ON MOBILITY

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MARCHETTI-057_
Pt.1

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Executive Summary

The human drive for a larger and larger territory has been served by faster and faster modes of transport developed during the last two centuries. Basically, every Kondratiev cycle (55 years) a new technology is introduced, progressively displacing the older ones and benefiting larger and larger strata of the population.

The car has been the speed-provider during our lifetimes and the working of the process is under our eyes. But the process worked the same before, when canals, railways, and paved road vehicles like bicycles were introduced. The next level speed-provider is the airplane whose penetration to date is roughly equivalent to that of motor vehicles during the previous Kondratiev cycle (1885–1940). With a population of about 400 million and 7 million cars, the mean European was spending about 1 minute per day traveling on cars. He now spends about 30 seconds per day on airplanes (Americans about 1 minute per day) out of a travel time budget of 60 minutes in both cases.

Cars are operated basically for short-distance travel. Typically 90% of the trips are below 20 km, i.e., they are essentially urban and suburban. In this market segment, the only competitor in terms of comparable speed (about 40 km/h) is the Metro. But Metros are high investment, high capacity and require densely populated areas. For distances larger than 300 km airplanes progressively take the upper hand. Airplanes permit one day business trips up to 2000 km, encompassing most of Europe. In fact, *50% of air trips are same-day return.*

Trains are basically an obsolete technology, started two Kondratiev cycles ago. Trains infrastructure and traffic grew during these two Kondratievs (1830–1885; 1885–1940). Infrastructure and traffic started shrinking here and there during the present Kondratiev (1940–1995) although *grosso modo* the *absolute* values of pass-km (and ton-km) were kept to the levels of 1930. Market shares, however, rank everywhere below 10% for pass-km. Following the rules of substitution, trains, at least in the classical form, should disappear during the next Kondratiev (1995–2050).

The decay has been cured by generous injections into railways of public money during the entire present Kondratiev and everywhere. But the therapeutic obstinacy did not change their fate. The great supporters of railway transport are now the Greens who have a special knack for pushing the solutions that will never work. Just to put things in perspective, only to have all goods transported by train, as the Austrian Greens propose, one should multiply *by 20* the number of goods trains. The same should be done for passenger trains. It is clear from this very simple observation that not only trains are slow, but the technology has *low capacity* adapted to the traffic of a century ago, but not to present days.

It is our opinion that *trains*, upgraded to present day and perhaps final technology, *should find their own niche, independent of the previous network.* In fact, both the Shinkansen and the TGV have separate tracks with appropriate characteristics and use only railway stations (and not always) from the previous infrastructure. Beyond 300 km the airplane is very hard to beat. It is true that airports are naturally outside inhabited areas, but their subway connections keep improving under the pressure of good examples. On the other hand, city planners and operators insist doggedly on making the centers of the cities, where train stations are located, increasingly inaccessible. Under 30 km trains cannot beat cars whose unique real problem is parking (a car normally travels 1 hour a day and parks 23 hours a day). Because the number of cars circulating in Europe has reached saturation by now, parking capacity will in due time reach satisfactory levels. So cars will stay.

The niche we identify for trains is in the range between 30 km and 200 km, under the configuration "intracity links" between preexisting cities sitting next to a large one serving as a hub. This will permit functional meshing of groups of cities without destroying their identity and internal way of life. In a sense migrating to the large city and bringing there skills and services can be substituted by the daily commuting. Speed of transport makes relocation unnecessary.

The penetrating branch of transport technologies today are airplanes, as said. *Air transport* takes only 30 seconds of the daily hour of travel in Europe, but a lot of interest, money, and prestige is bound to it. The fact that *it may grow by an order of magnitude during the next Kondratiev* makes it very important for planners, industry, and finance, not to speak of plain passengers. For that reason we gave a deep look at the last thirty years of its development at various levels of aggregation. As it happens the most dynamic but last in the series, feels worst the brunt of the end of the Kondratiev. As many other industries, when saturation keeps business constant, increasing productivity pushes toward a painful and slow reduction of personnel. This overstaffing brings the companies readily into the red. On the other hand, the logic of the system pushes toward much larger and much faster machines requiring huge sums for their development. It is a reasonable question to ask if the money which the public hand is ready to spend to give a last flash of life to the railway system, would not be much better spent as a contribution to develop these new objects. Furthermore, airports should be rethought from scratch both in their ground connections and in their functional layout, especially for what concerns the processing of passengers.

The airplane is well suited for "thin" connections, where a service is required for hundreds of passengers per day. *Above 5000 per day* one should start thinking of it as a low-flying, high-capacity airplane, the *Maglev.* This mode of transport that can mimicre all the dynamic characteristics of airplanes, but requires a very expensive infrastructure, is the natural follow-up of airplanes where high traffic intensity appears, e.g., Paris–London, Amsterdam–London, Milan–Rome, Madrid–Barcelona, or Tokyo–Osaka, etc. *A study could be desirable to identify and quantify in time the emerging corridors where Maglevs may become the instrument of choice.* Maglevs are also seen as very advanced trains.

A last reflection about "classic" railways. As said on many occasions, speed is their weak point. But it must be clear that present speed is much lower than what *existing* equipment would technically permit. Just to give a hint of a *Gedankenexperiment*, doubling current mean speed from 30 km/h to 60 km/h (over the entire network) would permit to do the same service with half the equipment and half the traveling personnel. On top of that, extending the range, in terms of time, would attract more pass-km. The move is basically organizational, but *railways* are calcified in their century-old bureaucratic immobility. *They only require prestige additions to justify the immobility of the rest.*

The Approach

Our approach to construct a model of the aviation system follows a conceptual line that proved successful in numerous other cases. Using our diffusion model we start mapping the system in its historical evolution. In the case of aviation, starting around 1950, i.e., over the last 40 years.

This modeling usually does not permit to go beyond 1995, the end of the Kondratiev cycle, because most diffusion processes end (saturate) there, to restart for the new Kondratiev with different parameters. However, describing the present situation in a historical context is already an important objective and we will try to draw conclusions from the modeling. The modeling is done at all levels where statistical data exist. From the world system to the single company and from the global network to the single airport. Because the system is usually fractal, this will generate a set of homing Chinese boxes which reveal the framework of the system and its hierarchical levels. This taxonomic analysis will provide insights into the working of the system, connections and leverages.

One of the subjects that we will attack is to construct the parameters of air transport (or more precisely, *very fast transport*) development after 1995, i.e., beyond the saturation point of the intrinsic logistics. To do that we have to go to a higher hierarchical level where the system has a longer periodicity permitting to overtake the suture of the Kondratievs. We have identified one possible line of research through the secular analysis of the evolution of the personal range (km per day). This range is split between the various modes of transport which should follow a logistic multiple substitution process. This may be better done in terms of time shares between the modes, which tend to have constant velocities. The logistic of planes (+ Maglevs) will give then the parameters for the future, if the envelope is predictable. The same procedure was successfully employed in predicting the shares for primary energies in relative and absolute values, for the next 50 years.

