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URBANIZATION, MOTORIZATION AND THE ENVIRONMENT NEXUS —AN INTERNATIONAL COMPARATIVE STUDY OF LONDON, TOKYO, NAGOYA AND BANGKOK—

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Abstract

Having realized that transport has become a significantly larger contributor to energy consumption and the environmental degradation, this study aims at identifying its comprehensive mechanism and providing a scenario analysis method to understand the future environmental consequences.

The mechanism is investigated on the basis of urbanization, motorization and the environment nexus within the transport domain. Each linkage between the components inside the mechanism e.g. population density and distribution, urban configuration, income level, car ownership, transport infrastructure supply, infrastructure investment level etc., has also been examined empirically. The subsequent attempt is to illustrate and validate the proposed premise on the basis of actual interrelationship among urbanization, motorization and the environment through an analogous approach of equivalent development patterns in four diverse metropolises — namely London, Tokyo, Nagoya and Bangkok — situating at various stages of economic development process and at different points of time.

The results of the study contain many-sided meaningful evidences and considerable findings to mechanize and support the presumable sequences of nexus. In addition to transport contributor, other environmental consequences are also analyzed. It is likely that the urban development path of a younger aged metropolis will typically follow the same manner as those of prior elderly aged metropolises but rather at an accelerating rate and with a shorter cycle time, as a result of technological progress and rapid economic growth.

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1. Introduction

1.1 The Objectives and Scope of the Study

The energy consumption and pollutant emissions, affecting local and global environment, by transport sector are both rapidly increasing ahead of those by industrial and domestic sectors. In advanced countries where urban land uses are virtually saturated, the main causes of environmental deterioration may come from their car-dependent (or motor-vehicle oriented) transport systems and the utilization habit of their people obviously supported by high car ownership. On the other hand, in developing countries the main causes may include (a) the increasing trip length due to the rapid expansion of urban areas caused by excessive migration from other rural areas and (b) the being worsened congestion due to the mismatch between the delayed supply of transport infrastructure and the increasing car ownership supported by income growth.

The above mentioned phenomena occur through the processes of urbanization and motorization. Therefore in this paper, the mechanism of the increase of energy consumption and environmental degradation is carefully examined on the basis of urbanization and motorization in reference to economic development. To identify and position all the phenomena corresponding to economic development, an international comparative study is conducted by selecting four metropolises of London, Tokyo, Nagoya and Bangkok. Each of these appears at a different stage in terms of economic development, urbanization and motorization.

This study aims at providing a scenario analysis methods to determine causes and results of environmental degradation in the field of land use and transport planning. Particularly, to find out the policy measures for preventing environmental deterioration is important for developing countries. This is because the deterioration of the local environment becomes more and more serious there and also because most of urban population increase in the future is expected to occur in the developing countries, even in an exploratory state, thus causing the dominant part of increase in energy consumption. The analogies obtained from this comparative study based on the measures and the results in land use and transport field of the preceding developed countries are believed to contain useful suggestions for the future policy formulations in other developing countries.

1.2 The Structure of the Paper

This paper consists of five chapters and the structure is as follows.

Chapter 1 includes the objectives and scope of the study and the chapter structure. Following the introduction, Chapter 2 investigates the contribution of transport sector to energy consumption and environmental load by reviewing the trend of energy consumption by sector and emissions of air pollutants in developed and developing countries. And then the mechanism of the influence of transport on the environment is analyzed.

Chapter 3 analyzes the characteristics and patterns of spatial development and urbanization process which have a strong influence on the environment. The changes in built-up area and distribution of population and jobs are included in the analysis and discussion. The degree of spatial development and stages of urbanization are also measured by introducing some indicators.

The following Chapter 4 mainly focuses on the analysis of the relationship between motorization, infrastructure and the environment. It includes a discussion on the environmental problem caused by the growing car ownership, delayed supply of road infrastructure and the consequent congestion. Traffic demand and road supply, travel speed, built-up area size, trip length and energy consumption in each metropolis are the components used to explain contribution of road traffic to air pollution.

Finally, Chapter 5 summarizes the findings and suggests the necessary further studies.

2. Transport as a Contributor to Environmental Changes

2.1 Economic Development Stage and Environmental Consequences

The characteristics and level of economic development strongly influence on the quality of environment. This is because the configuration of environmental problems depends largely on economic structure and economic growth rate. Generally, it is found that the awareness on environmental problems increase as income increase.

a) Income Growth and Environmental Awareness

Historically, air pollution in all metropolises has been considered as a serious problem once the annual per capita product level being approximately \$200–\$300. Some evidences included an attempt to reduce smoke concentration in London by shifting energy source from coal to oil in the early 1900s (approx. annual per capita product = \$280), the study on air pollution by the Tokyo City Office in 1927 and an investigation of motor vehicle emissions in Bangkok at the beginning of 1960s (annual per capita product = \$270). However, it seems that limited attention was paid on this problem, whilst the economic oriented expansion was the primary concern for major development during those periods. The writer in the British Building Journal pointed out the reasons why only little effort had been made for reducing smoke during the nineteenth century as follows: (a) smoke was a by-product of an activity which commanded the attention and the support of all financial interests; (b) the damage by smoke was not clearly visible to the individual; (c) since the damage done by smoke was due to a very large number of small producers of smoke, a clear relationship between cause and effect was difficult to establish (WHO, 1961).

b) Occurrence of Serious Environmental Problems

The changes in per capita gross regional product in terms of US\$ current prices and some major air pollution-related events are put together in Fig. 1. Nagoya's plot is omitted in this figure for simplifying the figure. The figure suggests that the severe air problem was likely to occur when the product level was around \$1,000–\$3,000. This can be inferred because many air pollution events and laws and regulations appeared frequently during this period. The 1952 London smog occurred at the annual per capita product of \$1,000 followed by the establishment of Clean Air Act. The monitoring of pollutants, environmental laws and regulation and the high concentration of pollutants appeared during the 1960s when the level of the annual per capita product was \$1,000 to \$2,000. Meanwhile in Bangkok, the high concentration of pollutants along roadside were higher than standards since the per capita product was around \$1,500.

c) Implementation of Countermeasures

In general, the figure also suggests that the awareness of the air pollution problem appeared when the annual per capita product level was as high as \$1,000 or more. The evidence of this is the implementation of regular or systematic monitoring of pollutants in both London and Tokyo. Such monitoring was started when the annual per capita product was around \$1,000. Meanwhile in Bangkok, it was delay to the level of some \$2,500. However, this may be because the impact from industrial development in Bangkok is not as much as those in other metropolises.

Considering the same type of air pollution problem, pollution from motor vehicle emissions, the figure shows that the countermeasure against air pollution from motor vehicles was first introduced in all three metropolises during the product level of around \$2,000. This implies that at this period the air pollution from traffic was considered as one of the major environmental problems. However, the introduced regulations were quite weak. Only CO was regulated in Tokyo while CO and black smoke were regulated with poor enforcement in Bangkok though the problem was already severe. More awareness of this problem is likely to appear when the product level reached some \$4,000 or more. At this level, the strict emission standards and unleaded gasoline were introduced in Japan and Tokyo. Meanwhile in Bangkok the unleaded gasoline and catalytic converter were introduced but the stricter standards are not established yet. In UK and London, the standards were improved, however, the remarkably change occurred when the product level was around \$8,000.

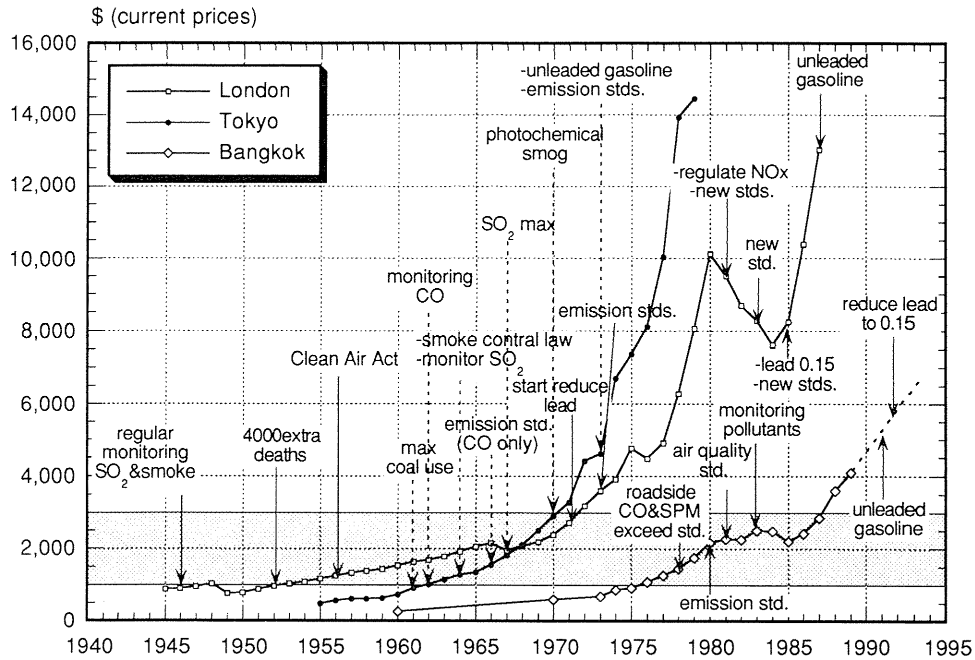


Fig. 1 Per capita GRP and air pollution events
Sources: Ref. 10, 11, 24, 45 and 84

Although the problems and the countermeasures took place in every metropolis during similar income levels, the main contributors in each city have differed. For London it was the domestic and industrial sectors in the 1950s, for Tokyo the industrial sector in the 1960s and for Bangkok the transport sector in the 1980s and 1990s.

2.2 Influential Factors on Transport Energy Consumption

It is intuitively understood that a compact city requires less transport energy consumption because of shorter daily travel distance. Fig. 2 shows the relationships between population density and annual per capita energy consumption in 32 cities located in Asia, Europe, Australia and US.

The plots are distributed from 10 giga-joule per person-year in Asian cities to 80 giga-joule per person-year in American cities. Globally observing the figure, the cities with higher population density are more efficient in terms of transport energy consumption with exceptions within Asian cities where income seems the dominant factor in determining the geographical boundary of cities.

The per capita energy consumption is slightly higher in European cities than in Asian cities though the population density is much lower in European cities than that in Asian cities.

The contrast between American and European cities may come from the following reasons: a) more rigorous land use control in Europe has strictly guided the cities' compactness, though the land legal system had been developed to achieve suburban sanitation and amenities early this century when no one anticipated today's environmental constraints, b)

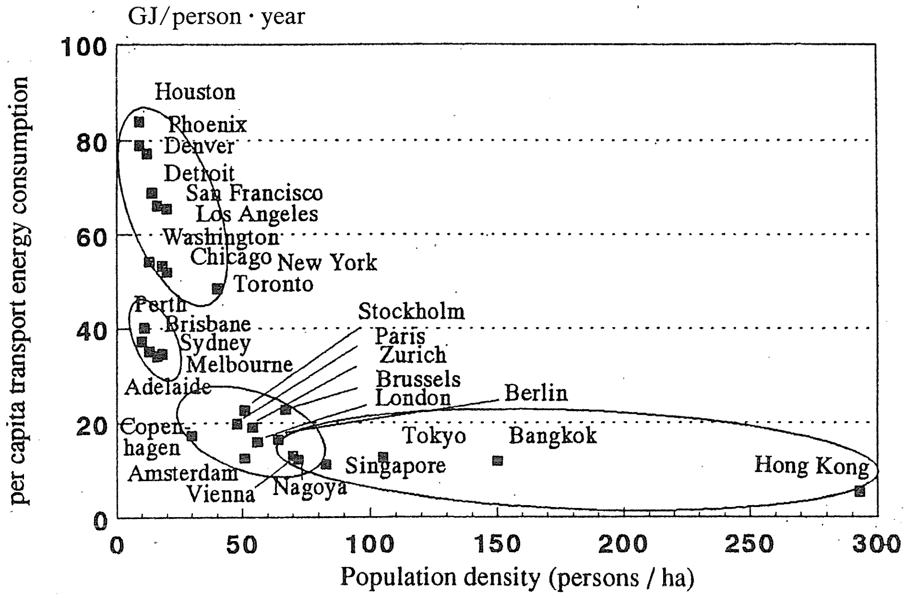


Fig. 2 Population density and transport energy consumption (1980)

