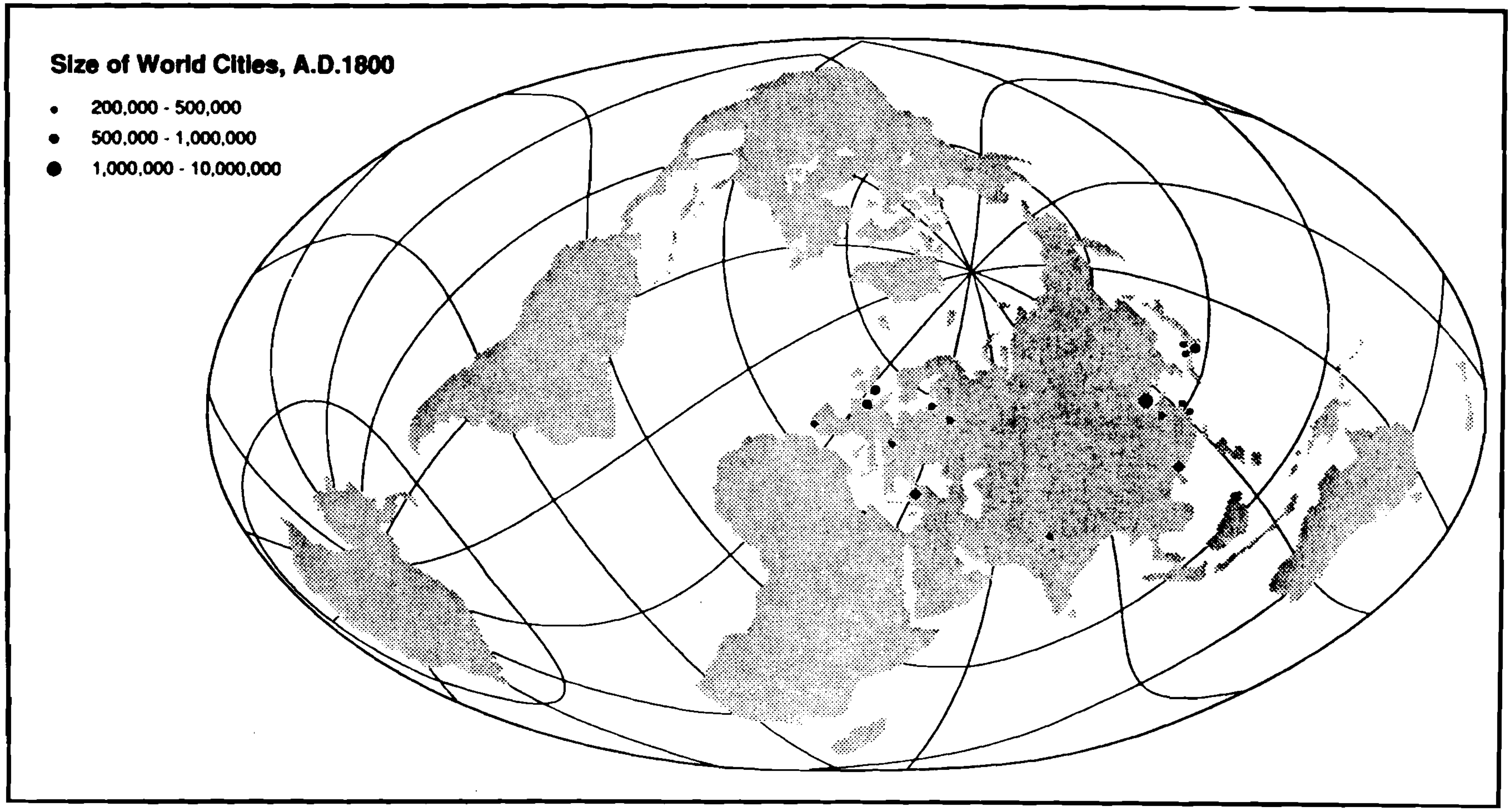
Size of World Cities, A.D.1800
200,000 - 500,000
500,000 - 1,000,000
1,000,000 - 10,000,000

Figure 16a,b,c,d,e,f.
World urbanization trends.

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Figure 16e.

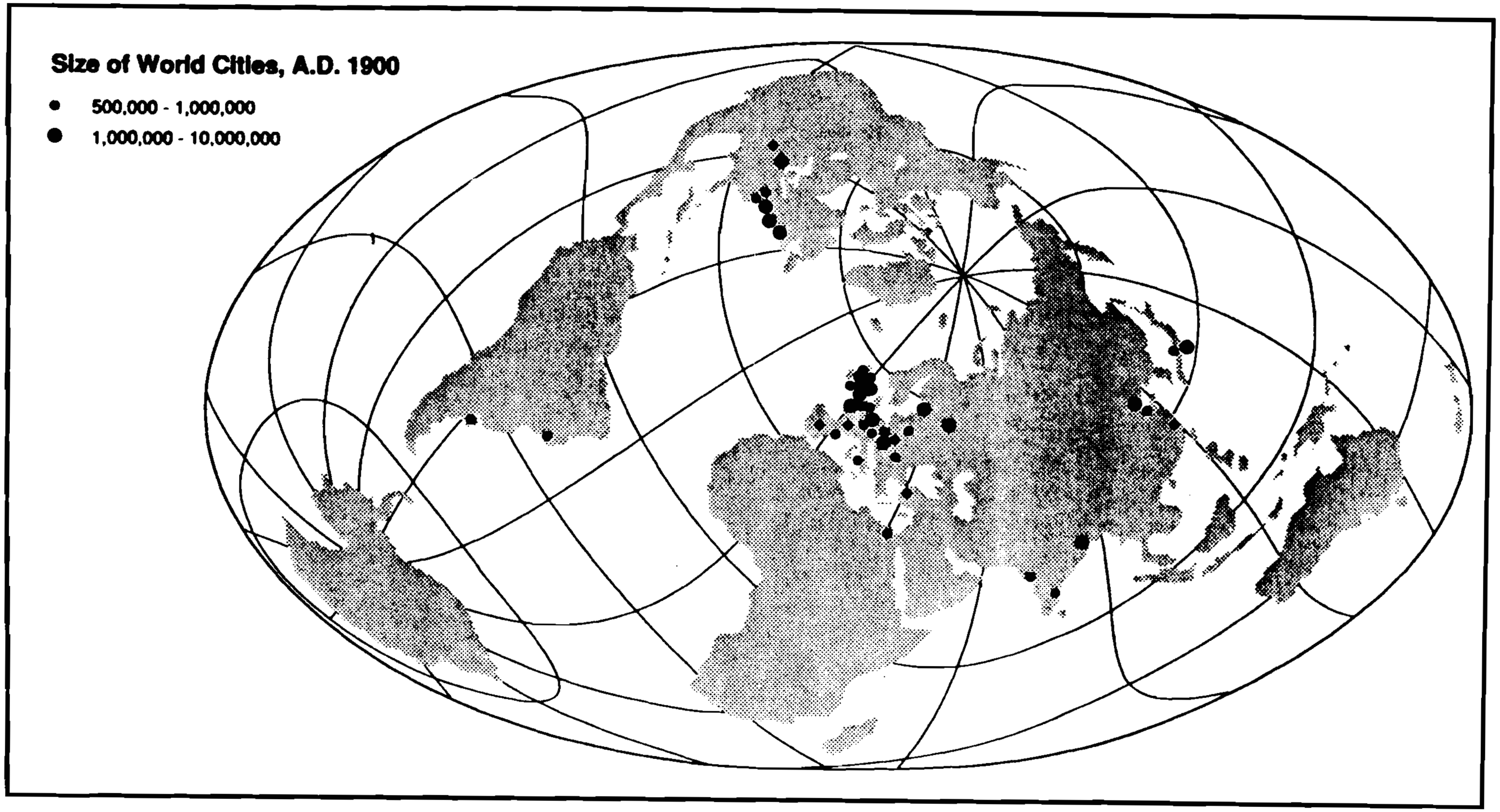
Size of World Cities, A.D. 1900
500,000 - 1,000,000
1,000,000 - 10,000,000

Figure 16a,b,c,d,e,f.
World urbanization trends.

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Figure 16f.

