

*Road Network Dimension  
and  
Average Journey Length*

*Measuring Network Efficiency  
with  
Fractal Geometry*

*by*

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*1 June 2000*



## **Abstract**

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Urban transport has been inefficient and its energy usage and emissions have been a major source of the global environmental destruction. This is largely because land-uses have been segregated, and thus journey length has increased to the extent that essential services have been too far. International discussion has concluded that the compact city is a possible solution, which many governments have adopted without enough verification. Even the definition of compact city is not yet clear.

In this thesis, I use the concept of *fractal city* as an analytical method of the need to travel in cities, as well as a design theory of sustainable development to reduce the travel need. Indeed, this concept represents the city's internal efficiency through the 'fine grain' of street pattern to which Jane Jacobs has given the name and many urban designers have tried to visualise since then. The concept of *fractal dimension* is used to analyse the efficiency of the city's road network by desktop GIS, while that of *generator* is used to describe the design rationale of sustainable development.

Therefore, I will postulate that fractal dimension represents the city's efficiency. The average journey length is used as an indicator of transport efficiency of the city to demonstrate the hypothesis. The results of the analysis shows a high correlation ( $r^2=0.658$ ), compared to the other factors such as density ( $r^2=0.493$ ) in English context.

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# **1 Introduction**

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## **Introduction**

How many problems addressed in the 19th century have been solved, or at least alleviated?

More than a century has passed since the modern town planning was born in Britain, notably by Ebenezer Howard, yet the environment continues deteriorating, its influence scale becoming global, the economic imbalance of the rich and the poor increasing, unemployment remaining, urban crime getting more violent. One may criticise the current economy: 'healthy' economy has not only caused high unemployment and corporate crime but also ecological disasters and social disintegration. "Conventional economists, whether neoclassical, Marxist, Keynesian, or post-Keynesian, generally lack an ecological perspectives" (Capra 1982: 431).

Among them, environmental change has become fatal to our existence as the increasing capacity of the human race to provoke adverse environmental change on a truly global scale after the Industrial Revolution, and environmental concerns appear to have entered a new era associated with human activity. Both the scale and scope of environmental degradation present fundamental challenges to the stability of the global environment, possibly posing a threat to the very survival of the human species as well as the other creatures. Some of these threats were identified as early as in 1972 at the United Nations Conference on the Human Environment (UNCHE) in Stockholm. Concerns over the global environment have grown, ranging from radiation pollution to acid rain, ozone layer depletion and global warming (Haughton and Hunter 1994).

Solutions have been sought on an issue-by-issue basis until the World Commission on Environment and Development (WCED) in 1987, where the so-called Brundtland Report was produced. This report introduced the concept of sustainable development with a chapter

dedicated to the problems related to cities, their form and development patterns in particular, as a result of the complementary nature of urban and regional strategies.

Sustainable urban development is therefore a major theme for planners by the early 1990s (Hall 1998). Despite successful institutionalisation in the UK, planners still fail to include certain environmental considerations in everyday planning unless the central government does not specify it (e.g. Owens 1992). This is largely because it is “not at all clear how this mapped into actual everyday decision in everyday urban contexts” (Hall 1998, p.412). Indeed, most environmental problems arise from, or consumed, in urban areas (Haughton and Hunter 1994). In worst cases, badly planned areas and new towns by the then urban policies of economic restructuring, for example, have promoted suburbanisation in North America and, to less extent, any developed countries which is one of the reasons of the current vehicle emissions (Hall 1998).

Some critics such as radical ecologists see the system of the current society as the cause of these problems (Capra 1982). One of theoretical failures in town planning is the approach taken to describe the cities. For example, most of urban models are static whilst the real cities are, and should be, dynamic. A typical example is Howard's Garden City, although his original intention was more dynamic and flexible, which produced many garden cities around London, yet “the core of the British urban problem was still seen to lie in London” (Hall 1996: 133). Form follows function, as many, if not all, architects believe. And the function has been determined by the mechanical vision of the world. Roads, for example, have changed as people's needs change from movement to the place to meet other people and exchange information and goods. Many of the current largest cities, including New York and London, are originally port towns developed as transport nodes. Town planning, derived from architecture, then merged with social reforming, economic regeneration and now sustainable development, has seen its function in a vary narrow way. The planning policy changes as

the nation's needs change. Howard (1898) saw it only as a solution to London's environment. Many of today's planners see it only as a tool to redevelop economically declined areas. Consequently, the form that followed the function defined by the planners has been dull, often removed the details as functions were removed.

A solution again came from physics. As early as in 1945, when town planning was to be legislated in Britain, Ilya Prigogine and his colleagues have shown that, in 'far from equilibrium situations' such as the cities, no optimisation principle and fluctuations can grow (Prigogine 1997). Since 1950s, the new science of form has followed this new science of function by Benoit Mandelbrot: fractal geometry came onto the academic stage, as well as design stage, with its ability to visualise the dynamic systems whose behaviour is either theoretically or empirically chaotic. In the study of urban morphology, despite the long relation of its location theory and central place theory and fractal geometry, there are still few attempts in relation to town planning. The analysis of optimisation in nonlinear mathematics, yet planners solution is very often linear, such as Le Corbusier's Paris plan for 3 million people.

Developments are, however, good examples of the processes of self-organisation, thus fractal geometry. A variety of land-uses are being continuously developed by the city's various internal and external demands. This spectacle that coloured map of land uses changes in the course of time reminds us of Conway's Life Game which boomed in 1970s.

In the thesis, I will explore how this new idea begins to answer, or at least help us to, the current planning issue of sustainable transport: reducing the need to travel in Britain's national policy. In addition to this, I have set a series of ambitious objectives: to link the practice-theory gap by supplying a method to view both models and real cities; and to construct a dynamic design theory based on it. By doing so, I shall seek to give some practical guide to everyday planning rather than pursuing academic interests as many researchers have done for the last few decades. The tool I use is fractal, the geometry of describing the nature, chaos and

complex systems. Indeed, there is a growing number of studies to see artificial systems as fractal, some related to urban morphology and geography. However, there is few discussion which has tried what it implies in the context of planning, what Hall (1998) calls “divorce of theory and practice” (p.418). In this thesis, therefore, I will seek to link the current studies of fractal cities with planning in reality. Some criticise that planners have transplanted many theories from physical science, often unnecessarily or wrongly, and this thesis may challenge this. The concept of fractal may not be one of them, or may be. Yet the potential of fractal geometry is enormous particularly when fractal dimension is defined to mention a physical value of the city in a way density does.

### **Fractal cities: a new paradigm towards 21st century?**

The city is often said a cancer, an overgrown organ which takes all the food, so much food it can no longer perform its proper function (Haughton and Hunter 1994). It is also said a parasite in a similar sense. However, there is a distinctive difference between cancers and parasites. Whilst cancers occur within the body and lead it to death, parasites are external and sometimes build a symbiotic relation with their host. We have, in this sense, an interesting study on parasites. William Daniel Hillis (in Levy 1992) interprets parasites in a comprehensive and unique way in his computerised Artificial Life. In host-parasite relation:

If a host population evolved strategic traits to foil the parasite, the parasite would in turn evolve a strategy to compensate. William Hamilton, among others, had suggested that the presence of parasites might have been integral in accelerating the pace of evolution to a rate capable of yielding its present diversity and complexity... If one thought of [hosts] as chessplayers, [the parasites] were chess impresarios, who produces a series of opponents. The fist ushered in fumbling novices, provided that experienced players when the beginners were consistently vanquished, and eventually flew in cunning grand matters.

Under continual attack from these challengers, the host were forced to devise evolutionary strategies that would maintain and even improve the quality of their sorting... (p.201).

The comparison of the systems with and without parasites is easy: the host with parasites found a better solution they could not have hoped to attain. Hillis (in Levy 1992) concluded, "the interesting thing in natural selection is not the evolution of a single species, but things like the coevolution of hosts and parasites" (p.203). We know that dinosaurs have, after prosperity, come to extinction for whatever reason. If cities and human beings are parasites, nature and us may be seeking the most efficient way collaboratively.

The naturally grown cities have some kind of symbiotic relations with nature and human beings and other creatures, thus sustainable not because it is natural but because it is the result of a continuous series of trials and errors. The thesis seeks a new paradigm by adopting and developing the concept of fractal cities to visualise the a possible form of sustainable cities. Fractal is a new scientific interest of anything with natural shape. Indeed, "many important patterns of Nature are either irregular or fragmented to such an extreme degree that ... classical geometry is hardly of any help in describing their forms" (Mandelbrot 1983: p.1) and more and more application on artificial objects have been sought rapidly. So far, I shall point five characteristics of fractal  $F$  in mind:

- i)  $F$  has a fine structure, i.e. detail on arbitrarily small scales;
- ii)  $F$  is too irregular to be described in traditional geometrical language, both locally and globally;
- iii) Often  $F$  has some form of self-similarity, perhaps approximate or statistical;
- iv) Usually, the fractal dimension of  $F$  (defined in some way) is greater than its topological dimension;
- v) In most cases of interest  $F$  is defined in a very simple way, perhaps recursively (Falconer 1990).

The first two characteristics are tightly related. Fine structure of an object is full of details that cannot be described in Euclidean geometry. Although its primary function can exist without any detail, it is usually thought as primitive. The only exception in human history is perhaps

modernism. Fractal brings back once lost details of urbanité in city planning. The third characteristic is related to one of design philosophies: consistency, or robustness and appropriateness in Bentley et al's (1985) term. When an architect designs a church, for example, all the details are related to the concept, as Michael Angelo's Last Supper has existed in the domo in Milano for four hundred years. As Camillo Sitte (1965) has pointed out, his other masterpiece, David, has lost its context completely since it was replaced in a museum. The remarkability of fractal is, however, largely in the concept of fractal dimension that combines art and science, idea and reality and simplicity and complexity.

## **Structure of Thesis**

The first two chapters discuss the necessity of a new paradigm to achieve truly sustainable cities. Chapter 2 reviews the current policies and practices of sustainable cities in North America, Europe and the UK because there is a gap between policies and practices (chapter 2) and academic studies (chapter 3). The development and design control should be responsible for the sustainability of cities because there is a potential for urban planning to improve our living as well as to deteriorate it, but planners have lost confidence because they have missed the way towards the ideal city if it exists. As Alexander (1997) has pointed out, all that practitioners need is now clear judgement of alternative measures. This issue is perhaps a common feeling among planners as the article attracted two comments and, probably more local discussions.

The new measure should be implemented. Planners no longer have the power once Georges-Eugène Haussmann had when he restructured Paris. Although in some countries, planners still have strong development control in transport and land-uses, not so in many countries. In such countries, planners are now to determine the development proposals issue. In the UK, for example, planners' most likely tool is development control based on the

development plan to determine each individual planning application. Therefore, the measure should be rather bottom-up approach than conventional top-down theories, such as Howard's Garden City, which have promoted New Towns and Urban Development Corporation.

Chapter 3 reviews the current academic studies of urban form and energy efficiency mostly, although not always, in terms of transport. Many of the theories are borrowed from physics such as gravity model and entropy, which have been taken completely out of its context and misinterpreted. In applying them, planners have removed many factors that give urbanity to the city, in order to make a 'model' of city. Yet, Fritjof Capra (1982) rightly addressed:

... Scientists construct a sequence of limited and approximate theories, or 'models', each accurate than the previous one but none of them representing a complete and final account of natural phenomena. ...

The question, then, will be: how good an approximation is the Newtonian model as a basis for various sciences, and where are the limits of the Cartesian world view in those fields? ... (p. 93)

When making an airplane, for example, this approximation does not cause a significant damage, even though we still have many accidents. The recent accidents of atomic power plants have reminded many people of this question. In the city where one factor may cause multiple effects that subsequently trickle down to minor, or in some cases up to major, effects as a result of accumulation, the appropriateness of approximation is often ambiguously discussed, or sometimes, completely ignored by planners.

Another issues found in the review is that most of them have ignored the context. Most notably, planners' favourite of international survey is criticised. Indeed, the cities in different countries are in different historical, ecological, social, political and economic context and none of the studies has considered to that extent that approximation does not fail to represent the reality. Banister et al. (1994), for example, compared five cities in England with varied sizes and varied transport policies. The analysis, as could have been predicted, failed to

identify which of them affected the travel demand in those cities, and to what extent. Newman and Kenworthy's (1989) international comparison of 30 cities vary up to 10,000 per cent in its sample city size.

Because these lack in academic sense, in the following chapter, I will have to undergo the background analysis of urban form and traffic demand. That is, the effects of self-sufficiency, size, population and density on travel demand in the context of medium English towns. The result is in some cases quite different. Also in this chapter, I will compare the effects of these urban factors on travel demand.

Chapter 5 will seek to construct a possible design theory of the sustainable city with less travel by adopting the new science of efficient natural forms. First, I will define fine structure and fractal city. Design of fine grain is the topic as well as that of urban hierarchy. Engwicht (1993) has observed:

The tragedy of many modern, Western cities is that they have become mono-cultural. By mono-cultural, I do not mean that they do not contain many cultures and a wide range of activities, but that these have been segregated and fenced off from each other much as a farmer may fence off different crops. (p. 27)

This, in terms of design, means accessibility and, in terms of urban design, permeability. And in this sense, fractal gives us a effective guideline because it is the most natural and efficient form of transportation in the reality. It is reasonable, therefore, I will postulate the hypothesis of fractal and locational optimisation. The mathematical analysis of optimisation, indeed, gives us a form that look like fractal.

And finally, fractal dimension is introduced as a method to prove the hypothesis as well as a planning tool to measure the city's fineness. The concept of fractal dimension is a crucial element of the thesis. With the dimension, it is now possible to compare the fineness of street patterns, and mixed-ness of land-uses of the existing cities and urban models, as if comparing size, population or density. And the measurement procedure is, thanks to the

power of the Geographical Information System (GIS), quite practical compared to the other studies reviewed in Chapter 3 as it takes only 10 minutes for a city. This fact is called a fine grain of the city and that of land uses and street patterns are widely recognised.

In chapter 6, I will introduce the theory of fractal dimension and develop an estimation method to apply to sample English towns to prove this hypothesis, using MapInfo, a desktop GIS application. Discussion follows the analysis, which focuses on the difference of reality and models and the relation of fractal dimension and travel demand.

## **2 Policies for the City, Roles of the City**

### **Introduction**

The modern planning has started when Ebenezer Howard (1898) addressed an issue of the Victorian slum and concluded the evolutionary solution of Garden City. It is ironical that, after almost a century had passed, 'planning turned from regulating urban growth, to encouraging it by any and every possible means' (Hall 1996: 343). Economics are "inescapably at the heart of achieving sustainability" (Rogers 1997, p.153). The current context of town planning politics towards sustainability is therefore quite pessimistic (Blowers 1992). Although the sustainability debate have attracted a number of local, national and international initiatives, many of these are only acceptable to politicians and public alike because they "tend to provide reassurance that present patterns of growth can be sustained provided there are marginal shifts in behaviour" (Blowers 1992: p. 25). This is, however, nonsense because the achievement of sustainability would require revolutionary changes, like Howard did, in the nature of production and consumption; in the balance of relations between developed and developing countries; and in the self-interested attitudes of nation-states.

There are political constraints on the prospects for such revolutionary change. Politicians will be motivated by: the net benefits of resource use, international competitive advantage, and short-term political survival. Only when the disbenefits arising from environmental damage outweigh the benefits, is self-interest likely to be compatible with sustainability. Self-interests will always be the determinant of change (Blowers 1992). Although I mentioned just above that we need an evolutionary change, it is hardly possible to achieve our objectives without considering the current context of politics. Also important is to understand the problem properly. As Breheny (1992b) has pointed out, planners tend to assert without understanding the

problems properly.

## **Diagnosis of The Current Transport System**

The transport sector is a major source of greenhouse gas emissions (Tables 2.1). Fossil-fuel combustion in vehicles and transport equipment accounted for about one-fifth of global carbon dioxide emissions in 1990. Transportation's global fuel consumption rose by 50% between 1973 and 1990, largely because of higher incomes and steady or declining fuel costs. Without new measures to slow the growth in emissions, the use of fossil fuel for transportation is expected to increase by another 35-130% by the year 2025 (Schwela and Zali 1999). Transportation also contributes to local and regional pollution problems through its emissions of carbon monoxide, lead, sulphur oxides (SO<sub>x</sub>) and nitrogen oxides (NO<sub>x</sub>).

Automobiles are the transport sector's largest consumer of petroleum and its largest source of carbon dioxide emissions. The developed world has the highest per-capita ownership of private cars today; developing countries currently claim a mere 10% of the world's cars, but are expected to account for most of the future growth in automobile use.

According to Banister (1992), in terms of energy, car and motorcycle are not only the dominating modes of transport but also the least efficient (Table 2.2). Compared to public transport such as railway and bus, the efficiency of car and motor cycle is three times worse and, to walk and bicycle, twelve times and thirty times. Combined with its modal share of all trips (77%) and its longer average journey length (8.66 miles for car drivers and 5.89 miles for non-car-drivers), the car accounts for over 90% of all energy consumption in transport. These figures do not include a significant amount of energy and emissions during its production.

The emissions and energy consumption (E) are given by two factors: engineering condition

Table 2.1: The United Kingdom Atmospheric Emissions by Source

USE	Emissions (Percentages)					
	Smoke	SO <sub>2</sub>	NO <sub>x</sub>	VOC <sup>1</sup>	CO	CO <sub>2</sub>
Domestic	33	3	2	2	4	14
Commercial	1	2	2	-	-	5
Power Stations	6	72	28	-	1	34
Refineries	1	3	1	*	-	3
Agriculture	-	-	-	*	-	-
Other industry	13	16	8	2	4	23
Railways	-	-	1	-	-	-
Roads	46	2	51	41	90	19
Civil aviation <sup>2</sup>	-	-	1	-	-	-
Shipping <sup>2</sup>	1	2	5	1	-	1
Total <sup>3</sup>	100	100	100	100	100	100

Notes: (1) Remaining 54% of VOCs are emitted by processes and solvents, gas leakage and forests.

(2) These statistics only cover estimates of the United Kingdom aircraft up to a height of 1,000 metres, and those for ships only cover the United Kingdom territorial water (i.e. up to 20 km off the shore). So the figures will tend to understate the proportion of emissions from ships and aircraft.