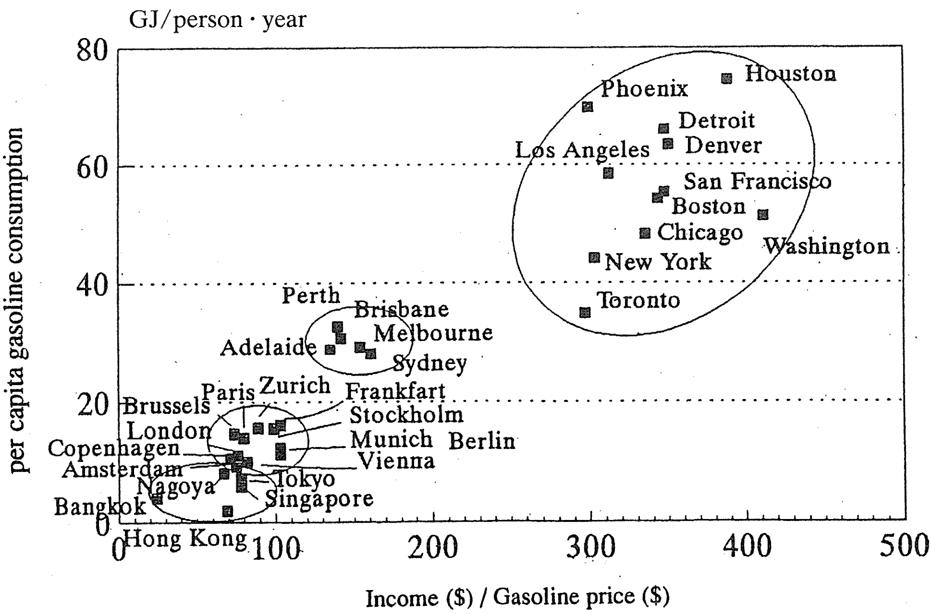


Fig. 3 Income/gasoline price ratio and gasoline consumption (1980)
Sources: 1. Ref. 28
2. The values for Tokyo, Nagoya, and Bangkok are estimated by the authors

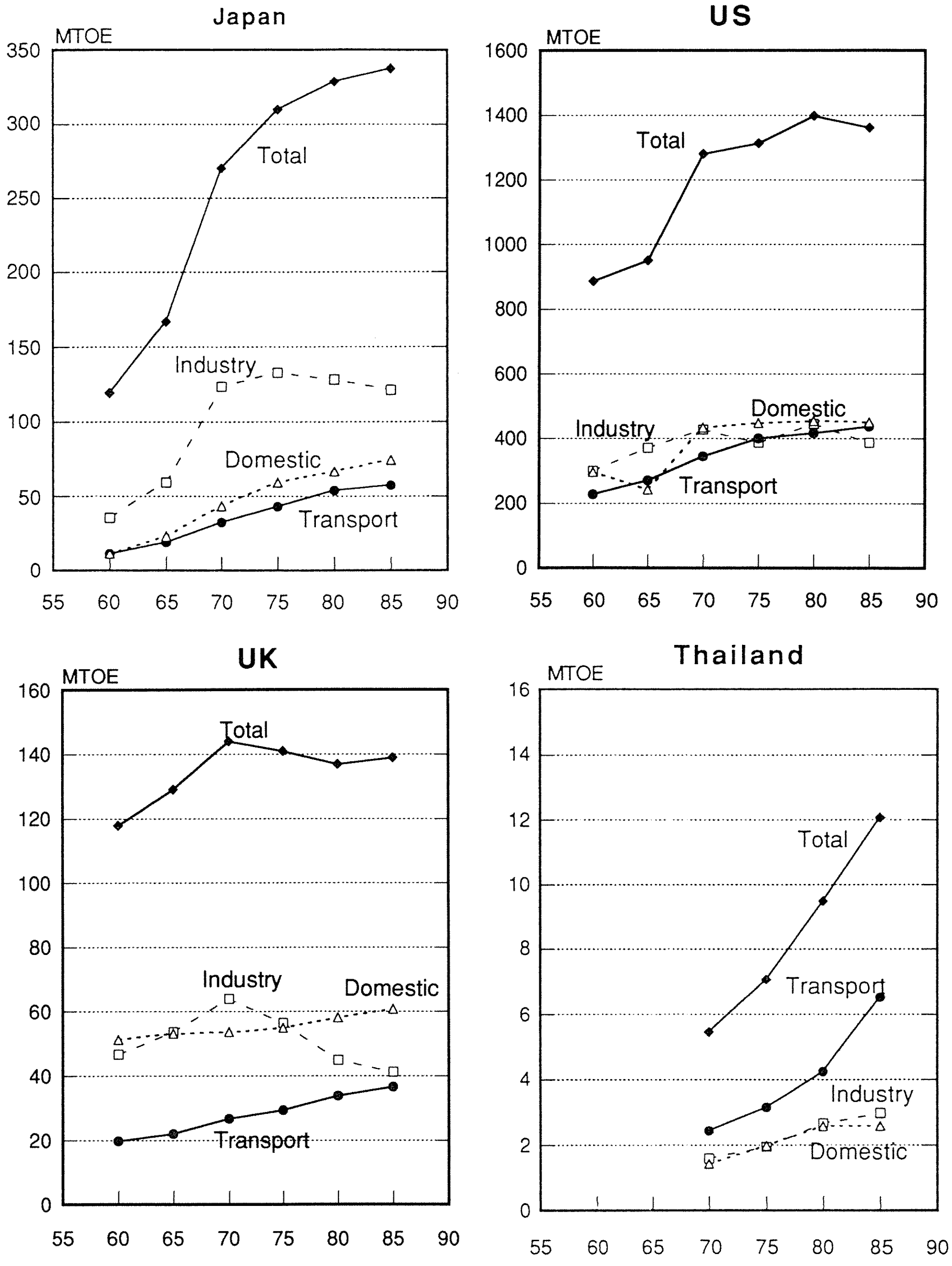


Fig. 4 Changes in energy consumption by sector
MTOE: Million Ton of Oil Equivalent
Sources: Ref. 94 and 95

besides the compactness of cities, better urban rail transit systems and a higher fuel price in Europe are effective in discouraging car use.

The fuel price effect can be also cited that American cities use twice as much transport energy as Australian ones though their population densities are almost the same. This could be a result of the difference in car use cost i.e. fuel cost.

Fig. 3 shows the relationship between normalized fuel price and the energy consumption in 32 cities. This clearly shows that even in the US, which is one of the richest countries, the fuel price elasticity to car energy consumption is very high. A cheaper fuel price encourages long distance car use and housing location in a remote area.

2.3 *Trend of Energy Consumption by Sector*

The investigation on trend in energy consumption found that, though economies have been expanding, energy consumption in the industrial sector seems to be stable or slightly increasing, especially in developed countries. But the consumption in the transport sector is increasing from year to year. As shown in Fig. 4 energy consumption in the transport sector of the US, UK and Japan has been increasing continuously while consumption in the industrial sector declining. Meanwhile the energy consumption in a developing country, Thailand, shows upward trends in all sectors. Transport energy consumption is increasing due to the economic growth so that more than 50% of the energy is now consumed in the transport sector in Thailand.

It is anticipated that transport energy consumption in developing countries will increase very much in the future due to the rapid growth of motorization. This may become the dominant factor in determining the future energy use and the greenhouse effect.

2.4 *Contribution of Transport Sector to Greenhouse Gas Emissions and Air Pollution*

At present, transport, especially road transport, is considered a major contributor to air pollution problems. At the global level, transport is an important source of CO_2 and CFCs (Chlorofluorocarbons) which are the major contributors to global warming. As shown in Fig. 5, CO_2 accounts for about 50% of the annual increase in global warming and CFCs about 20%, methane 16%, ozone 8% and nitrous oxide 6%.

Among them, the total contribution of road transport to the greenhouse effect is estimated at about 12% (7% from CO_2 and 5% from CFCs). For every kilogram of fuel consumed by a motor vehicle, about three kilograms of CO_2 are released in the atmosphere (Faiz, 1993). For the regional level, NOx and HC emitted from vehicles can be transported and transformed into secondary pollutants such as ozone and aerosols. These pollutants damage vegetation and cause corrosion of materials in many countries such as the UK, US, Germany, and Belgium. At the local level, transport dominates as a major source of various pollutants such as CO, NOx, suspended particulate matter (SPM) and lead. As shown in Fig. 6, road transport accounts for more than 80% of CO emissions in most cities both in developed and developing countries. Meanwhile Fig. 7 suggests that the contribution of road transport to the total NOx emissions is about 40%–90%.

The monitoring and survey on air quality in 20 megacities by the World Health Organization (WHO) found that at present each megacity has at least one major pollutant which exceeds WHO health guidelines. WHO suggested that motor vehicle traffic is a major source of air pollution in all megacities. (WHO & UNEP, 1992). The Pan America Health Organization estimates that an urban population of 81 million people in Latin America is currently exposed to severe levels of motor vehicle-induced air pollution (Leitmann, 1991). In Bangkok air pollution from motor vehicles causes 300–1,400 cases of excess mortality/year and about 900,000 minor headaches/day (USEPA/AID, 1990).