The Cadre

In the first round of our research on mobility, during the years 1990–1991, we concentrated on *surface transport*, with particular attention to the potential of very *fast trains* or TGVs, as they are often called. In this second round, we have concentrated our interest on *air transport to provide a fine-grained context for TGVs. Actually, a plan for introducing the TGV must take into account the context that may develop during the next 50 years.* There are various reasons that make aviation a hot spot of attention and worry.

- First, as our preceding analysis shows, people require increasing speeds to exploit larger territories, and this speed is basically acquired *displacing travel time over the latest and fastest technology of transportation.* During the present Kondratiev (1940–1995) this technology was the car, and during the next (1995–2050) it will presumably be the *airplane* and some direct competitor in terms of speed like the *Maglev.*

- Second, the explosive expansion of airplanes and Maglevs will attract very large investments in terms of machinery and infrastructures. Any *holistic view* of the process may avoid the many trials and errors usually connected to *proximity decisions* which are the current way the system operates. In the case of world industry where proximity decisions did not take sufficiently into account the long-term recession linked to the end of our Kondratiev cycle a few thousand billion dollars have been sunk in investments searching for a market.

- Third, between now and the expansion period there will be a very painful process of reorganization to face the difficult conjuncture ahead. We have *cross-analyzed the system, from the world level to the simple company, to extract valuable diagnostics.*

- Fourth, in 1993 we have the formal beginning of *air transport deregulation in Europe.* It comes in a period of hard times, and it may trigger overreactions. A conceptual frame may help contain them and to guide them into configurations useful in the long term.

The Mathematical Methodology

The mathematics used in this analysis is extremely simple. The basic concept of epidemic diffusion 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.

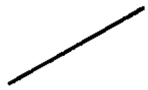
The integration of this equation gives:

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

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 the 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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1. Back to Basic

Anthropological Invariants in Travel Behavior

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

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

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

The work of Zahavi of the World Bank is most remarkable because it shows the *quintessential unity of traveling instincts around the world*, above culture, race, and religion, so to speak, which gives unity to the considerations relative to the history and future of traveling, and provides a robust basis for *forecast* in space and time. The empirical verification by Zahavi about the *exposure time* reports *one hour per day* as a mean over the year and over a population. The tails of the distribution are interestingly not spread much around the central value. Basic instincts are pervasive. Even people in prison for a life sentence, having nothing to do and nowhere to go, walk around one hour a day, in the open.

Walking about 5 km/h, and coming back to the refuge for the night, gives a radius for territory of about 2.5 km and an area of about 25 km^2. This is the definition of the territory of a village, and as Fig.1-1 shows, this is precisely the mean area of greek villages today, sedimented through the history of a pedestrian population. The same principle operates when a city through its importance, political or economic, expands her population and, as a consequence, her physical size. No city walls of large ancient cities (up to 1800) have a diameter greater than 5 km or 2.5 km radius. Even Venice *today*, still a pedestrian city, has exactly 5 km as the maximum dimension of the *connected core*.

When introducing mechanical transportation with speeds higher than 5 km/h, the physical size of the city can grow in proportion as the historical analysis applied to the city of Berlin clearly shows (Fig.1-2). The commuting fields, based on cars, of a dozen of American cities are reported in Fig.1-3. On the same chart and the same scale, the greek villages of Fig.1-1 are given in schematic form. *Cars make all the difference.* Having a speed 6 or 7 times greater than a pedestrian, they expand daily connected space 6 or 7 times in linear terms, or 50 times in area. Ancient cities had typically a maximum population of about 1 million people. We can move them today toward a 50 million people in conurbations like Mexico City (Fig.1-4) with a population density equal to that of Hadrian's Rome. If the Japanese will complete a *Shinkansen Maglev* connecting Tokyo to Osaka in less than one hour, with the large transportation capacity possible in Maglevs (e.g., 10^5 pass/hr) we will witness a 100 million people quasi linear city.

It we expand the reasoning, we can muse about a 1 billion people city which would require an efficient transportation system with a *mean speed* of only 150 km/h. This could happen in China, as *the aggregation usually stops at cultural and political barriers.* The accent is set then *on transportation as the unifying principle of the world, and not communication* as the current wisdom indicates. On one side the so-called explosion in communication during the last 20 years did not dent transportation expansion. Furthermore, transportation and communication expansion tend to move together as Grübler has shown for France (Fig.1-5), pointing to a synergic more than a competitive situation.

Because communication and transportation move together, we can use one as a proxy for the other for measuring the intensity of social interactions. We can look, e.g., at the intensity of interaction between communities of different language (e.g., culture), or between communities of the same language but different political aggregations to identify quantitatively the frontier effect. Telephone calls between cities in Quebec (French speaking) and Ontario (English speaking), and nearby United States are reported in Fig.1-6). *Cultural barriers or political barriers bring a reduction of communication (and supposedly of personal movement) by an* *order of magnitude.* The reduction is detected by applying the gravitational model as explained in the legend. A TGV or a Maglev system applied to the European core will link Europe but not really unify it in the sense of the Shinkansen at least in the short term of, e.g., 50 years. Mixing people may favor cultural compatibility, however, as history shows. But cultural traits are slow to modify and fast transportation may finally raise the central problem of *how to realize a viable multicultural society.* This is not only an inevitable political and religious problem, but also an *ecological* one so to speak, as it looks good to *preserve the cultural diversity* of human populations in parallel with the *biodiversity* of living species.

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

My *Gedankenexperiment* which I presented at Marrakech in a congress related to the problem of linking Africa (or better the Magreb) to Europe with a bridge or a tunnel across the Gibraltar Strait, was based on the *explicitation of the final potential of the Maglev.* At the Polytechnic of Lausanne a Maglev transportation system between the major Swiss cities has been proposed, having the characteristic of running in an evacuated pipe (air pressure equivalent to 15.000 meters). The rationale is to have a small tunnel, almost fitting the size of the train. Due to the conformation of Switzerland such connections have to go into tunnels for the most part, and the cost of tunneling is dominant over every other component of the system.

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

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

Speaking of a European core, I must say that functional integration at high hierarchical level (e.g., having a common foreign policy) may not require a full integration at lower level, that integration hitting against cultural and linguistic barriers. A suggestion in that sense comes from an analysis I did on the rank–size of world cities. This rank–size images the *distribution of tasks* between the largest cities of the world (or of a nation) in running the system and "filling" the territory. As shown by Zipf in his seminal work in the Forties, a well-developed system shows a fractal structure in the size of cities' population. In 1920 London was the world's largest city and her rank No.1 was obvious in terms of politics and finance. The ranking of world cities sat on a nice straight line *as it should* according to Zipf (Fig.1-7). If we repeat the exercise now, we find that the world cities line has a big knee (Fig.1-8). In a sense, either the world is short of large cities or in some way it is not at equilibrium.

