TRANSPORT SYSTEMS AND CITY ORGANIZATION

A Critical Review of the Relevant Literature

Principal Investigator:
C. Marchetti

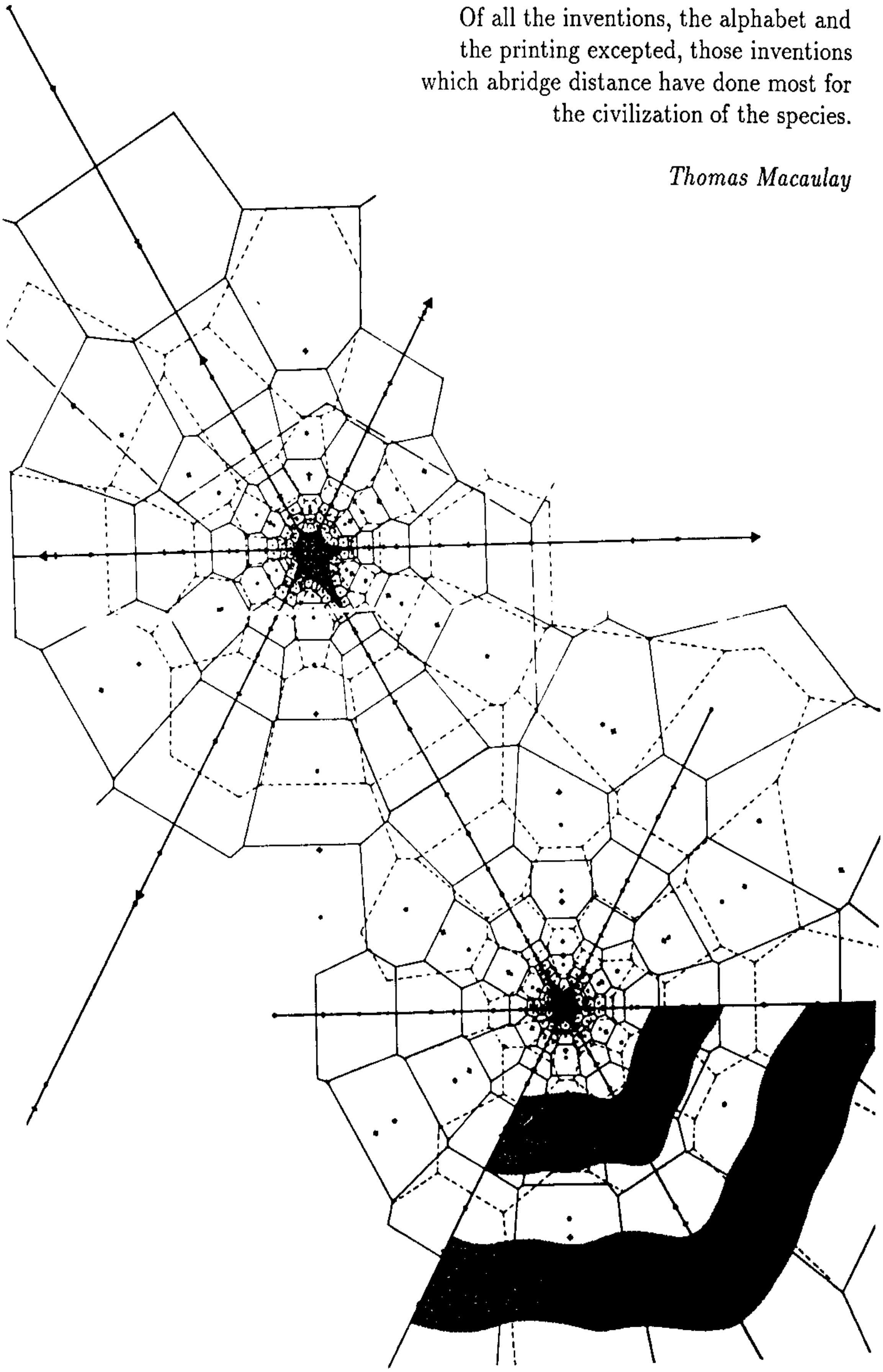
MARCHETTI-055_
Pt.1

Contract No. 10375-94 F1 ED ISP A

Laxenburg, May 1995

Of all the inventions, the alphabet and the printing excepted, those inventions which abridge distance have done most for the civilization of the species.

Thomas Macaulay



Executive Summary

Christaller, in his seminar work published in 1933 on *central places* in southern Germany, set the foundations to a rational interpretation of the geographical distribution of human settlements. The building stone is the village. Villages with their own territories fill the geographical area. Their territories, historically documented, and more often preserved today, are curiously of very similar size, *about 20 km*^{2}. As they fill the space like tiles, they have an approximately hexagonal shape.

Christaller observed, and quantified, that every village possesses the basic services of daily use, e.g., the bakery and the barber (and once the Church). Less frequently used services, e.g., a shoe shop, are concentrated in a village that also serves the six neighboring ones. In the bunch of seven it has the second-level hierarchy. The hierarchical process continues, and at the center of six bunches of seven, there is a seventh bunch with a central village, now a small city, providing third-level services. The constancy of the size of the village territories permits calculation of the maximum hierarchical level on the basis of the total area. It is five for Italy (or Germany) and seven for a unified Europe.

Hierarchical centers tend to have populations increasing according to their hierarchical level; however, their physical size up to 1800, never exceeded that of the village territory, i.e., 20 km^2 (or about 5 km in diameter). The reason for this is explained in Marchetti (1994a) and reduces to the fact that people travel about one hour a day and 5 km is one hour on foot.

Introducing mechanical transportation changes the scale of the basic unit, preserving however Christaller's hierarchical structure. Con-

sequently, taking the old territorial organization as a reference, the lower hierarchical levels disappear, melting into single units with sizes corresponding to the speed of the dominant mode of transportation. In the old order, the basic unit had 5 km diameter, the second level 15 km, and the third level 45 km. Cars have a mean speed of about 40 km/h, so that in a car society the first two levels may disappear. Slowly. The present situation is actually hybrid.