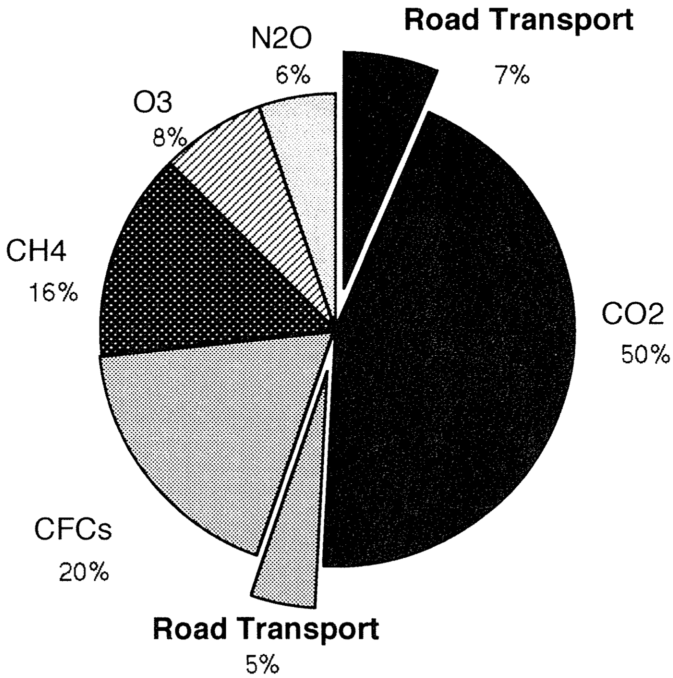


Fig. 5 Contribution of road transport to greenhouse gases

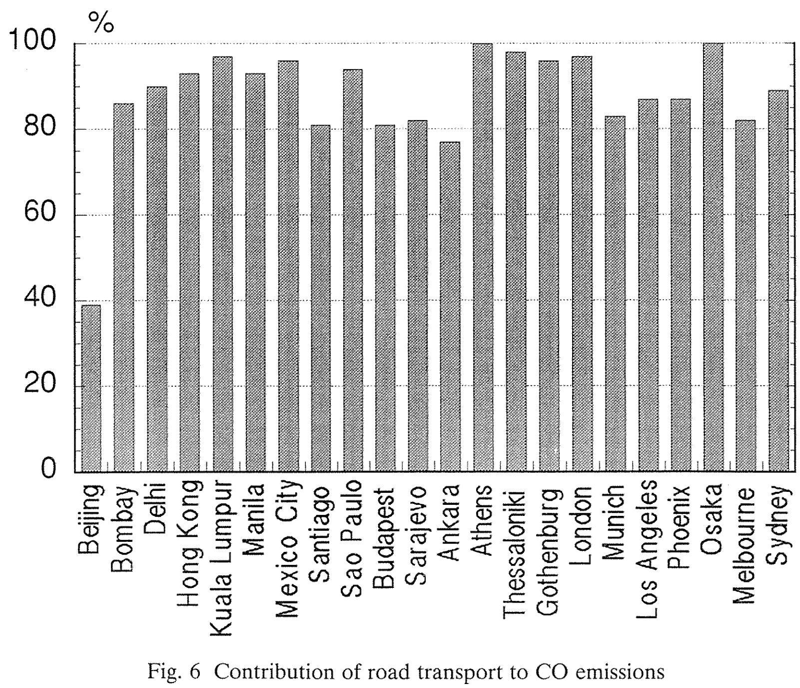


Fig. 6 Contribution of road transport to CO emissions
Source: Ref. 27

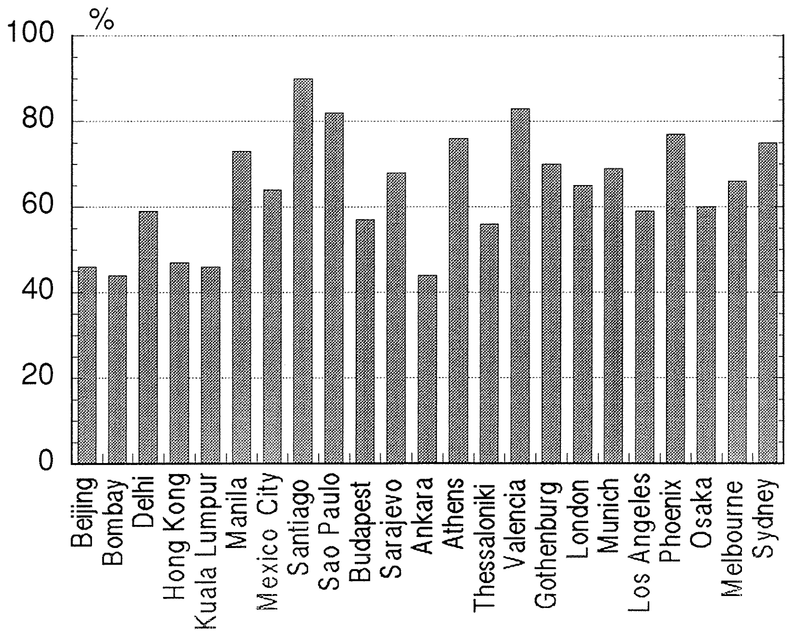


Fig. 7 Contribution of road transport to NOx emissions
Source: Ref. 27

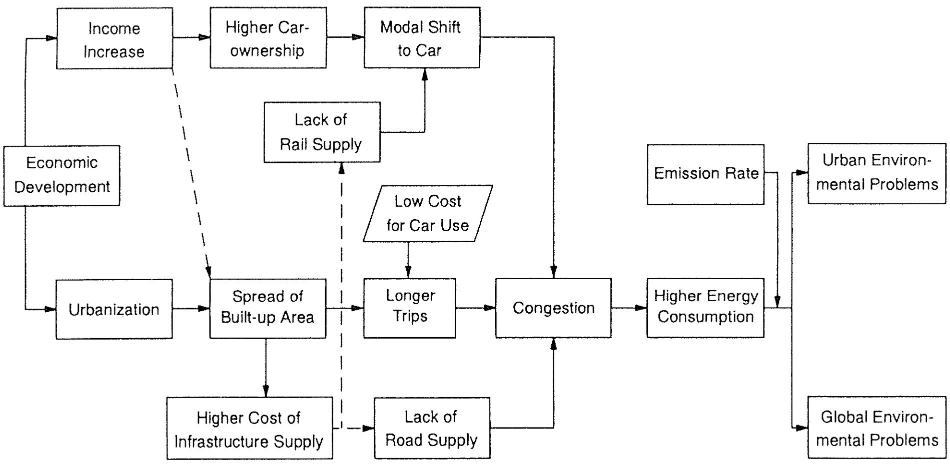


Fig. 8 Mechanism of economic development influences on the environment through increase of energy consumption

2.5 Mechanism of the Influence of Transport on the Environment

According to the important role of transport on the problems of greenhouse effect and air pollution described above, it is necessary to understand the mechanism that causes transport to become one of the main contributors to the environmental problem.

The mechanism of increasing energy consumption by transport sector may be illustrated as in Fig. 8.

Economic development brings income growth. Income growth encourages car ownership and thus modal shift from public transport to road oriented transport. On the other hand, economic development causes urbanization and further suburbanization. Suburbanization increases trip lengths and, if it is in a sprawling manner, difficulty in providing enough transport infrastructure to meet the demand and consequently, congestion and more energy consumption, are a result. Low cost of car use may also increase larger trip length and trip rate.

3. Spatial Development and Urbanization Process

3.1 Historical Development Patterns of Metropolises

3.1.1 Hierarchy and Boundaries of Metropolises

The administrative boundary of each metropolis has been changed so many times due to the continuous expansion of the built-up areas. Meanwhile the definition of functional boundaries such as inner area and metropolitan region are different from one study to another depending on the viewpoint of the interested researcher. This section explains the hierarchy of each functional area in the metropolitan region including the definition of names and boundaries referred to in the study.

Bangkok

The urban and regional functions of Bangkok may be divided into four levels namely, Inner Bangkok, the Bangkok Metropolis or the Bangkok Metropolitan Area (BMA), the Greater Bangkok Area (GBA) and the Bangkok Metropolitan Region (BMR). Inner Bangkok is generally referred to as the old city area covering the districts within the inner ring road. It covers an area of about 145 km^2 and contains a high concentration of both population and employment, including most of governmental offices and economic activities. Recently the population in this area has grown slowly or even declined in some districts, especially in the old urban area.

The Bangkok Metropolitan Area (BMA) is an area of Bangkok which is under jurisdiction of the Bangkok Metropolitan Authority. Bangkok and two other vicinity cities, Nonthaburi and Samut Prakarn form the Greater Bangkok Area (GBA), which was used as the boundary for urban planning purposes during the 1960s and 1980s periods. It covers an area of 3,195 km^2 and has a population of 7.2 million (1990). Recently, the Bangkok Metropolitan Region (BMR) has become an economic agglomeration and the focus of national development. BMR consists of Bangkok and five other cities. It has a population of 8.5 million, covers an area of 7,762 km^2 and shares almost half (48%) of the whole country's product (1990).

London

Greater London includes at least three smaller units, the City of London, Central London and Inner London. The City of London occupies the 274 hectares in the metropolis's center. Around the city it is the 26 km^2 central area or Central London which contains the heaviest concentration of employment in Britain. Meanwhile Inner London corresponds roughly to the pre-1914 built-up area. It may refer to two different areas, the area of the Inner London Education Authority (ILEA) and the area of ILEA plus Haringey and Newham which are so called "Group A Boroughs". However, the latter definition can provide more statistical data. (Hall, 1989).

In addition, Greater London and the Outer Metropolitan Area form the London Metropolitan Region (LMR) covering a much wider area of 10,624 km^2. However, the statistics offices stopped providing the data base on this boundary from the early 1980s. In contrast, the South-East Region is considered as more meaningful area in most recent statistical publications. With 17.3 million in population, the region is the most populous region and contributed 36% of the United Kingdom's total GDP in 1988 (SERPLAN, 1990 & CSO, 1990).

Tokyo

The boundaries of Tokyo may be classified into four levels as follows: Central Tokyo (CBD), Tokyo 23 Ward or the Tokyo Ward Area (TWA), the Tokyo Metropolitan Area (TMA) and the Tokyo Metropolitan Region (TMR). There is no certain definition about what is Central Tokyo. In some studies it refers to the area of 3 central wards (Chiyoda, Chuo and Minato) while in the others, it includes 5 surrounding wards (Taito, Shinjuku, Shibuya, Bunkyo and Toshima). Tokyo 23 wards (TWA) is the area which contains all subcenters and can be considered as the core area of the Tokyo Metropolitan Region. Some 70% of the population of the Tokyo Metropolis live in this area. In this study, this area is referred to

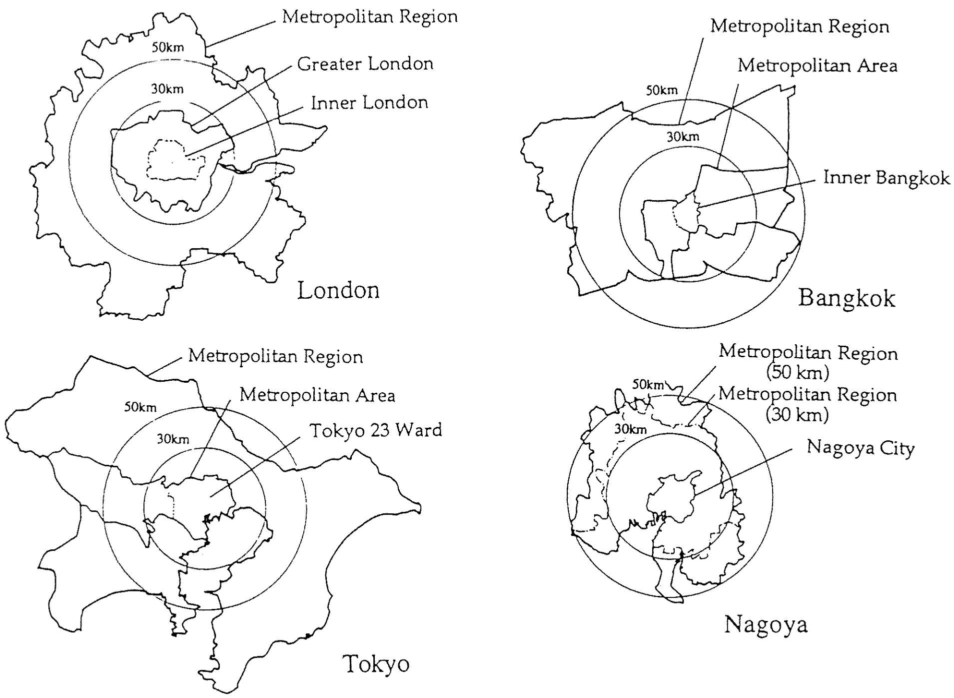


Fig. 9 Hierarchy of metropolises

as the inner area of Tokyo Metropolis. The Tokyo Metropolitan Area (TMA) is an administrative area of Tokyo Metropolis managed by the Tokyo Metropolitan Government (TMG). The TMA and three other prefectures form the Tokyo Metropolitan Region (TMR) which covers an area of 13,548 km^2 and has a population of 31.8 million and a share of 25% of the national product.

Nagoya

The hierarchy of Nagoya can be classified into 3 levels, namely the central area, the Nagoya City Area and the Nagoya Metropolitan Region. The central area of Nagoya (CBD) generally means the area surrounded by the Tokaido Railway line, the Central Railway line and the middle ring road. There is no official definition for this area. Nagoya City and the cities within a 50 km radius altogether form the Nagoya Metropolitan Region. The region has a population of about 8.4 million (1990), representing 6.8% of national population, and accounts for 10% of national product.

The hierarchy of each metropolis, including area covered and population, are summarized in Fig. 9 and Table 1 respectively.

Changes in population in each metropolis and metropolitan region are compared in Fig. 10. It shows that the population in London increased with a rate of 1—2% annually during the latter half of the nineteenth century and the first half of the twentieth century. But the population decreased during the latter half of the twentieth century. At present, it seems that London is moving from its declining stage, since population has increased during the 1980s. For Tokyo and Nagoya, the population grew rapidly in the post-war period with an average rate of 3—4% per annum. However, the growth was much higher during the latter half of the 1940s and the first half of the 1960s. In the case of Bangkok the rapid growth of population continued from the 1950s to the end of the 1970s, during which its growth rate was very similar to that in Tokyo during the post war period.