(3) Figures may not add up to 100% due to rounding.

Source: ECOTEC (1993)

such as engine efficiency, car tuning and catalysis efficiency and travel length driven as:

$$E = F(\text{car condition, efficiency}) \times G(\text{travel length}).$$

New technologies may increase the efficiency of automobiles and reduce emissions per kilometre travelled. New materials and designs may also reduce a vehicle's mass and increase the efficiency at which it converts energy, thus lowering the amount of energy required to move it. With improved transmission designs, engines can operate closer to their optimal speed and load conditions. Technological improvements in combustion-engine technology and in petroleum formulations have already started to reduce per-vehicle emissions of both greenhouse gases and conventional pollutants. The energy intensity of these engines can probably still be improved by 15-30% using current technology. More dramatic improvements could be achieved by, for example, adopting hybrid cars that use a combination of fuel-fired engines and electric motors.

Switching to less carbon-intensive fuels can also reduce carbon dioxide emissions. The fea-

Transport Mode	MJ/passenger mile
Car Petrol	3.21
BR Electric	0.89
LT Tube	1.08
LT Bus	0.83
Other Bus	0.83
Minibus	1.15
Bicycle	0.10
Motorcycle	3.13
Private Bus	1.40
Other Private	1.15
Walk >1mile	0.25

Source: Banister et al. (1994)

sibility of operating vehicles on fuels other than gasoline has been demonstrated in many countries. Alternative transport fuels include compressed natural gas, ethanol, methanol, and electricity derived from non-fossil sources. Compressed natural gas has been used successfully in fleet vehicles for a number of years in the US, Europe, and New Zealand. Brazil has a programme to promote the use of cars fuelled by ethanol derived from sugar cane and other biomass. Such programmes can offer long-term global climate benefits in tandem with immediate improvements in local air quality.

Although there is scope for further improvements in vehicle emissions as mentioned above, but in themselves they will not be sufficient. It is anticipated that there will be only slow increases in the energy efficiency of all modes and the rate of improvement is likely to be lower than the rate of increase in travel demand because the current economic and legislative environment is not providing a strong impetus for these developments (ECOTEC 1993).

On the other hand, the approach to reduce road traffic can save both emissions and costs and thus more feasible. For example, traffic management such as controlling the average occupancy rate for passenger vehicles; computerised routing systems for trucks; restricting the use of motor vehicles (ECOTEC 1993). Convincing people to switch from automobiles to buses or trains can reduce primary energy use per passenger-seat-kilometre by 30-70%. A vital part of encouraging this transition is providing safe and efficient public transport sys-

tems. Given the current quality and condition of public transport, however, this approach is not for the largest cities such as London. Cities can also promote walking, bicycling, and car pooling by limiting automobile access to certain roads, increasing the fees for public parking, and converting existing roads into bicycle lanes, bus-access roads, or High Occupancy Vehicle (HOV) lanes during peak hours.

As the variation in the shape, size, residential density, layout, and location of activities in cities can bring energy-demand variations of up to 150%, there is a strong possibility of land use planning to contribute (Haughton and Hunter 1994). Compared with the other means mentioned above, this approach seems less economically limited.

Modal shift to more energy efficient transport, such as bicycle, bus and railway, is a solution, although public transport also requires a significant amount of energy. In addition, the provision of public transport should be coordinated with other means since the introduction of free public transportation in the Netherlands for students merely increased the overall traffic, without discouraging the use of car (Murrain 1993). Table 2.2 and Figure 2.3 show that as journey length increases, we tend to use less efficient mean of transport.

Most land uses change only slowly, but high travel-generating uses, such as offices, convenience retail, and leisure developments are renewed more rapidly, providing greater scope for planning to influence travel behaviour. A simulation study, for example, indicates that planning policies in combination with public transport measures could reduce projected transport emissions by 16% over a 20-year period (ECOTEC 1993).

### **Practices to Reduce the Need to Travel**

Apart from academic and political discussions, there are already some practices with sustainability in mind. Some different approaches in different countries will be reviewed in this section. The Transit Oriented Development (TOD) is a practice in California mainly domi-

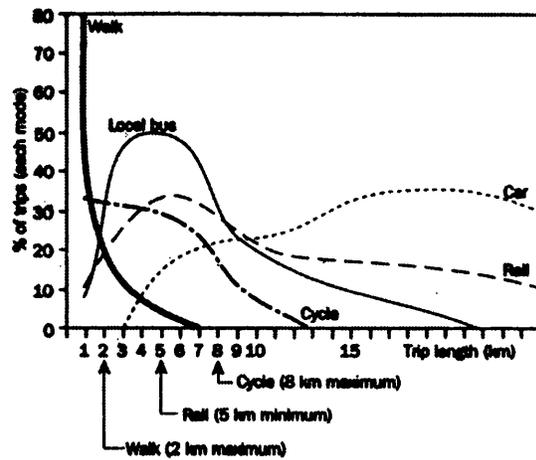


Figure 2.5: Threshold Distances and Journey Length by Transport Mode:  
 Source: ECOTEC (1993)  
 Original: National Travel Survey 1989/91

nated by private sector but has become the basis for the urban master plan for the state capital of Sacramento. Another review compares the large-scale new towns in the Netherlands and the UK started in the 1970s or late 1960s.

#### Practice 1: Transit Oriented Development

Peter Calthorpe (1993) is one of the architects that visualised Jacobs' words. The focus is therefore reasonably on the quality of life, rather than traffic demand as its fundamental qualities of towns are:

- Pedestrian scale;
- An identifiable centre and edge;
- Integrated diversity of use and population; and
- Defined public space.

These qualities was applied in the regional plan of California (Figure 2.5). The plan is subsequently applied to the cities in the area with populations between 100,000 and 3,000,000. The concept is simple: moderate and high-density housing, along with the regional transit

system. Calthorpe calls this type of developments as Transit-Oriented Development (TOD), in which 'walkable' environment is the key aspect of the concept.

In order to develop alternatives to drive-alone vehicle use, comfortable pedestrian environments should be created at the origin and destination of each trip. No one likes to arrive at work without a car if they cannot walk comfortably from transit to their destination or run a mid-day errand on foot. Gordon and Richardson (1989), in a reply to Newman and Kenworthy's (1989) discussion, mentioned that the time spent inside a vehicle is judged to far less onerous than the time spent walking, waiting, and transferring, by a factor of up to three or four times; for commuters waiting on platforms, the factor may be as high as ten times. On the contrary, Rudofsky (1982) found with surprise in Bologna that people goes out just for walking every afternoon. They simply did not know joyful walking because they are not supplied with comfortable 'walkable' street.

In order to manage the transit, Calthorpe advocates it is necessary to keep the density at least 10 dwelling units/acre. The higher the density, the shorter the interval of the transit. He also assumes the transit-oriented development at least between 25 and 50 persons per acre along the railway whilst bus, between 50 and 70. He also advocates that a new settlement should be redevelopment or infilling development as far as possible and that, if only unavailable, a new settlement development should be discussed. Existing on-site uses that are economically viable can serve as the starting point and in some cases will represent the nucleus for future economic revitalisation. The condition, density and intensity of these existing uses must be compatible with pedestrian and transit travel. New uses which are missing from the ideal mix of land uses can be introduced. Uses which rely solely upon vehicle trips, such as gas stations, car washes, storage facilities, models or low-intensity industrial uses, are not likely to contribute to pedestrian activity in the TOD and should be discouraged. Intensification and redevelopment must, however, be balanced with sensitivity to protecting

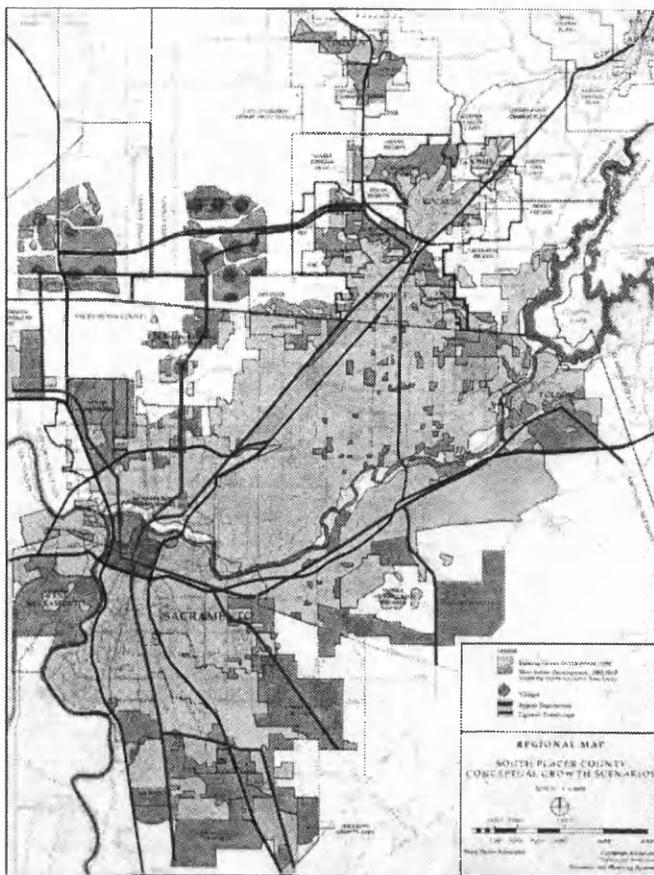


Figure 2.4: Sacramento County General Plan Update and Southport Area Plan  
 Source: Calthorpe (1993)

existing neighbourhoods and the problems of gentrification.

#### Practice 2: The New Towns in 1980s

Both in the Netherlands and the UK, several new towns were planned and implemented in 1980s based on the same academic principle but in different styles. Under the concept of the new integrated land use and transport planning, Second Transport Structure Plan (SWII), the planning of the new towns in the Netherlands is now seen as a good example of sustainable development (Hagino 1995). On the contrary, sustainability was not considered in the beginning of planning in the UK (DoE 1993).

One of these new towns in the Netherlands is Almere, a new settlement (85,000) "which has

a fully integrated transport and land use system with a clear emphasis on cycling and public transport" (Banister *et al.* 1994 p.35). A comparable town in Britain is Milton Keynes, in terms of size and timing (Table 2.5). The overall density is low in both towns, yet housing density is designed to be high with mixed land-uses (Banister *et al.* 1994).

The recent surveys, however, show different travel patterns between the two towns. First of all, as initially planned, the ratio of car use is significantly low in Almere (34.6%) than Milton Keynes (59.4%). In Almere, successfully, the most efficient mode of transport (cycling and walking) account for almost half of the all travels. However, this fact does not result in minimising the journey length as the work trip length in Almere is large (17.7km), compared to Milton Keynes (13.2km). This is largely because Almere functions as a satellite town of the Amsterdam conurbation rather than an independent town as self-containment (jobs to residents) is as low as 29%. Other Dutch new towns are more successful in terms of self-containment. The planning of Houten was accompanied by planning of a new business district in an adjacent area where 70% of Houten residents find a job (Hagino 1995).

### **Policies to Reduce the Need to Travel in Britain**

From the late 1980s, the impact of the new concept of sustainable development has closed in policy makers. The European Community published a document on the environment and sustainable development that included the compact city as the desirable urban form of sustainability (CEC 1992). Similarly, in Britain, DoE addressed new settlements in a number of documents: formal policy documents; a succession of appeal decisions; structure plan policy decisions; and environmental assessment requirements (Breheny, Gent and Lock 1993). The government published *This Common Inheritance: Britain's Environmental Strategy* with 352 proposals in 1990. In *Sustainable Development: The UK Strategy* (DoE 1994), the government identified a goal to 'meet the economic and social needs for access to facilities with

Table 2.5: The Urban Form and Traffic Demand in Milton Keynes and Almere

	Milton Keynes	Almere
Population	40,000 (1969) 173,000 (1991)	85,000
Area	9,000 ha	13,975 ha
Self-sufficiency (RW/R)	60%	40% (1980) 29% (1990)
	grid (1km) mixed land uses	each district is 2km radius
	Linford Ward	Almere Haven
Car journeys	59.4%	34.6%
Journey length to work	13.2 km	17.7 km
Journey length	7.2 km	6.9 km

less need to travel'. Things are easier said than done. So is reducing the need to travel in the UK. Although this concept is widely accepted among town planners, the government offered "little practical advice on that matter" (Walker 1997, p.75).

The Government requires local planning authorities to coordinate their policies for transport and other forms of development to reduce the need to travel in Planning Policy Guidance note 13 (PPG13, DoE 1994) by giving incentives to people through land use planning. PPG13 is Britain's solution of "joint land-use - transport packages" (Hall 198, p.415), following the Rio accords of 1991, to achieve the sustainable form of developments. In terms of urban form, the possible measures include location of developments: promoting development within urban areas, at locations highly accessible by means other than private car; locating major generators of traffic demand in existing centres; and strengthening existing local centres (Figure 2.6). A provision of new access road to support public transport is assumed to reduce the need to travel, with the provision of adequate public transport.

Although some practice guide (DoE1995) has later been attached to PPG13, there remain two issues. First, the models seem mere re-visualisation of Garden City or the neighbourhood unit used in the 1970s New Towns and not discussed in detail the difference from them.

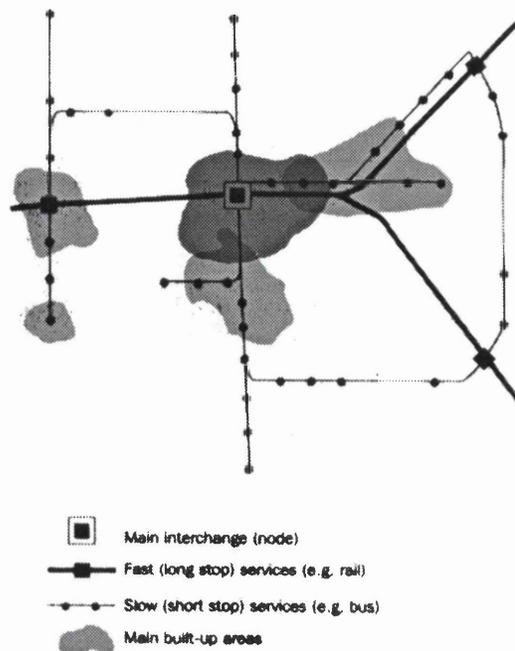


Figure 2.6: A Regional Plan Model by the Government  
 Source: DoE (1995) A Guide to Better Practice

The guidance mentions that this concept can be applied wrongly as the plan of Milton Keynes did not supply certain facilities despite consideration of the concept.

The other issue is if, when done most properly, it results in reducing the travel length. In fact, British urban planning and policy have not done much to achieve their objectives. More generally, planning has not affected urban geography as it was planned. During the rapidly changing 19th and 20th centuries, many cities have risen and lost their positions but these facts were not planners' intention. London is one of them, along with Paris and Tokyo for it did continue to develop, adapting to changed circumstances by developing new industrial traditions out of older ones, and for it subsequently changed their internal economic geographies from the inner city towards decentralised 'industrial corridors', yet this is rather accidental than planned (Castells and Hall 1994).

During this transition, London has experienced a growth in the 'Western Corridor', owing little to conscious planning. The westward shift of London's industry started the process in the

1930s, yet “alarm at the process in the 1930s was one of the main triggers in developing regional policy after the war” (Castells and Hall 1994, p. 152), which was supposed to control industrial growth in the SouthEast and encourage it elsewhere. So was the transport investment decisions: a freeway was started only at the beginning of the 1960s; Heathrow airport was placed with no consideration of regional strategy. They are placed indeed, to accommodate the demand rather than to control it (Castells and Hall 1994).

### **3: Lessons Re-learnt: A Review of Urban Studies**

#### **Introduction**

In the study of the cities, especially in urban and traffic studies for planning, the most popular approaches are modelling and comparative studies (Sue Batty at lecture), or theories and practices. However, modelling contains some issues to address before planners study because a subtle error may result in a totally different conclusion. Comparative studies are more useful if, and only if, it is done properly. This should be emphasised that the current studies of traffic amounts contain some common problems.

Travel behaviour is very complex. It is not possible to describe even one person. Researchers, as will be discussed in this essay, have made the models to statistically forecast the pattern and the models to fit people in. However, people do not actually move as the models imply, and do not follow the models planners and architects hope. Prigogine and Stengers (1984) explained:

To take the classic example cited by Waddington, a programme of slum clearance results in a situation worse than before. New buildings attract a large number of people into the area, but if there are not enough jobs for them, they remain poor, and their dwellings become even more overcrowded. We are trained to think in terms of linear casualty, but we need new 'tools of thought': one of the greatest benefits of models is precisely to help us discover these tools and learn how to use them. (p. 203)

In searching new tools, we have to be aware that linear modelling is such a delicate method, which many researchers have ignored, that a small error can cause a significant difference.

This kind of phenomena is called 'chaos'. By model, we discuss both simulation models like SimCity and analytical models. Cartwright (1991) explains this kind of models:

Gathering more information or constructing more elaborate models about chaotic systems can become pointless. In fact 'research' can even be counter-productive, if it creates a false sense of security about planning and what it can do. Our ability to predict the behaviour of chaotic systems is inherently limited. Looking for more accurate models of housing demand or traffic flow

is potentially a fool's errand if these phenomena are indeed chaotic. (p.53)

The chapter then sees comparative study a better solution to this approach in planning but as a starting point to find out a 'new tool of thought' rather than a possible tool itself. Although the approach seems appropriate, many of the current comparative studies have one or both of two essential problems: some comparisons are academically and/or practically inappropriate. The chapter then seeks what a new tool of thought can be, by reviewing some of the well-known urban studies to identify the inherent problems of urban models and comparative studies.

## **Review of Urban Models**

Since the early twentieth century, a number of urban models have been introduced and perhaps the same number of models have been criticised. In 1930s and 40s, the so-called 'central place theory' was developed and criticised its inability to "react to some change such as a modification of population density, or a transport innovation" (Allen 1997 p.29). The 1970s criticised the use of the systems approach due to their narrow conceptual base of the methods, inflexibility in the basic structure of the process, lack of any real theoretical development, and the fact that the models did not seem to be responsive to the changing demands of the city (Banister 1994). Large-scale models were criticised for its incapability to achieve the goals, which often had not been stated at the beginning of the study, and also for the fact that, for each objective offered as a reason for building a model, there was in many cases a better alternative (Lee, stated in Banister 1994).