In another seminal paper by Virirakis (1971), functional analysis of a city reproduces a similar scheme if in a smaller scale. The basic unit is here the quarter, whose size is again linked to speed, but in a more complex way: the size is inversely proportional to local population, meaning that the total traveling (walking!) for using the facilities is constant and independent of size.

Density decreases exponentially in cities, and in my literature search I could not find an interpretation. But the consequence is that the central quarters are very small, meaning all facilities are at short distance. That is why Manhattan is very practical for people living there.

The exponential tends to become flatter with time, even when population remains constant. Meaning that the structure is preserved, but on a larger scale. It seems obvious that this is due to faster transportation, but I could not find a paper where the relation is quantitatively theorized.

Resuming, human settlements are organized to provide hierarchical contacts in a *time* frame. The parameter that transfers this organization into space is *transport speed.* This speed is actually the independent variable regulating the entire system.

Resumé

We explored the work done during the last 25 years on the problem of the effect of transportation speed on urban structure. That speed is the quintessence of urban sprawl transpires in every paper or book we examined. However, to our incredulity, there is no decent theory that can interpret and reduce to first principles even the most elementary description of a city, the distribution in space of its population, i.e., the population density patterns.

Descriptions of this density pattern abound, even in terms of historical development. Well-studied cities like London and Paris are reported for almost two centuries (Figures 3 and 4). Density distribution can be well-fitted with a negative exponential (or a lognormal which helps provide a hole in the center) and all cities examined can be described in this way. Such a worldwide homogeneity in structure implies first principles (not yet found as mentioned). For a given city the exponential becomes less steep with increasing speed of transportation (the sprawl) and we expected that urbanists had searched for *at least an empirical connection* between this speed and the coefficient of the exponential. We found no trace, even in the heads of the specialists we contacted. We have thus discovered a very important unsolved problem that the experts avoid to stress in their papers. As a consequence, urban planning which is flagged as the final solution of a rational city, appears as a patchwork subject more to the push-pull of local interests than an illuministic view of the problems and the solutions.

From a methodological point of view we started with electronic searches, concentrating later on key names. As usual, most of the lit-

erature is trash or repetition. Out of the 1000 publications we searched, we chose about 100 papers and books containing at least some valuable information. They are reported in the indexes. We gave short comments on about 25 of them; for the best a resumé. The limited grant, equivalent to about three months basic salary of a Senior Researcher, did not permit a more articulated analysis.

Filtering so many actual statistical data we got the impression that the basic structure of a city is always the same in a sort of Christaller fractal scheme, where the module – the metric – is fixed through transport speed. This means a *city is a spatial structure invariant to (travel) time*: for a given city the travel time structure is basically independent of its spatial evolution.

Because such huge sums have been spent in modeling with little practical results, we propose a catalogue, as we have done at IIASA for energy modeling in the 1970s. Such a hindsight operation can provide a lot of foresight in terms of research money allotment. The work of Charpentier in this area is reported in the index.

Premise

In previous papers and reports we have reported that traveling is centered on the traveler's house and extends into a range depending on the speed of the transport modes available to him and on their cost relative to his disposable income (Marchetti, 1990, 1994a) The fact that the traveler spends about one hour per day for his daily movements, *creates a strict link between space and speed.* The structure of human settlements is then defined by the speed that can be extracted from the transportation system.

The situation was crystal clear in antiquity, and up to 1800, when basically one speed was available, the 5 km/hr a man can do walking. Horses were actually so expensive that their use was very limited and made no impact on the basic structure of the human settlements.

In the most elementary form of city – the village – there were a number of services available and a certain population lived in a small aggregate of houses, and the territory around was gravitating on it. Because this territory has a administrative significance, it is recorded and still tends to keep its historical shape. We find that the mean value of the extension of this territory is about 20 km^2, corresponding roughly to a roundish shape of about 5 km in diameter.

If the village was successful, e.g., as a trading center or a political and administrative unit, the housed part increased to fill, to the limit, the 20 km^2 of its original territory. This is neatly shown by the analysis of the size of the walls of ancient cities: Hadrian's Rome, Marrakesh, Persepolis, Vienna in 1700, or Venice today. They never exceeded 20 km^2 of enclosed space, usually in a radially organized city.

At the beginning of the sixties, Walter Christaller (in Norborg, ed., 1962) proposed the *central place theory*, where the organization of human settlements and economic activities is regulated by an interplay between the economics of centralization and the diseconomies of transportation.

His empirical observations where that there is a hierarchical structure in the size and location of cities, with the lowest level – the villages – distributed more or less evenly over the territory, and higher-rank conurbations occupying the center of bundle of six lower-rank conurbations, starting from the village with its size defined by walking speed.

We know from preceding reports that this size corresponds to one hour moving on foot. If one can use extensively a faster means of transportation, e.g., the car, the spacing between the settlements of lowest rank will increase in proportion to its speed, and the area they dominate as the square. Because the area is larger one can also suppose that the population in the centers will be proportionally larger. This would produce a simple interpretation about the progressive disappearance of hamlets.

Although these social processes are extremely viscous and a real speeding up of a population has occurred only with the large-scale acceptance of the car, i.e., after World War II.

A 40 km baseline (the speed of the car), instead of a 5 km one, will wipe out two hierarchical levels of old settlements: the village (5 km diameter), the central city with a bundle of 7 villages (15 km diameter), and the following superbundle (45 km diameter), which will become the basic unit. If we assume the population and the area of the country to stay constant, then a powerful urban movement will appear with larger and larger cities. The total level of hierarchies will be reduce by two, as the largest city already "occupying" the available territory cannot have a higher rank conurbation.

Assuming the central city of a bundle has a population of about half the sum of the six cities surrounding it (as observed by Christaller) we have a population reduction of one half every hierarchical step. If 100 is at the first level (the six outer villages of the lower bundle), the second will have 50 (the central city of the lower bundle), the third 25, the fourth 12 and the central capital 6 (with 5 levels). A total of 193. With infinite levels the number would be 200, so our illustrative example is realistic enough. Eliminating the first two levels and packing the population into higher level cities, this would give a migration of 150:193=0.78, or about three-fourth of the land population. *This seems to be what is actually happening.*

The above conceptual model *reduces modern urbanization to a spatial reorganization driven by faster transportation technologies.* Industrialization, in this light, appears more a consequence than a cause and social interpretations too may operate in the background without constituting in fact the basic mechanism.