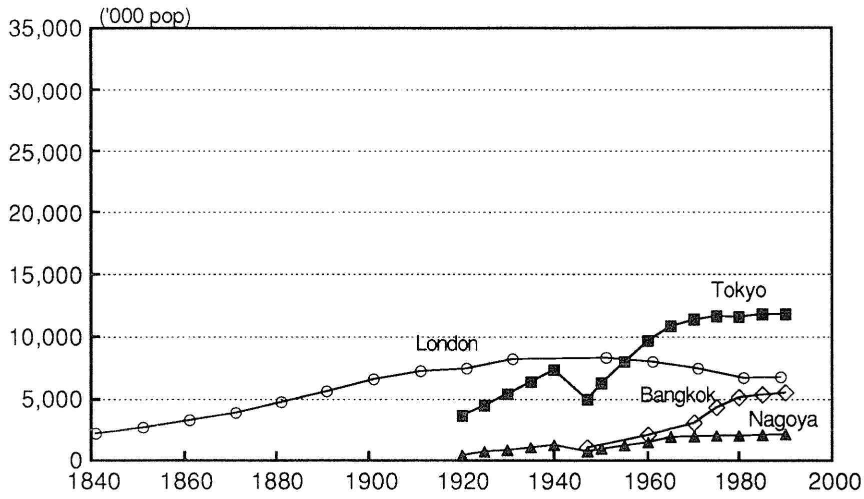
At present populations in all these metropolises are quite stable or slightly increasing. On the contrary, the total populations in the metropolitan regions are increasing considerably. The annual growth in the regions is more than double that of the metropolises' growth rate. This implies that the population growth occurs mainly in the surrounding areas of

Table 1 Area and population in each metropolitan function (1990)

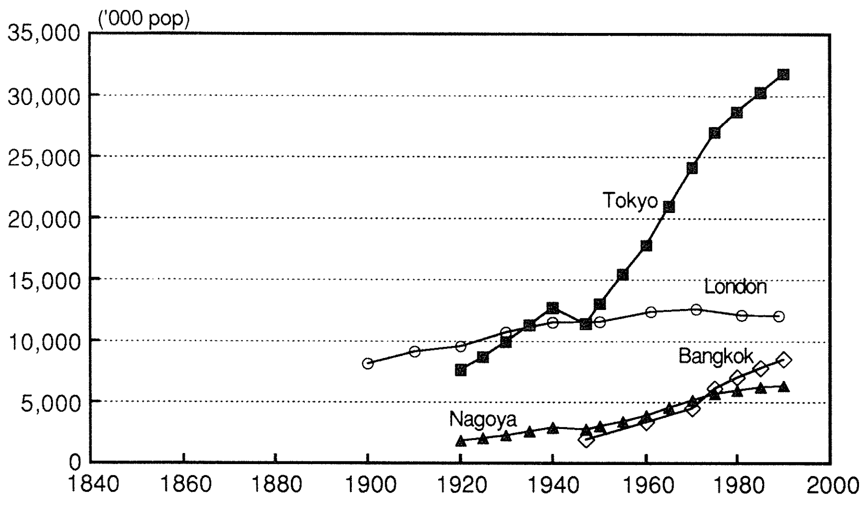
Area	Bangkok	London	Tokyo	Nagoya
Inner Area	Inner Bangkok	Inner London	Tokyo 23 ward	
- area (km^2)	145	302	612	
- population (million)	2.32	2.32	8.16	
- pop. density (person/km2)	16,000	7,680	13,330	
Metropolitan Area	BMA	GLC	TMA	Nagoya City
- area (km^2)	1,567	1,579	2,183	326
- population (million)	5.55	6.8	11.85	2.15
- pop. density (person/km2)	3,540	4,300	8,605	6,595
Metropolitan Region	BMR	LMR	TMR	NMR (50 km)
- area (km^2)	7,762	10,624	13,548	7,325
- population (million)	8.54	12.1	31.8	8.43
- pop. density (person/km2)	1,100	1,140	2,347	869
Other		South East		NMR (30 km)
- area (km^2)		27,222		3,027
- population (million)		17.4		6.4
- pop. density (person/km2)		640		2,110

Sources: Ref. 6 and 11

metropolises which represent the 'suburbanization stage' (more detail on the urbanization stage is discussed in section 3.3).



(a) Metropolises



(b) Metropolitan regions*

*Nagoya: Nagoya Metropolitan Area (30 km radius)

Fig. 10 Changes in population in metropolises and metropolitan regions
Sources: Ref. 71, 74, 78, 81 and 115

3.1.2 Spatial Development Patterns and Transport Infrastructure Provision

Bangkok

At earlier development in Bangkok, the built-up area spread in the area surrounding the palace and along canals and the river due to waterways being a major means of transport at that time. However, it was not until the beginning of the twentieth century that the built-up area shifted to the areas equipped with a road network, which started to develop from the end of the nineteenth century. As a consequence of population growth and land transport improvement, the built-up area has increased from 13 km^2 in 1900 to 43 km^2 in 1936 and to 67 km^2 in 1953 (Sternstein 1982). The ribbon development pattern, a typical development pattern in Bangkok, also can be seen in this period.

The large amount of infrastructure investment and economic expansion during the second half of the century, especially since the 1960s, induced migration and increased spatial demand for development. The built-up areas spread out rapidly and continued to the nearby cities. Meanwhile, suburban sprawl and ribbon development along major radius roads also appeared clearly. Between 1971 and 1984 the built-up area in Bangkok drastically increased by almost 5 times from 184 km^2 to 855 km^2.

London

During its earlier development stage in 1900s, the built-up area in London spread only within one's walking distance. However, the improvement of public transport system since the first half of the nineteenth century allowed the development to go further than before. The introduction of the steam railway during the mid-nineteenth century gave easy and fair access at distances up to 24 km from the city center. But the development appeared mainly surrounding the station because of the long distance between stations and poor feeder service. The development of electric trains, the tube and buses allowed suburban spread in all directions and over a wider area. The built-up area in London increased remarkably during the first half of the twentieth century. In order to control suburban sprawl the metropolitan green belt was introduced in 1938 at a distance around 24 km from the center. The spread stopped but development appeared beyond the green belt.

Tokyo

Like London, as a result of suburban railway improvement from the end of the 1920s, suburban development increased considerably especially around the station and along the route between Tokyo and Yokohama. In the 1950s, the built-up areas of Tokyo and Yokohama were connected, meanwhile the built-up area in Tokyo spread almost over the whole 23-ward area. The development around the suburban stations has expanded along the lines and connected with those spreads from the center since the 1960s. At present the development of Tokyo spreads over almost 50 km from center and some parts have spread along the railway line into the inner area of Chiba and Saitama prefectures.

Nagoya

Up to around the 1920s the built-up area in Nagoya spread mainly along the Tokaido line. As a result of the introduction of the zoning system, the built-up area changed to expand in all directions. During the Second World War, about one-fourth of the city was destroyed. After the war the city was rebuilt with various land readjustment projects. The built-up area and population increased considerably in the 1950s, with most of it in the city boundary. Since the 1960s the growth of population and the built-up area has appeared mainly in the surrounding area of Nagoya.

The review on the development pattern of built-up areas suggests that the supply of transport infrastructure is a major factor influencing the development pattern. Rail supply contributes to the development in the areas surrounding the stations. Meanwhile, road development in general causes ribbon development.

The difference in growth patterns among metropolises can be observed. In London, the built-up area increased rapidly during the first half of the twentieth century. The growth of built-up area occurred both in the metropolitan area and in the surrounding areas or cities. Meanwhile, in the case of Tokyo and Nagoya, the pattern of spatial development is similar to that of London but the degree of suburban spread was higher in the second half of the century. In addition, suburban development mainly appeared in the directions equipped with better transport network, especially railways. For Bangkok, the remarkable expansion of built-up area occurred in the second half of century. Unlike other metropolises, the ribbon development patterns can be seen clearly in Bangkok. This inefficient development is an outcome of poor land-use control, lack of rail infrastructure and inadequate distribution and local roads.

3.2 Measuring Spatial Development

Since the picture of changes in built-up area cannot give clear information on the speed and degree of spatial development, the indices of urban radius r_0, r_1 and r_1' are introduced for measuring this process and are noted as follows:

$$r_0 = \sqrt{\frac{\sum_{i=1}^{n} a_i}{\pi}}$$

$$r_1 = \frac{\sum_{i=1}^{n} a_i r_i}{\sum_{i=1}^{n} a_i}$$

$r_1' = 2/3\ r_0$ (the centriod of the area within r_0 km from center)

where a_i = area of built-up area a_i
r_i = distance between a_i and the city center
n = number of built-up areas in the metropolitan area

The index r_0 represents the degree of spatial development in terms of radius when the whole built-up area is shaped in a complete circle, while r_1 represents the average radius of built-up areas from the city center (the distance between center and centroid of built-up area). The index r_1' represents the radius r_1 if the built-up area grows like the circle shape with a radius r_0. The gap between r_1 and r_1' illustrates the degree of scatter development and sprawl (only in a radius direction). The bigger r_0 is, the bigger the built-up area is and the bigger r_1 is, the more suburban development there is.

Fig. 11a and 11b show the growth of the built-up area in the metropolitan regions in terms of development radius r_0, r_1 and r_1'. The growth of the built-up area in London is quite stable while rapid growth can clearly be seen in Tokyo and Bangkok since the 1960s and the 1970s respectively. The present size of the built-up area in Tokyo is as large as that of London. Though Bangkok's administrative area is much larger than Nagoya, the area of the built-

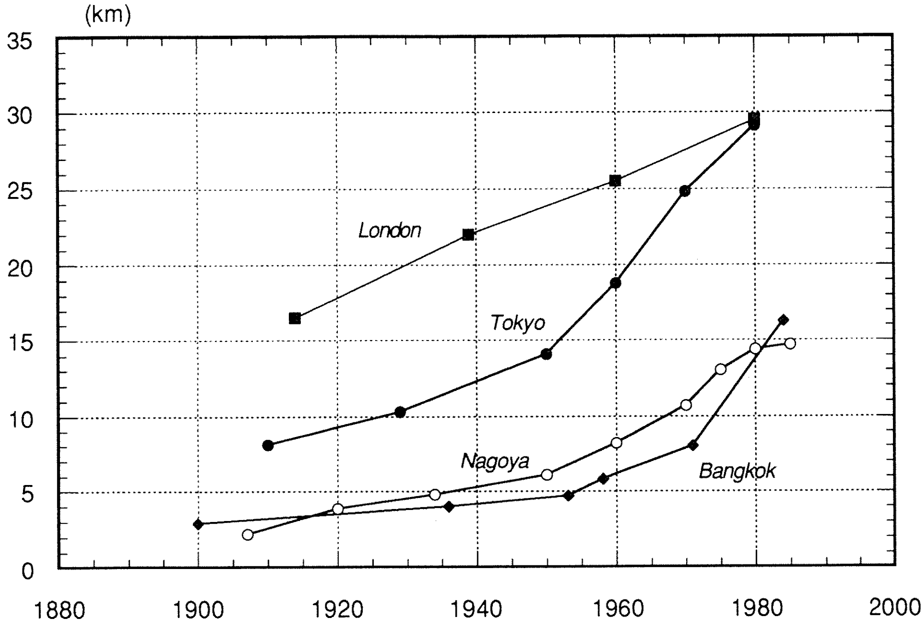


Fig. 11a Changes in development radius r_0

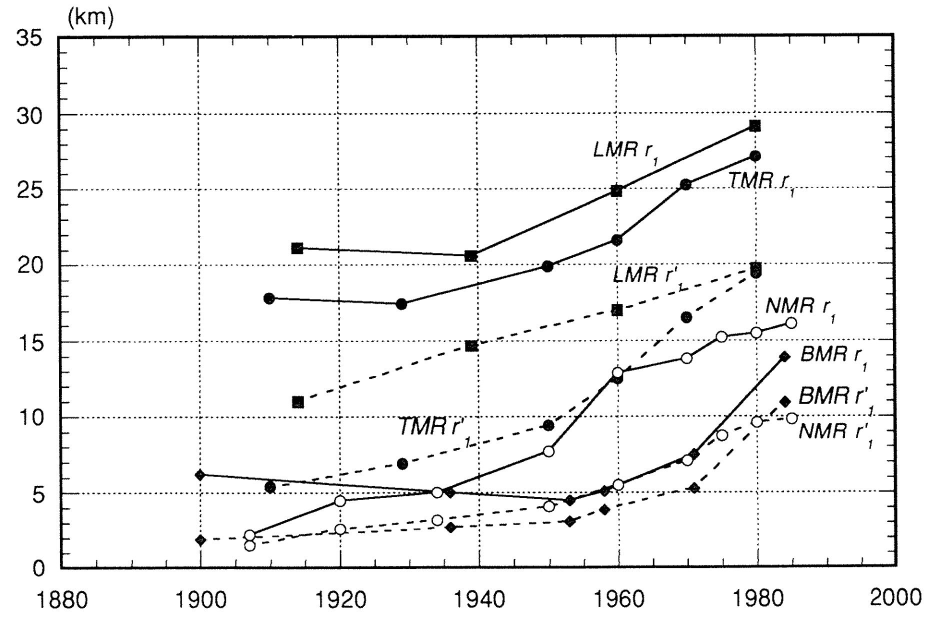


Fig. 11b Changes in development radiuses r_1 and r_1'

up area is almost the same as Nagoya, which implies that a large part of Bangkok is not developed yet.