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

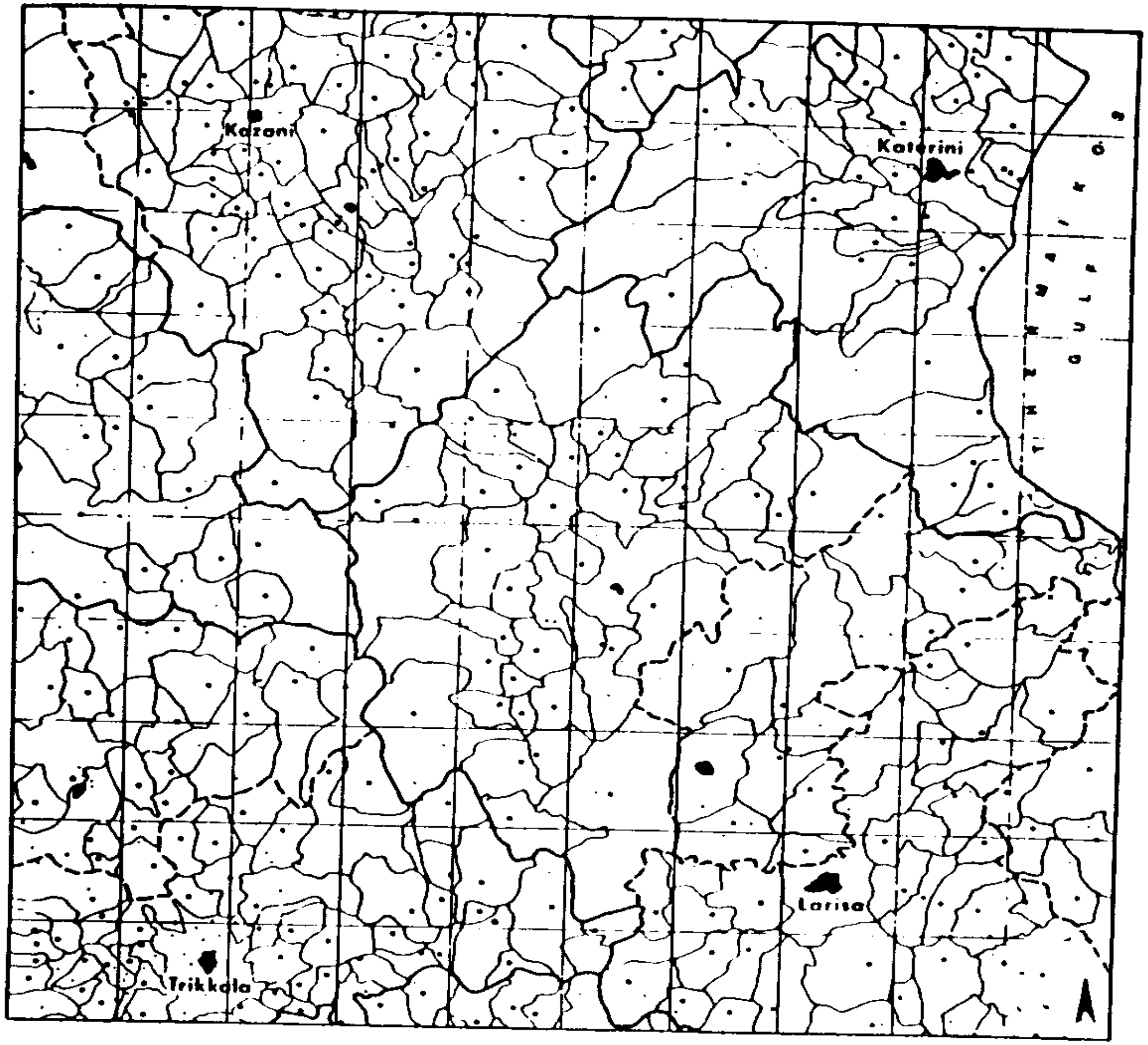
If these effects are not so strong as for the bulk, in the sense that they can be digested in a relatively short time, then *hypersonic planes,* operating shuttles at world level with elites coming back to their cave at night wherever they have to go, can become the *backbone of a single world. Speed is a unifying principle* as the case of the evolution of "on foot empires" and "horseback empires" in China shows (Fig.1-9). They finally reached the same final dimension *measured in time* of about *one month* for a return trip from the periphery to the capital. If it takes longer, as it happened when Rome lost the control of the sea, then the periphery splits, building an independent political unit (The Eastern Roman Empire).

Airplanes provide the technological frame for a world empire.

Fig.1-1

The agricultural area referring to a village has been settled by trial and error along the centuries. Here is reported a piece of Greece, with villages marked as points on the map. The mean area around the villages is a little above 20 km^2, pointing to a radius of about 2.5 km. This is also the *largest* radius of the walls of ancient citities, like Rome, Persepolis, Marrakech, or Vienna. The connected part of Venice has the same dimensions today. (Source: Doxiadis, 1974.)