The chapter reviews some of more recent models related to land-use and transport planning. The traffic need in the city, which is estimated by journey length or fuel consumption, is determined by a significant number of factors and thus multi-dimensional. One of the main purposes of modelling is to simplify the realities by removing the factors to reveal the relation of



the most efficient transport system at land use parameter 0. By modelling this way, a city is mapped on or within the Brotchie triangle (Figure 3.2).

Entropy  $S$  is, in Brotchie's triangle, a measurement of destination choice at a given land use parameter and is given by the logarithm of the number of possible commuting patterns.

Diversity  $1/I$  is, on the other hand, the qualitative range of occupation choices. In the statistical mechanics or thermodynamics, they are related as:

$$U = R + S/I. \quad (3.1)$$

The Triangle shows the city's potential and current efficiency of its settlement geography. It also shows that the efficiency varies significantly among different cities. Despite these characteristics, however, the Triangle contains four essential issues which are also found in other planning studies. The first two are involved in the Triangle itself, while the other two are the

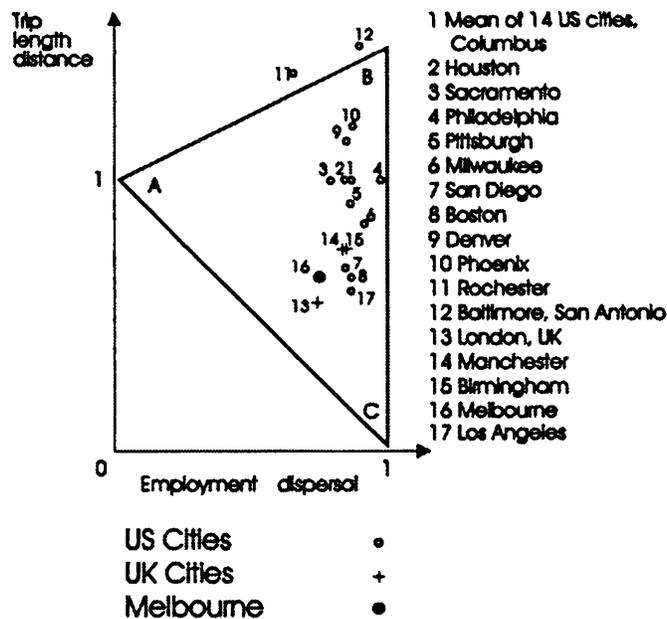


Figure 3.2: Brotchie Model of Land-use and Transport Models  
Source: Brotchie *et al.* (1996)

matter of comparison.

First, the procedure of modelling requires a significant amount of efforts. The measurement of land use and transport parameters are so hard that it can hardly be done frequently. Although the Triangle has some academic meaning, it is less practical in everyday planning.

The other issue of the model is more severe and critical. Entropy can, in fact, only be defined in an isolated system, yet the city is open, or more precisely 'dissipative structure' which entropy can not be defined. Capra (1982) has pointed out that:

..., although entropy is extremely useful as a variable for economic analyses, the framework of classical thermodynamics in which it originated is quite limited. Specifically, it is not adequate to describe living, self-organising systems - whether individual organisms, social systems, or ecosystems - for which Prigogine's theory provides a much more appropriate description. (p. 438)

This is a good example how planners misunderstand natural science. The failure is the assumption that the cities are at a static equilibrium. Intuitively, we know that any city is non-static but dynamic. Some urbanists even insist the dynamics as an essence of the cities. And it may not be surprising, but the cities are never at equilibrium, which is defined only in isolated systems. The systems like cities is called non-equilibrium or far-from-equilibrium systems. Statistical mechanics assumes that any system is at equilibrium, but human behaviours do not organise this kind of system as long as people are alive. The notion of entropy is, by definition, the randomness of a static isolated system, and thus can hardly represent the city.

One of the remarkable features of the city is that its each individual element is able to construct the city. This kind of systems in this sense are called self-organising system (Prigogine and Stengers 1984). This phenomenon is quite common as all the living creatures are self-organising. A machine is not self-organising because they do not construct themselves. Here is the gap between the reality and the modernists' beliefs that 'housing is the machine

of living in'. The city is able to maintain a certain form or even able to grow on their own, but only at far from equilibrium because the city maintains itself with continuous inflow and consumption of people, information, goods and energy and their mutual interactions. According to Prigogine (Prigogine and Stenger 1984), this kind of systems is called dissipative structure. As this example shows, planners are not expert in science and thus often make a wrong discussion in applying natural science to urban study. As a machine can not be dissipative, housing should not be 'the machine of living in' against Le Corbusier insisted.

Other mistakes found in the Triangle are from comparative view points. The first issue is a simple failure how to compare the parameters among several cities. When you make a comparison, in academic sense, you have to select comparable samples, which are identical with only limited exceptions. When you compare men and women, people would assume they are all both human, not dog male and human female. Even within the same race, you may make comparison such as scientists and artists, but in this case they must be, for example, both European scientists and artists, not European scientists and Chinese artists unless there is a reason. Jacobs (1961) have already given us a great insight of what comparative study should be, by referring four initially identical squares in Philadelphia:

... What has become of these four, all the same age, the same size, the same original use, and as nearly the same in presumed advantages of location as they could be made?

Their fates are wildly different. ... (p.120)

One of them is now Philadelphia's great asset, two of them still ordinary squares and one has been slum-cleared. These squares do not only illustrate the volatile behaviour that is characteristic of city parks, but also what comparative study should be. For example, in preparation of the development plan for a growing city with 100,000 population, planners should compare the current cities with those of population 200,000 to identify the best development pattern. None the less, planners compare very different cities such as American cities and

Asian cities without examining other factors. In the worst cases, they justify their study as the samples are collected all over the world even though they are incomparable. Consequently, the study is scientifically unreliable.

Urban study is supposed to contribute to urban planning. The other issues is the samples themselves in this sense. In Brotchie Triangle, the issue is that there is little variation in land use parameters among the sample cities. Although it does show us how far the city has the potential to reduce the traffic demand at the condition, the study does not show us what to do. This issue will be reviewed in the later part of the essay.

#### Review of Urban Models 2: Cellular Automaton model

Cellular Automata (CA) is a new class of the computer models of how a small number of cells form a strange patterns, by giving us the opportunity to simulate existing urban form and to provide for the design of optimal forms (Batty 1997). The concept is, the city is complex, so are the CA models, thus the city might be expressed as a cellular automata model. Since a CA system seems to consist of agents and a limited number of rules, the analysis of the rules may help understand the changing of cities.

CA are models in which contiguous or adjacent cells, such as those that might comprise a rectangular grid, change their states - their attributes or characteristics - through the repetitive application of simple rules. The current urban models based on CA are usually two-dimensional whose rules for transition are quite simple (Batty 1997). The rules for transition from one cell state to another can be interpreted as the generators of growth or decline, such as the change from an undeveloped to a developed cell or *vice versa*. This change acts as a function of what is going on in the neighbourhood of the cell, and the changes in the neigh-

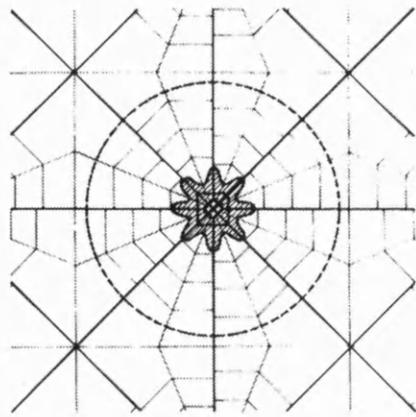
bourhood trigger the change of the cell state.

This approach seems appropriate when it is linked with common and understandable rules (Semboloni 1997) and the analytical approach which draws on established studies in urban morphogenesis and economic, social and cultural phenomena (Erickson and Lloyd-Jones 1997). The current researches are, due to the performance of the computers, still stuck in very basic models with a few rules, reacting only to the cell's small neighbourhood. In addition, the rules should be expanded to the internal emergence mechanism of the cell and external factors of the system to express urban and regional models as the urban system is self-organising as well as 'dissipative'. It is therefore impossible to explain the emergence of New Towns, for example. Another example is that a person (an agent) invented a mass production system of private vehicle (a rule) in the city or elsewhere, which, through a significant effort of marketing research, will rule the transport system. This subsequently affect the people's (agents') life styles (rules) and the environment itself.

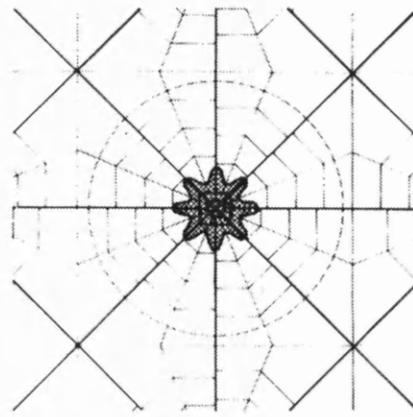
### Review of Urban Models 3: Six Settlement Patterns

Another approach of models is to create several settlement patterns to compare. Rickaby (1987) reasonably demonstrated the relationship of urban form and energy consumption by creating six settlement patterns of English towns of population about 100,000. He concluded that the development for this size of cities should, in order to save the fuel consumption and the cost of fuel savings, be one of two types: concentrated-nucleated configuration or dispersed-nucleated (villages) configuration (Rickaby 1987, Figure 3).

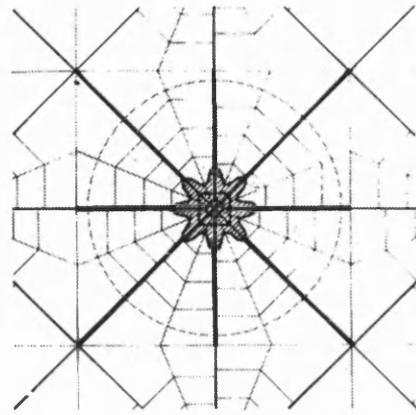
His interest was moved to investigate the impact of various incremental development strategies on archetypal English towns (Rickaby 1991). A single model was created based on twenty English towns with populations about 100,000 with the settlement diameters ranging



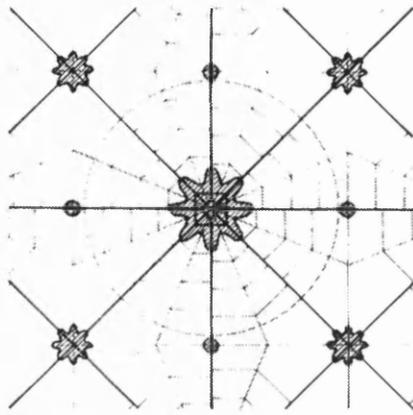
(a) Pattern 0: existing configuration



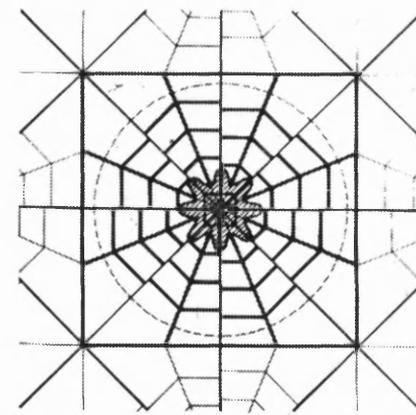
(b) Pattern 1: concentrated-nucleated configuration



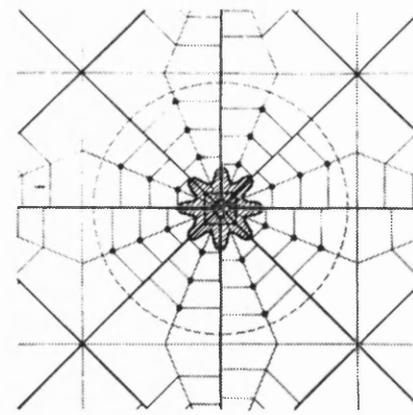
(c) Pattern 2: concentrated-linear configuration



(d) Pattern 3: dispersed-nucleated (satellite towns) configuration



(e) Pattern 4: dispersed-linear configuration



(f) Pattern 5: dispersed-nucleated (villages) configuration

0 5 10 km

Figure 3.3: Six Settlement Models

Source: Rickaby (1987)

between 5 and 10 km. According to Banister *et al.* (1994), these sizes are within the ideal settlement size for walking or cycling. Rickaby (1991) concluded that there was little evidence in the energy impacts of a variety of development strategies as far as the development was within the boundary.

Although Rickaby's models are reasonable, they addressed an issue. It is often indescribable to which settlement pattern a town belongs. The current tools of planning, in many countries including UK, development control, takes a bottom up approach such as development control (Roberts and Lloyd-Jones 1997). The model-based planning seems to require a top-down approach such as government intervention. Now that planning has lost its political and financial power and confidence (Hall 1996), it is unlikely that the town can be developed towards a certain model at large scale.

## **Review of Comparative Studies**

### **Review of Comparative Studies1: Gasoline Consumption and Density**

Many comparative studies have one or both of two failures found in the Brotchie's Triangle case. That is, which cities to compare and in what way. Even the most influential researches such as Newman and Kenworthy (1989) contain these problems, which has led most planners to believe in the relation of density and car traffic. Dangerously, even policy makers, such as CEC, have adopted this view without enough verification (Breheny 1992b). In fact, since 1970s, there have been a significant number of contradictory evidences (see Owens 1986).

The most impressive and influential result is the exponential relation of density and fuel consumption, derived from about thirty cities in America, Australia, Europe and Asia. The higher is the density, the less fuel is consumed in the city. If you remember the argument of the Brotchie Triangle, however, you can view the graph in a different way. First, it does not take

a full account of other factors which affect the fuel consumption. Fuel consumption is, in fact, largely influenced by economic, social and environmental conditions. The efficiency may vary significantly, for example, between cities in cold regions and in warm regions. Also, the size of sample cities, varied from Zurich (the population of 370,000) to New York (the population of 7,070,000; Greater New York 16,180,000) or Tokyo (Greater Tokyo more than 30,000,000), may affect the fuel consumption.

It is more reasonable, therefore, to take the sample cities into several categories: American, Australian, European and Asian cities because, within the category, the conditions of the cities are closer although it is still incomplete (Figure 3.4). The result is clear in Europe. There is little correlation between density and fuel consumption, if any. The density of Copenhagen is as half as that of Frankfurt or Brussels, for example, yet the fuel consumption is also lower than them. The effects of density on fuel consumption still cannot be denied, but only when other factors are properly taken into consideration.

The other issue is how to interpret the meaning of the result, which is not the failure of the discussion but rather of planners. That is, although the effect of density is significant at lower density, so is not at medium and high density. To reduce the fuel consumption to half may require another 10% of density in US, 100% in Europe and 1000% in HongKong and Tokyo, as the figure implies. It is, however, the least practical to raise density by 100% of the existing towns. In Europe and Asia, therefore, it is inevitable that this higher density scheme will fail.

Banister et al. (1994) surveyed five cities with variable sizes and structures: Liverpool (450,000), Leicester (270,000), Milton Keynes (170,000), Oxford (124,000) and Banbury (30,000). In the same paper, they assumed the relation between the size and the main transit mode, but they do not seem to have considered it in the latter chapter which discussed the relationship between energy consumption and urban form. What makes it worse is, they

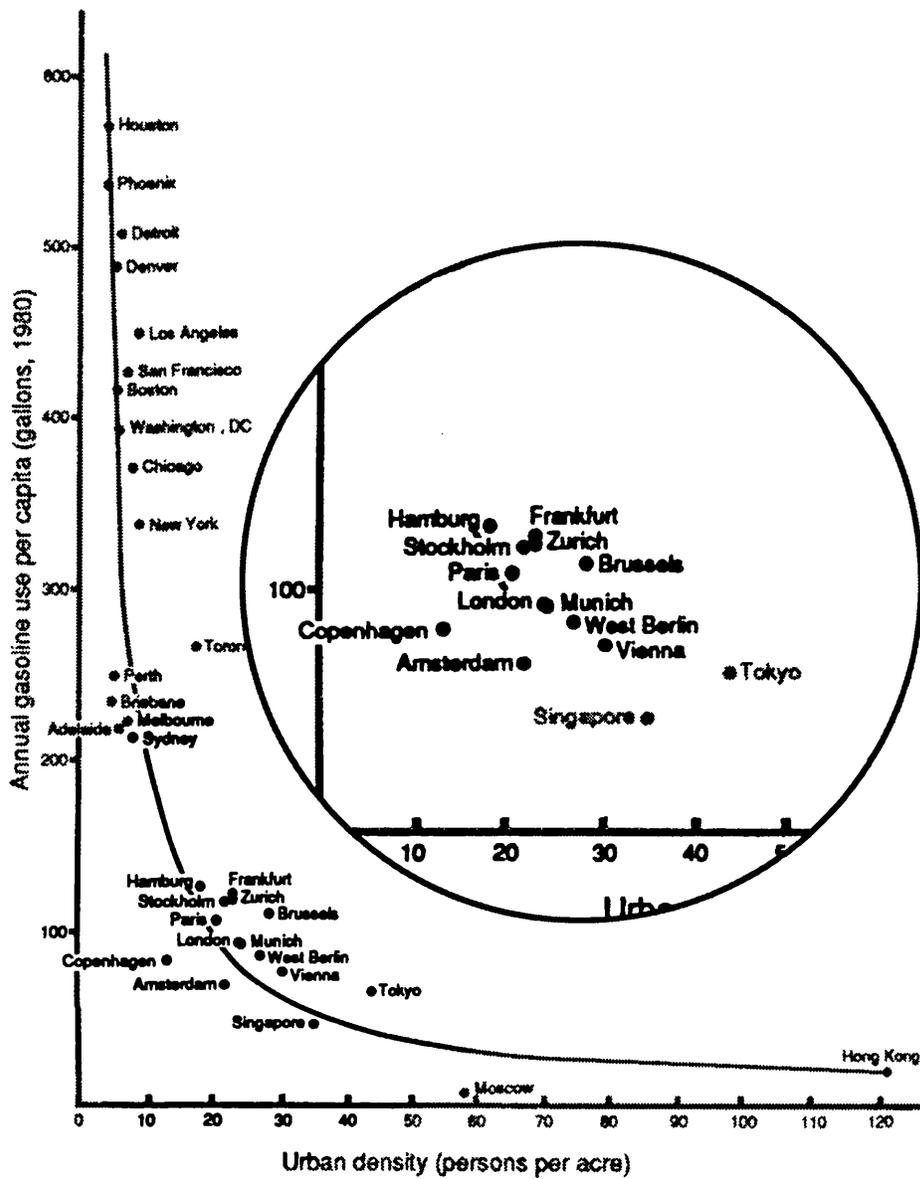


Figure 3.4: Density and Fuel Consumption in Europe  
 Source: Modified from Newman and Kenworthy (1989)

mentioned the difference of the transport policies in the beginning as a reason to compare these cities. The consequence is predictable: the results were so complicated and they had to compare the policies. They even mentioned “[p]hysical concepts such as density, size and shape are all important, but so are economic factors such as degree of self containment and

local employment" (Banister et al. 1994: p. 8), which they ignored in the latter discussions.