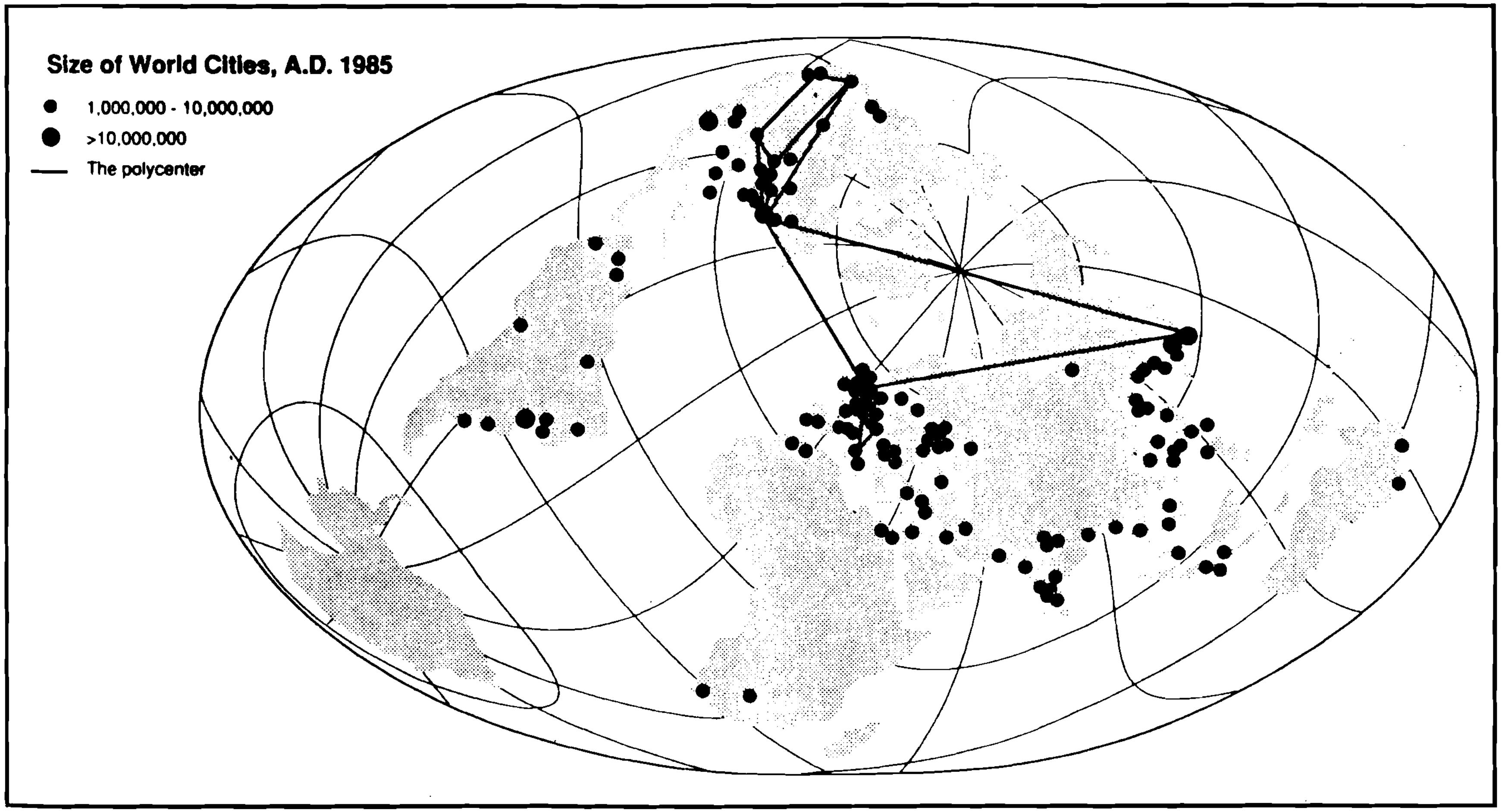

Size of World Cities, A.D. 1985
1,000,000 - 10,000,000
>10,000,000
The polycenter

Figure 17.
Intense connections in Europe.

To see how intensely two centers interact, one can resort to various indicators, telephone calls, and mail, i.e., communications, or travel, i.e., transportation. As long-range business travels almost exclusively by air, a measurement of the air connection intensity can throw some light on how things move, and in any case generate some reference structures to be analyzed later in more detail.

The chart here presents cities connected by more than 25 flights per week (workdays). The number is a minimum and the maximum can be much larger. London–Paris, to take the example on top of the list, has 250 flights or ten times as much. But less evident cases like Barcelona–Madrid have ~ 150 and Rome–Milano ~ 130.

It is inside these connections that one shall look for segments suitable for a fast train link.

Figure 17.

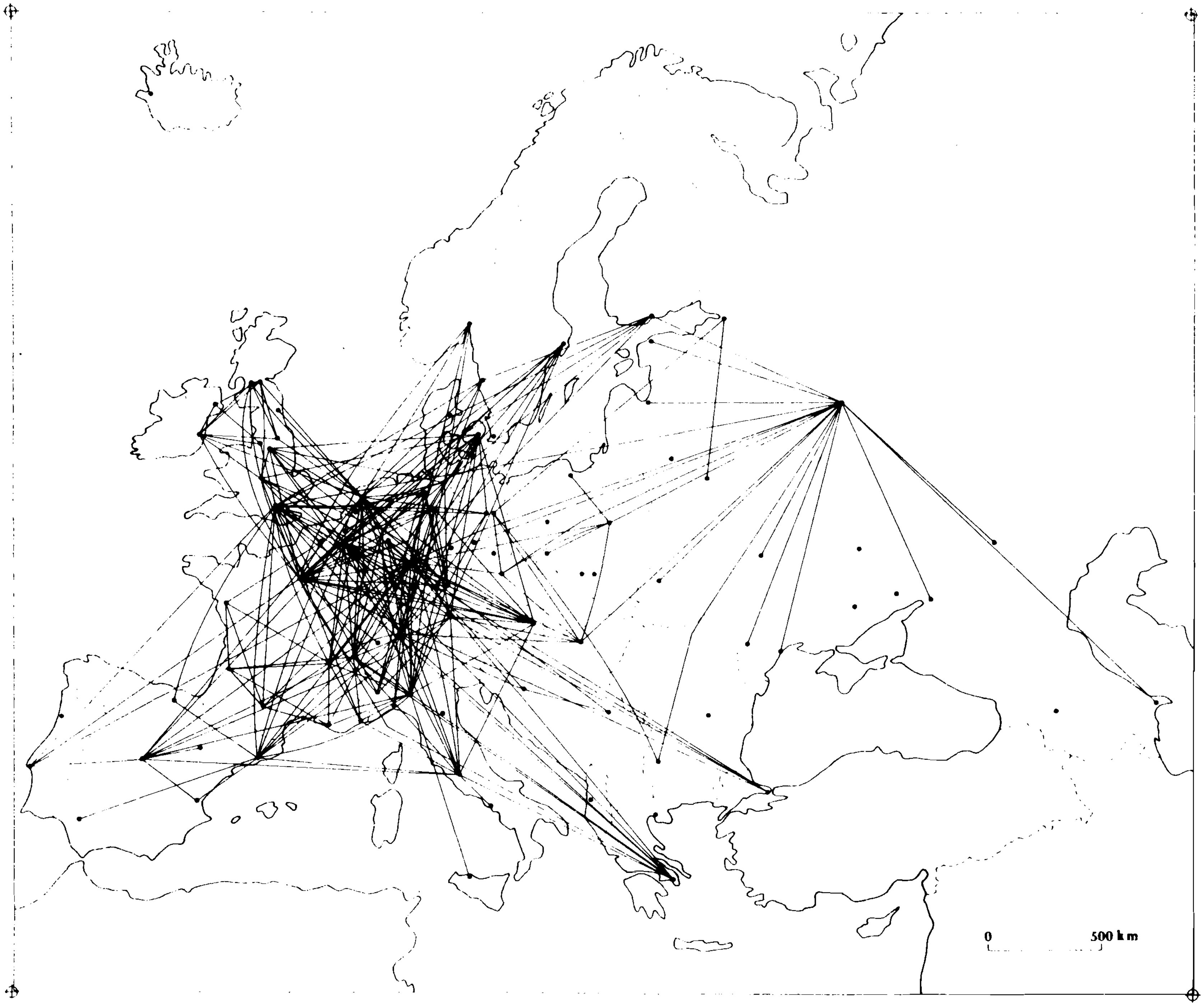
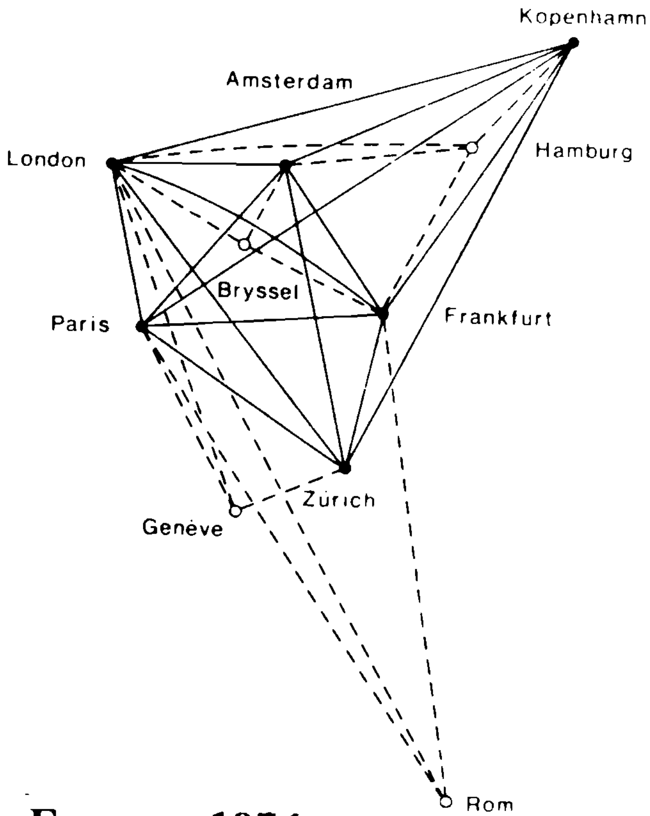


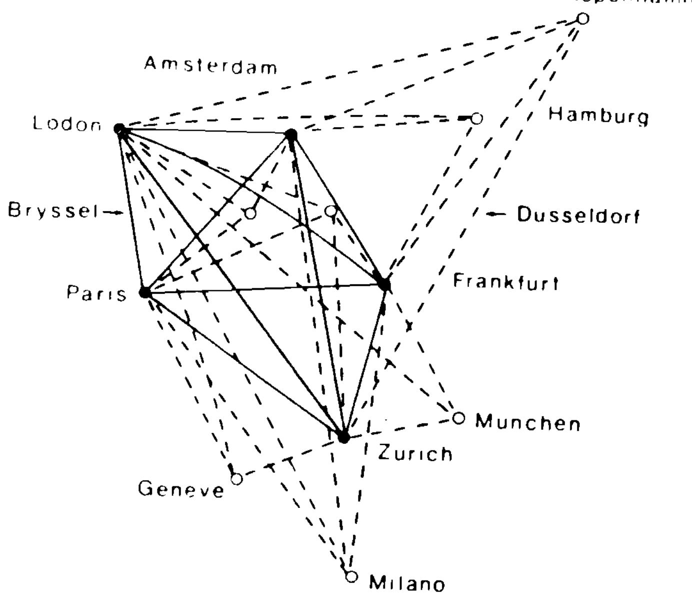
Figure 18a,b.
Central core of European business connections.

In order to select the core of these connections, U. Erlandson of the Geographic Institute of Lund University, chose the criterion of hard core putting together the centers connected with *all* the others by at least 25 flights over the five workdays of a week. The results of his analysis are reported in ***Figures 18a*** and ***18b*** in a time frame covering 1965, 1970, 1976, and 1988. The base core stays substantially the same although when one of the cities lacks only one connection (dashed lines) it can easily flip in. Milano is in fact in with the air timetables of 1991 as it has now more than 25 connections per week with Zurich.

Figure 18a.



Europa 1976.



Europa 1988.