If third-level cities swallow the territory of first- and second-level cities, then their suburban territory will include a lot of agricultural land. Because this land is seen as a potential periphery, there will be a pressure to build into it. Some of the old constructions will be rehabitated and others built afresh, but again in the spirit of periphery. This is how neighboring administrative units (communes) are absorbed, administratively, by the expanding city (e.g., Milan or Vienna).

Because 50 km diameter or about 2000 km^2 can accept a city of 50 million, there will be a pressure to build hierarchical levels upward. This is not possible, as said, if population and land are fixed, but it becomes possible if lands (and population) are fused, as it happens in the European Community. This fusion, it must be clear, is not necessarily political in the brood sense, but functional. To leave people freedom to move and to relocate their activities should be sufficient. A 50 million European capital could well top the present capitals, with a population comparable to their sum (which is not far from 50 million). Incidentally, such a city, on a 2000 km^2 area would have the same population density as Hadrian's Rome. Which, incidentally, was awfully jammed.

With very fast trains, e.g., Maglevs, providing speed in one direction only, the structure of the city can be completely different and assume the form of a chain of beads whose centers are connected by the fast train and whose *fast* subways provide the funneling of the passengers in and out. Japan will approach this configuration when a Maglev between Tokyo and Osaka will be in place. Present plans assume a Maglev running at 600 km/hr, but the tubed version under development in Switzerland under the same *Swissmetro* has the potential for much higher speeds. In which case the already dense conurbations of Japan can melt into a single city of 100 million inhabitants.

The size of a city is not just a statistical number. A large city can afford a large hierarchy of specializations providing dominance in the competition with other cities. In the long run the largest become the dominant one (or vice versa). Thus, we may expect a dominant role for Japanese cities, as London had 100 years ago (then the largest world city).

If the city has the drive to grow, the most modern means of transportation provide the tools.

In the present search we are looking for the relevant literature on city shape and function versus transportation. The size of this literature as one can imagine is immense. We have tried to select *and comment* the best hundred objects we have found; we comment a couple of dozen. Our selection criteria are extracted from the work we have already performed for the EU and the CNR on the area of transport. Having publicly discussed and compared these results, they appear to be at the forefront of modeling and conceptualizing in the area of transportation.

Notes on the Literature Searched

We can start with review papers or symposia that get a picture at a certain point in time.

Norborg, 1962 (Proceedings of IGU Symposium). In spite of the fact that 35 years have passed since the symposium was held, this is one of the most brilliant books in urban geography that surfaced in our search. Walter Christaller presented his epoch-making theory of central places, where space is subdivided in a fractal form (but with upper and lower bounds) starting from the village and building clusters (of seven) of higher and higher hierarchy. As we have shown (**Marchetti, 1994a**), the size of the modulus at the lowest hierarchical level has been fixed for anthropological reasons to a diameter of about 5 km and an area of about 20 km^2. The 5-km distance is one hour walking, and the use (after 1800) of mechanical transport has put all the organization (à la Christaller) in a state of flux. The module becoming larger (up to 40-km diameter with the extensive use of cars, the lower hierarchical levels (the villages) are eroded away (if with time constants of centuries).

The book is worth to be kept as a reference since it presents a photography, made by an outstanding group of scholars, of the state of the art in 1960. No theory appears on population density distribution, and also travel times have not been given any special importance. The quantification is on a geometrical basis.

Webber, 1979. For the historically-minded this is recommended reading. Information shuffling and processing is at the base of human thought and action and inevitably it is central to man's occupation of space. However, as Webber says in the discussion of 6-6, the wealth of models produced along these lines and the few reported, finally fail to reach the final objective of a faithful and predictive description.

In his words:

> It is possible to argue about the merits and demerits of particular models as embodiments of elegant thought or as descriptions of reality. Yet the following is clear: all the ideas reviewed in Sections 1 through 4 are weakened by the disturbingly wide distinctions between operational and theoretical models.
>
> Two modes of investigation contribute knowledge in an empirical science such as urban geography. In one mode, prior beliefs about the spatial structure of urban areas are compared with the results of observations and are revised in the light of this evidence. In the other mode, highly simplified circumstances are postulated in order that deductive models can be manipulated theoretically to derive information about the causal relations between variables. (For brevity, such models are called analytic.) Wisdom lies in matching the results of these two modes. Since analytic models are intended to be highly simplified (which allows them to be manipulated) their conclusions do not correspond directly to experience and cannot be evaluated by naive appeals to evidence; yet empirical observation much be allowed to contribute to the manner in which analytic models are constructed. It is the task of urban theory to make this link. The theory must provide complex models, which can be directly compared to experience, as well as analytic models which yield theoretical knowledge: since the analytic and empirical models are derived from the same theory, and so share underlying assumptions, the conclusions drawn about empirical models can be transferred to analytic models. *In the past, urban geography has developed slowly because it has lacked a general theoretical structure*: such analytic models as the so-called central-place theory and as the Alonso family of models do not constitute special cases of theories which also yield empirically testable models.

Because the book is basically a review of models, it is also enriched by a broad bibliography covering 14 pages.

Wigan, 1988. This is a review paper, centered on our subject, and reporting basically the results of a conference on the subject held in Australia, and assembling various disciplines in a melting pot attempt. The melting pot did not work, as usual, specia-lists being species that do not interbreed, as is well known.

The paper is worth reading to get a flash of the situation in 1987, although it is not of great help in solving the problem of urban form versus transportation speed. In the conclusions the author states: *The interaction between transport, communication, and urban form is now being perceived as a single problem focus*, which is good news. He then continues suggesting complex interdisciplinary interactions which, as he noted before, do not work.