On the other side, the value of r_1 in Bangkok decreased throughout the first half of the century while gap between r_1 and r_1' became smaller. This implies that the growth of the built-up area was mainly in the form of continuous expanding and concentrated in the core city of the region (Bangkok). As a result of rapid urbanization in the second half of the century, the built-up area increased rapidly while the degree of suburban development was also higher due to the wider gap of r_1 and r_1'.

In London, r_1 decreased slightly after the suburban sprawl was controlled by the introduction of the 'Restriction of Ribbon Development Act 1935' and the 'Green Belt Act 1938'. However, as development appeared beyond the Green Belt, the value of r_1 increased at a rate higher than r_1. This means that the degree of scatter development and sprawl increased.

The large gap between r_1 and r_1' in Tokyo during the beginning of the 1900s represents large-amount scatter development in the metropolitan region. However, the gap had decreased continuously until 1960. The rapid growth of both r_1 and r_1' since the 1950s implies the rapid continuous expanding of the built-up area rather than scatter development.

The development in Nagoya is quite different from other metropolises. The gap between r_1 and r_1' has become wider and wider since the beginning of development. This is because, compared with other metropolises, the developments are less concentrated in Nagoya due to the fact that it is not a single economic-dominated city in that region.

In addition to the above phenomena, the major findings are listed as follows:

—The degree of urban sprawl and scatter development seems to be the lowest in Bangkok as the rapid growth is in the form of continuous expansion and ribbon development along major trunk roads but not in the form of scatter development.

—Though in 1980 Tokyo and London had the same r_1' the radius r_1 in London was larger, which meant more suburban development. The picture can be explained by the fact that as much development occurred in the area beyond the green belt.

—The calculation of changes in r_1 found that at present the built-up area in Bangkok is spreading at an about 0.5 km/year which is more than double that of London and Tokyo and triple that of Nagoya (see Table 2).

Table 2 Growth rate of development radius (r_1)

Metropolis	period	growth of r_1 (km/year)	compare with Bangkok
Bangkok	1971-84	0.49	1: 1
London	1960-80	0.22	1: 2.2
Tokyo	1970-80	0.19	1: 2.6
Nagoya	1970-85	0.15	1: 3.3

3.3 The Stage of Urbanization of the Metropolises

3.3.1 Urbanization Cycles

The difference in spatial development pattern among metropolises depends on urbanization stage in which metropolises are located.

In most studies on urban spatial development, the stage of urbanization is defined by the percentage of population in the urban area or percentage of urban population in the city. A high percentage means a high urbanization level. However, since this study pays attention not only to the number of the population in the urban area but also the dynamics of urban development (where the population grows or declines) and most of the population in selected metropolises are in the urban area, the Klaassen's urbanization concept is applied. According to Klaassen's concept (Klaassen, 1981), the stage of urbanization may be divided into four stages according to the patterns of population growth in the agglomeration core (core city) and the ring (surrounding cities). These stages are as follows:

1. *Urbanization*: The stage in which population growth is mainly concentrated on the core city.
2. *Suburbanization*: At this stage, the population growth in the ring is higher than that in the core and sometimes the growth of the ring population is accompanied by population loss in the core.
3. *Disurbanization*: This is the stage in that total population in agglomeration decreases due to population loss in the core exceeding population gains in the ring. The case in which the growth of the core is a stronger negative than that of the ring is also included in this stage.
4. *Reurbanization*: At this stage the agglomeration still loses population but the loss is less serious in the core than in the ring, or the core even grows while the ring declines.

According to the concept of the urbanization stage described above, one may see that the use of the amount of population growth is not reasonable if the size or population of the core and ring area are much different. In order to reduce the influence of area size, this study considers the percentage growth of population as a variable for indicating the stage of urbanization. In addition the following index f is introduced as an indicator for identifying the stage (Hayashi et. al, 1991),

$$f = /PC_r/ - /PC_c/$$

whereas, PC_r = percentage change in population in the ring
PC_c = percentage change in population in the core

According to above relation, the urbanization process can be shown in terms of the changes in value of index f (see Fig. 12) which move as the following cycle: (−) → (+) → (−) → (+).

However, it should be noted that this index does not give information on the exact period when the agglomeration declines.

In this study, the agglomeration is considered as an area covering the metropolitan area, and its surrounding cities which totals about 5−10% of the trips commuting to the metropolis. According to this definition, the agglomeration of each metropolis including the core and the ring which are applied in this study are listed as Table 3.

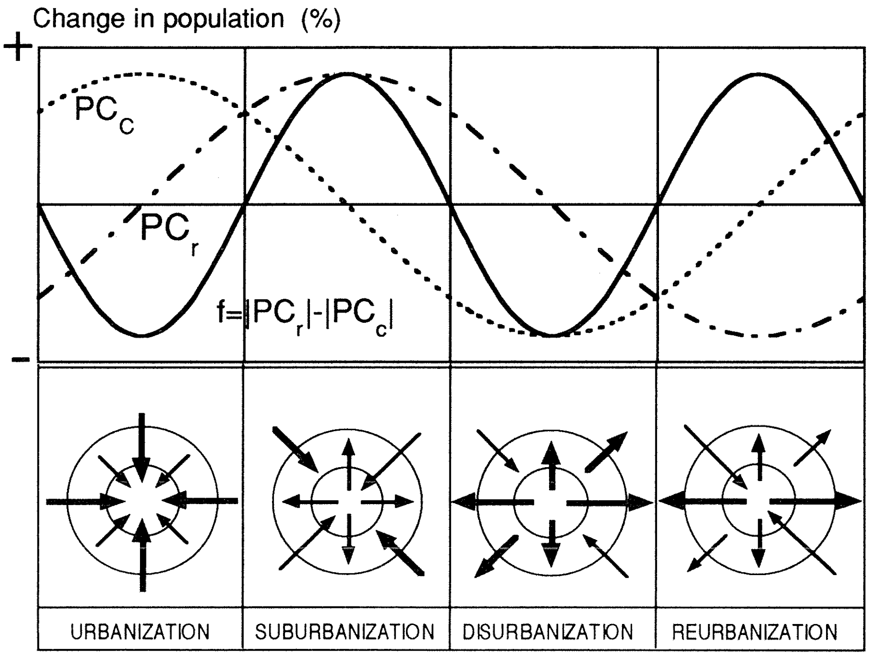


Fig. 12 Conceptual pattern of urbanization cycle

Table 3 Definition of the core and the ring of metropolises

Metropolis	Agglomeration	Core	Ring
London	London Metropolitan Region (LMR)	Greater London	the rest of LMR
Tokyo	Tokyo Metropolitan Region (TMR)	Tokyo 23 Wards	Tokyo's Tama area and the rest of TMR
Nagoya	Nagoya Metropolitan Region (NMR) (30 km radius)	Nagoya City	the cities within 30 km. radius from center of Nagoya
Bangkok	Bangkok Metropolitan Region (BMR)	Bangkok but excluding low density districts (less than 1,000 person/km^2)	the rest of BMR

3.3.2 *Identifying the Stage of Urbanization of the Metropolises*

Based on the index f defined in the previous section, the urbanization cycle in each metropolis can be drawn as in Fig. 13. These cycles are based on the percentage growth of population in the core and the ring in a 5 year period except in the case of London in which a 10 year period was applied. The figure suggests that London experienced the '*suburbanization stage*' at the end of the 1900s. It passed into the 'disurbanization stage' in the 1970s which is in accordance with the fact that the population in the London Metropolitan Region decreased from the 1970s. At present it seems that London is moving to the 'urbanization stage' again since the population of both Greater London and the region is increasing.

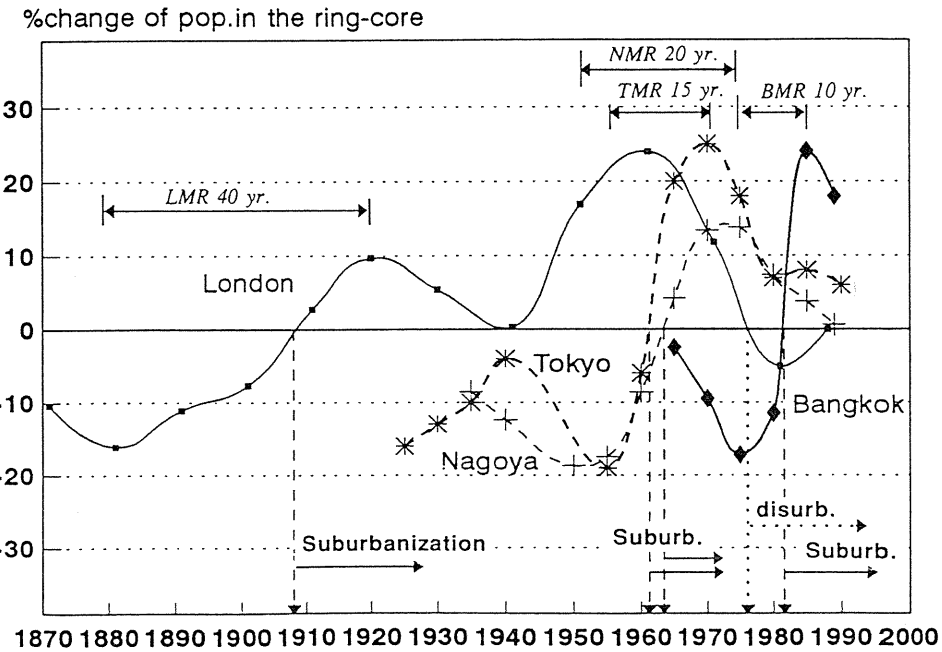


Fig. 13 Changes in stage of urbanization in the metropolises

Tokyo experienced the 'suburbanization stage' at around the beginning of the 1960s. At present, it is still in the same stage but the growth of population is quite low. Urbanization in Nagoya is very similar to that of Tokyo. It passed the 'suburbanization stage' at around the mid 1960s and is still in the same stage. However, unlike Tokyo, the population in Nagoya City has not declined.

The 'suburbanization stage' took place in Bangkok at the beginning of the 1980s. This implied that Bangkok is the youngest metropolis from the viewpoint of the urbanization process. The urbanization cycle of Bangkok is similar to that of Tokyo but the curve seems to be steeper. By comparing the period that each metropolis changed from the 'urbanization stage' to the 'suburbanization stage', one may see that Bangkok lags 80 years behind London and around 20 years behind Tokyo and Nagoya.

Moreover, the urbanization cycles show that London took 40 years from the peak of the 'urbanization stage' to the peak of the 'suburbanization stage', while it took 20 in Nagoya, 15 years in Tokyo and only 10 years in Bangkok. This implies that the urbanization cycle speed in Bangkok is 1.5 times as fast as that of Tokyo, twice that of Nagoya and four times that of London. In other words, the change of people settlement in Bangkok is the fastest. The rapid growth of population and fast urbanization cycle speed are the major contributors to infrastructure supply problems in Bangkok. This is because the development pattern doesn't allow the infrastructure supply to keep up with the demand.

From the comparison between Fig. 11 and Fig. 13, most metropolises have experienced drastic spatial changes in the suburbanization stage. However, the spatial pattern of development is different by metropolis, i.e.: in London, both population and employment decentralized according to the Greater London Plan. While in Tokyo and Bangkok, only population has suburbanized in a sprawling manner to bring inefficient suburban land use and locational imbalance between population and jobs as seen later in section 3.4.

3.4 Spatial Density of Population and Jobs

In the previous section the comparison and discussion concentrated only on the spatial development in horizontal dimension. Then in this section an interest is paid to development density of both the population and the employment.