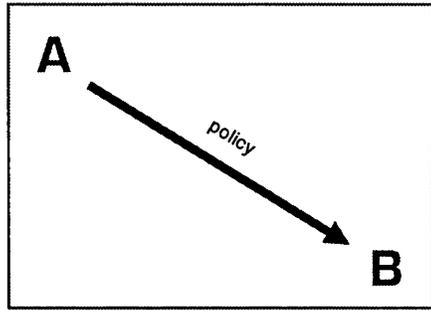
## Lessons Re-learnt

These issues do not deny the possibility of a model that can describe a city. Yet, it can be concluded that it is practically impossible to describe a city with this kind of models reviewed here. By making a model, details are removed. However, as Jane Jacobs and Christopher Alexander discussed (see Chapter 5), details are one of the crucial factors which make the city livable and organic. None of these models is able to answer the questions addressed by Jacobs (1961): "why some slums stay slums and other slums regenerate themselves even against financial and official opposition[?]" (p.5)

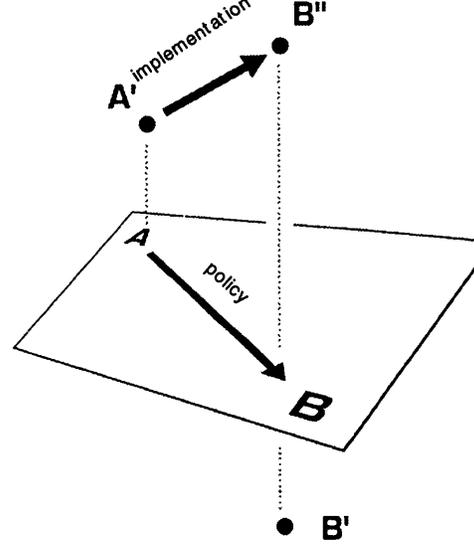
The real city is oo-dimensional, taking account of political, economic, social and historical effects. People develop a land not only because two objects interact each other, but various interested groups interact each other. The resulted equation is therefore multi-dimensional, yet the dimension of a model is always lower. Suppose that the current condition of city is A, in Figure 3.5a, which is mapped A on the model which has ideal condition in B. The policy from A towards B can be implemented in any way in reality as Figure 3.5b shows.

Allen (1997) modelled the city as self-organising to "show how the macroscopic pattern of settlement, the hierarchy of cities and towns, results from the aggregate effect of individual decisions, each of which is being made in pursuit of personal goals and limited information." (p.27) A possible solution to overcome these problems is to see the city as dissipative structure. Limited information, though, can be stored in a set of hard discs, which may be piled up to the moon (Klauss 1995).

Comparative studies, on the contrary, of similar cities but with varied traffic demand is worth considering. Given that the population in the urban areas is growing, it seems the most practical style of study to compare the cities with the same population, the same economic con-



(a) Model



(b) Reality

The solution based on a lower-dimensional model (a), no matter how accurate in theory, may not function as intended in much higher-dimensional reality (b).

Figure 3.5 Model and Reality

dition, the same polices but varied traffic demand, when preparing the development plan for a smaller city. Or, in Jacobs' example above, planners should study the city that have solved the same problem in the same condition.

Hence the chapter title 'Lessons Re-learnt'. Again, we "came back full circle" (Hall 1996 P.421). The review here shows that planners have kept making the same mistake Jacobs pointed out forty years ago, and will they?

## 4 Urban Form and Internal Transport Efficiency

### Introduction

The comparison of internal traffic demand between cities is, if the other conditions are exactly the same, determined by the urban form. For example, English towns with population 100,000 but varied density (and thus area) will show a reasonable correlation with traffic demand, with higher correlation coefficient.

One of the reasons is that the definition of city boundary varies in different countries and in different datasets, yet this consideration is not always taken (see chapter 3). For example, cities in China usually contain a vast area of agricultural land while administrative Tokyo region relies heavily on the commuters from outside. Even within a country, different boundary for different purposes, such as administration, education, and census, may be open to question.

Taking account of them, I shall start to discuss what urban factor affects the traffic to what extent. The discussions reviewed in the previous chapter focus much on self sufficiency and density. However, few of them have discussed in the way that these factors can be compared. That is, the discussion on density does not do the same on city size in the same way even other research demonstrate it. I shall, therefore, analyse as many urban physical factors as possible in the consistent way to compare the effects of these factors.

### Data and samples

There are two available data sets about travel length. Travel survey by DoT, now DETR, has constantly collected travel data of all modes and purposes. However, it has lacked the data of the trips below 1.6 kilometres which do not just account for 35% of all trips (Banister *et al.* 1994), but also are significantly important in the recent discussions of transport policy.

Therefore, the Census journey length to work dataset is used to compare the efficiency in different cities. It may not seem useful as trip to work accounts only for about 30 per cent and the ratio has been declining (Banister *et al.* 1994). However, although it is weak, it surely has a correlation with overall journey demands and fuel consumption (Newman and Kenworthy 1989).

All the Census data are obtained through Manchester Information Data Archive and Statistics Computing Centre (MIDAS, [midas.ac.uk](http://midas.ac.uk)) in digitised formats. The tabular data of area, persons present, density and workplace in districts and metropolitan area are in Small Area Statistics (SAS) for England while journey length to work are in Special Workplace Statistics (SWS) data. They are exported as DBF format in SASPAC on MC6000 via telnet and then imported in Microsoft Excel on a workstation.

The average journey length to work (*AJL*) is calculated based on two datasets: census SAS and SWS. SAS supply with the number of residents in the area and the number of residents whose workplace is home ( $P_0$ ) while SWS supply the number of residents whose work journey length is less than 2km ( $P_1$ ), 2~4km ( $P_{3.5}$ ), 5~9km ( $P_{7.5}$ ), 10~19km ( $P_{15}$ ), 20~29km ( $P_{25}$ ), 30~39km ( $P_{35}$ ), more than 40km ( $P_{60}$ ). Thus, *AJL* is:

$$AJL = \frac{P_1 + 3.5 \times P_{3.5} + 7.5 \times P_{7.5} + 15 \times P_{15} + 25 \times P_{25} + 35 \times P_{35} + 60 \times P_{60}}{P_1 + P_{3.5} + P_{7.5} + P_{15} + P_{25} + P_{35} + P_{60}}$$

## Definition of City

It is one of the most controversial part of this thesis how to define a 'city'. It will directly affect the measurements we will use in this chapter and subsequent chapters. However, as Atkinson and Moon (1994) have attempted to isolate the geographical and social meaning of the term 'urban' and have drawn a conclusion, it is impossible to draw a line round an area on a map and call it urban. It is inevitable to define, in some way, to define the boundary for

the purpose of the thesis, not for general use.

Self-sufficiency is the starting point because it defines the boundary of the city. This has often been ignored by urban developers as the post-war new towns in Britain now show little advantage in this term compared to other towns (Breheny 1992b). However, it was one of the necessities in many urban theories such as Howard's original Garden City plan. It, in the thesis, refers exclusively to employment, although it usually includes the foods and service sufficiency, because the thesis seeks the relationship of journey length to work and urban structure. Of importance is, therefore, the ratio of residents working in the same area to all working residents in the area ( $S/R$ ). Here, a city is a census district or a metropolitan area with enough self-sufficiency as  $S/R$  greater than 0.800.

On the other hand, the districts with high  $S/R$  are also excluded. The boundary of census and administrative districts and metropolitan areas is not necessarily the boundary of the district's urban area and may contain a significant area of countryside. Districts tend to be larger when they are seen more self-sufficient. At an extreme, England as a whole is fully self-sufficient, but it is hardly a city. Another example is isolated islands which have high self-sufficiency tend to have different travel patterns. In this thesis, therefore, only the districts with  $S/R$  less than 0.900 are chosen as samples.

## **Self-sufficiency**

Many theoretical discussions of ideal and/or sustainable cities start with, or assume as essential, self-sufficiency. Howard (1898) devoted most pages to achieve economic and food sufficiency, yet the Garden Suburbs, including those influenced by Garden City but modified significantly, have also been generated all over the world with little consideration of self-sufficiency (Hall 1996). Despite its importance, however, self-sufficiency has not been taken into account in many researches and practices, or sometimes ignored intentionally. Among

the urban studies reviewed in Chapter 3, Banister et al. (1994) analysed survey data of six parishes in South Oxfordshire. Only 41% of full-time workers live and work in the same parish and the ratio varies among the parishes. It is easily expected that the distance and public transport availability to the nearby cities, London, Oxford and Reading significantly affect the journey-to-work pattern and length.

Figure 4.1 shows four different self-sufficiency indicators related to employment. Some empirical research uses Independence Ratio ( $I$ , also known as Independence Index) defined as the number of residents working in a town divided by the sum of residents working outside the town and the workers in the town residing outside as:

$$I = \frac{S}{(R-S) + (W-S)}$$

where  $R$  is the number of the residents in the town,  $W$  the workers and  $S$  those residing and working in the town (see ECOTEC 1993, Breheny, Gent and Lock 1993). Through this chapter, residents means those who are self-employed or employees, residing in the same area or another area. The second diagram shows the ratio of working residents to jobs in the district or metropolitan area ( $R/W$ ).  $R/W$  therefore implies the potential of how far the district can be self-sufficient ( $R/W = 1$ ). The next diagram is for the residents working in the same area to all jobs in the area ( $S/W$ ). And the last, as already defined to identify the city boundary, the ratio of residents working in the same area to all working residents ( $S/R$ ).

Three sets of ten samples are selected at a given density and area (Table 4.1). The results are also graphed in Figure 4.2. The towns in the first set are compact, i.e., dense (3,400 to 4,000 persons per sq km) and small (23 to 50 sq km). The second set is medium towns (density between 1,000 and 1,500 and area between 70 and 200). The last set is countryside towns (density between 200 and 250, area between 400 and 700)

As  $R/W$  implies the potential of self sufficiency in the district, the cities with  $R/W$  less than 1

supply jobs while those with  $R/W$  more than 1 offer workers. It can be assumed in job supplier cities such as major cities, that people are able to find a job near where they live and thus tend to have less journey length to work. The diagram supports the assumption. However, we have to be aware that job supplier cities can live only together with their satellite cities and towns.  $S/W$  seems to have less relation than the rest. This is explained by that the journey length is counted for those who reside, not work, in the area.

Of significance are  $I$  and  $S/R$ . At a given density and area size, ten samples show a linear correlation between the average journey length ( $AJL$ ) and  $S/R$ , with reasonable correlation in countryside towns. This tendency is available in the figure for all districts and metropolitan

Table 4.1: Samples for the Analysis of Self Sufficiency and Average Journey Length to Work

Zone ID	County	Zone name	A /sq km	HR /km	P	$\rho$	I	R/W	S/W	S/R	AJL
<b>COMPACT TOWNS</b>											
25JP	Hampshire	Southampton	49.7	3.98	195,906	3,941	0.94	0.82	0.59	0.72	6.68
20GG	Dorset	Bournemouth	46.1	3.83	154,677	3,358	1.06	0.92	0.65	0.71	6.85
10DJ	Bedfordshire	Luton	43.2	3.71	167,009	3,864	1.04	0.97	0.67	0.68	11.38
23HS	Essex	Southend-on-Sea	41.6	3.64	154,102	3,704	0.98	1.09	0.69	0.64	15.99
11DQ	Berkshire	Reading	40.3	3.58	128,266	3,184	0.68	0.72	0.49	0.69	10.29
34NF	Norfolk	Norwich	38.9	3.52	122,661	3,156	0.68	0.56	0.45	0.81	4.70
37PE	North Yorkshire	York	29.4	3.06	101,436	3,455	0.92	0.75	0.57	0.76	5.90
28KT	Humberside	Great Grimsby	28.0	2.98	89,345	3,195	1.05	0.75	0.59	0.79	5.23
11DR	Berkshire	Slough	27.3	2.95	98,790	3,613	0.56	0.80	0.48	0.60	8.04
22HC	East Sussex	Hove	23.8	2.75	82,891	3,480	0.52	1.14	0.55	0.48	9.86
<b>MEDIUM TOWNS</b>											
14ER	Cheshire	Warrington	175.4	7.47	179,986	1,026	1.08	0.98	0.68	0.69	8.73
03BQ	Greater Manchester	Rochdale	159.1	7.12	196,899	1,238	1.23	1.12	0.75	0.67	7.41
06CH	Tyne & Wear Met	Gateshead	142.8	6.74	197,051	1,380	0.70	0.99	0.58	0.59	7.13
04BZ	Merseyside	St. Helens	132.9	6.50	175,826	1,323	1.08	1.18	0.75	0.63	7.56
23HG	Essex	Basildon	109.6	5.91	157,781	1,439	0.68	1.11	0.61	0.55	15.34
30LP	Kent	Thanet	102.9	5.72	123,079	1,196	3.05	1.16	0.93	0.80	9.83
44QZ	Surrey	Elmbridge	96.4	5.54	110,580	1,148	0.50	1.21	0.55	0.46	11.46
38PH	Nottinghamshire	Broxtowe	80.8	5.07	105,418	1,305	0.42	1.48	0.57	0.38	8.12
25JF	Hampshire	Eastleigh	79.6	5.03	103,742	1,304	0.50	1.15	0.54	0.47	9.83
45RM	Warwickshire	Nuneaton and Bedworth	78.7	5.01	115,653	1,469	0.79	1.33	0.71	0.54	8.50
<b>COUNTRYSIDE TOWNS</b>											
25JD	Hampshire	Basingstoke and Deane	632.0	14.18	141,823	224	1.29	1.06	0.74	0.70	11.98
31LZ	Lancashire	Lancaster	574.3	13.52	126,682	221	4.21	1.04	0.91	0.88	8.07
46RW	West Sussex	Horsham	529.3	12.98	107,354	203	1.04	1.11	0.71	0.64	14.71
47SD	Wiltshire	West Wiltshire	515.5	12.81	106,255	206	2.20	1.08	0.85	0.78	8.35
10DK	Bedfordshire	Mid Bedfordshire	501.3	12.63	108,113	216	0.75	1.36	0.71	0.52	14.96
27KE	Hertfordshire	East Hertfordshire	474.9	12.30	114,831	242	0.73	1.14	0.64	0.56	14.02
41QE	Somerset	Taunton Deane	461.2	12.12	93,958	204	2.95	0.93	0.82	0.89	8.20
24JB	Gloucestershire	Stroud	459.4	12.09	102,024	222	1.58	1.19	0.83	0.70	10.13
14EL	Cheshire	Crewe and Nantwich	429.1	11.69	102,231	238	2.10	1.01	0.81	0.81	7.98
38PN	Nottinghamshire	Rushcliffe	407.9	11.40	95,941	235	0.49	1.39	0.59	0.42	10.15

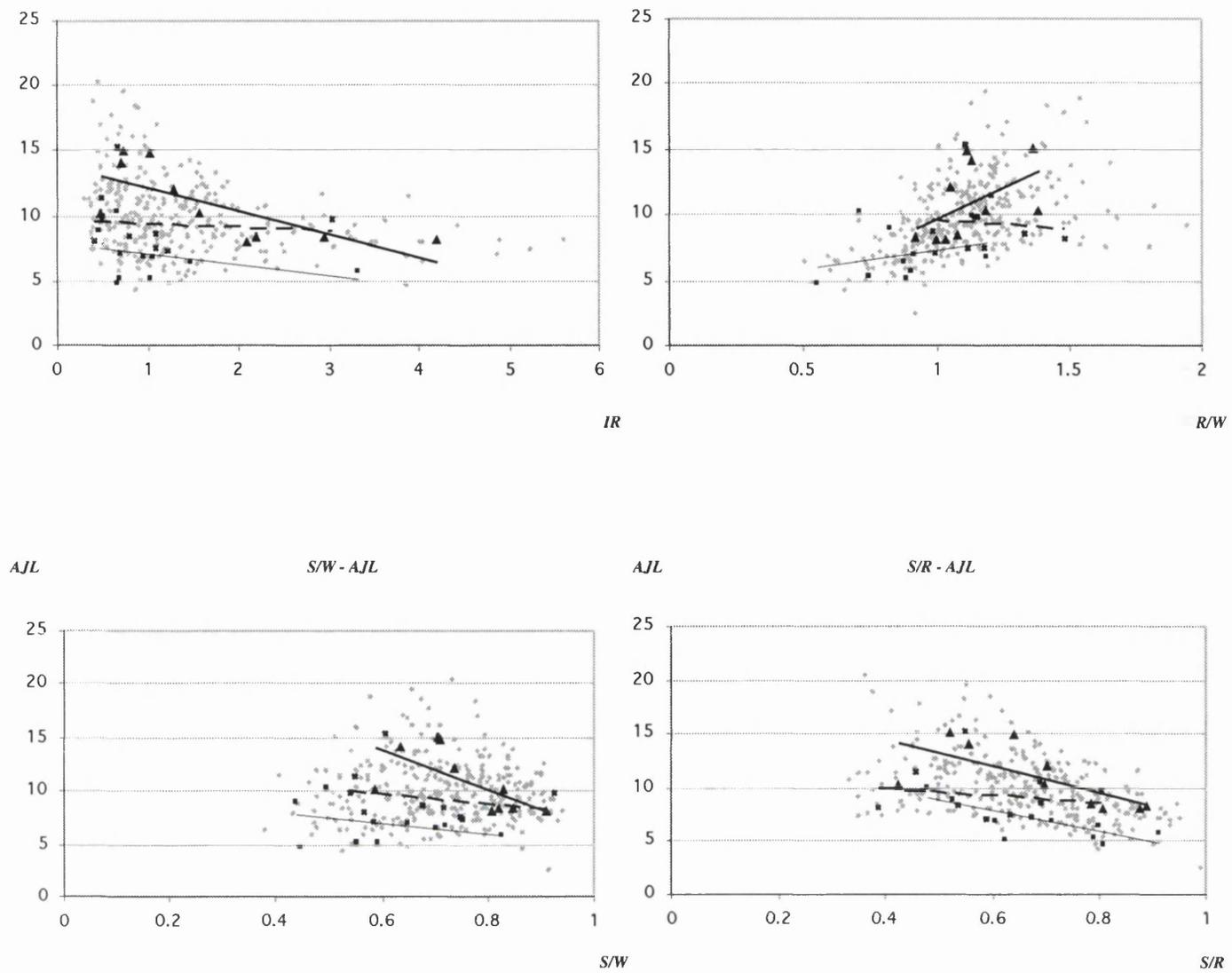


Figure 4.2: Analysis of Self-Sufficiency and Average Journey Length to Work in England

Table 4.3: Results of Self-Sufficiency - Average Journey Length Analysis

	<i>I</i>	<i>R/W</i>	<i>S/W</i>	<i>S/R</i>
COMPACT TOWN	-0.856x + 7.92 0.128	3.00x + 4.37 0.097	-5.61x + 10.0 0.103	-9.27x + 13.4 0.397
MID TOWN	-0.256x + 9.65 0.006	-1.27x + 10.9 0.006	-4.46x + 12.4 0.048	-3.42x + 11.4 0.030
COUNTRY SIDE	-1.78x + 13.9 0.529	9.61x - 0.011 0.245	-18.2x + 24.7 0.422	-12.6x + 19.6 0.470

areas in England. A triangle in the figure implies, at any size and density, that higher  $S/R$  is likely to require less journey length.