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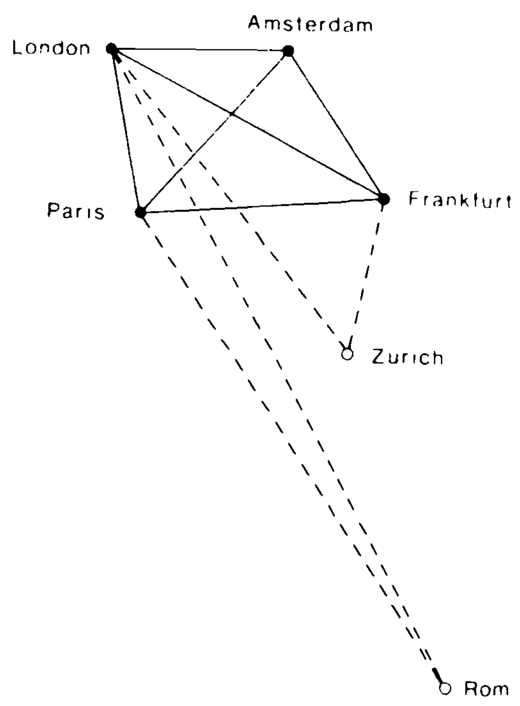
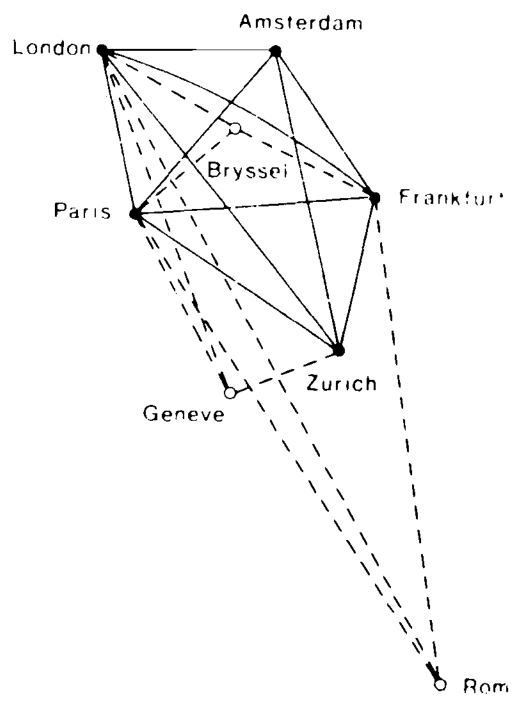


Europa 1965.



Europa 1970.

Figure 19.
A German Eperopolis.

To illustrate in detail the concept of Eperopolis, an area where one can do business and come back the same day, I report here the case of a German Eperopolis as identified by Doxiadis.

The center of the Eperopolis is the Ruhr agglomerate, and the connection includes all means of transportation. The longest tracts operate through frequent air connections (if not shuttles in a literal sense).

An existing structure like this one could be strongly reinforced, introducing in some critical segment a very fast mass transportation system.

Figure 19.

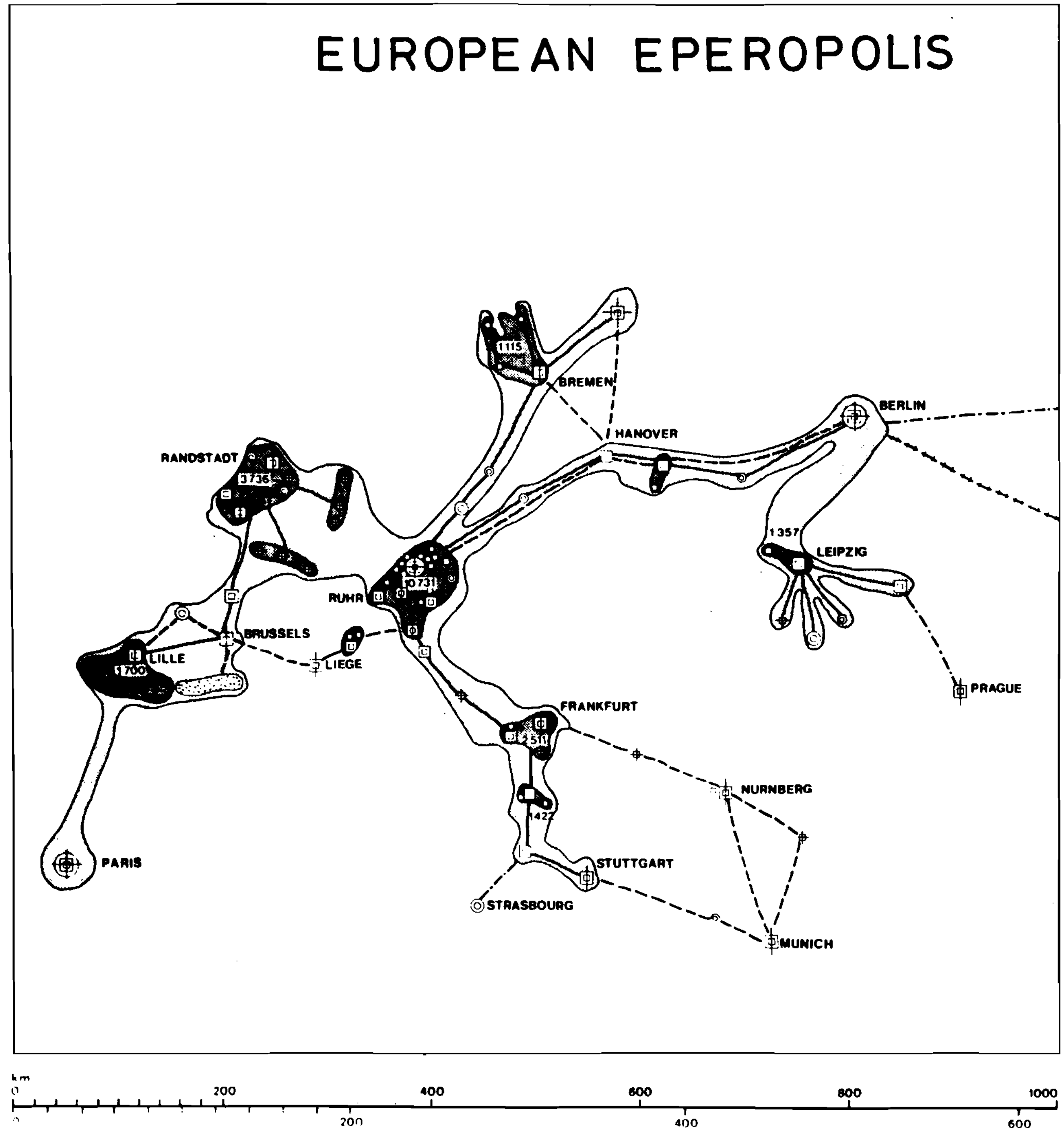

EUROPEAN EPEROPOLIS
RANDSTADT
3736
1115
BREMEN
HANOVER
BERLIN
RUHR
10731
BRUSSELS
LILLE
1700
LIEGE
PARIS
1357
LEIPZIG
PRAGUE
FRANKFURT
2511
1422
NURNBERG
STUTTGART
STRASBOURG
MUNICH
km
0
200
400
600
800
1000
200
400
600

Figure 20.

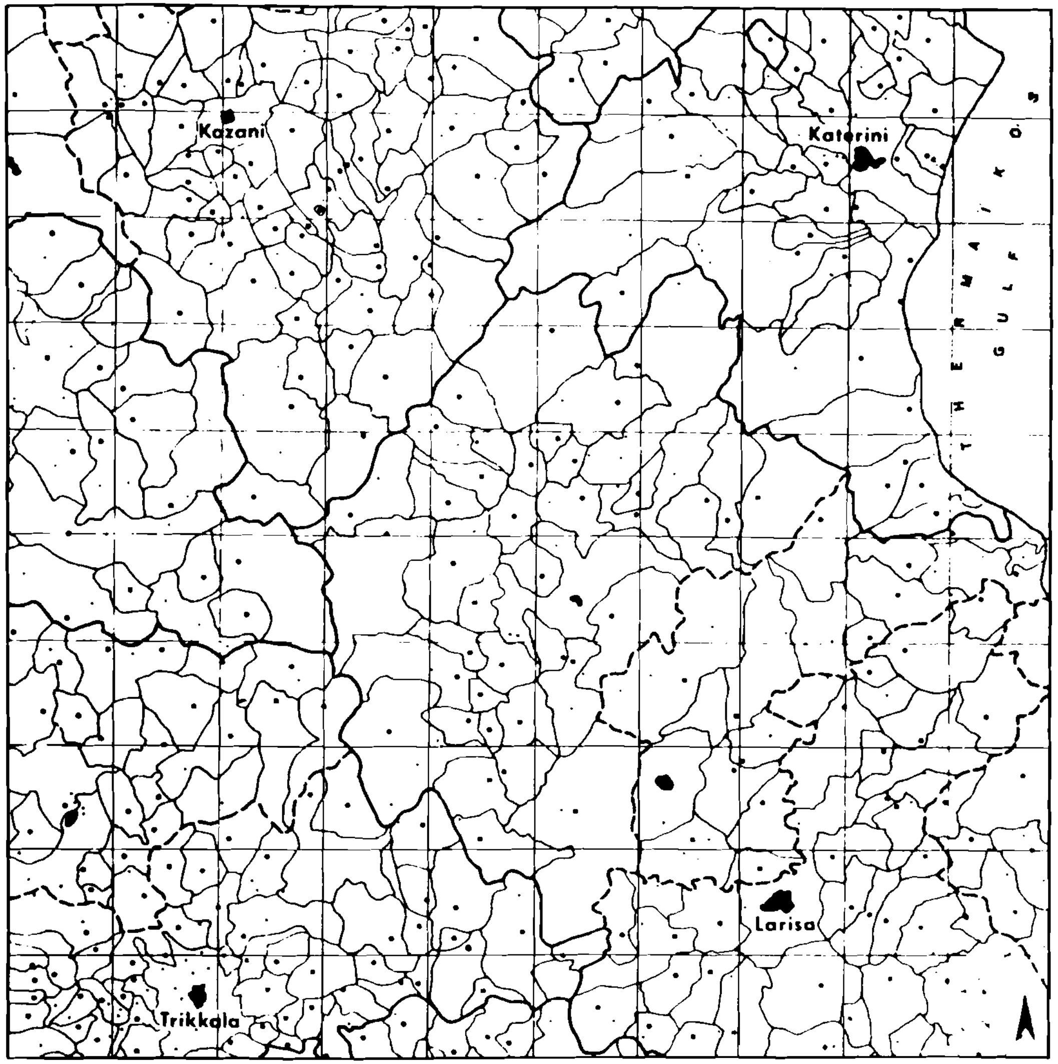
The area connected to the center, in this case a village, is defined by administrative boundaries which notify a territorial structure built up during millenia. The mean radius of these territories is about 5 km, the distance that can be traveled on foot in one hour. We find here again the principles that define the size of a city. Ancient cities, even the largest ones like Rome or Persepolis, had about 5 km diameter inside the walls as said in the legend to Fig.9.