As we all know, some people are naturally interdisciplinary and they might be put in charge of solving interdisciplinary problems. However, when money is sorted out the "disciplines" have the formal status and tools to pick it all. Sponsoring agencies do not seem to have been able to break this stalling mechanism.

A complex system like a city is an obvious challenge to modelers. But complex systems are hard to encompass with analytical models. We had a direct experience at IIASA in the Seventies, when we tried to model analytically energy systems at various levels of aggregation, without success. An analysis of about 100 models made at different institutions around the world, most of them prestigious, showed that no two of them gave compatible results in forecasting (and backcasting), **Charpentier (1974, 1975a, 1975b, 1976, 1978)**. We found one that worked, a synthetic one, based on diffusion processes and logistics, which showed that *a phenomenological* description was possible, capable of forecasting and backcasting.

In the case of city modeling, we cite the remarkable (if in our opinion unsuccessful) effort by the International Study Group on Land Use/Transportation Interaction (ISGLUTI), which published a report in **Webster et al. (1988)**. The main characteristics of the models are reported in Table 1; the book contains their mathematical description and the results of their testing. the conclusions are prudently worded, saying that the results of the models *tend to be plausible.* But as in the case of energy models quoted before: "*different models often indicated different strengths of the impacts of policies and occasionally different directions also*" (quote from page 417).

Because the success of these analytical models is very poor, at whatever object they are applied (energy, urban structures, economics, sociology) it is astonishing to observe that still so much money and faith is spent into them. Instead we would propose a research to understand *why they do not work!* A first step would be to put them together, one page per model, giving the basics and the results as in Charpentier's case.

The distribution of people over the countryside and inside the perimeters of cities always fascinated geographers and historians, because of its regularity transpiring from its apparent casuality, and because of its obvious strategic and economic importance.

To have some sort of overview of the ancient Mediterranean tradition of urban networks, we cite **J. Gottmann (1986)**. Gottmann is a historical geographer, and his accent is more in the description of connectivities and the stress on the importance of the logistic system to keep the empires working as single units. Furthermore the Mediterranean has produced the templates for the modern development of northern Europe and the Americas. Although he does not attempt any modeling, a model should fit these descriptions of the ancient systems. The paper has an encompassing bibliography on ancient settlements and networks.

Another relatively recent paper on *human interaction and spatial mobility* has been authored by **T. Hägerstrand (1987)**, a life student of diffusion processes through social interaction and professor of geography in Lund. Because social contacts require mobility, Hägerstrand has become an acute student of the effects of mobility. In his words: *in an economic context the reallocation of factors of production in general and of labor in particular is referred to as mobility.*

In terms of modeling he uses time–space charts, where the position of individuals is mapped, forth and back during the day, showing in graphic form the "territories" of individuals, or the use of the territory by an individual. He seems, however, to miss the point about the archetypical urge for the individual to expand his territory, and, as aged person, sees all that running around as slightly mad and too energy-consuming. When he was younger, however, he wrote a more favorable article on the impact of transport on the quality of life (Hägerstrand, 1973).

M.J.H. Mogridge is an analyst of transport and urban population distribution whose work is mostly centered on London where he resides. His papers show much insight into the links of transportation and urban structure, and an open mind to new ideas that encroach the – in our opinion – obsolete models economists still shuffle around. In a study we did on the effect on traffic of new bridges and tunnels, all previous cost–benefit analysis actually proved wrong in hindsight.

Having to work with a very large city like London, Mogridge tends to be pessimistic-fatalistic when coming to traffic, as is well identified by the title of a paper (1985): *Jam yesterday, jam today, and jam tomorrow?* The question mark shows there is still some faith (or doubt). He shows that jam is an invariant in time. London was jammed in 1800 as it is today (Figure 1: from Gustav Doré, 1860). And that jam is invariant to transport technology. Most important, speed in central London is invariant to everything.

All this can be seen, optimistically, as a miracle. In fact, London's metropolis grew by 5 times and built up area 50 times, since 1800. Technological improvements in transport made it possible (Figure 2). The analysis can be found in *Metropolis or Region* (1994). His thesis is that improvements in transportation speed keep the size of cities expanding and appropriately quotes in the introduction of this last paper the visionary **H.G. Well (1901)**: *"It is not too much to say that the London citizens of the year 2000 AD may have a choice of nearly all England and Wales south of Nottingham and east of Exeter, as his suburb"*. Transport speed expands a city even with constant population. Figures 3 and 4 are taken from **Mogridge (1994)**, showing population, density from center and density fitted with a lognormal, all for London. The situation is not different for Paris (Figure 5).

Density distribution is well fitted by a lognormal, or an exponential (if we cut the hole in the center). It is to observe that in all our search we did not find any theory explaining population density distribution inside a city. Why it is not constant following a square function instead? The shape of the distribution is very important conceptually, economically *and for planning purposes.* We suggest a research specifically centered on this subject: *Why population density in a city is lognormal.* Because the metric is probably linked to transportation speed, this would give a precise interpretation of the problem we are looking at.

An interesting *empirical* analysis has been done by **P.W.G. Newman et al. (1995)**: *Transport and Urban Form in the Thirty-Two of the World's Principal Cities.* The data refer to 1980, when cars were already well established, although the effect of their use on city structure probably not yet. This is shown, for example, by the fact that urban densities can cover such a wide range, being very high in Asia, medium in Europe, and very low in the USA and Australia. South American cities are not included, they could have shown the influence of culture on top of that of history. Mediterranean cultures favor urban living with compact structures, perhaps related to the concept of fortress cities.

In numbers, European cities tend to be three or four times more dense than US and Australian cities. Asian cities are again even more extreme, with densities ten times those of the US and Australian cities. Hong Kong is by far the highest-density city in the sample and probably in the world: almost three times that of Tokyo and five times that of London.