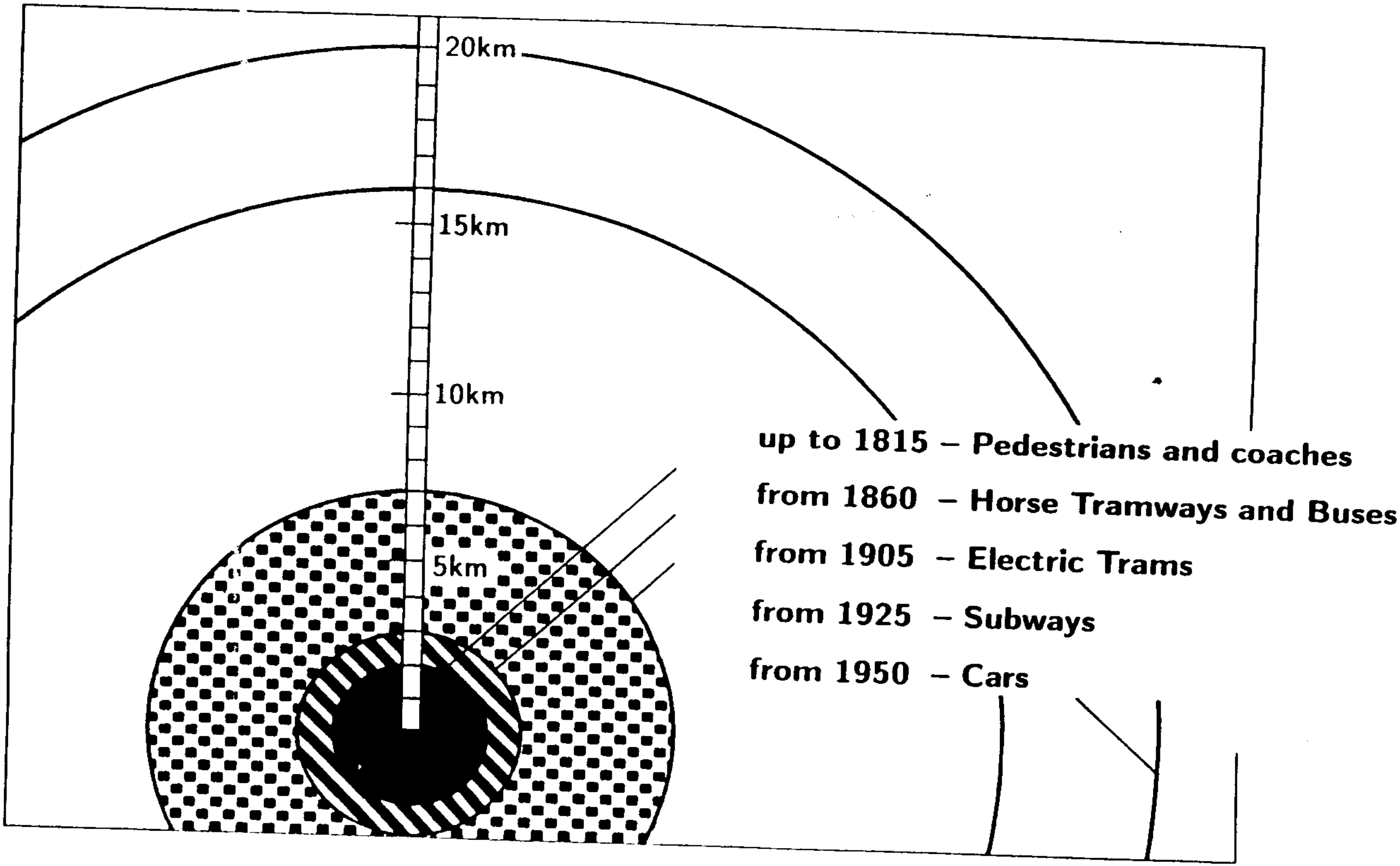
Village Patterns in Greece



Mean area 22 km^2

Fig.1-2

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



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

Fig.1-3

The geography of the walking man is here reported on the same scale together with that of the driving man, commuting in a number of American cities. As cars have a mean speed about 8 times that of a pedestrian, so are commuting distances. The areas accessible, *the territory*, however, grow as the square, so the driving man has a territory about 60 times larger than the walking one. (Source: Doxiadis, 1974.)

Commuting Fields of Eleven American Cities

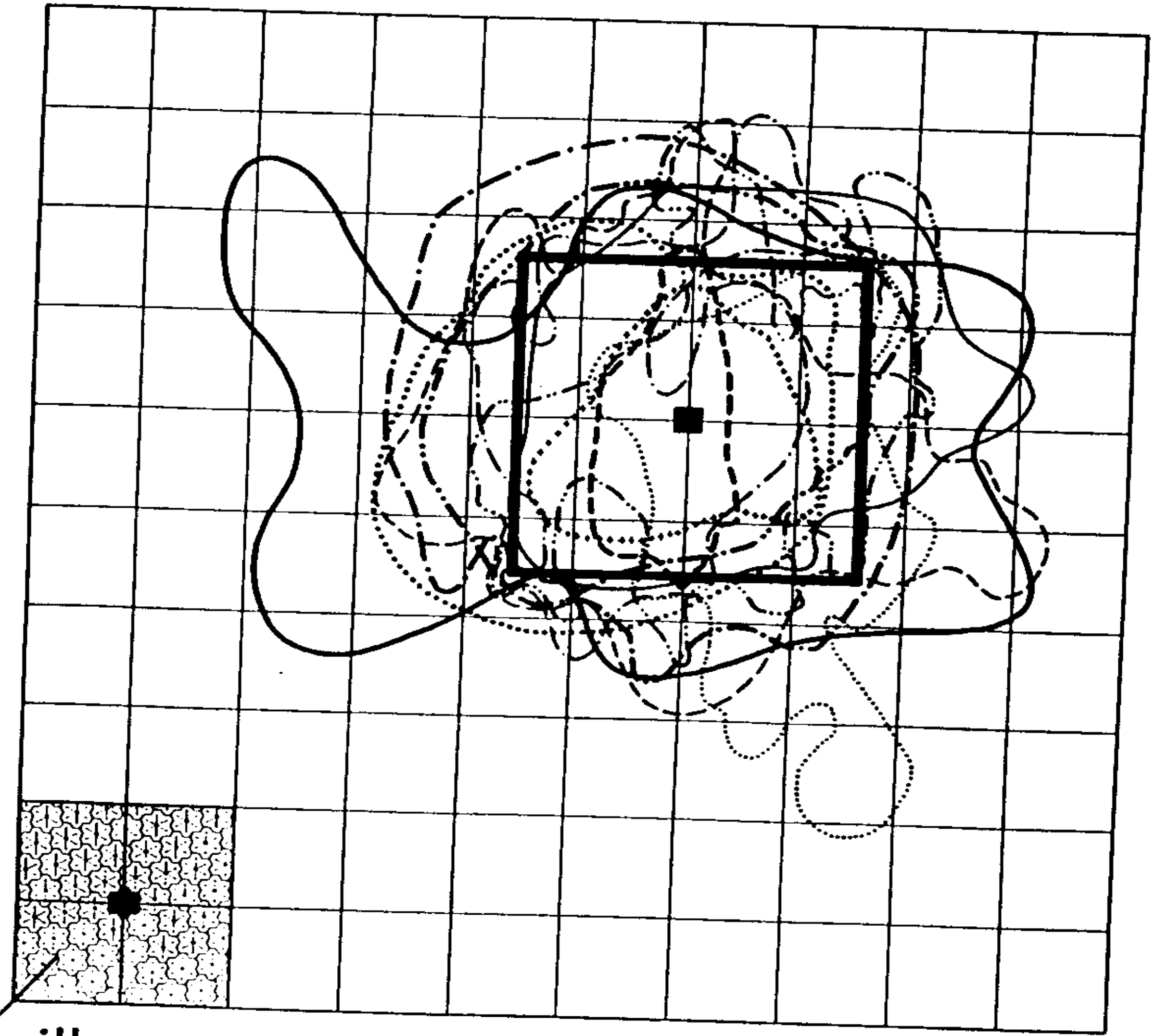
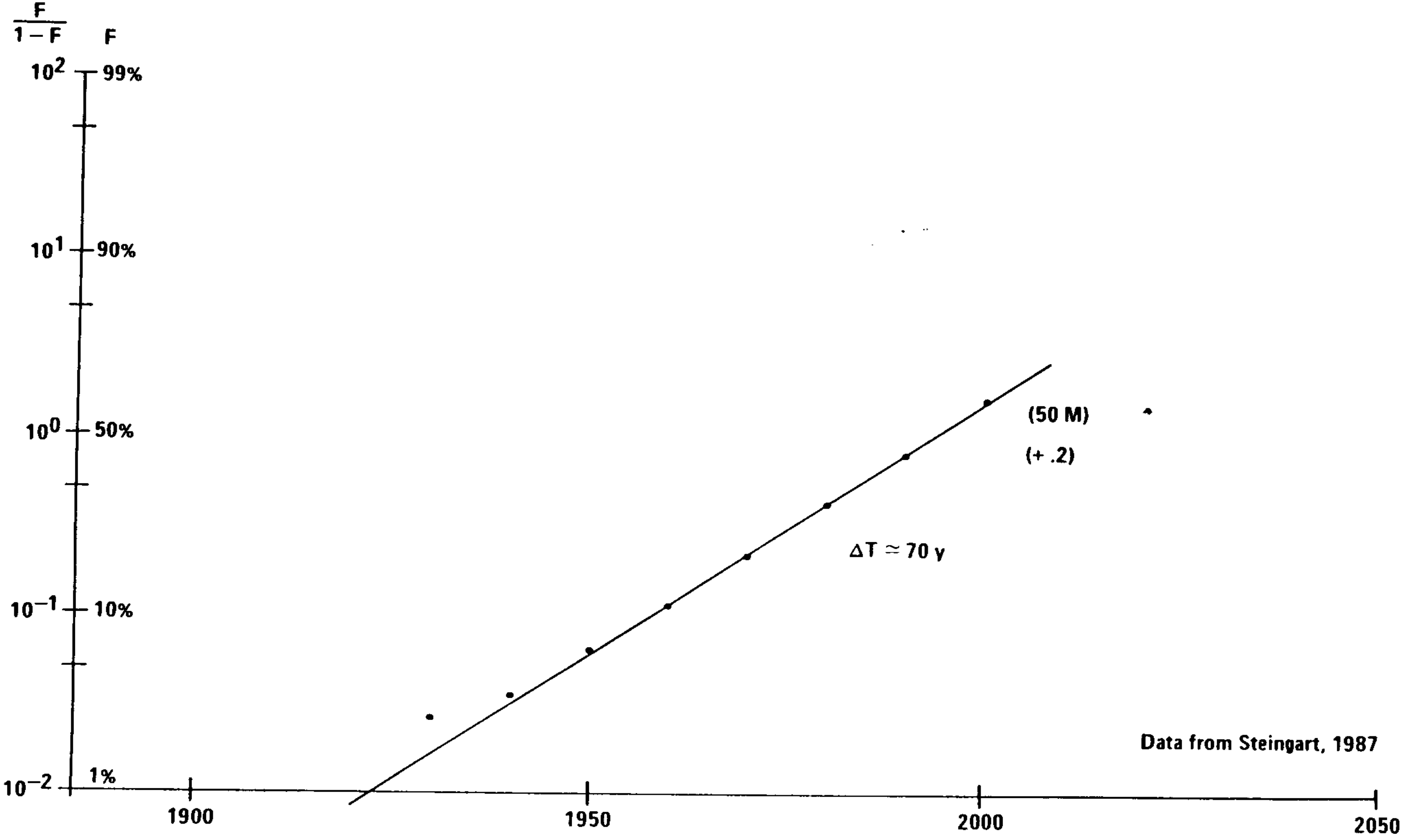