These boundaries define *daily trips*. Normally *once a week* these villages had a market in the center of a bundle of seven villages. *Annually* there was a fair in a center far away encompassing a number of these bundles.

This historical detour is important for the purpose of establishing a strategy and a value set for TGV lines, because the *same basic anthropological drives are operative today* as it will appear in the text. The only difference in spacial scale is brought in by the higher speed in the transportation technologies of today. But the larger system tends to be homothetic to the previous ones, the ratio in speeds being the spacial coefficient.

Figure 20.

Village Patterns in Greece

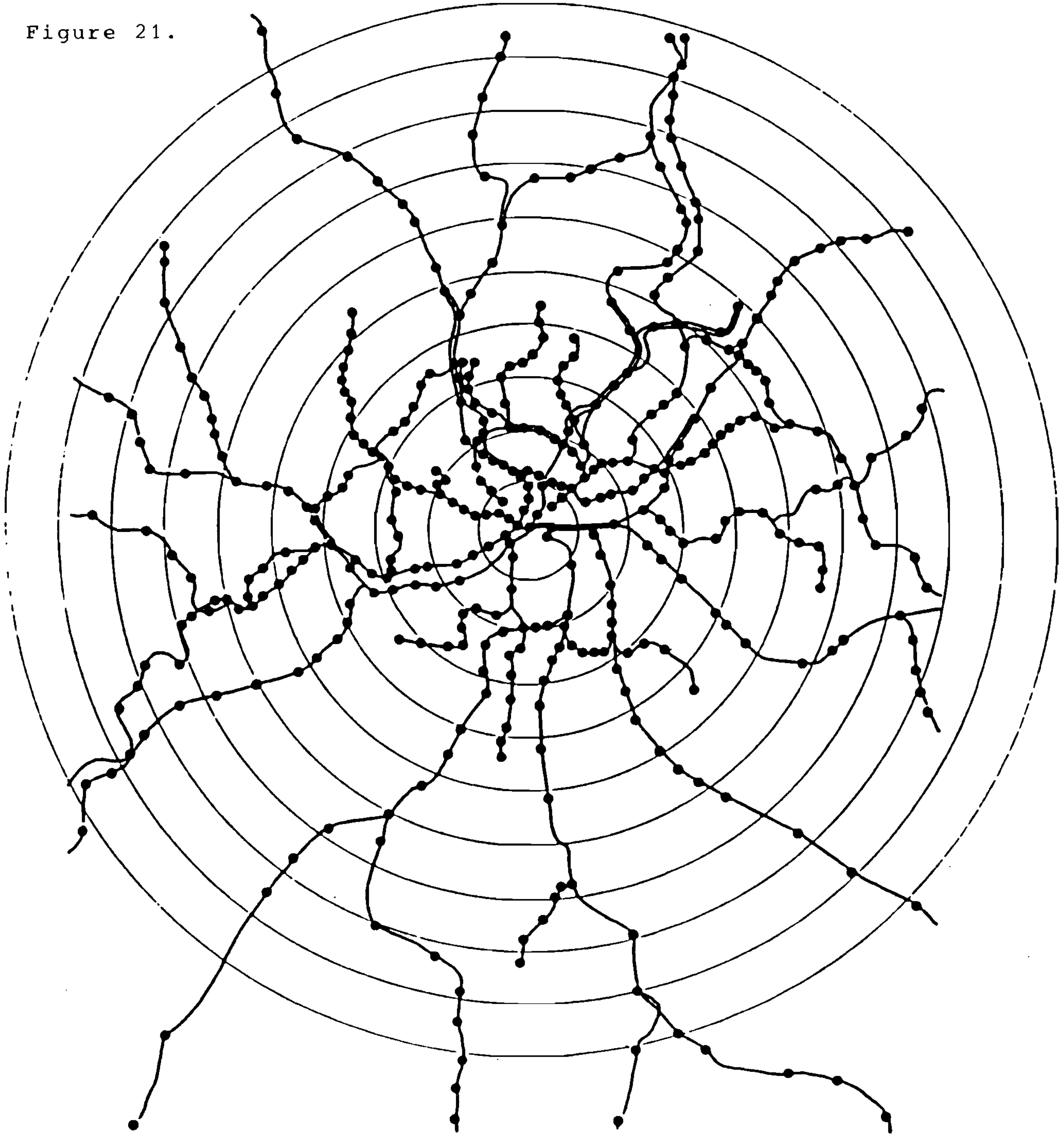


Mean area 22 km^2

Figures 21, 22.

The map of the metro of Paris is reported here in scale, with metro stations in evidence. The circles are drawn 1 km apart from the dead center. The analysis, reported in Fig.3, measures the cumulative number of stations as a function of distance from the center. A sharp knee is apparent at a radius of about 2.5 km. Inside this radius the metro stations are homogeneously distributed (at 1 km mean distance) and their density starts abruptly to fade away starting from this border. This defines a city *on foot* practically inaccessible to cars, which have a very limited utility due to low speed, separated from a city where cars progressively pick up the transport function. *This shows how an efficient public transport can substitute cars and both can mesh together.*

Figure 21.



Figures 21, 22.

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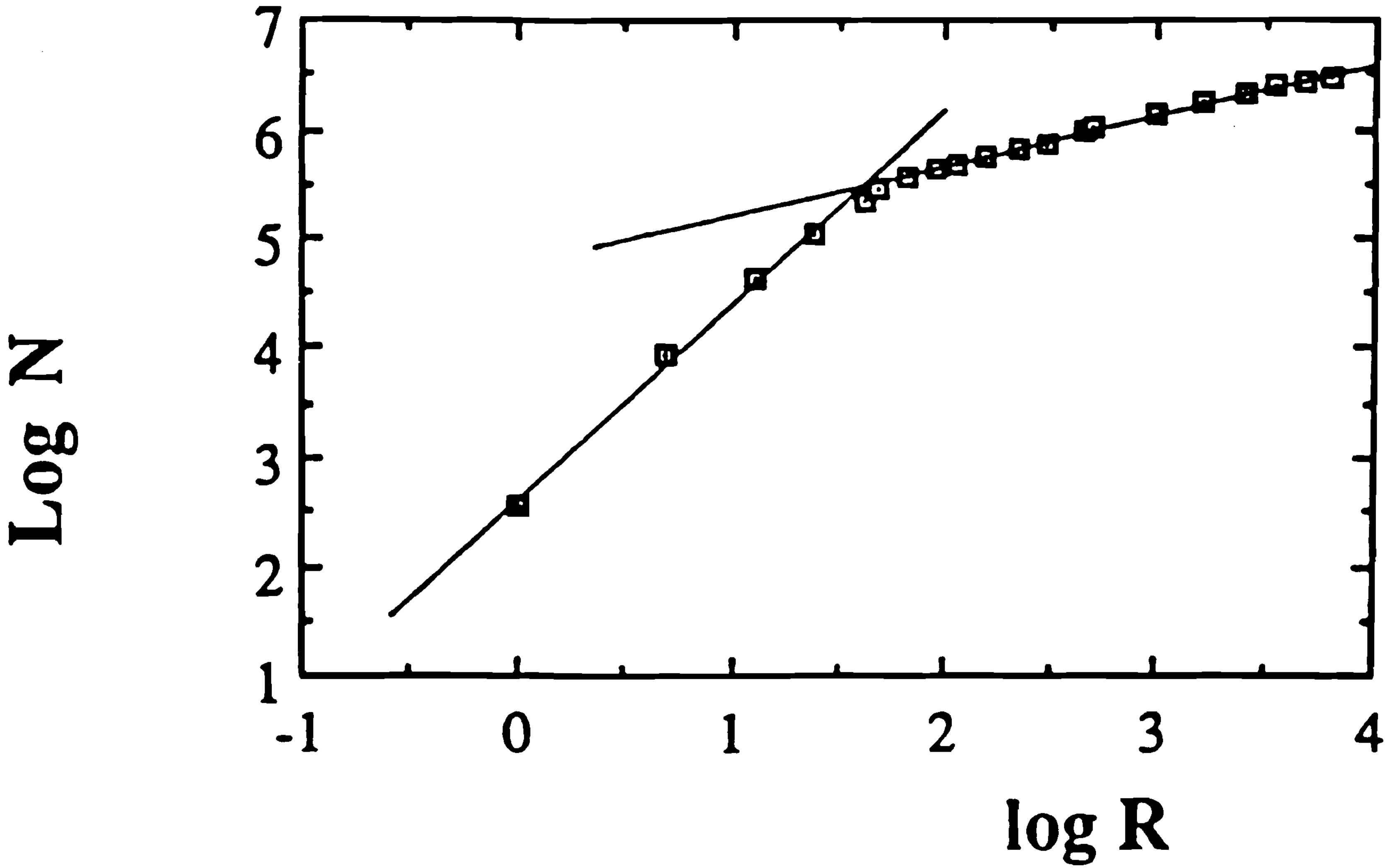


Log-log Plot of the Cumulative Number of Stations as a Function of the Distance to the enter of the City. Two successive regimes may be defined, with slopes 2 and 0.47, respectively.

Figure 23.

Once cars can move, all the geography is upset. This chart shows superposed and on the same scale the commuting ranges of 11 American cities and the schematized structure of the system of greek villages with their territories. The ratio in linear size is about 9 or 10, which is the ratio of the speed of a walking man (4 to 5 km/h) to that of a car ($\sim$ 45 km/h mean). The taxonomy remains the same and the size grows homothetically with speed. It must be clear that the *number of trips* per day and their subdivision in short, medium, and long *stays the same.*

Figure 23.