The paper by **J. Viririakis (1972)** *The Minimization of Energy as Determinant of the Grouping of Community Facilities*, stand out because it reconstructs the basic principles on which human action is based, making the general logic very simple and clear. Incidentally, Virirakis is an engineer. The organization of a city appears to come out from the interplay between economic operators who provide city services and the residents who use them. The objective of the economic operator is obviously economic survival, and that of the resident is to minimize the effort to reach the services with appropriate frequency. The final result of a trial-and-error process where services (e.g., shops) open up more or less stochastically, and close if they are not sufficiently patronized, leads to a remarkable internal organization of the city where boroughs or communities of different population density, but organized in clusters of 7, where the central borough serves the surrounding ones for the less frequently used services. These clusters organize hierarchically into an upper level cluster of 7, etc., with 5 hierarchical levels identified for the city of tens ($7^5 = 2401$ communities). The remarkable result of this organization is that the corresponding distribution of services minimizes the total length of trips, *i.e., travel time*, for the population, relative to any other distribution (e.g., a random one would require an *order of magnitude more travel time.*)

As we are chasing for the Arabian Phenix, a theoretical model for the exponential distribution of population density in a city, we have found in the paper a lead for constructing such a model: *The theoretical requirement of energy minimization* (travel time minimization in our optic) *was then found to be expressed by the relation PR = Const, where P is the population and R the radius of the community.* Although organization seems to adjust to density, one could try the other way round. Linking the two in a feedback system may permit calculation of the optimal density distributions.

Quite interesting, if in an indirect way, are two books which relate city transport and livability. Although no explicit theory exists, when penetratability into part of the city – usually the center – is reduced, decay begins. People and business leave. It is like a tissue deprived of blood circulation, becoming cold and finally going into gangrene.

The first one is **P. Hall and C. Hass-Klau (1985)** *Can Rail Save the City?*, which compares pedestrianization, in principle reducing traffic through a reduction in speed, plus rapid transit systems, which increase it, for various cities in Britain and Germany. The cities compared are reported in Table 3.6. They differ much in history, structure, and population, but especially in cultural context. The Germans seem to have well understood that *no blood, no life*, and made pedestrianization together with compensatory measures. The consequence, reported in the introduction (page 2) is that: *"British visitors to Germany ... could not help noticing that the cities looked remarkably attractive. Indeed most of them seemed to be positively bursting with life. The pedestrian streets were packed with people. Trade in shops was booming. There seemed to be very few of the "To Let" signs that festooned many British cit centers. The new rail systems were full of passengers. Generally German cities seemed to be free of the blight and depopulation that disfigures British cities."*

We find here, in anecdotical form but quantitative, what we have stated in our previous research on transport (**Marchetti, 1994a**), that the mode is not so important but the speed. People are ready to accept the incommodities of public travel if there is a marginal speed gain over private transport. And they avoid going into spaces where speed approaches zero, as in city centers not sufficiently organized.

The second book by **P.E. Peterson (1985)**: *The New Urban Reality,* reports case histories in America, and is more general in scope than the previous one dealing with the various facets of urban change. There is, however, a chapter by Kenneth A. Small, specifically on *Transportation and Urban Change*. He starts with a critic about *old* policymakers ignoring the interrelation between transportation and land use, showing that some elementary intuitions take very long time to get perceived by the decisionmakers. It is obvious for anybody opening, e.g., a shop, to ask himself if the prospective customers have a reasonably easy way to reach it. And also the reverse is true, the choice of the residence place is almost always done with an eye to the accessibility of the working place.

The author, although appreciating the central importance of transportation for city structures, is not really capable of making sense out of it, oscillating between the assumption of it being cause or effect, perhaps more of the second as he takes a quite fatalistic attitude toward the possibility of reversing historical trends of central city decay, by making it more accessible in terms of travel time. As many economists, the author fails to appreciate the importance of time, per se, as an anthropological constraint (**Marchetti, 1994a**). However, he rightly concludes that improving intracity transit is necessary for central districts revival.

Putnam, 1983, 1991. Putnam is a key author in the area of urban modeling and the relation between city structure and transport and the book is an excellent review of what has been done in the art. The book of "Integrated Urban Models" (1983) makes available the results of more than a decade of investigation of transportation–land-use interrelationships in metropolitan regions. Both theoretical and empirical analyses are described. The theoretical work begins with accounts of simple models of transportation and land use, while the empirical work *attempts* to fit these models into an observed reality. The development of the first successful integrated transportation and land-use model is then described, together with the results of prototype applications.

Many of the future research suggestions made in this book are described as completed work in "Integrated Urban Models 2". The author then traces a series of theoretical developments, empirical verifications, and subsequent policy analyses, as well as their effects on one another.

The author himself states in "Integrated Urban Models 1":

> At first, despite the empirical evidence of their interrelationships, research on transportation systems and research on urban spatial phenomena were conducted with very little interchange of theory or practice. Later, with the entropy-maximizing derivations of spatial interaction models, the connections, in theory, between location models and transportation system models became more apparent. Yet, in practice the two endeavors were conducted virtually in mutual isolation. While many of the professionals in the field gave lip service to the need for their integration, in practice, little was done. This was a classic example of analysis of portions of a system, with a variety of factors, not the least of which was bureaucratic tradition, militating against analysis of the whole system. There were technical reasons as well, as will be described in later chapters of this book. Nonetheless, it was not until 1971, with the beginning of the first phase of the research work described here, that either an empirical or a theoretical analysis of the interrelationships between urban transportation and location was undertaken. The study of urban spatial dynamics is well into the discovery phase, having accomplished extensive stating and testing of relationships amongst the components of the system.

In "Integrated Urban Models 2" (1991) the author writes:

> There had, of course, been considerable development of mathematical models of location (land use) and of mathematical models of transportation. Even

> so, the models were often improperly specified and their workings only poorly understood. The interactions between such models were largely unexplored. In the twelve years' research described in "Integrated Urban Models" considerable work was done to develop and test improved, *practical*, versions of the models and to examine and understand their interactions.
>
> Time after time during the experimental work and the writing of this book the issue of complexity arose. In some of the more recent theoretical works in this field the reader is confronted with dizzying cascades of ever more complex equations. Even in this book where the emphasis is deliberately placed on the practical consequences of the developments in the theory some fairly complex model structures are presented. There are two worrisome points in this regard. First, there is the issue if obtaining the data necessary to test and evaluate such complex structures. The field must beware of becoming too well described by a remark attributed to Mark Twain: "There is something fascinating about science – one get such wholesome returns of conjecture out of such a trifling investment of fact." Second, there is the possibility that even as data become available, the systems and their requisite solution procedures may become so complex as to make it quite difficult to understand what is happening in any case. These issues will have to be faced time and time again as work in this field continues.