Changes in population density by distance from city center in Greater Bangkok Area (GBA) between 1960 and 1990 is shown in Fig. 14. During the 1960s, the city center had the highest population density which was like the development pattern of cities in continental Europe such as Munich and Lyon (Webster, 1984). The density declined as the distance from the center increased. However, as a result of economic expansion, the population declined in

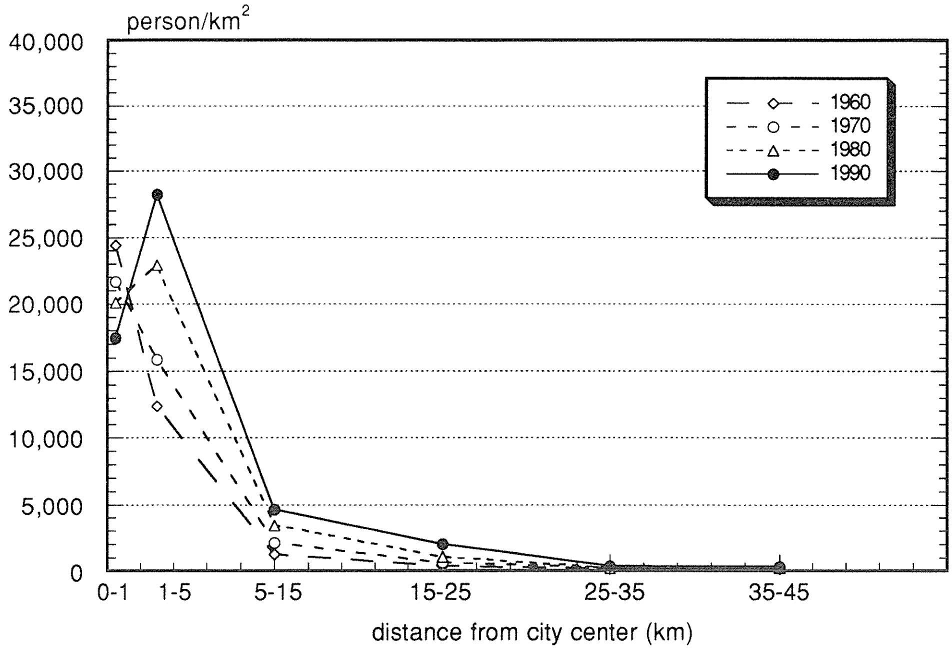


Fig. 14 Dynamics of population growth in Bangkok

the city center while it grew in surrounding areas, especially in the areas within about 5 km from the center. The highest population concentration area is shifted to the district in the radius of about 1—5 km from city center.

The decline of population in the city center is also found in the other three metropolises. London experienced a decline from the 1850s when population density in City of London decreased from 47,000 person/km^2 in 1851 to 41,000 in 1861 and to only 1,600 in 1989. Meanwhile, this phenomena happened in Tokyo and Nagoya around the year 1955 and 1960 respectively.

Fig. 15 shows the pattern of population settlement in terms of changes in population density by distance from city center. According to this figure, some phenomena can be observed as follows:

—In all metropolises, the maximum population density appears at some certain distance from city center.

—Bangkok is the most centralized metropolis in terms of population distribution. Its highest density is about 1.3 times higher than that in Tokyo and about 3 times those of London and Nagoya. The density declines sharply as distance from the city center increase. The contrast of population density can be seen more clearly in Fig. 16 which shows the density by district in three dimensional views. The figure illustrates an extreme concentration of population in central Bangkok.

—Tokyo shows the largest agglomeration in terms of area of high density development. In other metropolises the density of 5,000 person/km^2 can be found only within a distance of approximately 10 km from city center but for Tokyo it appeared up to 20 km.

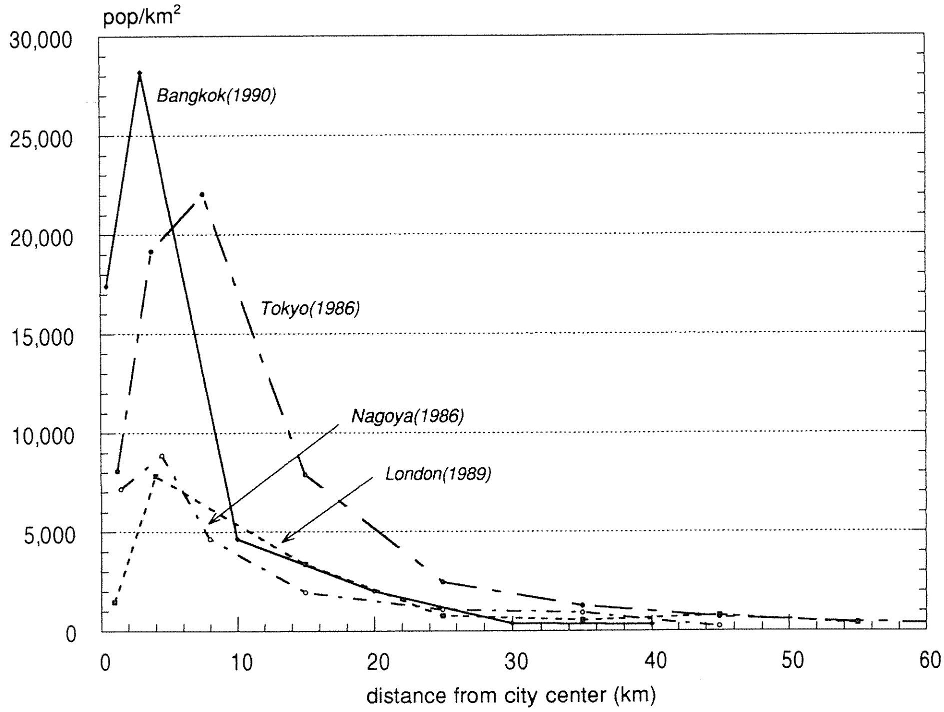


Fig. 15 Changes in population density by distance from city center

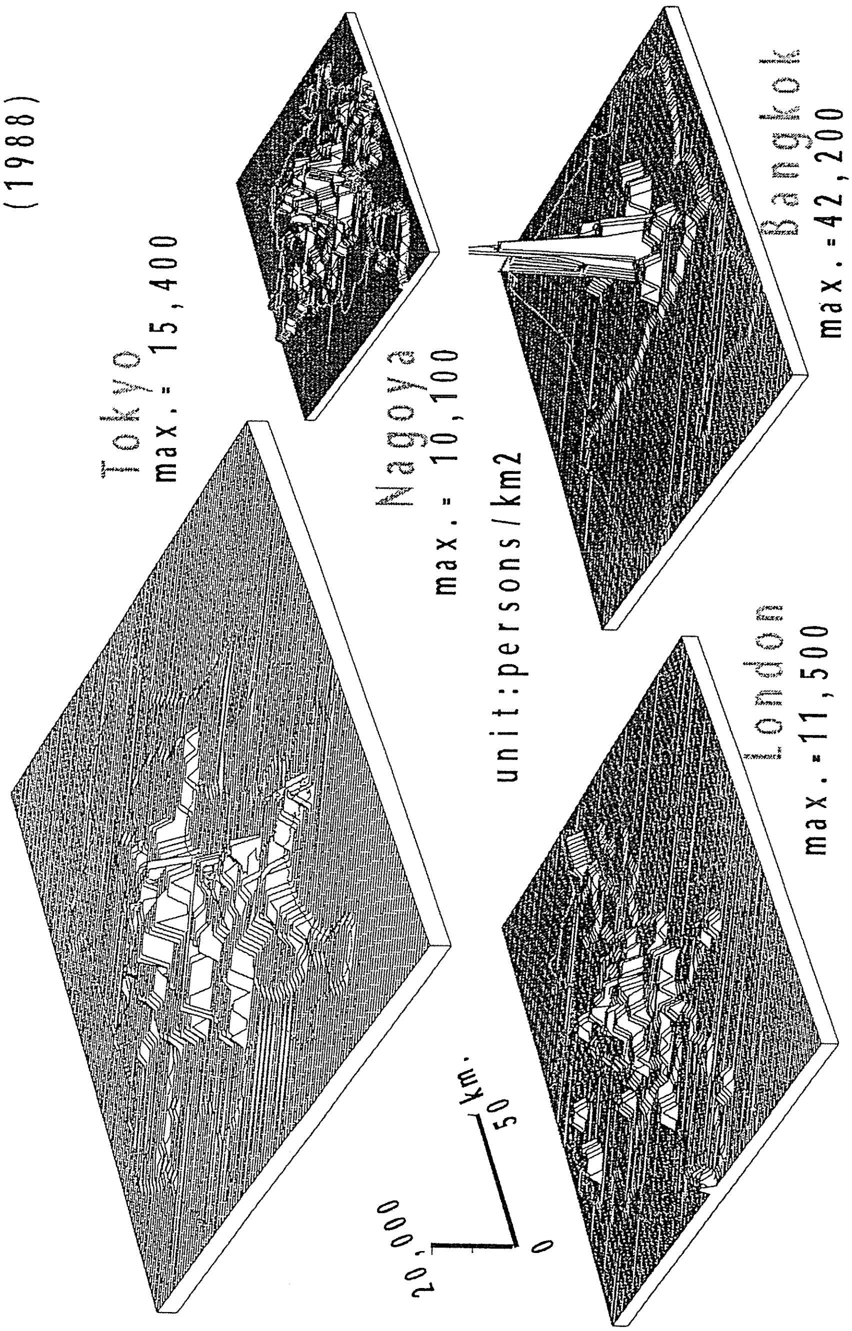


Fig. 16 Comparison of population distribution in three dimension view (1988)

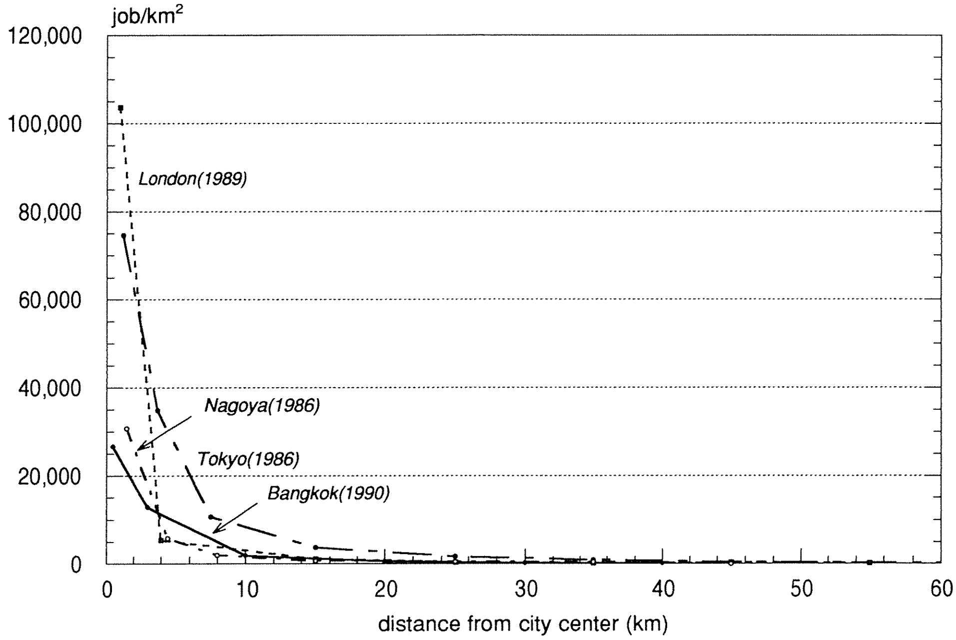


Fig. 17 Changes in job density by distance from city center

In addition to population density, the development in terms of employment distribution in each metropolis is compared as shown in Fig. 17. The employment distribution patterns are different from that of population distribution. The maximum density of employment appears at the city center in all metropolises. The figure also shows a high concentration of employment in the inner area both in London and Tokyo due to their economies depending largely on the service sector. London (City of London) has the highest central job density. This is about 1.5 times higher than that in Tokyo (Chiyoda-ku) and about 3 times of those in Bangkok and Nagoya.

Contrary to the above information, Fig. 18, which shows the employment density by district in three-dimensional view, suggests that the maximum job density in Bangkok be as high as that in Tokyo. This contrasting pattern occurred due to the fact that the spatial development in Bangkok is in the forms of multi-nucleus and mixed land use. The central area for business or central business district is settled in a different location from the central area of government offices and is mixed with residential areas. This pattern of development can shorten the travel length if the jobs and residents are well-matched but if not, it can cause more traveling conflicts.