Fig.1-4

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

MEXICO CITY: CITY SIZE



C. Marchetti, IIASA, 1989

Fig.1-5

There is much talk about the communication explosion and the possibility that it substitutes physical transport of persons. Up to now communication in terms of messages exchanged and transportation in terms of pass-km, seem to move together. The increase in the personal territories increases the number of information exchange points accessible only by telecommunication. In a village all exchange is done face to face without any need of mechanical devices to communicate. (Source: Grübler, 1990.)

France – Transport & Communication Index

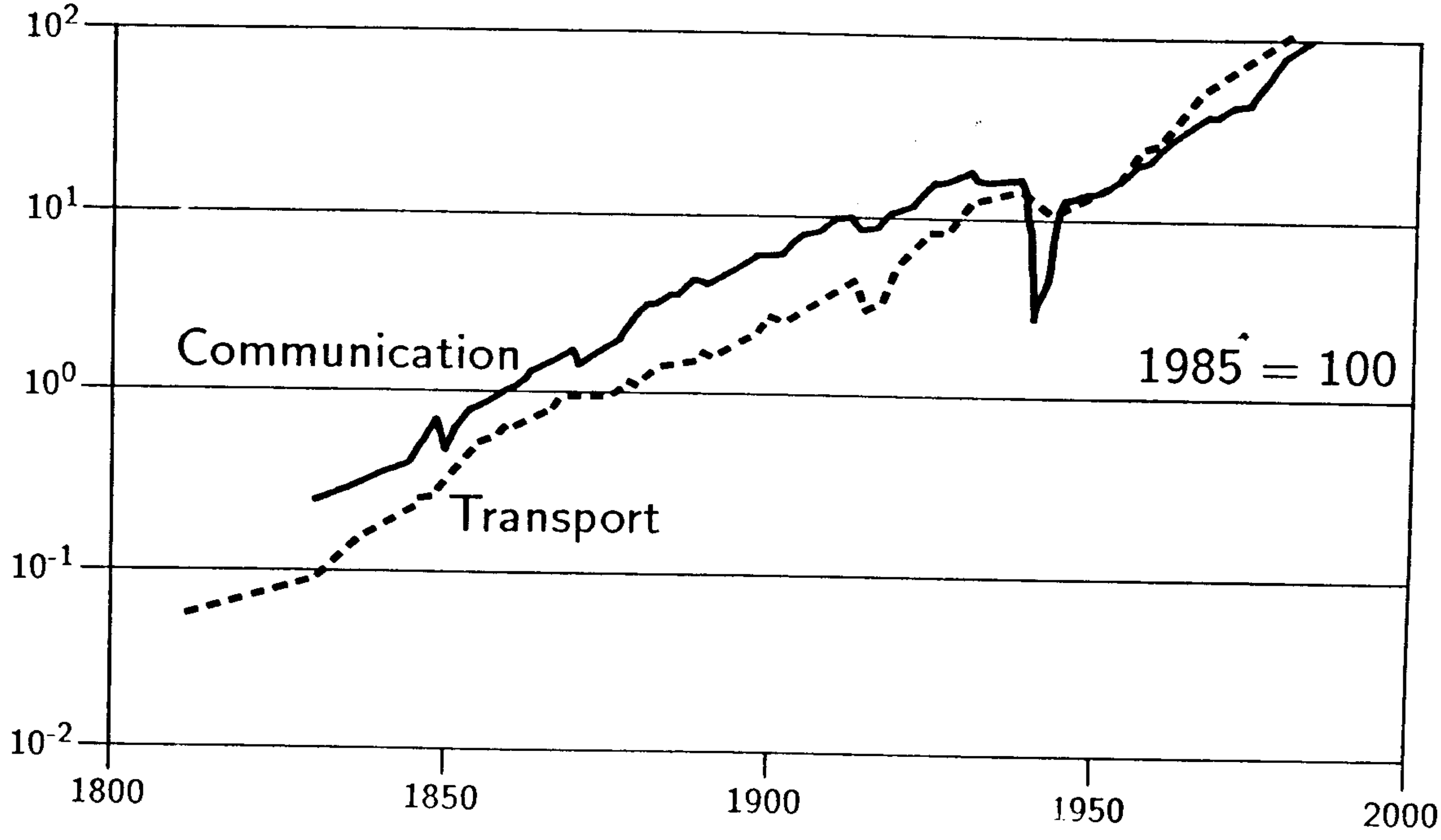


Fig.1-6

Due to parallelism between message exchange by telephone and traveling we may use the first as a proxy for the second, at least as a first approximation. Here we are trying to assess the barrier effect of political and cultural differences. The reference model is gravitational (Zipf), meaning that in a homogeneous system telephone calls between two cities are proportional to the product of their population divided by some power of their distance.