In other words, the modeler is entangled in the mathematical net. Although the cross-sections analyzed are partial description, the supersimple models used by Marchetti (1990) may give the tools for a restart. We have the impression, gathered especially from our familiarity with energy modelers, that they are too proud of their mathematical prowess so as to dedicate insufficient time to the *"meditation on the object"* which is at the basis of the simplicity a physicist can reach when faced with very complex systems.

Also the practical idea of progressive modeling, starting, e.g., from the village and let the complexity of the model grow when sufficient experience on the simpler case has been gathered, does not seem to penetrate into the mind of urban modelers. They start from London or Tokyo and get lost. There is also a certain academic preference for mathematical virtuosity. Our very simple models are often snobbed at becaused "so complex problems *cannot* be described in such a simple way". On the face of Newton.

Anyway, the two books by Putnam are recommended reading to get a synoptic view of the state of the art.

Table 1.

The main characteristics of the ISGLUTI models

MODEL:	AMERSFOORT	CALUTAS	DORTMUND	ITLUP	LILT	MEP	OSAKA	SALOC	TOPAZ
MODEL TYPE:	Predictive	Predictive	Predictive	Predictive	Predictive	Predictive	Predictive	Optimising	Optimising
MODELLING TECHNIQUES USED*:									
Spatial interaction	✓	✓	✓	✓	✓	✓			✓
Utility maximising		✓	✓		✓	✓	✓	✓	
Market equilibrium		✓	✓			✓	✓		
Cohort/Markov survival			✓		✓				
Input/output economic base						✓			
Micro simulation			✓				✓		
Linear regression		✓					✓		
Mathematical programming								✓	✓
LAND-USE LOCATION:									
Number of categories of:									
population	3	1	80	4	3	4	1	1	1
housing	1	2	30	-	1	**	-	2	1
employment	1	15	40	4	12	5	18	2	1
Workplaces	-	-	40	-	12	**	-	-	-
Model includes: land prices		✓	✓			✓	✓		
housing rents			✓			✓			
TRANSPORT REPRESENTATION:									
Model predicts: trip pattern	✓	✓	✓	✓	✓	✓			✓
traffic congestion		✓	✓	✓	✓	✓			
car ownership			✓		✓				
Number of: trip purposes	1	5	4	2	5	4			4
transport modes	1	2	4	2	3	3			2
DATA BASE:									
City represented:	Amersfoort	Tokyo	Dortmund	San Francisco Bay Area	Leeds	Bilbao	Osaka	Uppsala	Melbourne
Population (thousands)	153	27,904	1,075	4,064	497	970	14,556	160	2,697
Area (square kms)	202	14,565	833		164	75	8,000		3,000
Number of: internal zones	26	76	30	30	28	28	40	49	41
external zones 7	12				12				
lower level zones 77		14,500					840		

NOTES:
- * See Section 3.4 for explanation of techniques.
- ** Supply of accommodation is represented by available floorspace for which the different categories of demand compete.
- 7 External zones to handle in-and out-commuting.
- 77 Models contain two level zonal hierarchy: larger number of zones at lower level offer greater spatial detail.

Figure 1.

Population growth of alternative 'Londons', 1801-1991

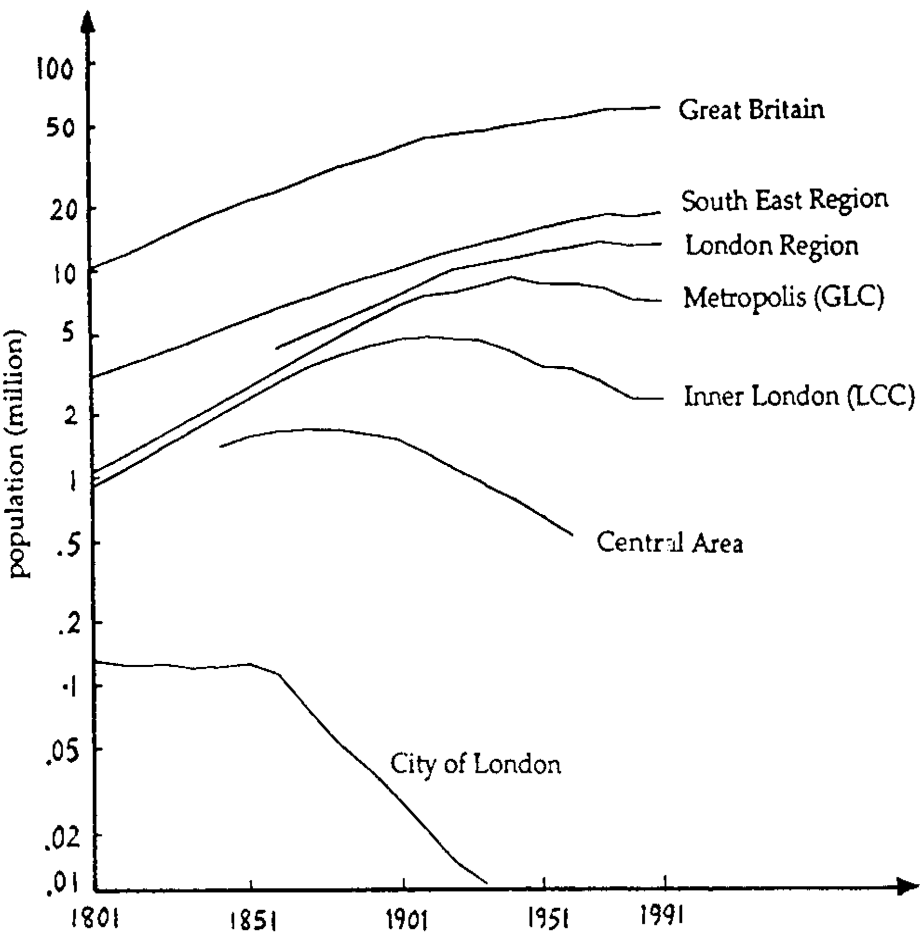


Figure 2.