The ratio between the number of jobs and population in the area is one of the indicators which can represent the suitability of spatial development. Fig. 19 shows the ratio between the number of jobs and population in the metropolitan regions by district. The balance between the amount of jobs and population in Nagoya is comparatively higher than other metropolises. Meanwhile, imbalances can be seen clearly in Tokyo and Bangkok. In Tokyo, most of the area beyond the central area has a ratio of job/pop. less than 0.4 which implies a centralization of jobs. This type of development encourages a long trip length. The 1985 transport census found that more than 60% of workers commuting to the three central wards

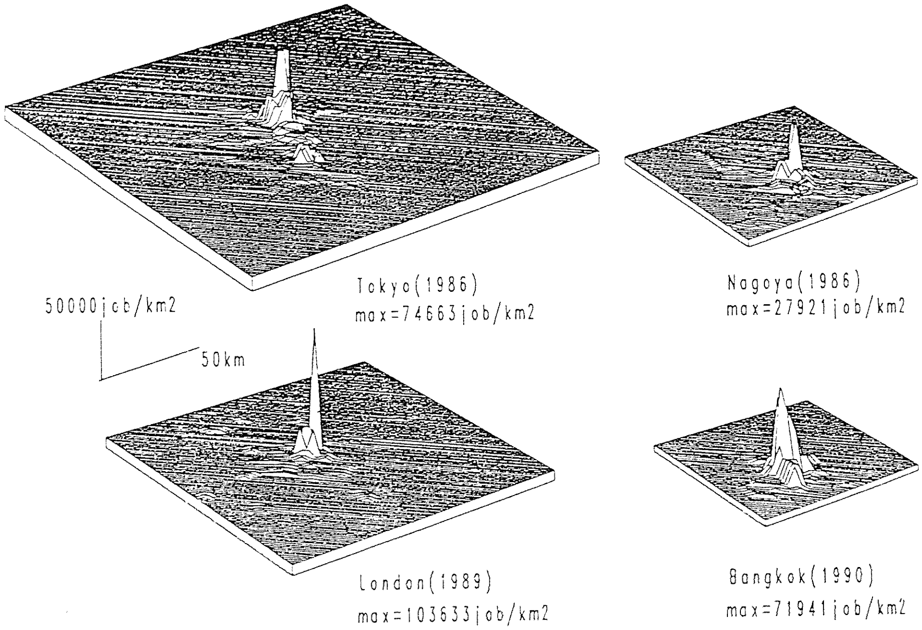


Fig. 18 Comparison of job distribution in three dimensional view

Fig. 19 Comparison of ratio of job density to pop. density

spent over an hour to reach their workplaces (TMG 1991). Meanwhile, in London, less than 40% of workers commuting by London Transport spend more than an hour (Johnson & Nash 1982).

In the case of Bangkok, the ratio varies among districts, in some areas the ratio is high and in some low. However, the previous two figures suggest that jobs be also centralized in Bangkok as the ratio for most districts in the inner areas. The concentration of both population and employment in the inner area, on one hand as multi-nucleus pattern, contributes to a shorter travel length. On the other hand, it also contribute to high activity density which is a major cause of many urban problems such as difficulty of infrastructure supply, traffic congestion and high pollutant intensity.

4. Motorization, Infrastructure and the Environment

4.1 Growing Car Ownership

a) Comparison of Growth Rate of Car Ownership

Fig. 20 compares the changes in car ownership among four metropolises. London was the most progressed in motorization in 1960. At this time its car ownership level per 1,000 inhabitants was about 8 times as high as those of Bangkok, Tokyo and Nagoya. It is surprising that in the year 1960, Bangkok's car ownership level was as high as those in Tokyo and Nagoya. However, a review on the history of the vehicle industry found that the real motorization period in Japan just started at the beginning of the 1960s, when small cars were introduced. Major evidence of this is the emergence of the word 'my car' which means owning a

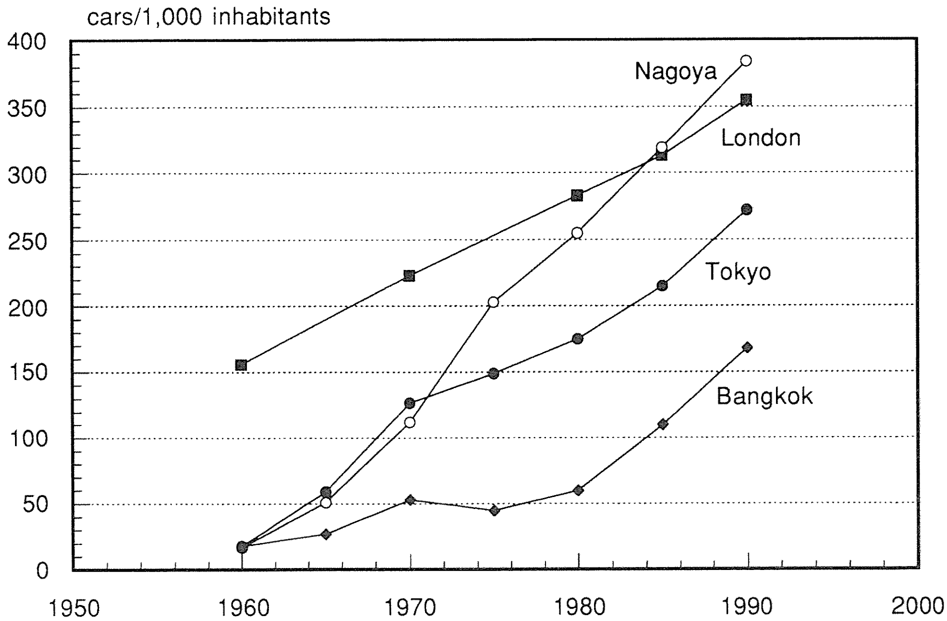


Fig. 20 Changes in car ownership

car. Between 1960 and 1965, the number of registered small cars in Tokyo increased by 13 times and in Nagoya 12 times. While the rapid increase in car ownership in Tokyo shows a downward trend in the 1970s and 1980s, this is not in case of Nagoya. The rapid growth of car ownership in Nagoya has been continuing and Nagoya has had the highest car ownership per inhabitant metropolis from the mid-1980s.

The figure also shows that the present car ownership in Bangkok is about half of those in London and Nagoya and about 0.6 times of that in Tokyo. In addition, it suggests that the growth pattern of car ownership in Bangkok 1975–1990 was very similar to that of Nagoya 1960–1975, so that the motorization in Bangkok follows that in Nagoya with a time gap of about 15 years.

In order to identify the relative rate of motorization to economic development, the relationship between per capita GRP and car ownership are shown in Fig. 21. By considering car ownership at the same per capita GRP level in the figure, following comments can be drawn:

a. The trend in London is similar to those in Tokyo, Nagoya and Bangkok but at a different level since, at the same per capita GRP level, car ownership in London is much higher than those in the other metropolises.

b. Growth rate of car ownership in Bangkok was significantly higher than those in Tokyo and Nagoya since the latter half of the 1980s.

c. During the low per capita GRP (less than US$ 3 or 4,000), car ownership in London, Tokyo and Nagoya changed linearly with the per capita product. This implies that the relationship in Bangkok is consistent with those in the other three metropolises.

b) Causes of Higher Car Ownership in Bangkok

According to the above analysis on the relationship between economic development and motorization, it may be said that recently car ownership in Bangkok is slightly higher than

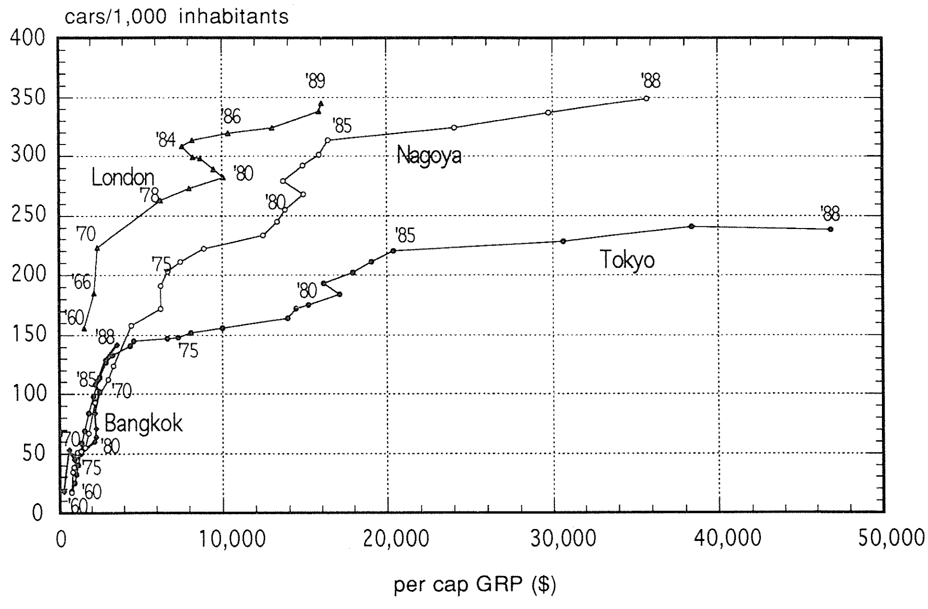


Fig. 21 Per capita GRP (current price) and car ownership

Table 4 Comparison of motorization level at the same per capita product level (cars and motorcycles)

Metropolis	Car ownership (veh./1000 persons)	Motorcycle ownership (pcu/1000 persons)	Car + Motorcycle (pcu/1000 persons)	Compared to Bangkok
Bangkok (1988)	142	34	176	1.00
Tokyo (1971)	135	3	138	0.78
Nagoya (1971)	126	11	137	0.78

those in Tokyo and Nagoya (considering the same per-capita GRP level). As the contribution of motorcycles in total vehicles is quite high in Bangkok, then to get the real figure of motorization, motorcycle ownership should be taken into account. In this study, the factor 0.25 is applied as a factor for converting the number of motorcycles to passenger car units (pcu). Table 4 compares the motorization level both in terms of car ownership and car plus motorcycle ownership. The motorization level in Bangkok rises about 24% in the case where motorcycle ownership (in pcu unit) is taken into account while the levels slightly increase in the case of Nagoya and Tokyo. The motorization level in 1988 Bangkok was about 1.13 times as high as that in 1971 Nagoya and 1.05 that of 1971 Tokyo if only car ownership is considered. However, it increases to 1.28 times and 1.28 times respectively if both car and motorcycle ownership are considered. This implies that the present motorization level in Bangkok is about 30% higher than those in Tokyo and Nagoya were during the same economic development level.

If attention is paid to car price, as generally it is considered as a major factor influencing the level of car ownership, one should be surprised by Fig. 22 which illustrates the extremely

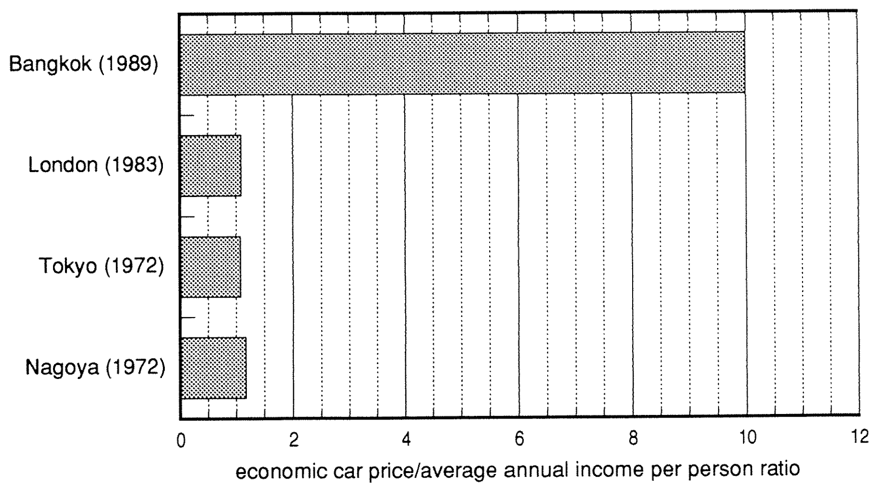


Fig. 22 Ratio between price of economic car and av. annual income per person

high price of cars in Bangkok. The figure shows that the ratio between price of an economic car (~ 1200 cc) in Bangkok is about 10 times higher than those in Tokyo and Nagoya during the similar motorization and economic development level. Meanwhile the ratio in London, Tokyo and Nagoya are almost the same. The poor bus services and lack of urban rail rapid transit in Bangkok force people to rely largely on private cars, though car prices are much higher than their incomes. This implies that without the alternatives for private vehicle use, the pricing measure just makes transport more costly but does not reduce private car use and congestion.

4.2 Delaying Supply of Road Infrastructure

Fig. 23 shows the time serial changes in the shares of road investment in GNP in UK, US, Japan and Thailand. The declining road budget share in the UK and the US is understandable because they have already provided a high level of infrastructure stock and therefore their needs for new construction are not very high. It is well known that the steep decline in the 1960s and 1970s in the US brought serious infrastructure deterioration for which roads and bridges were obliged to be closed. We clearly remember the accident on the Brooklyn Bridge and the closure of the West Side Highway in Manhattan, New York as symbolic events.