The model works also for systems of different language (here Ontario and Quebec), but same political system, and for systems with same language (Ontario and nearby USA), but different political systems. However, the *proportionality coefficients are an order of magnitude smaller, showing that cultural and political differences are very powerful exchange barriers.* Similar results are obtained looking at travel inside Europe whose real unification may take longer than the abolition of frontiers or the construction of a fast transport grid. (Source: Abler *et al.*, 1972.)

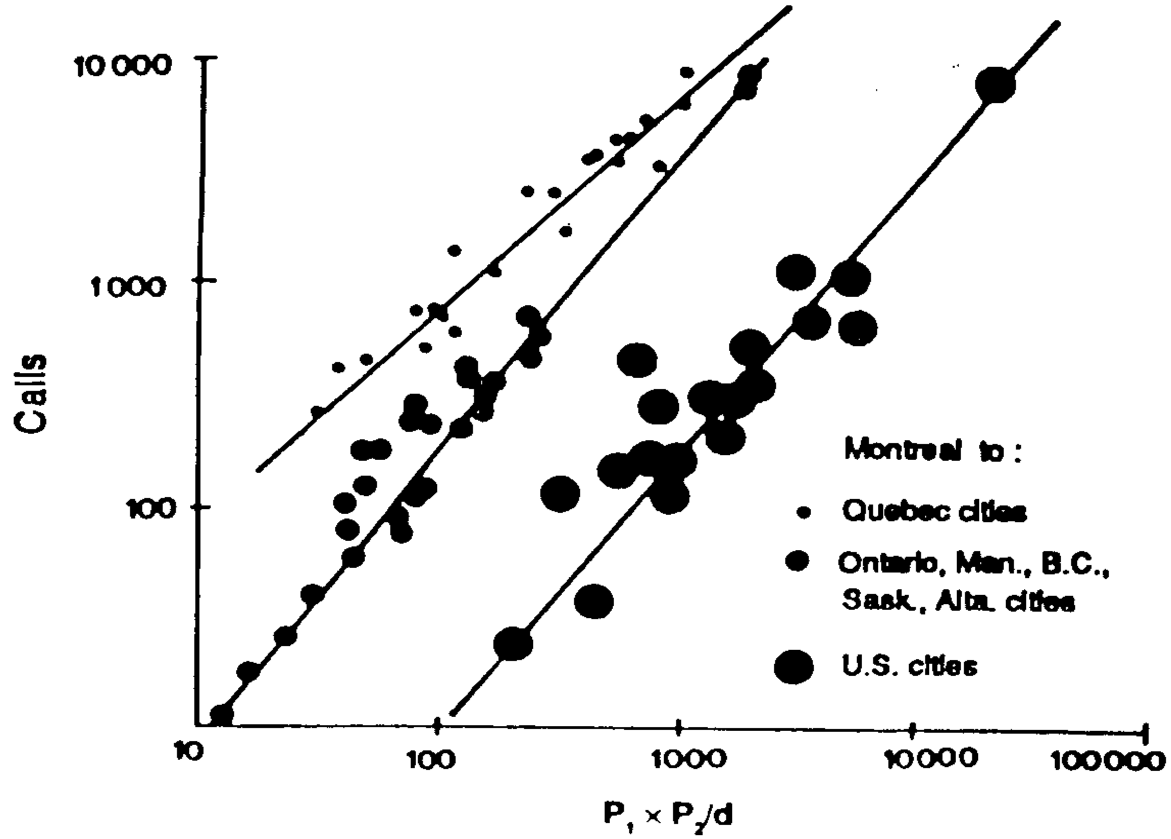
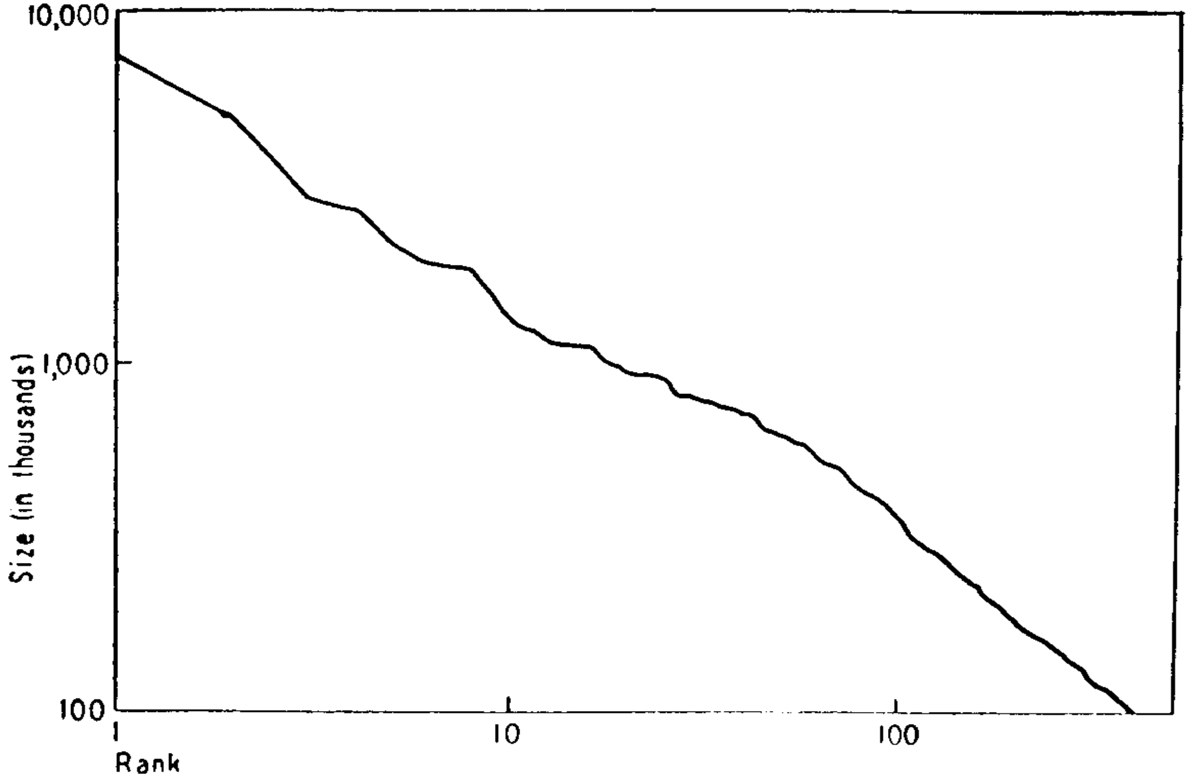

Calls
10 000
1000
100
10
100
1000
10000
100000
$P_1 \times P_2/d$
Montreal to :
Quebec cities
Ontario, Man., B.C., Sask., Alta. cities
U.S. cities

Fig.1-7

Zipf showed that in an interconnected system the population size of the largest world cities tends to be in constant ratios when ordered in a decreasing size sequence (rank). According to Zipf, who ordered these sequences in a log-log “rank-size”, matching a straight line is the manifestation of some sort of equilibrium in the distribution of tasks. Rank No.1 belongs to the city with the highest rank functions in world politics and finance. London fitted well into that position in 1920. (Source: Zipf, 1972.)