Fitted lognormal distribution of population within a London region for 1971 and 1981

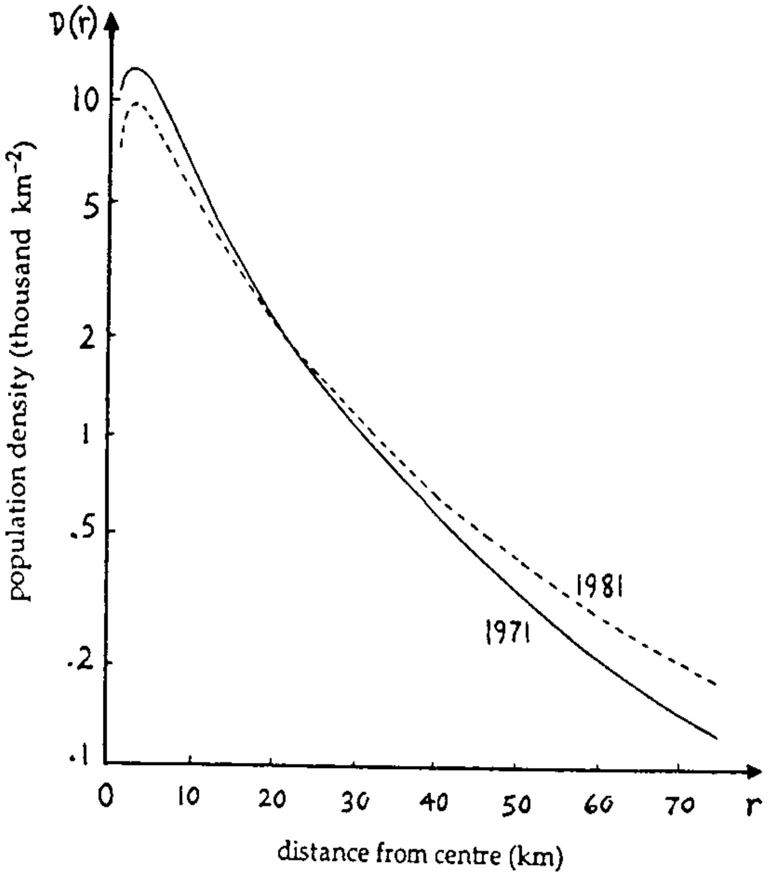


Figure 3.

Distance-density plots for London Metropolis in selected years, 1801-1981

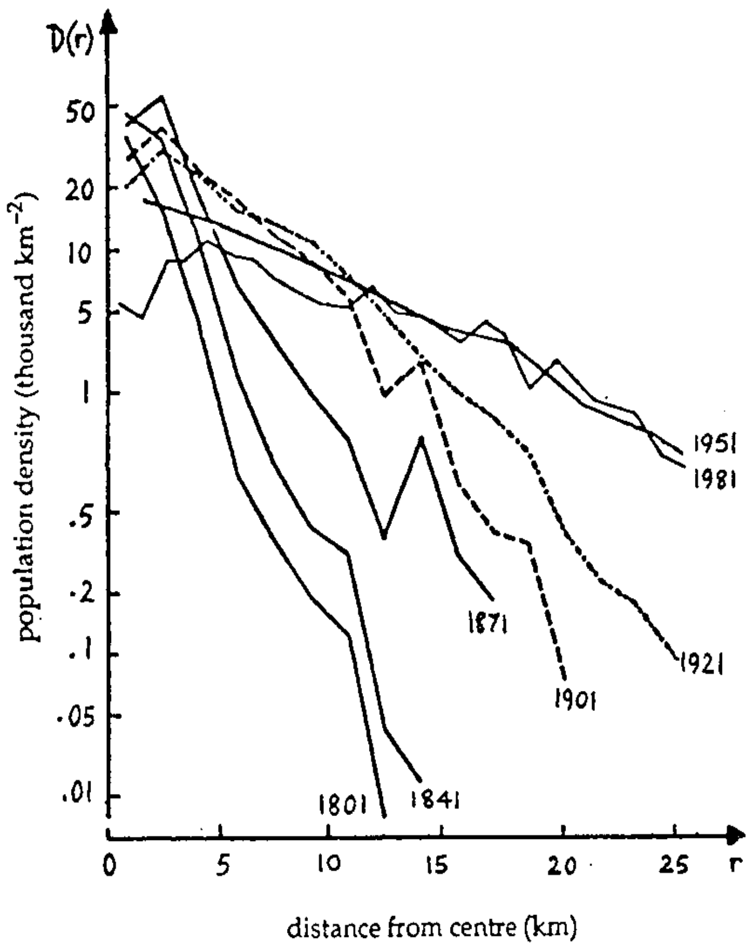


Figure 4.