This result shows that the average journey length is dependent on self-sufficiency, density and area size. Intuitively, this can be explained easily. At low self-sufficiency, many people work outside the area. Therefore,  $AJL$  for those working outside the area is longer than the radius of the area, which subsequently result in the larger value of total  $AJL$ . And high-density seems to supply services and jobs in walkable distances.

### **Size of Area and Population**

Rapid urbanisation is the most visible effect of the industrialisation on cities and is seen as potentially undermining the overall efficiency of a country because it supposedly creates an unbalanced settlement pattern, especially in the case of urban primacy, where cities are exceptionally dominant in relation to the rest of country. Regarding the growth of very large cities, there is particular concern about whether they are economically efficient in their own right and about whether they efficiently drain their hinterland areas of natural, financial and human resources, weakening these economies in the process (Haughton and Hunter 1994). However, we are also concerned with the effects of population and settlement size on traffic demand because it is assumed as an area becomes larger in population terms its capacity to support a wider range of job opportunities and services will tend to increase, generating greater potential for self-containment (ECOTEC 1993). Large areas may also be better able to support a wider range of public transport services, both to accommodate internal movements and travel to other cities. Conversely, with a given urban structure, the average distance between places will tend to increase as population and city area increase. These conflicting considerations suggest, as turns out to have been the case, that the relationship

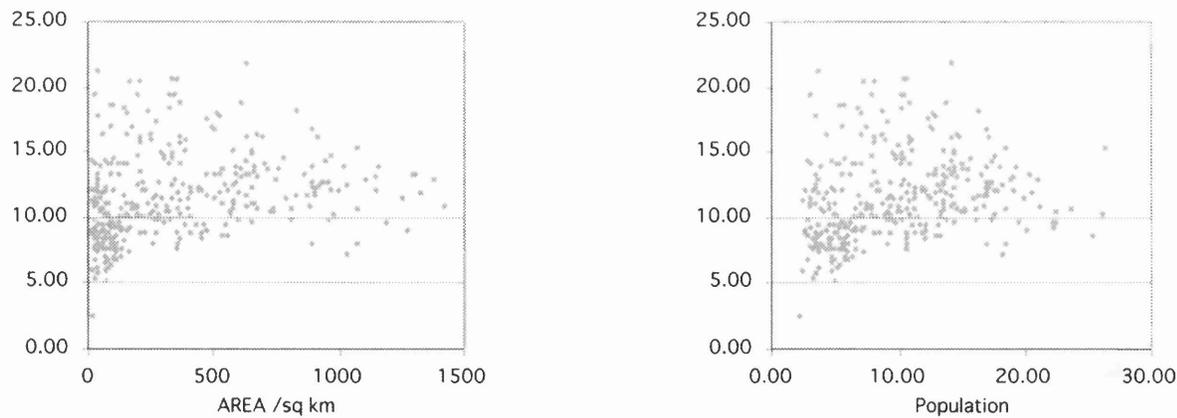


Figure 4.4: City size (area and population) and Average Journey Length to Work in England

between population size and travel is unlikely to be a straightforward one.

PPG13 is also concerned with this issue: settlement size is an important influence on the range of activities within settlements and hence the scope for reducing the need to travel. A medium or large settlements can be relatively more self-sufficient in that it offers a full range of employment, goods, services and activities. This myth is, however, easily tested and denied. Although there is such tendency, the Figure 4.4 shows that this does not always happen. Even smaller districts can be more self-sufficient than larger districts. Although it is obvious that settlements, in PPG13, are smaller category than districts, it is still possible to say that settlement size does not determine the self-sufficiency nor the journey length on its own, but rather it is one of the determinant elements.

## Density

Because of Newman and Kenworthy's (1989) impressive evidence, as discussed in chapter 3, the most planners have been misled to the compact city as a sustainable urban form. The likely effect of density is "low density appears to have a multiplicative effect, not only ensuring longer distances for all kinds of travel but making all nonautomobile modes virtually impossible, since many people live too far from a transit line and walking and biking become

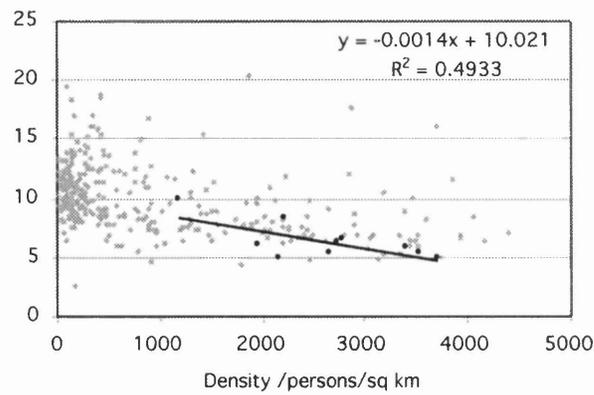


Figure 4.5: Analysis of Density and Average Journey Length to Work in England

impossible" (Newman and Kenworthy 1989 p. 29). The discussion seems appropriate if, and only if, the city supplies enough jobs and services. Therefore, it would finally make to the end the long lasting myth of density-prejudiced view.

According to PPG13, both the length of car journeys and the share of journey made by car are lower in high density areas and therefore residential densities should be planned to take advantage of proximity to activities. However, as discussed above, Newman and Kenworthy's result rather shows less impact of density on journey length in European context (Figure 3.4). The evidence in England shows the tendency that, in even low density towns, *AJL* can be as small as, or even smaller than, high density towns. This tendency is found even in England as a whole; there is less contribution of area size and self-sufficiency. The result is not contradictory with Newman and Kenworthy discussed, but it does not have effect in Europe as much as in North America.

Figure 4.5 is for the districts and metropolitan areas in England. Ten samples are selected at a given condition ( $1000 < \rho/\text{persons}/\text{sq km} < 4000$ ,  $0.8 < S/R < 0.9$ ,  $45 < A/\text{sq km} < 110$ ). Although there can be seen a linear relation with  $r^2 = 0.493$ , *AJL* is limited within a narrow range by the condition and shows less relation with density than with self-sufficiency and

Table 4.6: Density and average journey length to work in England

Zone ID	County	Zone name	A /sq km	HR /km	P	$\rho$	IR	R/W	S/W	S/R	AJL
39PQ	Oxfordshire	Oxford	45.46	3.80	124058	2729	0.90	0.62	0.52	0.84	6.35
19FX	Devon	Exeter	46.89	3.86	101395	2162	1.37	0.74	0.64	0.86	4.98
19GD	Devon	Torbay	62.91	4.47	122885	1953	2.88	1.03	0.87	0.84	6.03
28KW	Humberside	Kingston Upon Hull	71.47	4.77	253111	3541	1.54	0.83	0.69	0.83	5.43
32MM	Leicestershire	Leicester	73.08	4.82	272133	3724	0.93	0.67	0.54	0.81	4.93
18FP	Derbyshire	Derby	77.78	4.98	215866	2775	1.60	0.86	0.71	0.83	6.45
35NM	N'shire	Northampton	80.51	5.06	178570	2218	1.76	0.89	0.73	0.83	8.29
42QP	Staffordshire	Stoke-on-Trent	92.44	5.42	244317	2643	1.42	0.84	0.68	0.81	5.38
30LP	Kent	Thanet	102.88	5.72	123079	1196	3.05	1.16	0.93	0.80	9.83
09DD	Avon	Bristol	109.23	5.90	372088	3406	1.19	0.76	0.62	0.81	5.78

size. This result is consistent with the assumption made earlier.

Despite these evidences, we can hardly ignore the density effect as a diversity generator (Jacobs 1961). It is not net density that causes this effect, nor "numbers loosely added up indefinitely from thinly spread populations" but concentration and distribution of people "for whatever purpose they may be there" (Jacobs 1961: 213). The cities are spatial objects, and have undulations in population density. No matter how much is the net density, if the jobs and services are well distributed around the residential distribution, the journey lengths are likely to reduce. We, therefore, devote a section and subsequent chapters for a new kind of discussions on density, or more properly distribution of settlement, jobs, roads and land uses.

### Urban Form and Travel Length: An Unsolved Issue

Spatial factors such as land uses and transport have been identified as important factors because most traffic arises between different land uses. Indeed, commuting traffic and shopping traffic are two major traffic generators as commuting accounts for about half of all kilometres travelled by private motorists and one-third of all trips. As a result of travel demand and transport management, the road network may well reflect the traffic demand of the area (ECOTEC 1993). However, it has not been sufficiently discussed because it has been impossible to compare those of the actual cities.

Most planners are ambiguously aware that settlement distribution does not consist of size and net density but also of spatial structure. Wang (1998) describes "over the past decades,

design and development of higher residential density in suburbs have always been a challenge for planners. The benefits are obvious: cost savings on infrastructure, preservation of farmland, less commuting and promotion for public transport." (p. 246) In his research, a simulation revealed that increasing suburban road density has more noticeable impacts on suburban population density than adding more radial roads towards the central business district. Therefore, it can be easily estimated that higher road density in suburb tend to reduce travel and thus energy use.

It is easily understood that the road network in the city is developed by the transport and traffic demands to deliver people, goods and information. In the simplest form, the traffic arises as the gravity model. This modelling is useful when, and only when, the number of places are few and clearly defined. However, the actual cities and towns contain large numbers of neighbourhoods and urban villages which let the road network fairly complex. By complex, I shall review in chapter 5 that it is not just complicated, but it generates unpredictable internal effects. Suppose you start your journey at A, through B and C and go back to A. However, you may see your old friends by chance on the way home and may go back to pub with them.

This kind of complexities cannot be well incorporated in simpler Euclidean geometry of lines and circle, within which the ideal forms of road network proposed are limited. Moreover, the ideal road network is never achieved. The hierarchical V7 plan in his city plans, Le Corbusier proposed a combination of hierarchical gridiron road network. Any existing road network is fractal, unlike city models, no matter how simple or complex it is.

## **5 Hypothesis of the City with Less Travel**

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### **Introduction**

The city is a fractal: its structure is fine at any scale. One of the most remarkable characteristics of fractal geometry is its ability to study irregular and natural forms. This is a great leap from urban models to fill the gap of ideal and real cities. To understand the structure and irregularity, fractal geometry uses the hierarchy. We discuss the five dispositions of fractal, referred in chapter 1, as a new tool of thought to materialise and visualise this concept as an attempt to overcome the issues addressed in the earlier chapters.

The current classic, but essential, texts of town planning, such as Jane Jacobs' (1961) *Death and Life of Great American Cities* and Christopher Alexander's (1966) *A City is Not A Tree*, can be read again from fractal viewpoint. 'Fine grain' is now a widely used term in planning which Jacobs (1961) coined in describing a city's component. Many urban designers, including Ian Bentley (Bentley *et al.* 1983) and Peter Calthorpe (1993), have implemented in design (Roberts and Lloyd-Jones 1997).

Special focus will be on the transport system because the system is efficient when its transport form is fractal. Any transport system takes up some space. 70 per cent of the surface area of the city of Los Angeles is in some way, such as roads, garages, and parking, dedicated to the vehicles, whilst the blood system in animal's body takes up only 5 per cent. What is remarkable in blood system is, every single cell is no longer than three-cell away from the nearby blood vessels. Because transport system does not produce anything by itself, widening roads means losing the place of production. Production, of course, does not only mean those of industry and manufacture but also creation of society, community, culture and busi-

ness.

## City with Fine Structure

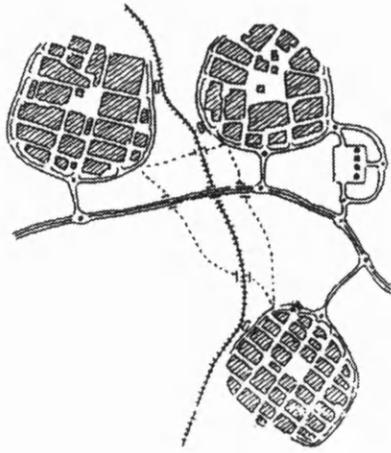
*F* has a fine structure, i.e. detail on arbitrarily small scale.

In her remarkable book, Jacobs (1961) advocated the importance of streets and neighbourhoods of the city for social vitality. Jacobs' eyes were mere eyes, but with a great insight. She found four principles common in the livable and attractive cities. They are all physical: fine grain of street patterns and road network, mixture of differently conditioned buildings, variety of land-uses and density. Largely influenced by what most academics agreed that development should be based on fairly small neighbourhood units by various groups from transport engineers (e.g. Engwicht 1993) to environmentalists, some of which are reviewed in chapter 3. As Hall (1996) has pointed out, the difference among them is either that cities should be denser and more compact or that they can be dispersed unless jobs are separated from people. However, you will easily notice that they are not necessarily contradictory with each other as long as the concept of 'fine grain' is understood properly.

Of the four essences, 'fine grain' is the most ambiguous word that has misled many urban designers (Figure. 5.1). The most recent and notable one is Urban Village Group's diagram (Aldous 1992). Although each of three urban villages has some fineness within the village, the region supplies only one road, one pedestrian street and one railway linkage to outside. This is because they focus too much on the scale and the village centre and care less on other scales and the edge of the villages. The truly fine structure of transport, at first glance, is more complex.

Let define 'fine structure' of transport in the city: any size of neighbourhood of any point in the city is given as many access opportunities as other places and at other scales.

Peter Calthorpe (1993) has been trying to give physical expression of such idea in the cur-



(a) Segregated Urban Villages

(b) An Integrated Part of Fine Structure

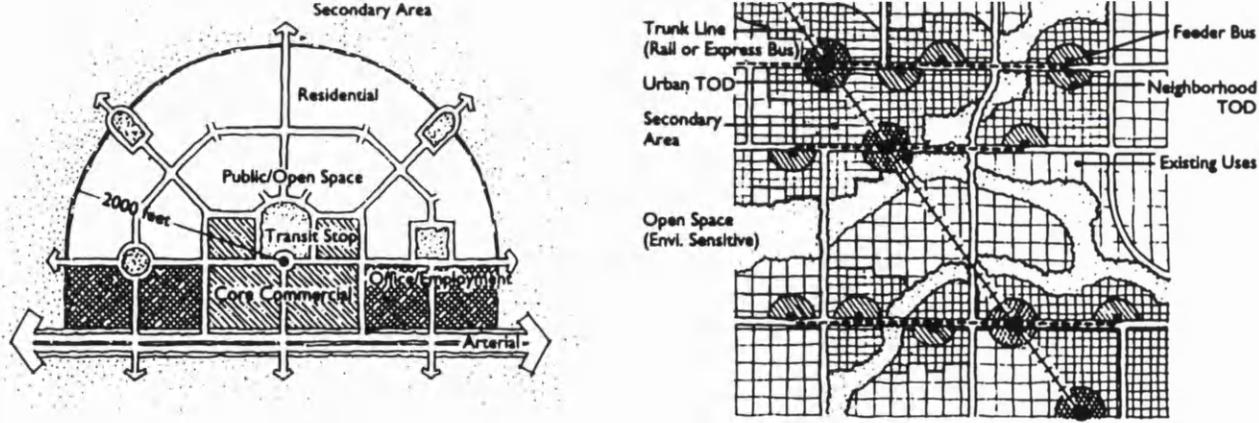
Figure 5.1: The City with Fine Structure

Source: (a) Aldous (1992), (b) Murrain (1993)

rent context of sustainability. His practice is reviewed in chapter 2 and I shall add his theoretical concept in this chapter because it well represents the definition of 'fine structure'. Hall (1996) misunderstood in much the same way as Urban Village Group, mentioning "resulting prescription sounded and looked uncannily like Ebenezer Howard's Social City of 1898"(p.413). He has failed to see what is at other scales such as local and what fills in between the neighbourhood units, that determines the city's fineness, completely missing in Howard's discussion.

In Calthorpe's TOD principles, a certain minimum proportion of uses is always required to stimulate pedestrian activity and to provide economic incentives for developing with mixed-use patterns. As a result, every TOD should have public space (5%-15%), core/employment space (10-70%) and housing (20-80%), none of which exceeds 80%. What should be emphasised, especially compared to Howard's Social City, is this mixture of uses be achieved within walkable distance (Figure 5.2a).