Cities of the world (about 1920)

Fig.1-8

If we repeat the Zipf chart of 1920 today, we find that world cities' rank-size line bends sharply at around 7 million population. Projecting from the smaller cities upward one could say that, in the Zipf logic, we are short of very large cities. However, counting "corridors", i.e., set of cities connected with air shuttles and very fast trains, as single units, we find Zipf's order again. This may mean that the daily movement of the elites is sufficient to ensure the highest rank functions, with corresponding sizes equal to the sum of the connected cities. A good omen and pathway for the unification of Europe in the concert of world powers.

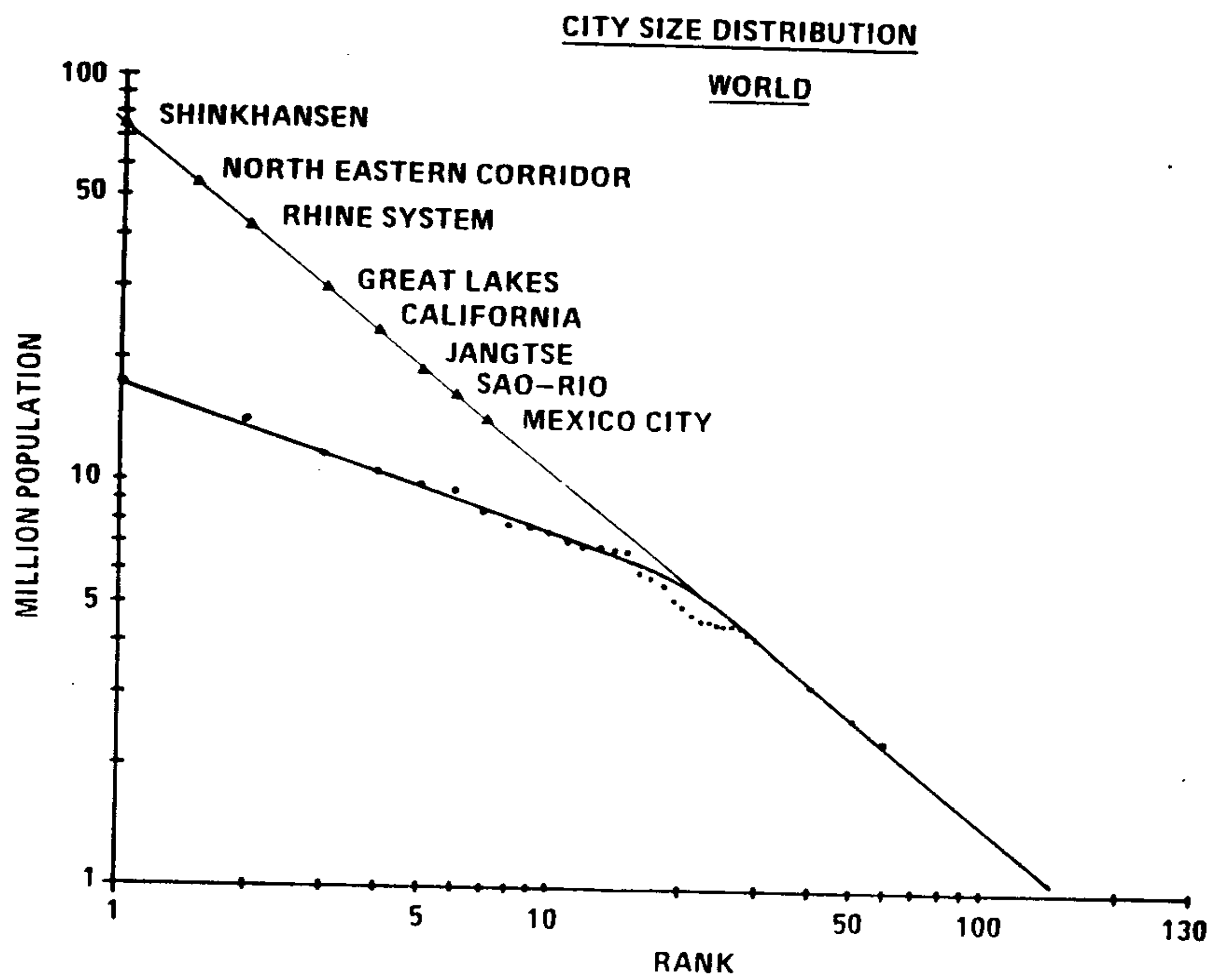
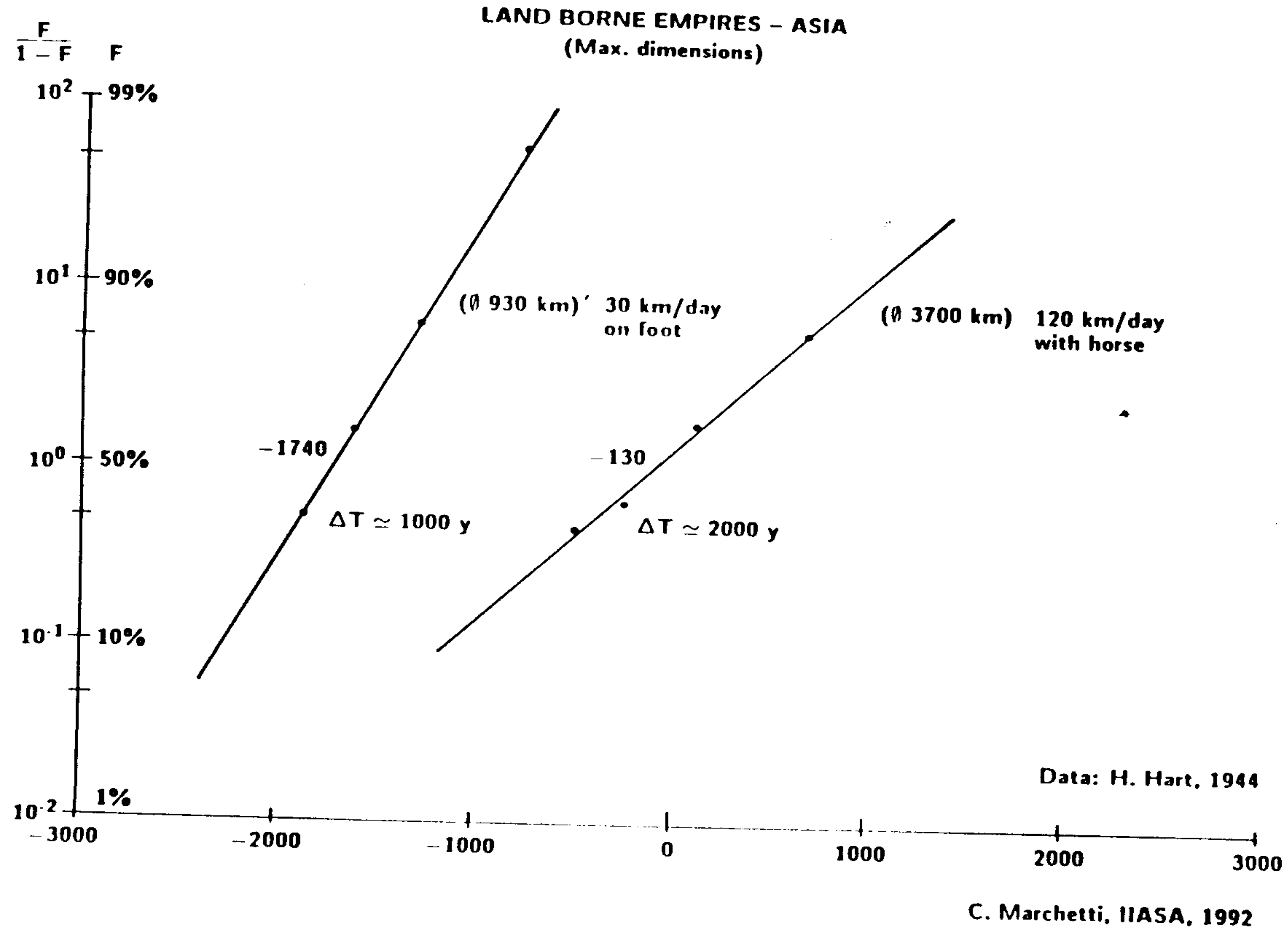