Commuting Fields of Eleven American Cities

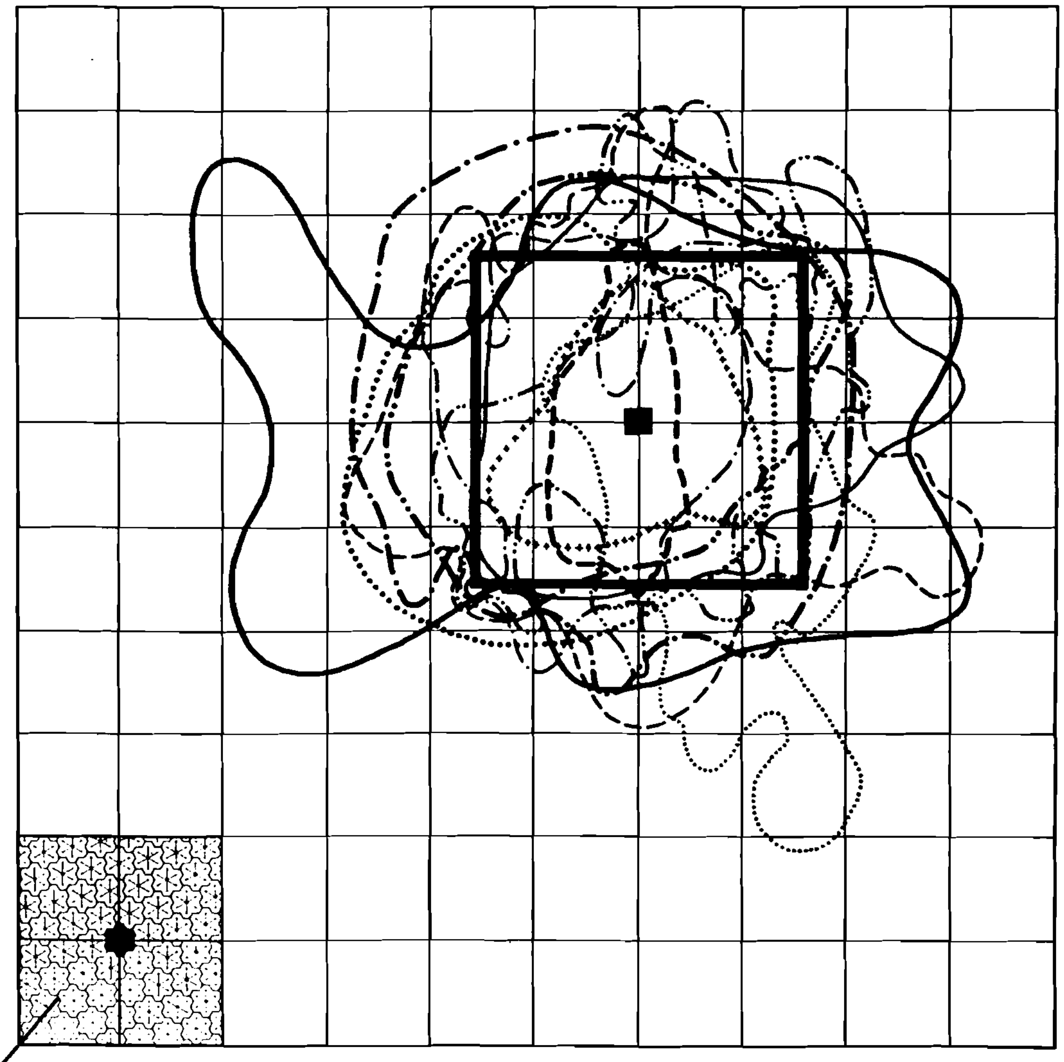


Figure 24.

As we have said in the text, long trips are rare, about two orders of magnitude less than trips in the daily territorial range. They are, however, important for keeping the macrosystem together. This trickle of traveling is channeled through *facilitated corridors*, where not only roads but also a variety of services are provided. Again a historical backview shows how stable these corridors are. The map reported here depicts the road system connecting norther to southern Europe *five centuries ago*, and is strongly reminiscent of the most important railways and motor ways of today. TGV planning should keep this historical and cultural matrix in sight, at least in terms of priorities. Incidentally, Rome is *still* isolated from northern Europe.

Figure 24.

MAIN OVERLAND ROUTES TO AND FROM ANTWERP IN THE 16th CENTURY

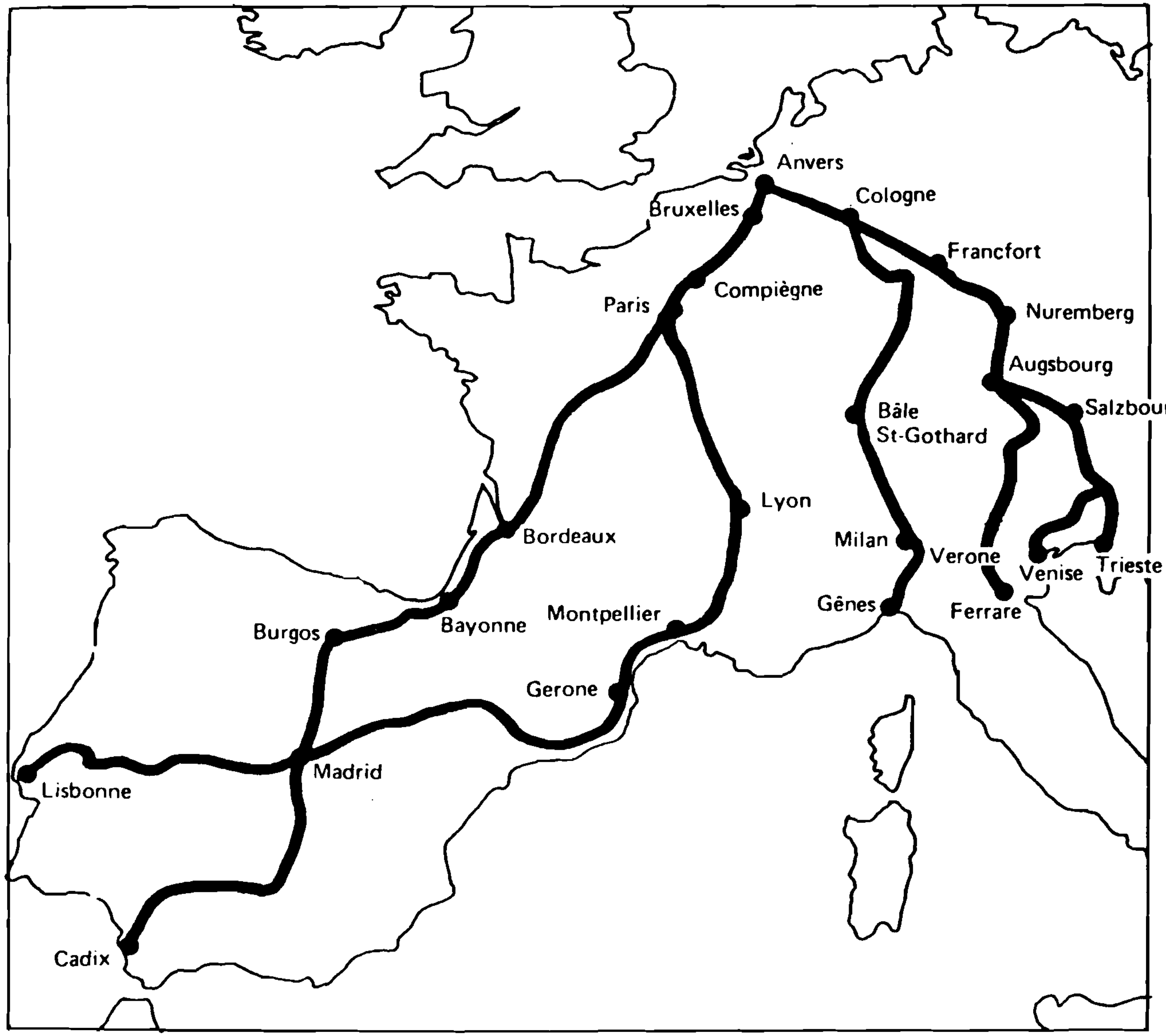


Figure 25.

This table reports in neatly interpretable terms the quantities for travel taxonomy. The tale is done for a mix of cities around Europe, but as we keep stressing, the basic structures are always the same. The difference coming from the constraints of speed and money are here relatively limited except perhaps for the use of airplanes that require a fair level of wealth. S.s.p. are short stay personal trips done for personal purposes. The other legends are self-explanatory. A detailed analysis of this table is contained in the text.

Figure 25.

<u>Summary of Trips, by City</u>

	No. of persons in sample	% of households with car	Number of trips per head							
			total	business	holiday	s.s.p.	car	train	bus	air
Toulouse	1,373	72	12,7	2,5	2,6	7,6	11,3	0,8	0,2	0,4
Genève	1,119	65	9,5	2,3	3,5	3,7	6,2	1,8	-	1,5
4 small French towns	1,601	79	8.4	1,5	2,2	4,7	7,5	0,6	0,2	0,1
Düsseldorf	1,208	46	7,3	2,8	2,0	2,5	5,4	1,1	0,1	0,7
Lisboa	1,549	47	6,8	1,3	1,9	3,6	5,1	0,7	0,7	0,3
Linz	1,408	55	6,5	3,0	1,5	2,0	4,8	1,0	0,4	0,3
Torino	1,533	71	6,5	1,1	2,1	3,3	4,6	1,5	0,2	0,2
Den Haag	1,941	63	6,4	0,9	1,5	4,0	5,2	0,7	0,1	0,4
Bruges	1,743	65	6,2	2,5	0,9	2,2	4,6	1,2	0,2	0,2
Valencia	1,729	47	3,6	0,7	0,8	2,1	2,9	0,3	0,3	0,1

Figure 26.