Bentley *et al.* (1985) has discussed in a different way to achieve 'responsive environment'



(a) Transit Oriented Developments (above left and right) both give ample examples of fine structure at varied scales from personal to regional.(b) Responsive Environments (above)  
 Figure 5.2: Designing Fine Structure  
 Source: (a) Calthorpe (1993), (b) Bentley *et al.* (1985)

(Figure 5.2b). Figure 5.2a shows an example to increase 'permeability' and make smaller blocks by creating more junctions. Also seen in the figure are legibility and robustness issues: combining the landmarks and nodes makes the city more legible, while longer over-all streets with shorter blocks have people use the space more, and thus create a secure community.

### Irregularity, non-linearity and efficiency

*F* is too irregular to be described in traditional geometrical language, both locally and globally

The design of a place affects the choice at many levels. Figure 5.1 shows an example of two

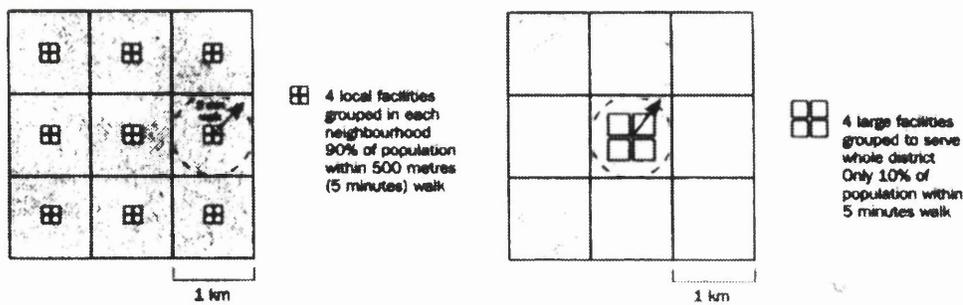


Figure 5.3: Locational Optimisation of Facility  
Source: DoE (1995)

possible design solutions of a shopping centre in Oxford. With the increasing segregation of activities, journey lengths are increased (Banister *et al.* 1994). As reviewed in chapter 2, Calthorpe's (1993) concept is to bring, in the walkable distance, as many uses as possible. A successful town may offer services as many as 90% of its residents, while a badly planned can do only 10%. The figure in Better Practice Guide, appended to PPG13, brought remarkable characteristics into sharp relief (Figure 5.3). A district with nine smaller facilities are preferred to a district with one large facility because only 10% in the district are in the walking vicinity. One of the common misunderstanding of this fine structure is to segregate these towns from one another (Murrain 1993, Figure 5.1).

One of the criticisms of urban models is its incapability of irregularity. A place has a function. But irregularity adds extra to the place. This is an essential component of fine structure. Irregularity to our eyes, indeed, can be categorised into two: disorganised complexity and organised complexity. The focus here is on the latter as it is the most efficient form in the nature.

In general, many unintended actions occur at the edge of two different things. Watching other people, for example, is an important component to keep the street safe (Jacobs 1962). This mostly happens at the edge of the space, which offers a sense of refuge as well as a prospect of what is going on (Bentley *et al.* 1986). Although cities are finite in space, these edges can be infinite, and at that time, the city is robust. The more safe is the street, the more people enjoy walking and more attractive will be the street. Irregularity gives more edge to

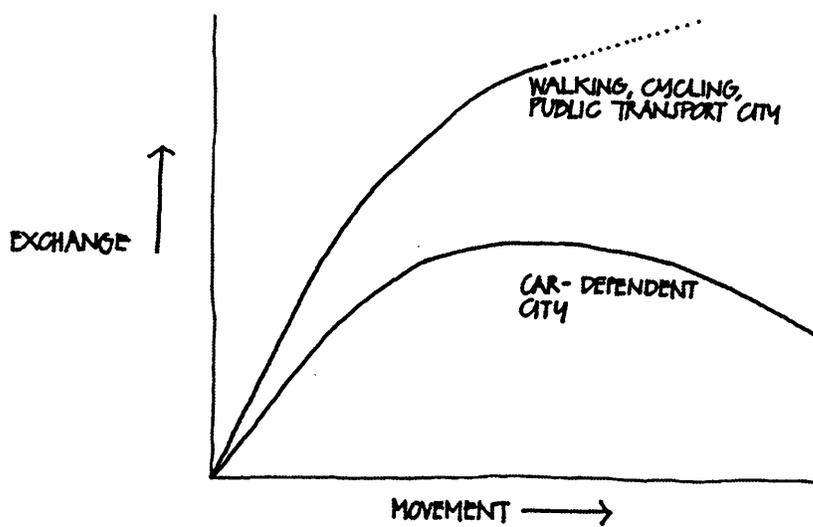


Figure 5.4: Optimum Point of Exchange Efficiency for Two Types of Transport Systems  
Source : Engwicht (1993 p.129)

the city.

Another feature of irregularity is its efficiency. The current economy, however, has pursued the amount of exchange, rather than the efficiency. To some extent, the amount and the efficiency grow simultaneously (Figure 5.4). But in the current situation that road and vehicle-related uses occupy more than 30% of the urban area, the efficiency does not cope with the amount. In mathematical words, it is said as follows. At an optimum point of road space area, the exchange rate reaches the highest. Over the point, therefore, the exchange efficiency will reduce because the cross commuting brings about unnecessary travel. Consequently, commuting patterns in Sydney, Melbourne Adelaide and Perth, cross-commuting doubles the amount of travel really necessary, and because converting dual-purpose exchange/ movement space to exclusively movement space erodes exchange opportunities and demands the city spread (Engwicht 1992).

He implies that, at the optimum point, the road network takes fractal form. In other words, the efficiency grows with the fractal dimension of the city's road network. And it is possible to describe the way to make it more fractal. In most cases, the urban model has some form that of Garden City, Rickaby's settlement patters or Transit Oriented Developments. What makes

it fractal does not only depend on these patterns (generator) but also on that the pattern should appear at any scale and at any place. For example, most cities have their central business districts (CBDs), and the city's efficiency rises when every smaller district has their secondary CBDs, no matter how smaller districts are defined. The form of CBD is, in this case, the generator of the fractal. It is therefore important to identify the generator. The mathematical analysis of optimal form gives us the answer of the form to which the average length from the points in the space can be minimised. On the contrary, the simple forms such as rectangles and circles are the least efficient. To make it simple, the city is assumed to consist only of developed areas and roads and its settlement density is homogeneous in the developed areas. It is practical that the roads occupy a certain area of the city but less road area is preferred not to lose the developed areas because they are the place of business and residence. In addition, the demand of road is also homogeneous and the distance to the road network from any point in the developed area is measured in Euclidean metric way. In this way, how to locate the road network in the city is solved by a mathematical analysis of locational optimisation for multi-polygonal spatial facility. In the analysis, another assumption may involve the upper limitations of facility perimeter for technical reason. The limitation is then relaxed to show the 'real road network to minimise the distance to the road network.

The road network is, in this analysis, assumed as a polygon  $P$  which consists of  $n$  sides,  $(x_1, x_2, x_3, \dots, x_n)$ . The question is now a non-linear mathematical analysis with a given area and perimeter. The smallest distances of a point  $x$  to another point  $x_i$  and a line  $\overline{x_i x_{i+1}}$  are  $\|x - x_i\|^2$  and  $d(x, \overline{x_i x_{i+1}})^2$  respectively, and thus the question is expressed:

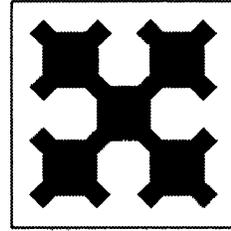
$$\min_{x_1 \dots x_n} \left[ \sum_{i=1}^n \iint_{V(x_i)} f(\|x - x_i\|^2) dx dy + \sum_{i=1}^n \iint_{V(x_i, x_{i+1})} f(d(x, \overline{x_i x_{i+1}})^2) dx dy \right] \quad (5.1)$$

where the limitations of area and perimeter are

$$S \leq \begin{cases} \frac{1}{2} \sum_{i=2}^n (x_i - x_1)(y_{i+1} - y_{i-1}) & (n = 2k + 1) \end{cases} \quad (5.2)$$

$$S \leq \begin{cases} \frac{1}{2} \sum_{i=2}^{n/2} (x_{2i-1} - x_1)(y_{2i} - y_{2i-2})(x_{2i} - x_2)(y_{2i+1} - y_{2i-1}) & (n = 2k) \end{cases} \quad (5.3)$$

Figure 5.5: Mathematical Optimisation of Form to Minimise the Traffic Demand  
Source: Shiode (1995)



The solution of this nonlinear analysis gives us an optimum form of facility (Figure 5.5). As the boundary length increases and the area decreases, the form look like a star-shaped, or in our terms, fractal. If the length restriction is infinite, then the form will 'fill' the area.

### **Robustness and Hierarchy in the City**

Often  $F$  has some form of self-similarity, perhaps approximate or statistical.

There is a myth that a city should have a hierarchy, but what for? On the contrary, the city should have less hierarchy. More precisely, the less is the differences at two adjacent levels, the more robust is the city. The city has several sets of hierarchy, if intended or not. Road hierarchy, for example, consists of main roads, distribution roads, local streets and those only kids know. They are created by their users and modified, as the users need change. In the most robust road network, however, the differences are subtle so that lower level roads are able to accommodate in the case of accident.

In a thin hierarchy, on the contrary, real problems of accessibility are found. Since 1900s has occurred thinning of hierarchy (Short 1996). Thereafter, "paved roads and automobile use allowed consumers to bypass smaller centers. As the small store is replaced by the out-of-town shopping center and as hypermarkets provide better bargains than the neighborhood grocery, then the provision of goods moves up the hierarchy. Smaller centers lost some of their vitality" (Short 1996 p.64-65). Despite their resemblance in theory (Hall 1996), there-

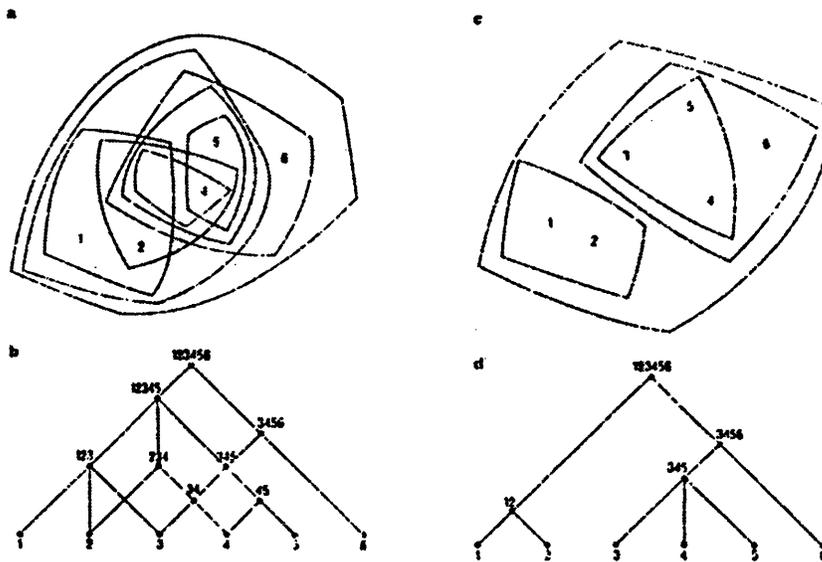


Figure 5.6: Hierarchy Diagram  
Source: Alexander (1961)

fore, Calthorpe's bottom-up approach is more versatile than Howard's top-down thinking.

Capra (1982) has also pointed out

The traditional symbol for these (hierarchy) structures has been the pyramid. By contrast, most living systems exhibit multileveled patterns of organization characterized by many intricate and nonlinear pathways along which signals of information and tradition propagate between all levels, ascending as well as descending. (p. 305)

In reality, the hierarchical planning has been deteriorating the city because it has led to zoning that divides the city into segregated parts to inhibit diversity of exchange (Engwicht 1993). This is because the boundary of areas with different land uses, or the interfaces between these function, is greatly diminished by zoning (Bentley *et al.* 1985). The city, its every street and every neighbourhood, therefore, must be the city in microcosm, reflecting the full diversity of the city, then a richer range of exchange is facilitated.

Alexander (1966) has given us a diagram to help us understand this (Figure 5.6), which is quite compatible with the definition of 'fine structure'. No matter where you are, you have more choices, thus more permeable, in fractal city (Figure 5.6 a and b) than model city (c

and d).

## Fractal Dimension of the City

Usually, the fractal dimension of  $F$  (defined in some way) is greater than its topological dimension.

The concept of fractal in town planning is to visualise the city's fine structure. The concept of fractal dimension is, on the other hand, to enumerate the extent of irregularity and hierarchy so that city's fineness can be compared. Symbolically, rather than mathematically, it can be expressed as:

$$\text{Fractal Dimension} = \text{Irregularity} / \text{Hierarchy} \quad (5.4)$$

which implies that a structure with high dimension has a fine structure. In the basic principle, fractal dimension ( $D$ ) is defined:

$$D = \log N / \log r \quad (5.5)$$

where  $r$  scaling ratio and  $N$  the number of subsets. In Figure 5.3, for example, the DoE's proposal of nine smaller facilities has higher dimension, assuming that the facilities are further divided into  $9^2$  smaller facilities, which are divided into  $9^3$  smaller facilities. Although the scaling ratio is not defined in Figure 5.3, it is likely that  $D$  will have higher dimension than 2.

Let us take Rickaby's (1981, 1987) six (actually five) settlement patterns (Figure 3.3). This comparison is useful because energy demands have already been estimated. The patterns are: Pattern 0 is the original archetypal pattern with single town centre with rural hinterland. Pattern 1 is concentrated nucleated, pattern 2 is concentrated-linear configuration, pattern 3 is dispersed-nucleated (satellite towns), pattern 4 is dispersed-linear configuration and pattern 5 is dispersed-nucleated (villages).

The estimation method is discussed in chapter 6 in detail. Here it suffices to say that the frac-

tal dimension can be defined to various objects in the city. The fractal dimensions of settlement distribution and road network are shown in table 5.7 for Rickaby's six settlement patterns. The result gives us some hints. The settlement patterns with higher fractal dimension of inner population (patterns 1, 3 and 5) tend to be more efficient. This is most remarkable in med scenario.

Rickaby simulated energy consumption in six different settlement patterns. Pattern 0 is the original, fairly concentrated city and all the rest are development options based on pattern 0. In the pattern 1, the development is only in the brownfield for higher density. Patterns 2 and 4 are linear developments, 2 along several radial and 4 along several radial and angular directions. Patterns 3 and 5 are planer, 3 with some medium satellite towns while 5 with smaller villages. Table 5.7 shows the estimation by Rickaby and fractal dimensions of population and road for each settlement. The estimation method is based on Benguigui and Daous (19xx), which will also be used and explained in detail in the following chapter.

There is a tendency, in all the patterns, that the fractal dimension vary significantly between in inner city and in outer city, which cannot be found in the existing cities in the following chapter (Table 6.5). This is due to oversimplification of 'inner' and 'outer' area and thus none of these settlements reflects the reality. In table 5.7, the estimated fractal dimensions both for inner and outer areas are shown. In inner area, as in the real cities, the fractal dimensions fall within the range between 1 and 2, which means it is planer (two-dimensional), while the outer area, linear (one-dimensional). Although they are in a reality range, the inner road fractal dimensions are approximately 1.2 in all the settlements, which is quite low compared to many real cities. This will cause a confusion in the latter discussion and policy-making of ideal settlement, if any, towards less energy-demanding city.

The pattern 1 is the intensification of brownfield areas, which does not only result in higher density in the inner area but also in higher fractal dimension. This is because the develop-

Pattern	0	1	2	3	4	5
<b>Energy Consumption</b>						
High scenario	8672	6591	7885	7011	7244	7244
Med scenario	6140	4601	5382	4739	5228	4999
Low scenario	4529	3405	3826	3367	3796	3714
<b>Fractal Dimension</b>						
Population (Inner)	1.79	1.83	1.21	1.86	1.21	1.86
Population (Outer)	0.37	0.01	0.56	0.17	0.57	0.21
Road (Inner)	1.24	1.17	1.21	1.18	1.21	1.23
Road (Outer)	0.54	0.47	0.56	0.4	0.57	0.55

Table 5.7: Fractal Dimensions of Rickaby's six settlement patterns

ment is intensified more in the outer area of inner city. As there was little development outside the inner area, the fractal dimensions in the outer area will be smaller.

In the patterns 2 and 4, some population in the inner city moved to outer area. Pattern 2 is developed along several radial directions while pattern 4 along radial and angular directions. In terms of fractal dimension, there is not much difference between them and between them and the original settlement since the developments are both linear (one-dimensional).

The patterns 3 and 5 are the attempts to disperse the population homogeneously in the city and thus gives the highest fractal dimensions particularly in the outer area. However, because of the models' oversimplification, the both developments remain linear with fractal dimension less than 1, which is unrealistic. By definition of fractal dimension, the number of satellites divided by scaling ratio, the difference of the patterns 3 and 5 are subtle.

## Generating the Fractal City

In most cases of interest  $F$  is defined in a very simple way, perhaps recursively.

It is not a difficult procedure to create a fractal image. You need an initial object and a motif called *generator*. If generator is applied to the structure at every scale and at every place, it will be a fractal. Applying the generator once again at this new scale results in a further elaboration of the design at yet a finer scale, as if you see the fine detail of a cathedral, and this

process is continued indefinitely towards the limit.

An example of generator is, in town planning, development which can be controlled to make the city fractal. There are many patterns of generators, including the current development patterns. However, once a generator of sustainable development is integrated into development control, the efficiency of sustainable development will be maximised.

Possible generators are Calthorpe's TOD and Bentley *et al.*'s design principles. Adopting TOD in Figure 5.8, the surrounding areas with less housing, less retail, less open space and less public transport are all given the opportunity to solve their problems, without compromising the development area's benefit. In a sense, this looks like the agents work in a cellular automata model. With this method, the developments in the city proceed gradually to improve the city's overall mixness.