CITY SIZE DISTRIBUTION
WORLD
SHINKHANSEN
NORTH EASTERN CORRIDOR
RHINE SYSTEM
GREAT LAKES
CALIFORNIA
JANGTSE
SAO–RIO
MEXICO CITY
MILLION POPULATION
100
50
10
5
1
RANK
1
5
10
50
100
130

Fig.1-9

As the Chinese say, past history contains all useful precedents to interpret the present. It may be interesting to muse how transportation speed shapes the empires. Here the size of the largest empires in Chinese Asia are reported. They can be ordered in two logistics having saturation points of $0.7\ 10^6$ km^2 and $\sim 10\ 10^6$ km^2, or *mean radii* of ~ 450 km and 1800 km. In both cases this corresponds to about a 15-day trip on *foot*, and on *horseback*, respectively. Apparently empires, where the periphery is more than 15 days away from the capital, split, showing that *fidelity to the central power has a holding time of one moon*. Rome's empire had to split when Rome lost the control of the seas. Overland, a trip to the Black Sea took one month.

The good news is that with current airplanes *a world government is possible.* With mach-7 airplanes and matching Maglevs also *a world city* is possible. The assimilation of the technologies in political terms, however, may take centuries.


LAND BORNE EMPIRES – ASIA
(Max. dimensions)
F/(1 – F)
F
10^2
99%
10^1
90%
10^0
50%
10^-1
10%
10^-2
1%
–3000
–2000
–1000
0
1000
2000
3000
(Ø 930 km)' 30 km/day on foot
–1740
ΔT ≃ 1000 y
(Ø 3700 km) 120 km/day with horse
–130
ΔT ≃ 2000 y
Data: H. Hart, 1944
C. Marchetti, IIASA, 1992

2. On Transport Machinery and the Way People Use It

For eons man moved on foot. At about 5 km/h. The first machinery for personal transport were horses and carts. They always had a great importance for military and political objectives, but they were *too expensive* for general use and limited to the top elites. Consequently, this technology did not penetrate the daily life and shape the structures connected to it. Still in 1800, a vital and powerful city like Berlin had a diameter of 5 km (Fig.1-2).

But since 1800 progress in vehicular transportation was explosive. The horse-drawn tram, on iron tracks, made horse transport in bulk possible, bringing the cost at the level of the then already richer popular purse. Then came the electric tram, the city train (subway or Schnellbahn), and finally the private car. *The process took two centuries*, bringing the speed from the 5 km/h on foot to about 40 km/h on car, and increasing the surface of the personal territory (*and of the city!*) by almost two orders of magnitude. It should be clear that it *makes no difference if the speed is provided by personal or public means.* The oldish and uncomfortable but fast Metro in Paris carries about 4 million passengers per day, most of which own a car.

We can look now at the details of the adoption of new means of transportation, as to acquire experience to forecast what will happen to airplanes. A good first synoptic view is given in Fig.2-1, where the distance/day/person *covered on vehicles* is reported for France, since 1800. The procedures of adoption are here very clear. A new means of transportation enters the market slowly and progressively providing a higher speed (trains versus horses).

Speed is expensive both because faster machines have always been more expensive than slower ones, per kilometer, but also because people travel on time budgets (one hour a day!), and for the same time they make more kilometers if they move faster. Cars and planes cost in fact more or less the same in the USA, per kilometer. But per hour a plane costs ten times as much. Allocation of time to air travel from TTB (Travel Time Budget) is cautious because of disruptive action on TMB (Travel Money Budget). Americans dedicate about 60 seconds/day, mean over the population, to air travel, and about 50 minutes/day to car travel (in 1940, the time on cars was 20 minutes/day and the same value can be estimated for the time spent on horse-drawn vehicles in 1920).

Speed being expensive the *new means of transportation* is *absorbed slowly*. For about 50 years it takes only the growth in travel all for itself, and another 50 are needed to sweep the competitors out of the market. We see that with railways blocking the growth of horse transport around 1850, and phasing it out in 1900. Motorized road transport blocked the growth of railways (in terms of passenger kilometers) around 1930, and we may expect to phase them out after year 2000. With the same logic air transport should now take the growth, blocking the increase in road transport. *This logic is very important for estimating the expansion of air transport during the next 30 years.*

The chart of Fig.2-1 is strategic in visually conveying the secular structure of the basic trends. The analysis can, however, be much refined by zooming into the detailed processes, using the more sophisticated tools of systems analysis. A glimpse into the substitution of horse -drawn omnibuses with motor-buses in Britain is given in Fig.2-2. The straight lines actually represent diffusion logistics (see Mathematical Methodology on page 0-9). Here we focused on a limited sector of the transportation market, and on a limited area. But we can repeat the exercise on a broader scale, looking, for example, at the evolution of the infrastructures that support the transport machinery (Fig.2-3), monitored through their length. Length of canals, railways, and paved road in the USA is here reported fitting the data with logistic equations. We see here that the system is splendidly self-consistent. One single and very simple equation can describe *the whole process* of expansion of an infrastructure.

Fig.2-3 also contains a detail of great importance and generality: the central points in the development of these infrastructures are spaced exactly 55 years. *These 55-year cycles, a generalization of Kondratiev economic cycles, haunt all sorts of human activities, from air travel to homicide rates*, and will play an important role when we look at the future development of civil aviation.

Coming back to our *travel protheses*, what we normally observe is that people distribute their time and money budgets between the different modes, ordered in terms of increasing speed, and tries to privilege the faster ones. The fastest is usually very expensive and the most used is the second best. *In our times this is the car.* When a person can take hold of a car he will, in fact, spend on it most of the hour of his travel time budget (Fig.2-4). But car speed seems to be bound to stay around 40 km/h as the yearly mileage per car clearly shows (Fig.2-5). This means that the increase in mileage of 3% per year as shown in Fig.2-1, which has