This chart reports the modal split for *business trips* in terms of transport technology. The dominance of the car for short trips below 200–300 km is evident. The car in fact provides sufficiently low, door-to-door, travel time, on top of being more comfortable and for a company more "representative" than any other transport mode (if chauffeured). Company jets do better but do not make statistics yet. The fact that cars, trains, and planes meet at about 500 km to share equally the traffic, should not rise excessive hopes for the *volume* of traffic TGV can steal from planes. Most trips are, in fact, below 200 km, leaving the lion share to the car, unless TGV is conceived for *short distances.*

Figure 26.

Business trips - modal split

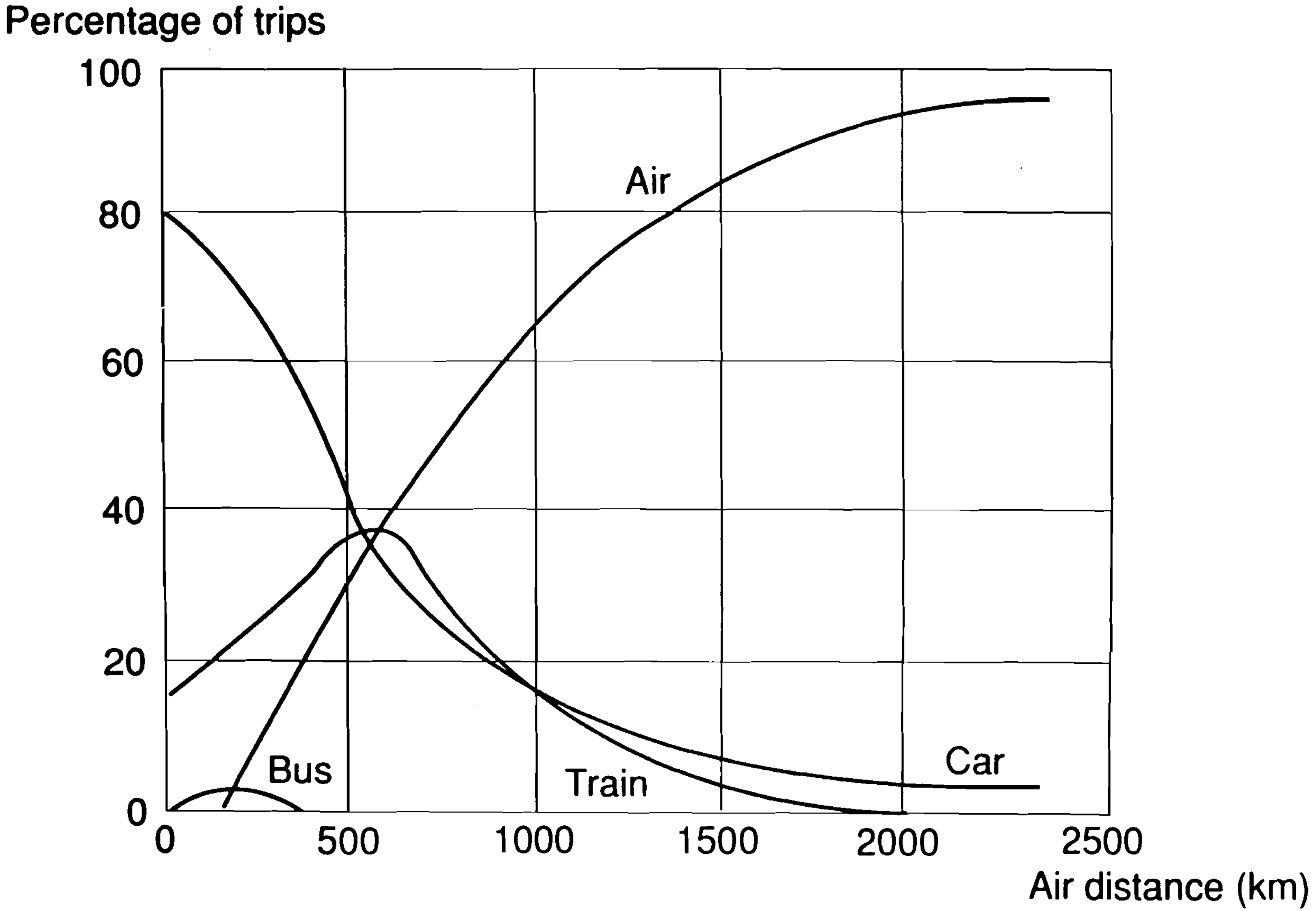


Figure 27.

Measuring the speeds of intercity trains in Germany (in terms of air distance between stops) we get this barchart showing a mean speed of about 65 km/h. It is true that in some cases the top is 95 km/h, but the panorama is bleak. It is clear that speed (and frequency) is the weak point of the railway system, and the suggestion to improve it explicitating the potential of present technologies make sense on paper. But the calcified organization of the rail system makes that doubtful. This raises the important questions of whether railways should incorporate TGV or whether the system should run independently. As many lines are constructed *ex-novo* and travel point to point, the second alternative appears feasible also formally.

Figure 27.

QUALITY OF SERVICE PROVISION IN DB LONG-DISTANCE RAIL PASSENGER TRANSPORT

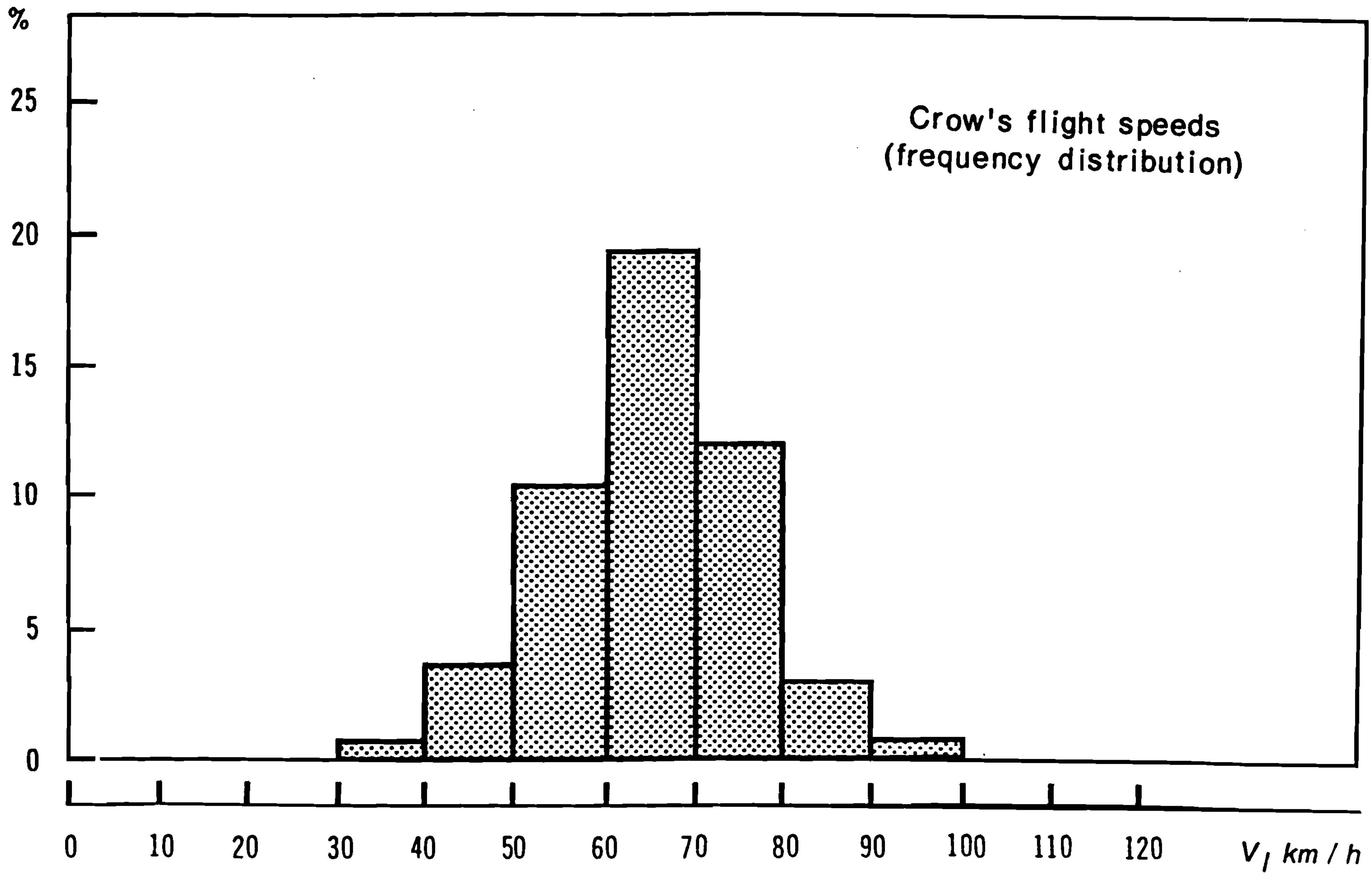


Figure 28.

Holidays represent the very long trip of our villagers going to the yearly fair. It is done once a year, when possible. The analysis in Valencia and Bruges (Fig.25) shows their citizens making a holiday every two years (trips are counted one-way). For households holding cars the car is the right holder of the familiar package, neatly substituting the ox cart of the villagers, with family goods and provisions perched on top and dog trotting underneath.

Trains emerge in the 1000 km range and planes beyond that. The possibility to use planes for that purpose comes mainly from the strong reduction in prices made possible by group tariffs and charters. Price is the most important deterrent in using airplanes over Europe. Any intercountry journey costs the equivalent of one month basic salary, and falls outside the TMB of even middle classes. If air fares were nearer to the American ones (about 1/5) the chances for long-distance TGV would be very dim.

Figure 28.