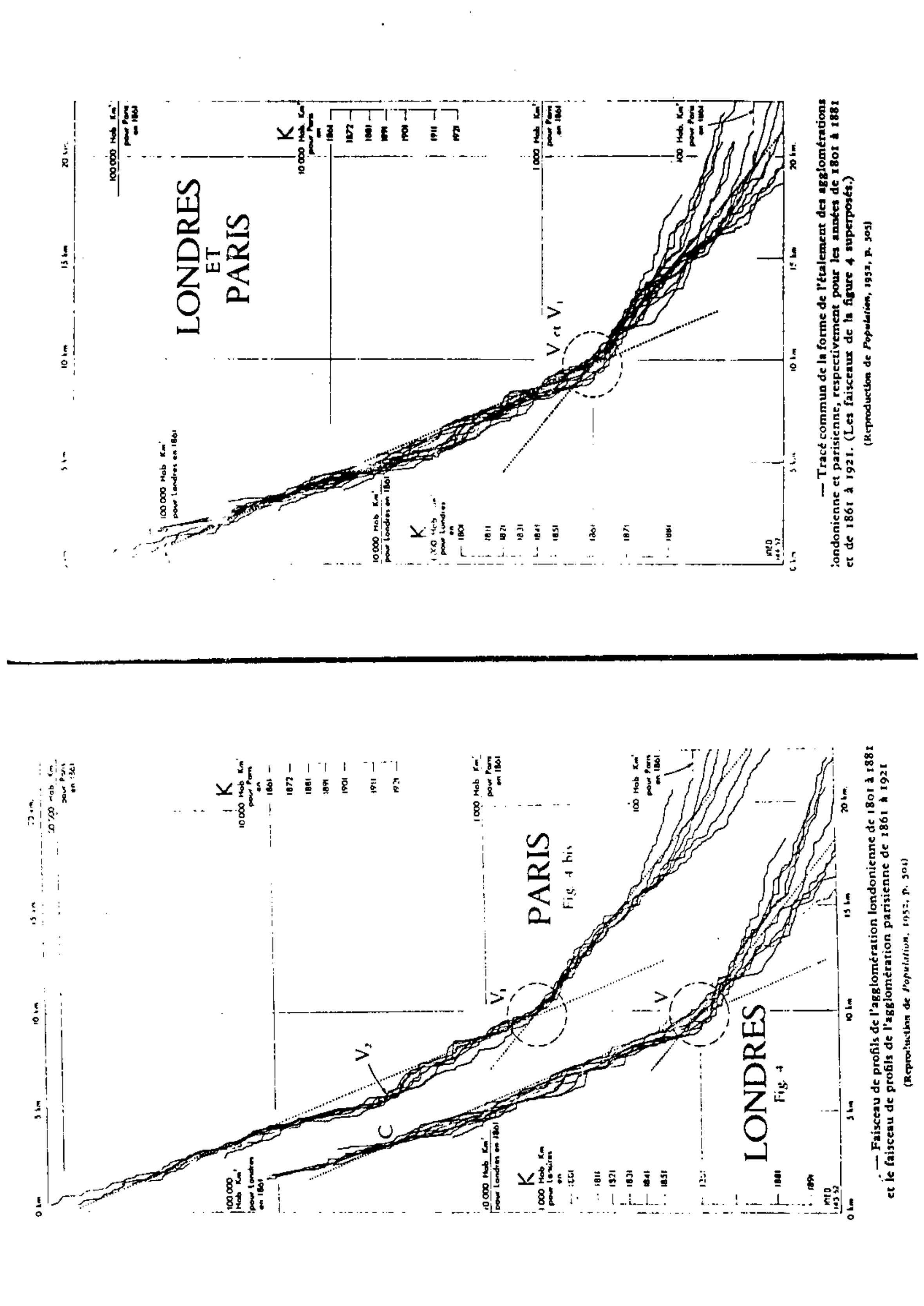

LONDRES
ET
PARIS
V et V1
— Tracé commun de la forme de l'étalement des agglomérations londonienne et parisienne, respectivement pour les années de 1801 à 1881 et de 1861 à 1921. (Les faisceaux de la figure 4 superposés.)
(Reproduction de Population, 1952, p. 305)
PARIS
Fig. 4 bis
LONDRES
Fig. 4
— Faisceau de profils de l'agglomération londonienne de 1801 à 1881 et le faisceau de profils de l'agglomération parisienne de 1861 à 1921
(Reproduction de Population, 1952, p. 304)

Figure 5.

Loose Comments on Quoted Literature

Konvitz (1994) is somehow marginal to our subject, but describes a development in city structure (*the edge city*), where the periphery develops the functions of the center: *it involves a decentralizing redistribution of economic civic and transport activities as a pattern of polycentricity replaces the concentration of functions in the city center. Examples include Tyson Corner hear Washington DC or La Defense and Marne-la-Vallée on either side of Paris.*

In our opinion this is the consequence of the city having been unable to solve its transport (accessibility) problems to the satisfaction of the users. Especially toward the center.

Levinson and Kumar (1994) present the empirical and analytical counterpart to Konvitz (1994). They analyze the historical evolution of travel times (1968 with reference to 1957 and 1988) in the Washington area, showing that they stayed constant (see Marchetti, 1994). This means that transport problems have been solved in a city that changed much in 30 years, or that the citizens solved them by relocation into a viable context. This can be the "edge city" quoted by Konvitz (e.g., Tyson Corner for Washington). The concept of *"Randstadt"* is also developing in the densely populated Europe of Ruhr-Holland. In our opinion *it constitutes a de-optimized solution by respect to a well-served central city* (or a lumped city).

Morris (1994) (third edition) produces a magnificent collection of urban shapes in sketches and drawings, more than 1000 of them. We consider it as the ideal book for the *meditation on the object* that every mathematical modeler should do (for a month) before starting to shuffle his mathematical tools.

The same could be said, for modern cities, of the book of **Brian J.L. Berry and Quentin Gillard** on *The Changing Shape of Metropolitan America* (1977). The wealth of quantitative data in terms of shape and movement (commuting) is really impressive.

As noted by **G.K. Zipf (1946)** in his *Human Behavior*, cities organize according to a hierarchy of size (later interpreted by Christaller), following very simple rules (basically a Pareto distribution). Usually a larger size corresponds to a higher hierarchical level. Functionally the area commanded by the influence of a city depends on the speed of the means on transport (about two weeks travel is indicated in Marchetti, 1994). That London could be the functional capital of the world, or Rank No.1, during the second part of 1800, was made possible by the new transport technologies. Now that the airplane makes the world still more a single unit, it is interesting to see the process of globalization in a historical context. **R. Kasaba, ed., (1991)** *Cities in the World-System* does that, although in a fragmentary way. But subjects like the Ottoman realm are brought up with richness of information.

O'Brien (1992) is interesting for our question of urban morphology, because it touches, in the special area of finance, deals with the question of the necessity of personal contact, i.e., travel, to run the necessary contacts of current life.

In the case of financial transactions, the system operates in an abstract, electronic way the world over, and the operators can be completely delocalized (but they sit at their desk in the city). The problem of telecommunication versus travel has been extensively and unconvinc