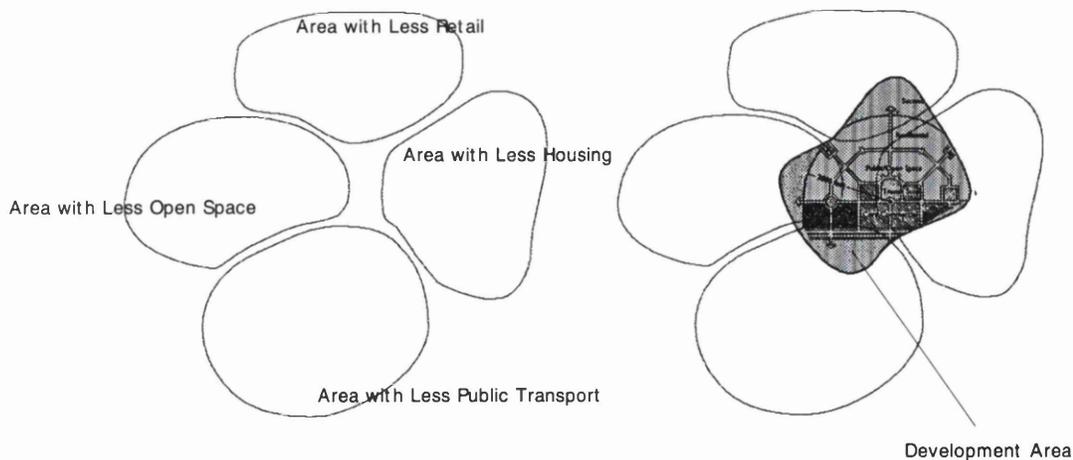


Figure 5.8: Adopting Generator in Development

## **6 City Dimensions and Efficiency**

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### **Introduction**

In Chapter 5, we assumed cities are and should be fractal for their function as place of exchange to maximise the efficiency and thus sustainability in terms of transport energy use. This paradigm itself is not an entirely new concept. What makes fractal a useful planning instrument is its fourth and fifth dispositions referred in Chapter 5. These two are, in fact, closely related in the definition of fractal dimension, a measure of the extent to which the city is well developed in some way.

A first practical application of fractal dimension in town planning is introduced in this chapter to express the road network dimension which is, postulated in chapter 5, roughly assumed to contribute to the city's transportation efficiency. This chapter first reviews some theoretical background more deeply why fractal road network is the most efficient in a conventional mathematics of locational optimisation.

There are two most frequently used methods to estimate the fractal dimension: scale method and area methods. In the beginning, fractal geometry has been developed around the scale method, yet the convenience of scale method is used more frequently in urban studies. This chapter seeks to estimate two fractal dimensions in the city: those of population distribution and road network, both of which are based on the area method. These two different dimensions are chosen to show the potential of this new concept, that is, fractal dimension can be applied to any physical object, such as a group of points (population distribution) and lines (road network).

### **Conventional measurement**

In the preceding chapters 4, 5 and 6, we have studied some of the physical factors which

affect average journey length to work in the city, especially by introducing fractal dimensions in Chapters 5 and 6. These chapters have isolated each element of the urban structure and sought how it contributes to the journey length. Our interests are, however, not confined just in isolated discussion but also in the relationships between them and the exchange efficiency, which have been identified by many practitioners but have not been discussed in academic fields. The elements of urban structure, such as size, population and density, are not independent. In the same country, larger cities tend to have higher density, but this fact is not comparable between different countries, as the large cities in US have extremely low density, lower than small cities in Europe and Asia. Also, we intuitively assume that these elements affect each other. For example, we usually think large cities tend to have high density and population. It is a fact in England that the largest city, London, has the largest population with the highest density. Gravity model is an approach to verify this assumption, but the study of gravity model has rather sought the application in the practical field based on the assumption. This is therefore an academic interest to study these relations quantitatively to which this chapter is devoted.

Indeed, most urban analyses have so far ignored this fact. In *Beyond Walking Distance*, for example, Manning (1984) discussed travel distances and city size, with a little attention to density. Given the assumption that all the residents working in the city centre, i.e. the so-called single centre model, there is a clear relation between average work journey length and density and between average work journey length and area size (Figure 6.1). This is because the density has decreased and the area has expanded as the time has passed. It is not possible to conclude, therefore, that the density is the determinant factor of the average journey length to work in cities, given that the discussion lacks consideration of size effect. As the conclusive chapter, then, I will seek to reconstruct these findings in planners'

### Time scale in Melbourne

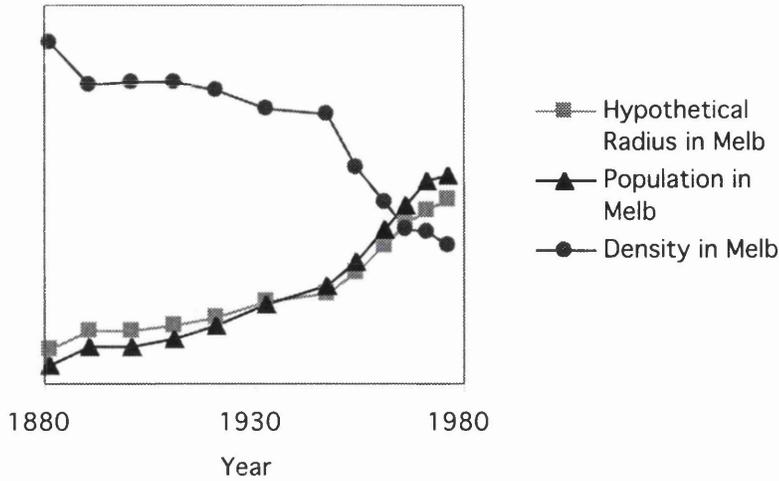


Figure 6.1: Area and Density Shift in Melbourne  
Source: modified from Manning (1984)

terms. The approach I will use is bottom-up, rather than planning tradition of top down.

By definition, there is no clear relation between the size  $A$  and density  $r$  in the city, which are given with population  $P$  as:

$$\rho = P/A. \tag{6.1}$$

None the less, we intuitively assume that large cities tend to have higher density. Figure 6.2 shows the relations between size and density and between population and density respectively, which is consistent with our intuitive perception. There seems some relation between area size and density. Negative exponent regression shows its correlation coefficient 0.711 while inverse power regression 0.823. we may assume here the inverse power function for its highest correlation coefficient as:

$$\rho = \kappa A^{-d}. \tag{6.2}$$

From equations (6.1) and (6.2), we obtain an equation:

$$P/A = \kappa A^{-d}, P = \kappa A^{d'}. \tag{6.3}$$

These relations have some implications. First, city's net density, area and population are not

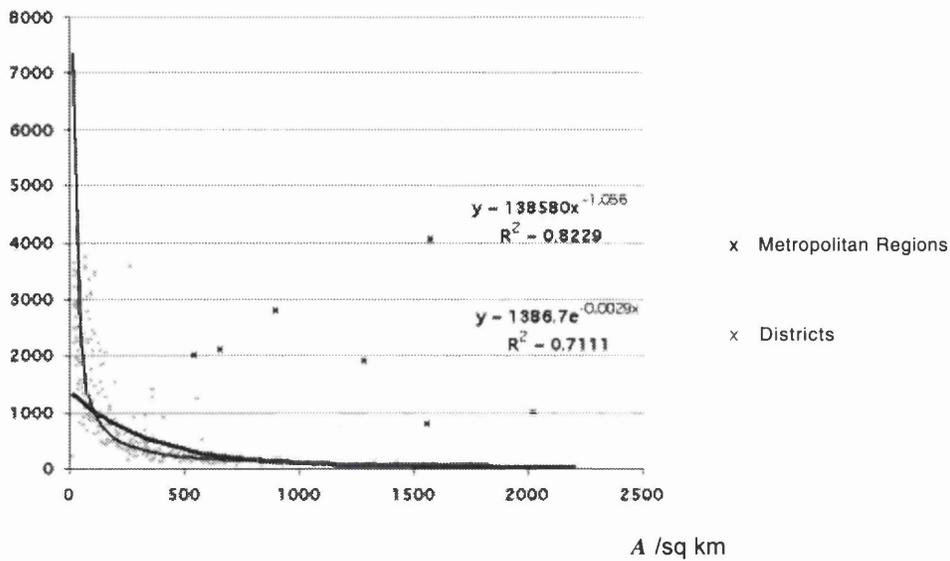


Figure 6.2: City Size and Density

independent but rather deterministic in its geographical and contemporary context. This finding is significant, especially in making policies of city forms. The current policies in the UK, reviewed in Chapter 2, seek high density as a key concept of the compact city. In low-density districts, however, it seems against the law of the natural city as the figure shows that the density is determined largely by its area.

### Urban Population Distribution and Fractal Dimension

Some of the early discussions on urban allometry and density, are equivalent to fractal geometry (Batty and Longley 1994). Since the 1940s, it has been identified that, within a adequately self-sufficient city, there is a scaling relation of radius  $r$  and population  $P(r)$  within the radius:

$$P(r) = \phi r^D \quad (6.4)$$

$$\rho(r) = P(r) / \pi r^2 = r^{D-2} / \pi \quad (6.5)$$

In the early observations, oddly,  $D$  tended to have a value larger than 2, which implies the density to increase with distance, not to decline. Woldenberg (in Batty and Longley 1994),

for example, has shown that  $D$  varies from around 1.6 to 2.4 depending upon the data set used, and Batty and Longley (1994) see its cause as "researchers have paid very little attention to the definition of area, thus throwing into question the validity of the parameter values estimated, at least in terms of the sorts of theory invoked here" (p.320).

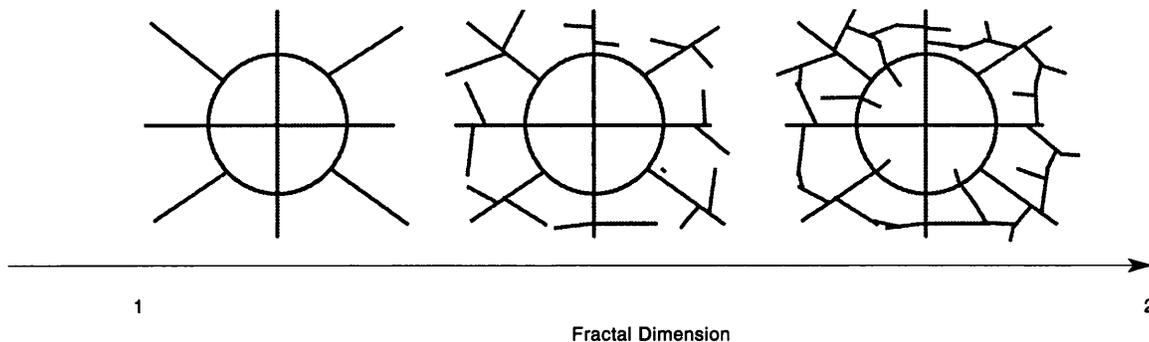
### Road Network and Fractal Dimension

When the radius increases, the area ( $A(r)$ ) also increases as  $A(r) \sim r^2$ . How about the total road length in the circle ( $L(r)$ )? Empirically, it is known that  $L(r)$  increases at the ratio more than  $r$  but less than  $A(r)$  (e.g. McDonald 1989):

$$L(r) \sim r^D, \quad (1 < D < 2) \quad (6.6)$$

because the roads cover the area with some entities. It shows that, at  $D = 1$ , the roads are merely lines which connects the city with other cities but do not provide any distribution roads within the city (Figure 6.3). At  $D=2$ , on the contrary, the roads cover the area, that is, roads are available evenly in any place of the city. As a result, the city provides alternative roads, which provide alternative place to work (Figure 6.3).

Perhaps, what Murrain (1993) and other gridiron pattern advocates insist is, in this sense, the road network which covers the area with as higher fractal dimension as possible. Fractal



(From left to right) Generating an efficient road network from simple model in a fractal way.  
Figure 6.3: Road Network and Fractal Dimension

gives gridiron network a dimension 2 while simplified radial form a dimension merely 1.

### **Estimation of Road Network Fractal Dimension**

Of the most importance is, as has been repeated through the thesis, that it is possible to estimate the dimension of the existing cities and towns. In order to estimate the fractal dimension, there are two types of methods: scale and area methods. A fractal dimension can be estimated by measuring the length (or the number of points, area of objects) at varied scales or areas. Batty and Longley (1994) showed four scale methods. The scale methods require a high resolution map to measure line length over varied scales, and subsequently, enormous time.

The area methods are, on the contrary, less demanding in time and map quality and thus widely used (see Batty and Longley 1994). It is useful particularly when the area is not clearly defined. In this analysis for the discussion of journey length and road network, the census boundary of districts does not define closed city. Rather, we are sometimes interested in a wider region than a district. Here, we take this method to estimate the fractal dimension. Benguigui and Daoud's (1991) estimation method is used, although it is modified because the sample towns are smaller than theirs.

First, the most dense area in road and population is identified as the city's centre. In the case a centre is not such clear, the lowest value of several estimations is used. Next, the total road length  $L(r)$  is measure at several radii  $r$ . In Benguigui and Daoud's (1991),  $L(r)$  is calculated at radius  $r = 1\text{km}, 2\text{km}, \dots, 10\text{km}$ . In the thesis, because of the smaller size of the samples,  $L(r)$  is summed at  $r = 1\text{km}, 1.5\text{km}, 2\text{km}, \dots, 6.5\text{km}$ . Indeed, within the largest radius 6.5km, the conurbation and geographical factors are subtle, although the range of  $r$  still seems larger than the hypothetical radius of the sample cities (Figure 6.4).

This is not actually a new concept, as many studies are equivalent to fractal dimension. In

its regression analysis, for example, Wang (1998) found that his population density simulations are best fitted with function:

$$\log \rho(r) = \rho - \gamma \log r \quad (6.7)$$

Where  $\rho$  is the intercept and  $\gamma$  is the slope. In the article, the slope  $\gamma$  varies between 0.4 and 1.7 depending on road density, network pattern (strictly radial and strictly gridiron) and suburban beltways. Taking logarithm of equation (6.7), however, it is clear that:

$$\gamma = 2 - D. \quad (6.8)$$

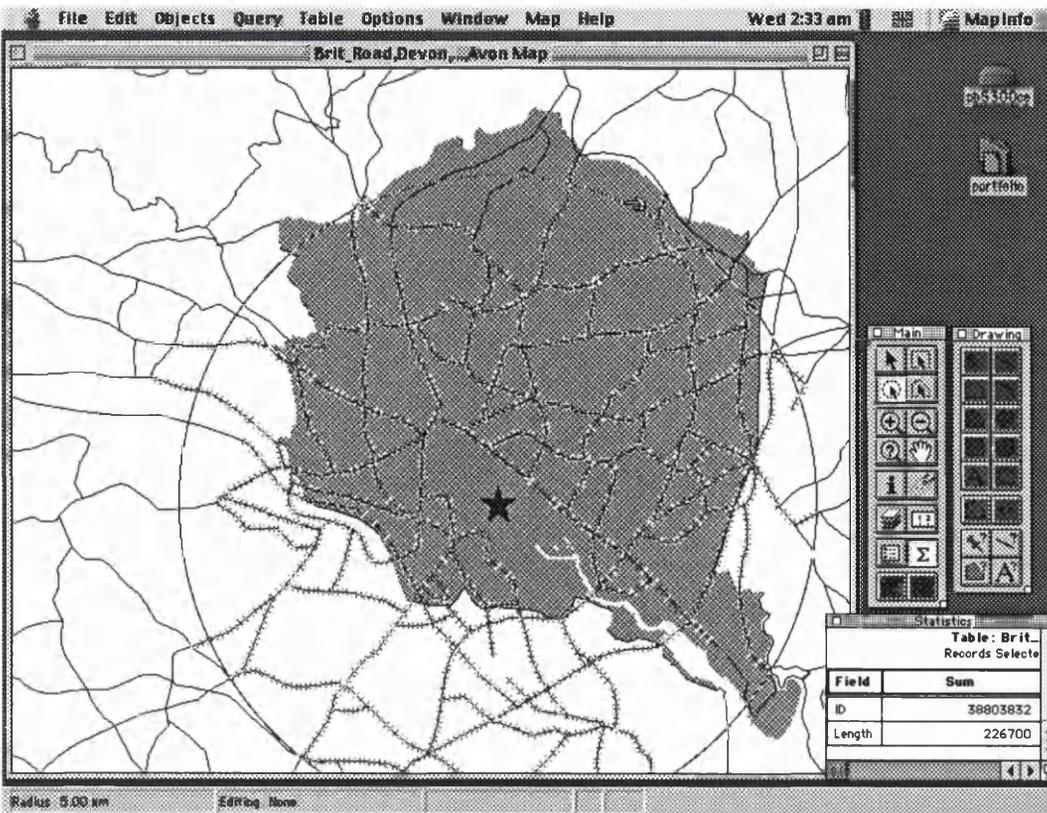
## Samples

The samples are all obtained in England to avoid the differences of urban economic, climatic, regional, political, social and other conditions. As reviewed in chapter 4, it is non-sense to compare the cities in the world. In this thesis, therefore, samples are extracted from the districts and the metropolitan areas with at least one town centre. A city may be a district or a metropolitan area. A district may contain non-urban area within.

The road network data are obtained from Bartholomew through Manchester Information Data Archive Service (MIDAS, [midas.ac.uk](http://midas.ac.uk)) in ArcView format which are exported to DXF format for analysis on MapInfo. The ArcView formatted data contain road length and other tabular data, which are not available in DXF format. The road lengths are, then, calculated in MapInfo on a workstation. The resulted road lengths are slightly lower than those original in ArcView.

The 1991 Census Digitised Boundary data (UKBORDERS), available from Edinburgh University Data Library (EDiNA) through MIDAS, are used to identify the boundaries of the census districts and metropolitan areas.

The cities which are not self-sufficient imports and exports goods, workers and information



Calculating the total road lengths in the circle on MapInfo  
 Figure 6.4: Estimating Fractal Dimension in GIS

more than necessary, which results in longer journey length beyond the city boundary. The extent how the travel length is increased is largely determined by the distances and supply abilities of the nearby cities and, this uncertainty should be avoided. In order to do so, we select the cities with  $S/R > 0.800$ . Density and size are also known to affect the journey length. The samples are selected to have hypothetical radius approximately between 2km and 3km and density 20 persons/hectare and 40 persons/hectare. In this procedure, we gained ten sample cities (Table 6.5). The samples cities also vary in the average journey length to work from 4.70 to 8.29 (excluding home-workers). These cities are, taking account of their high self-sufficiency, small size and high density, well varied in the journey lengths.