HOLIDAY TRIPS - MODAL SPLIT

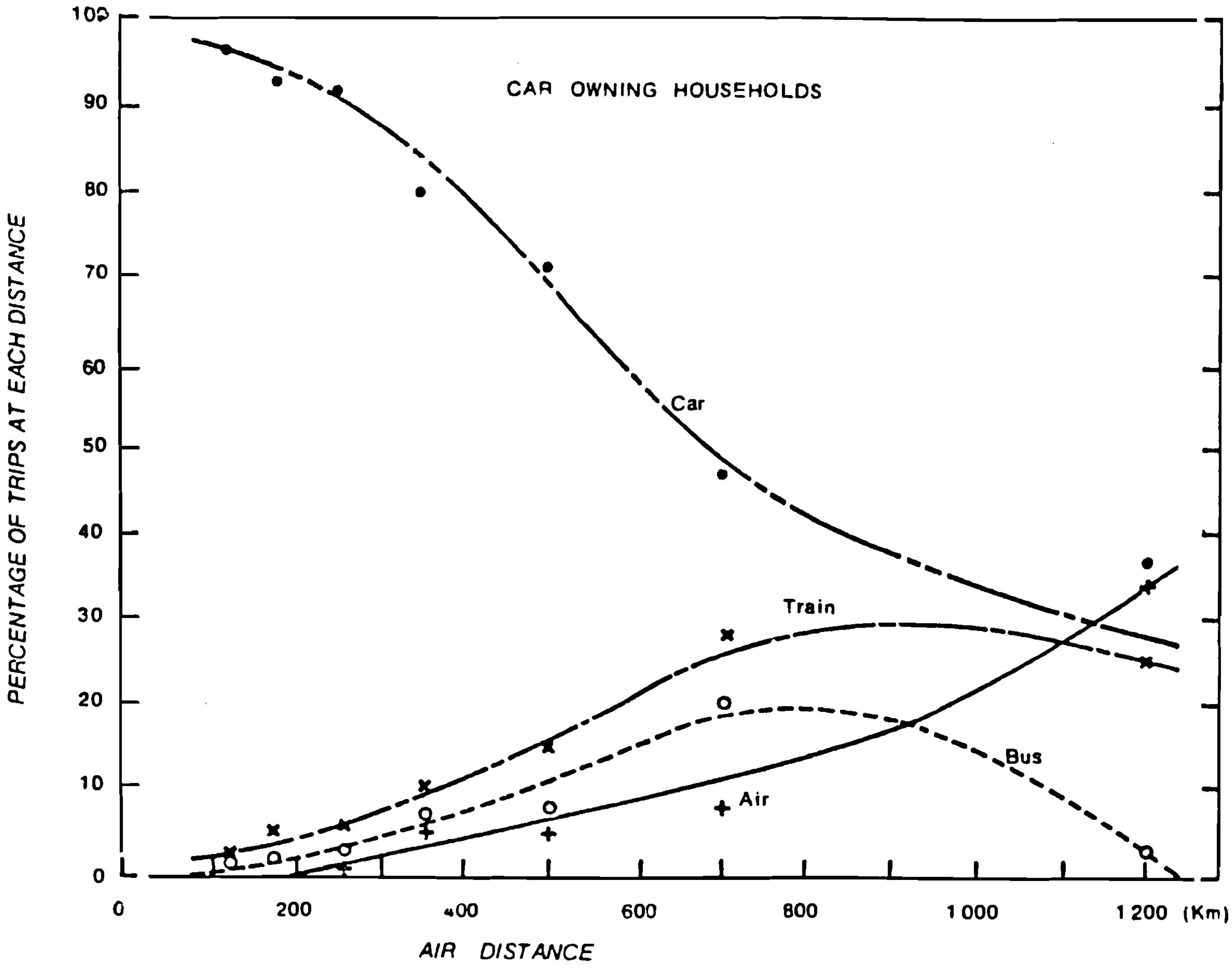


Figure 29.

As buses may provide a package configuration similar to cars, one might have expected it to substitute cars for non car-owning households. In fact, even these households manage to travel by car, equally shared with trains for the short distances below 300 km, which are anyway the most frequented. Trains dominate in all intermediate distances (300 to 1300 km). The only point is that non car-owning households are becoming rare in Europe.

Figure 29.

HOLIDAY TRIPS - MODAL SPLIT

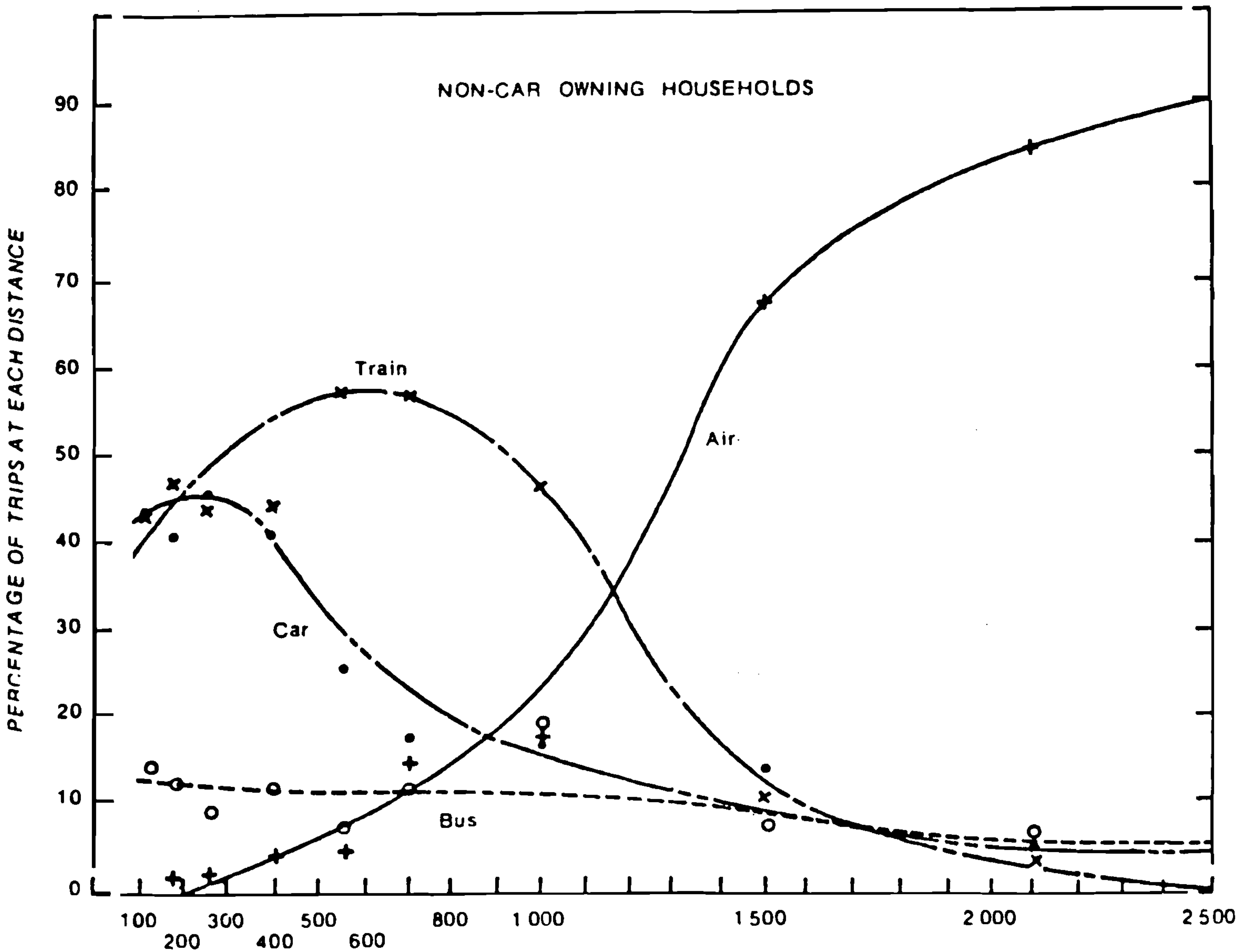


Figure 30.

The largest number of trips (50%, as seen in Fig.25) are done for short-stay personal trips. Great attention should be devoted then to this potentially large market. We see here the car dominating up to 1000 km, for the families owning cars, with comparably very little share of the train at all distances. It must be clear that most of these trips are in fact done by car-owning households. Consequently, TGVs should compete with cars again at all distances but specially at the short ones. As we will see in Fig.23, 95% of these trips are below 200 km.

Figure 30.

SHORT STAY PERSONAL TRIPS - MODAL SPLIT

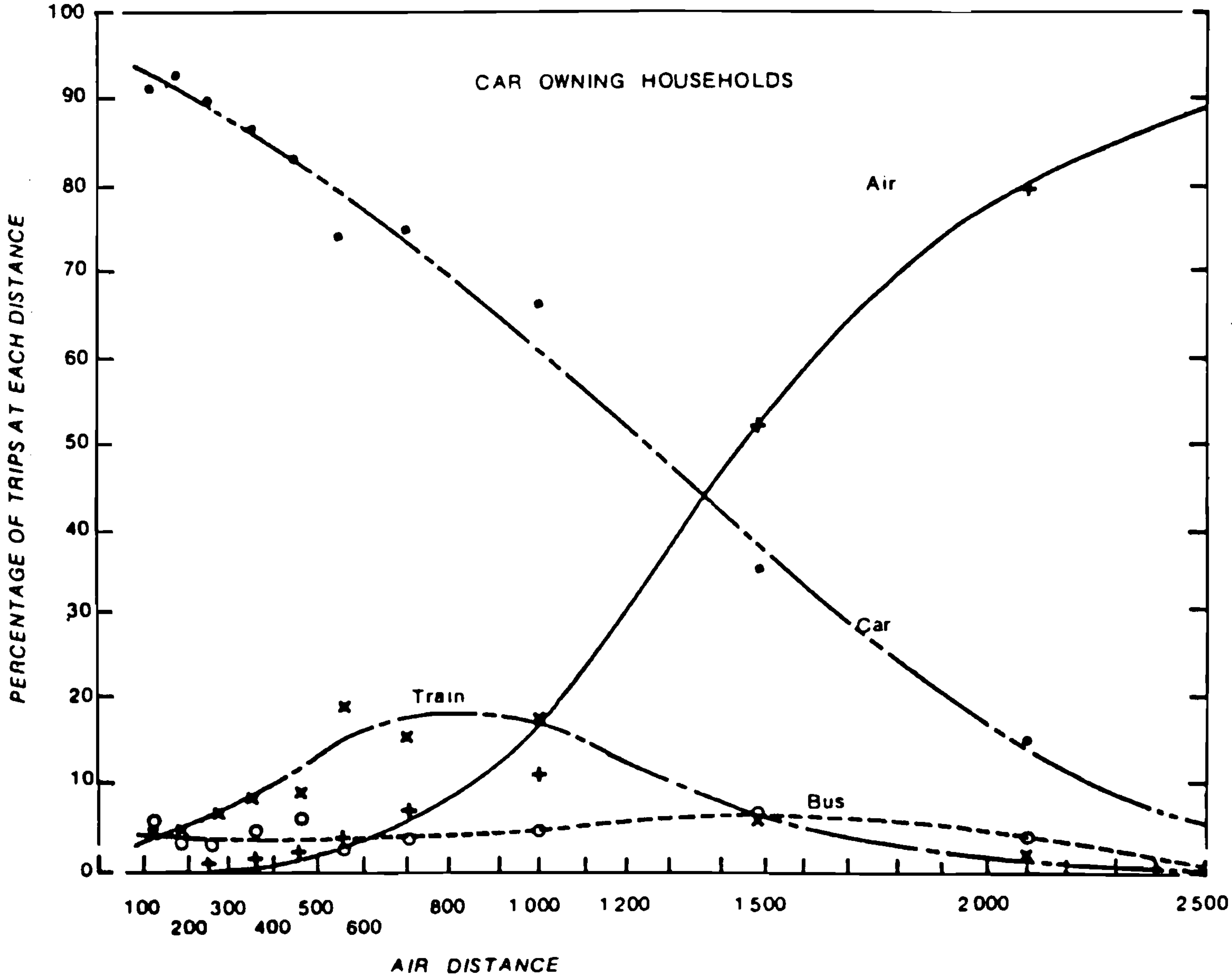


Figure 31.

For persons belonging to households not owning a car, the short-stay personal trips in the range of interest (<200 km) are equally shared between trains and cars. The percentage by air is negligible, as we will see in Fig.32, due to the rapid fall-off of trip rate with distance.

Figure 31.

SHORT STAY PERSONAL TRIPS - MODAL SPLIT

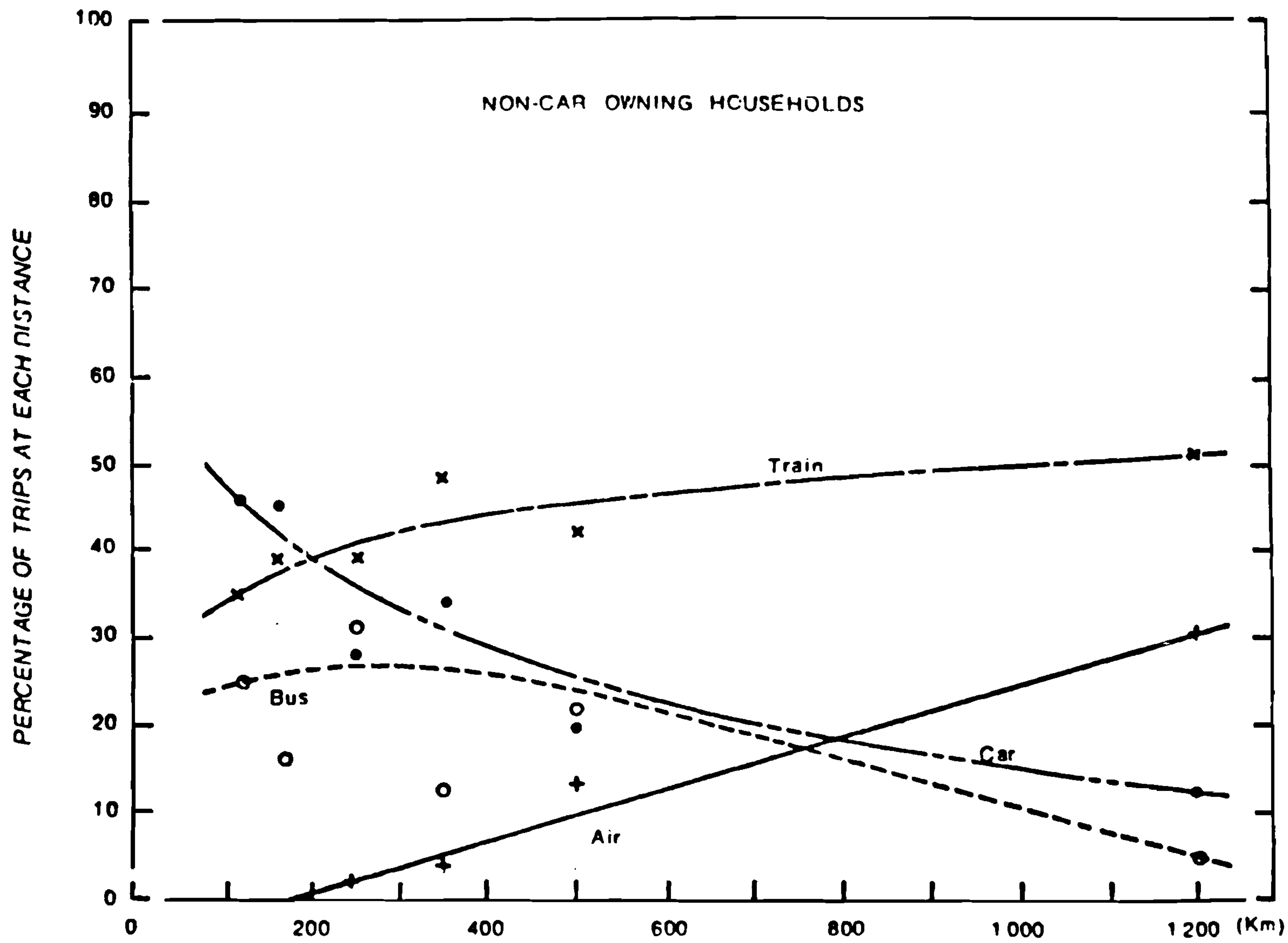
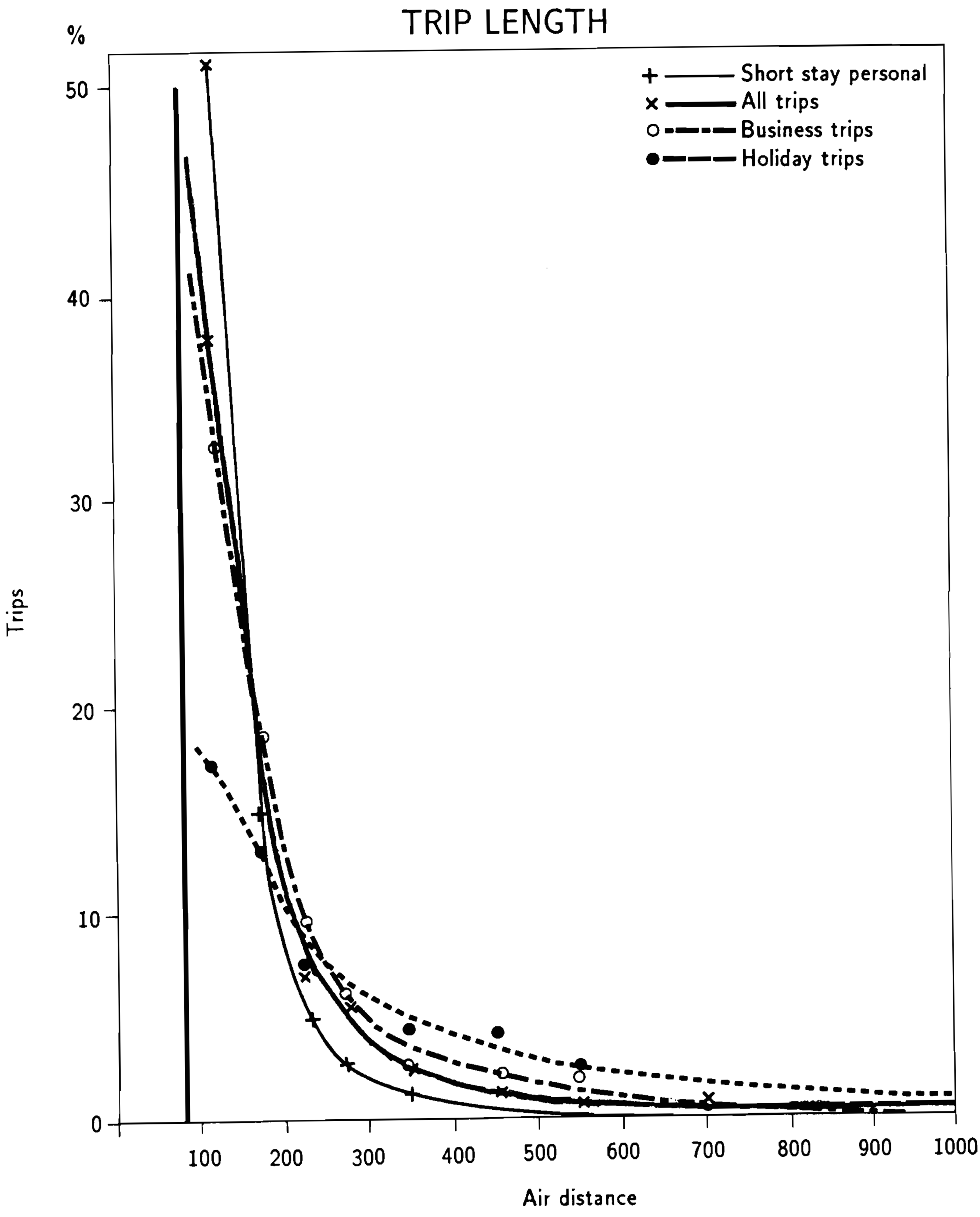


Figure 32.

This is the most important chart in the list. It shows the very fast fade-out of trip rate with distance. For business trips, 90% are done below 250 km, short-stay personal has a 90% cut-off at 200 km, the same for holiday trips and for all trips summed up.

In other words, for taking markets from other means of transport the *TGV should probably forget the large integrated European network and concentrate on the 200 km range.* The Italian Pendolino has faced the problem in terms of reduced occupancy for the non-stop stretch Milano–Rome. Occupancy grew dramatically with the Bologna and Florence stops, due to pick up of local traffic, where the one-hour trip time appears very convenient for business travel.

Figure 32.



TRIP LENGTH
%
Trips
50
40
30
20
10
0
Short stay personal
All trips
Business trips
Holiday trips
100
200
300
400
500
600
700
800
900
1000
Air distance