The estimation procedure for Plymouth is shown in Figure 6.4, where we have plotted on a double logarithmic scale  $\ln L_r$ , against a function of  $\ln r$ . The solid line is a linear fit giving an

average slope, which is the estimated fractal dimension. The results are show in Table 6.5.

## Results and discussion

As intended, the selected samples with as similar a size and density as possible with adequate self-sufficiency. Their areas, however, vary from 38.87 sq km to 96.21 sq km and population from 101,395 to 295,005. Although all the samples have high  $S/R$  as intended and other self-sufficiency indicators does not affect significantly in Chapter 4, the difference in other self-sufficiency parameters may affect the analysis. However, the results are consistent among the cities of this thesis as well as of other studies (Benguigui and Daoud 1991, Batty and Longley 1994). First, the slope is almost consistent throughout the radii measured with correlation coefficients  $r^2 > 0.980$ . Next, the dimension is ranged from 1.4 to 1.9. This means that the roads does not only link to the nearby cities, but also wraps the area to some extent. This range implies how models are different from the reality as the dimensions of Rickaby's six settlement patterns are either less than 1.3 or greater than 1.8 (chapter 5).

As we assumed that the road network dimension affects the average journey length in Chapter 5,  $AJL$  is plotted against the function of  $D$  (Figure 6.6). The samples show a linear relation ( $r^2 = 0.658$ ) if Norwich is ignored which showed very small fractal dimension. The result is consistent with our hypothesis that more efficient urban forms take more fine road network at the edges as well as the town centre. In Norwich the smallest travel length despite low road network dimension can be explained to some extent by its smaller area. In addition, although more than 80% of its residents work in the city, not much of its workers (44.9%) live in the city. Indeed, the number of jobs exceeds the number of residents nearly 100% ( $R/W$  55.5%). Approximately 45% of jobs are therefore occupied by those from nearby districts, whose longer journey lengths are not taken into account.

Table 6.5: Fractal Dimension and Average Journey Lengths of Ten Sample Cities

	Area /km <sup>2</sup>	HR /km	Persons /1	$\rho$ /km <sup>-2</sup>	R/W	S/W	S/R	D	AJL /km
Norwich	38.87	3.52	212,661	3156	0.555	0.449	0.808	1.15	4.70
Kingston Upon Hull	71.47	4.77	253,111	3541	0.835	0.693	0.830	1.90	5.43
Coventry	96.21	5.53	295,005	3066	0.879	0.702	0.798	1.58	6.47
Derby	77.78	4.98	215,866	2775	0.855	0.707	0.827	1.45	6.45
Exeter	46.89	3.86	101,395	2162	0.742	0.639	0.860	1.83	4.98
Plymouth	79.49	5.03	241,663	3040	0.909	0.829	0.913	1.65	5.74
Leicester	73.08	4.82	272,133	3724	0.674	0.544	0.807	1.63	4.93
Northampton	80.51	5.06	178,570	2218	0.887	0.734	0.828	1.33	8.29
Oxford	45.46	3.80	124,058	2729	0.624	0.521	0.836	1.68	6.35
Stoke-on-Trent	92.44	5.42	244,317	2643	0.842	0.681	0.808	1.73	5.38

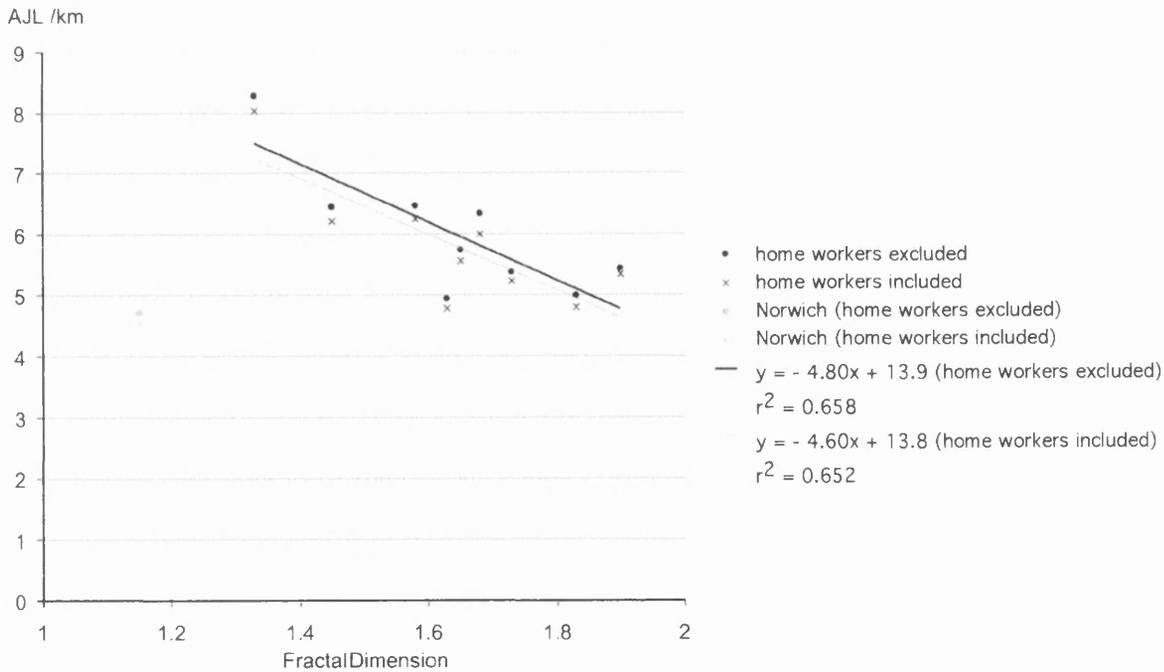


Figure 6.6: Fractal Dimension and Average Journey Length

## **7 Conclusion: New Urban Morphology**

### **Summary**

For more than a century our duty has been to improve the urban environment. Throughout the last century, as we have removed the problems out of the cities, they have been gradually spreading outside the urban areas. By adopting intensification of particular land uses through zoning and suburbanisation, moreover, our cities now largely depend on mass transportation, even in this information era. Subsequently, urban problems have not been merely delivered outside the urban area, but its scale has changed from local to regional and global.

In our current life style, A significant number of us live in a suburb of a medium or large city, commute every morning and evening from Monday to Friday and go to regional hypermarket on Saturdays or Sundays. As the suburbs have grown, people's commuting time has increased as much as two hours per day in many cities. Because so many people move in the same way, the transportation system, be it roads or public transport, are intensively used in certain areas at certain times. Because of people's movement pattern, many of the current proposals of new transport systems are not adequate. In London, where the public transport is already saturated, the proposed approach of modal shift from cars to public transport will simply end in further congestion. More important is to reform this travel pattern so that people need to travel less, by bringing the workplaces as close to where they live as possible. By receiving these reports, the European and British governments have adopted the concept of 'compact city' and 'Urban Villages' respectively without enough verification (CEC 1992; DoE 1994).

The urban morphology is not a new study. However, it is only recently that we have studied it in relation with transport efficiency and demands. Density and population have been stud-

ied since late 1960s or early 1970s, yet the two-dimensional analysis of land uses and transport network is still at its infancy. The approaches taken are mostly simulation of model cities, the same idealistic approach as Howard and Le Corbusier did, and would fail for the same reason as they have failed, as the ideal city is modified when developed or is difficult to develop. In addition, this top down approach is not favourable because, unlike Howard and Le Corbusier's era, we planners have neither political or financial backgrounds.

Taking account of them, I have discussed a new approach by introducing an urban transport network dimension as a parameter in the same way as standard deviation or variance in statistics. I set a parameter that reflects the ratio of suburban road density to urban road density, which takes a value between 1 and 2. This parameter is called fractal dimension and can be obtained both for actual cities and model cities; can be compared with self-sufficiency, density, population and so on; and can be estimated as long as ten minutes with any GIS application. Therefore, I will discuss fractal and fractal dimension in relation to planning practice in this conclusive chapter. Fractal is a new concept in town planning, and can be misunderstood easily, and thus is explained again. Then, the influence of road network dimension is compared with that of self-sufficiency, density and population. In the last section, I will discuss the future possibility of this new concept.

### **Fractal Means Accessible**

We have postulated the hypothesis that a more efficient road network has higher fractal dimension, but not necessarily vice versa. We have examined it by estimating ten comparable cities/towns of England that have similar population size and high self-sufficiency to avoid these effects. The estimated fractal dimensions have high linear correlation with average journey length with correlation coefficient 0.658.

In theory, there are several benefits of fractal transport system. First, fractal form covers the

whole area. To understand this, imagine a simple urban model with a ring in the centre with several spines (Figure 6.3). As you move from the city centre to suburb, you will find the gap between the spines growing larger. People living in that area, thus have to travel to the nearby spine, go back to the city centre and go along the next spine, even though the destination is close. In this city, to accommodate this unnecessary traffic, roads have to be widened and, consequently, the total road area will be expanded. As the roads occupy more space, the density of other uses decrease and you have to travel more. In the city with efficient transport network, on the other hand, you are supplied with more opportunities so that you are likely to have shorter ways. This is true because people commute less in the cities with higher fractal dimension as discussed in Chapter 6.

In order to design a local settlement, we have discussed a concept of neighbourhood in Chapter 5. Of importance is to think from the local. It should be stressed that the higher fractal dimension does not always bring fruits of the efficiency to the road network. Logically, the thesis verified that efficient networks tend to have higher dimensions, but not vice versa. It is not straightforward to show a model of the efficient road network by simply giving higher dimensional layout but is necessary to construct design theories that match the finding of the thesis. In Chapter 5, for example, we have discussed a concept of neighbourhood, or how to think neighbourhood. In the conventional planning, neighbourhoods are separated parts of the city. In reality, however, the administrative boundaries of neighbourhoods are not the same as residents'. For the residents, any point in the city should have an adequately self-sufficient neighbourhood, rather than every neighbourhood is self-sufficient, so that the traffic demand will reduce significantly. Such neighbourhoods often share their boundaries with adjacent neighbourhoods (Figure 5.8, p.63) where "[r]esidents may define different neighbourhoods depending on their personal location and associations" (Barton 2000 p.139). Similar comments are found in Murrain (1993) and Haywards and McGlynn (1993). Bill Hillier (1996) takes a different approach that leads to a consistent conclusion as our findings. His

"spatial laws are the 'first filter' between the boundless morphological possibility for such aggregates and the properties of the vanishingly small subset we call cities" (p. 339). One of the most important findings in his study is that more crimes occur at the streets of low hierarchy because they are less accessible and thus few 'streetwatchers' that maintains the society at the most basic level.

Politically, minimising the need to travel requires a discussion in a more broader sense. In order to alleviate the air pollution caused from transport, the most efficient measure is the modal shift from private to public transport, or ultimately, to walking and cycling. The study of journey length is still quite useful because the relation of journey length and transport mode is apparent (Figure 2.5). Alternatively, the pollutions generated from transport and energy consumption in transport and other means are to be studied. Apart from the discussions of sustainability, fractal dimensions may be used to estimate the transport cost.

The analysis taken in the thesis is of using average journey length to work, and therefore ignores other transport purposes such as for shopping, social, entertainment, within work and freight, which are less likely to correlate with urban form. On the contrary to work travels, these journeys do not tend to move between city centre and suburbs but have very different patterns. For example, journey for social purpose include meeting their friends and family who might live close or very far. Unlike work travel, the destination is not fixed, and travel is less frequent so that people do not pay much attention to accessibility. I, myself as a Japanese living in Britain for example, go back to Japan once a year however long the journey is. On the contrary, I would not go back home more than a few times even if I lived much closer. Similar pattern is applied to entertainment journey. Shopping journey is more similar to work journey although it tends to be smaller. Travels related to business and freight have less relevance with urban form because much of them is interurban, regional or inter-

national.

## Urban Form and The Need to Travel

We have examined the physical factors of the city: self sufficiency, size, density and the fractal dimension of road network. As reviewed in chapter 3, there has been few attempt to compare them. Policy makers therefore have to prioritise one over the others based on their instinct, rather than research. Theoretically, they all affect the need to travel in the city, but how much each factor does may differ and is not obvious. It is not difficult to compare these factors, if research is done consistently. One approach is to compare the correlation coefficient values (Table 7.1). It clearly shows how a factor is related to the traffic need over the other. The result extracts the importance of road network, Independence Ratio (*IR*) in the countryside, Density ( $\rho$ ), and *S/R* in the countryside. In urban areas, therefore, road network and density have the highest correlation.

Yet, it is too early to conclude that they are actually dominant factors of the need to travel. In figure 4.6, as the density varies from 1196 persons/sq km to 3541, *AJL* ranges only from 4.93 to 9.83. It is politically and financially the least practical approach to triple the density of already established towns, particularly in the current context of sustainable development. On the contrary, although less practical within a short period, changing road network towards higher fractal dimension does not seem to require much political opposition, as the practices reviewed in chapter 2 are welcomed in many practices.

The conventional measurements of urban form, population and density in demography and total road length and road density in transport, have no implication of two- or more dimensional aspect of urban form such as land use patterns. As Jacobs (1961) discussed, this is the reason planners have been confused with density and congestion. Indeed, high density and congestion are the sign of successful cities. Imagine, for example, two identical shops

Table 7.1: Correlation Coefficients

Urban Factors	Correlation Coefficient		
<i>IR</i>	0.128	0.006	0.529
<i>W/R</i>	0.079	0.006	0.245
<i>S/W</i>	0.103	0.048	0.422
<i>S/R</i>	0.397	0.030	0.470
Area	Not Available		
Population	Not Available		
Density	0.493		
Road Network <i>D</i>	0.658		

located nearby to each other, but one full of customers and the other with little. The successful shop needs to design a good shopping environment for the customers, not to reduce the number of customers, by aligning the items, the cashier, information so that the customers have enough space. In the city, where variety is highly prioritised than the average and in which departure and destination can be anywhere, it is of importance not to assert that any mean density or any particular form has a dominance. Using the concept of fractal gives a measure to combine a missing dimension of space, which gives two-dimensional implications to population or density, and gives one-dimensional value to urban form by measuring the deviation of the distribution.

### Designing Fractal City in Practice

The concept of fractal does not suggest any particular urban form. Instead, it gives us the measure to compare the forms. Theoretically, however, there is a good mathematical attempt to seek a sustainable urban form (Figure 5.5). There is little relation known of this non-linear spatial analysis and fractal geometry. The former suggests a star-like shape while the latter emphasises decentralisation. They do not seem identical at first glance, yet it is of academic interest to seek the fractal dimension of this efficient form.

The concept of fractal transport system can be applied in practice. One of the misunderstandings I have most received is that it suggests to build more roads. By definition used in

the thesis, fractal dimension is merely the distribution parameter of road density, and is independent from the total road length. In addition, although building roads in the suburbs surely increases the fractal dimension, we accept some assumptions that roads are always built reasonably. Therefore, it is emphasised that the hypothesis of the thesis as 'the more efficient the land uses tend to take higher fractal dimension of its transport network', rather than 'the higher fractal dimension always means better transport'.

In practice, roads are not built if there is no housing, offices, shops or factories. An example of developing new roads is to link two existing adjacent villages/towns. This may provide more employment opportunity in the neighbouring area than within the town, although it is not always true, by increasing the overall travel lengths. Another example is development of new settlements. As you build settlements, you are more likely to build roads. If located carefully, the development will reduce the fractal dimension of the whole city transport and will make the transport more efficient.

It is, therefore, suggested that the councils analyse the fractal dimension of their road systems, which would not take more than thirty minutes, to know its current condition. The county council collects this data, and can use a parameter in deciding the location of new settlements so that fractal dimension will be increased. By doing so, it is possible to reduce the need to travel with supplying new housing.

It should be noted that, in practice, transport is one of the considerations, so that it can be compared to other parameters, such as sustainability indicator of town centre studied at CASA (<http://www.casa.ucl.ac.uk/sustain/>), in which retail, services, crime, telecommunication and real estate are addressed. However, because fractal form is more accessible, it is likely that these approaches, especially those related to spatial accessibility, overlap the concept of fractal city. And again, as the analysis of fractal dimension is easier than any other

kind of spatial analysis, it can be used to estimate in advance of detailed analysis.

## **Further Discussion**

The hypothesis of the possible relation between road fractal dimension and journey length is tested to a very limited range of cities in a condition. It is of interests to further research for smaller and larger cities as well as in different conditions. Also, it should be attempted to mathematically discuss the relation of fractal dimension and optimisation of form to minimise the average distances. It should be noted that the hypothesis advocated and tested in this thesis requires more observations as well as theoretical background. It should include the application of scale methods which require more intensive efforts but surely the mainstream of fractal geometry. The area method is, indeed, able to accommodate only half the definition of fractal city, yet it does not guarantee the possibility that the city supplies adequate opportunity at lower and larger scales. Also of interest is the mathematical relation of non-linear analysis and fractal dimension. More elaboration is required to mathematically link the fractal to Shiode's (1995) analysis of locational optimisation.

The concept of fractal is quite useful in town planning, especially to understand the ambiguous concepts of good city form, such as 'fine grain', 'mixed-uses', 'permeability' and 'hierarchy'. It is, for example, possible to define the dimension of 'land-use mixedness' to measure how much the land uses are mixed in the city. Also implied is the relation with social and economic factors. Some measurable social and economic factors such as income variation may be discussed in much the same way as travel demand discussed in the thesis. The concept can be further applied, for example, to land-uses once its generator, and thus fractal dimension are defined. Transit Oriented Development, for example, is reviewed twice in the thesis as a possible generator of land-uses. Land-uses are two-dimensional and require more effort than perimeter or road length to estimate fractal dimension, yet it is quite practical if a

high resolution map is available. In either case, using fractal dimension is advantageous to help us understand the ambiguous planning concepts of social cohesion, economic variety, fine grain, semi-lattice and so on. Fractal dimension is as useful as standard deviation and variance in statistics, in the case fluctuation is more important than averages, such as town planning.

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*End of Thesis*