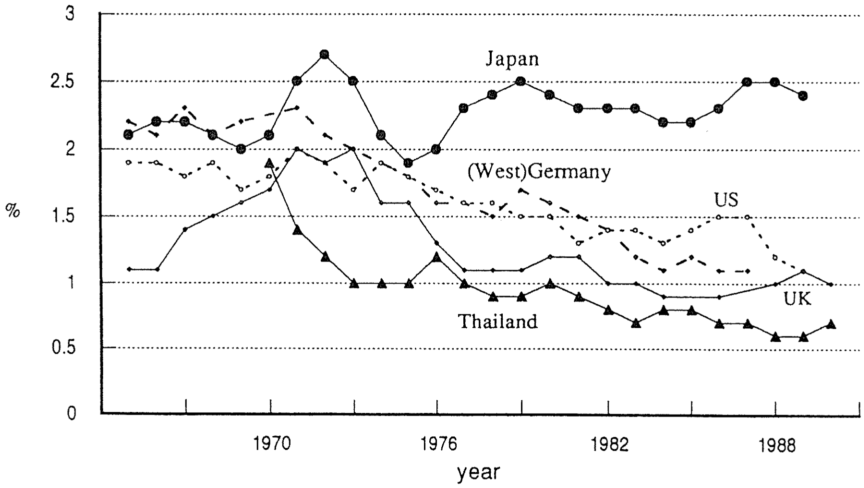


Fig. 23 Ratio of road investment to GNP
Source: Ref. 13

Thailand had road investment of about 2% of GNP in the late 1960s but it has declined steeply to reach the level of less than 1% of GNP, which is the lowest among the four countries. It is also clearly seen in Fig. 24 that in Bangkok the increase rate of budget for investment in infrastructure improvement has been much lower than that of GRP while in Tokyo these indices stay close to one another in the period of rapid economic growth (Hayashi, et al., 1993b). In Bangkok, it has definitely been a big problem that the insufficient investment brought about a big gap between car traffic demand and road infrastructure construction as seen in Fig. 25 in section 4.3.

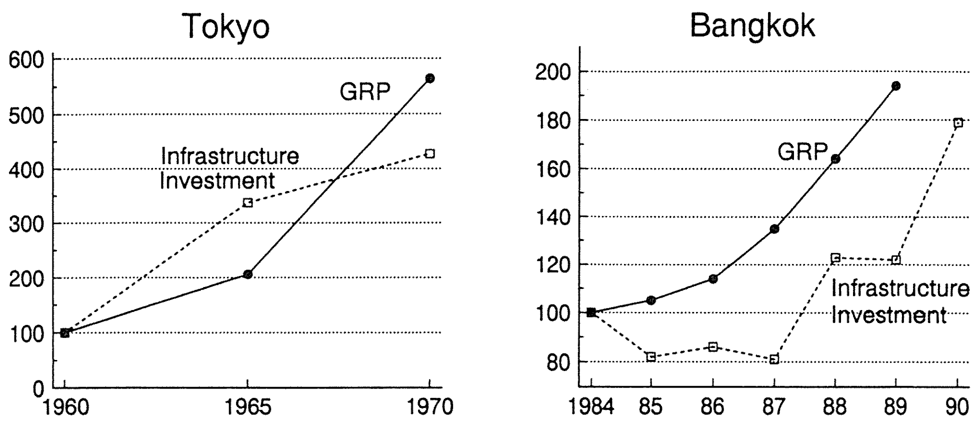


Fig. 24 Economic growth and infrastructure investment (index)
Source: Ref. 11

On the other hand, Japan has invested in road infrastructure almost in proportion to its GNP at a rate of 2.0—2.7%. The share of new construction is still high. Japan has a fuel tax as an ear-marked tax which has made it possible to construct road infrastructure at a close rate to that of GNP growth. Because the increase rate of car traffic demand is higher than that of GNP after a threshold level (about 1000 dollar per capita income) which Thailand has already passed, general budget which dominantly consists of income tax can not follow the rapid increase in the construction costs for roads. This implies that a budget which increases in proportion to car use is necessary. Tokyo and Nagoya are good examples which have managed to avoid catastrophic congestions by proportionately increasing their budgets for road investment to increasing car traffic demand.

4.3 Congestion and the Environment

4.3.1 Imbalance between Traffic Demand and Road Supply

Road traffic congestion occurs due to the gap between car use and the level of road infrastructure. Fig. 25 illustrates the relationship between car ownership per thousand inhabitants and road length per car.

The car ownership level of Bangkok in 1988 is about 150 cars per thousand inhabitants which is about equivalent to that of Nagoya in 1972 or Tokyo in 1976. However, the level of road infrastructure improvement in terms of road length per car is only one fourth of that of Nagoya in 1972 or one third of that of Tokyo in 1976. It is not difficult to imagine that Bangkok will face more and more serious congestion and air pollution.

4.3.2 Decline of Road Service Level and Change in Efficiency of Energy Consumption

Fig. 26 compares the recent traffic volume (in terms of passenger car unit, pcu) on the main roads among three of the metropolises. The rapid growth of vehicles and lack of road and rail supplies in Bangkok results in high traffic volume on almost every road. In average, traffic volume on the roads in Bangkok is higher than that in Tokyo by about 1.5—2 times. High traffic volume causes a high energy intensity and a high concentration of pollutants along the roads.

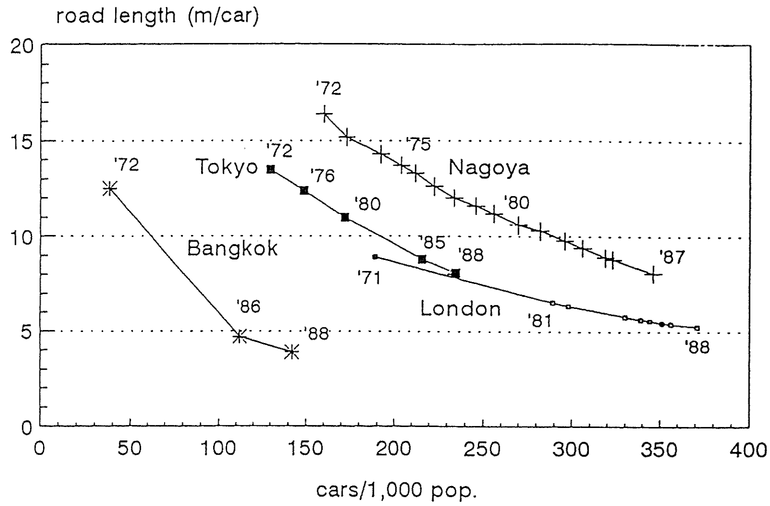


Fig. 25 Motorization and road supply level
Sources: Ref. 14, 17, 18, 22, 23, 42

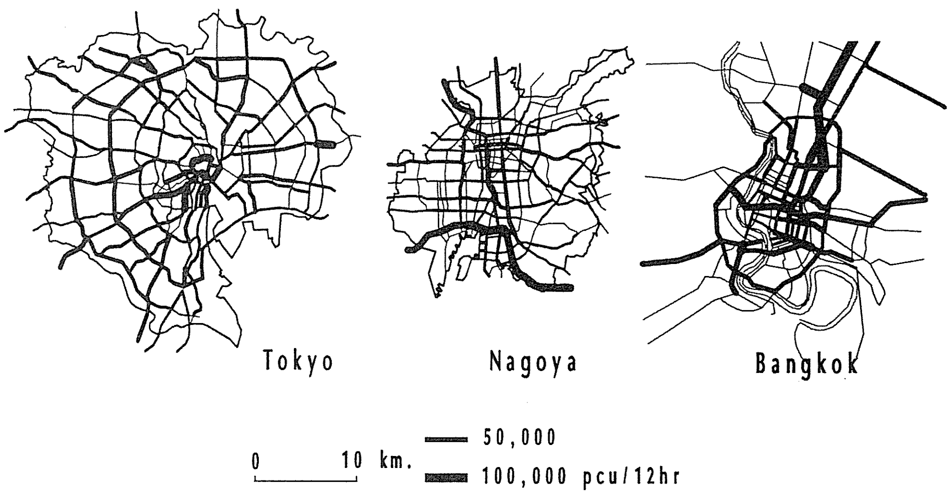


Fig. 26 12 hour traffic volume on main roads (GIS)
Sources: Ref. 50 and 73

The decline in travel speed due to the road supply not keeping pace with the growth of traffic volume is a phenomenon happening in most cities. As shown in Fig. 27, the 1972 peak hour speed in Bangkok was as high as that in London but 1989 speed was only slightly more than half that in London. Between 1972 and 1989, the peak hour speed in inner area of Bangkok dropped by more than half, from 22 km/h to 10 km/h.

Unlike Bangkok and London, the peak hour speed in both Tokyo and Nagoya improved considerably during the recent year. The improvement is mainly a result of the extension of urban expressways in both metropolises.

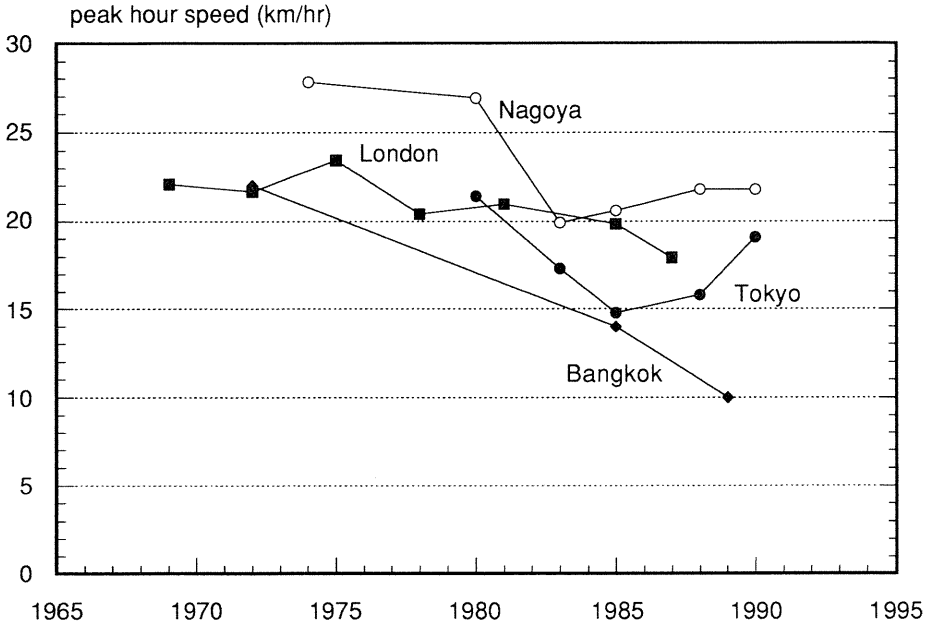


Fig. 27 Changes in average peak hour speed
Sources: Ref. 22, 50, 56, 73 and 113

4.3.3 Travel Speed and Fuel Consumption

Fig. 28 illustrates traffic conditions and transport energy consumption in the four cities. A 100 km long drive requires 10.0 litres in Nagoya, 11.3 litres in London, 13.3 litres in Tokyo and 17.0 litres in Bangkok. The differences depend mainly on average travel speed on the streets in inner areas: 21.8 km/h in Nagoya, 18.7 km/h in London, 15.8 km/h in Tokyo and 10.0 km/h in Bangkok. From Fig. 29, the efficiency in energy consumption for gasoline cars is approximately 1.5 times different, comparing between the cases of 10 km/h and 20 km/h. It is reported that, in Bangkok, sixty to seventy thousand cars have been newly registered per annum in the five years until 1993, the average travel speed on the road has been lowered drastically and traffic jams have become extremely serious.

4.3.4 Compactness of Built-up Area, Trip Length and Energy Consumption

a) Contribution of Urban Growth to Car Trip Length

To analyze this mechanism we use an indicator which is entitled "urban radius" r_1 defined as the average radius of built-up area specified by the equation shown in section 3.2.

Fig. 30 illustrates how the total car trip length increases due to suburbanization in London, Tokyo, Nagoya and Bangkok. As also shown in Table 5, the relative ratio of trip

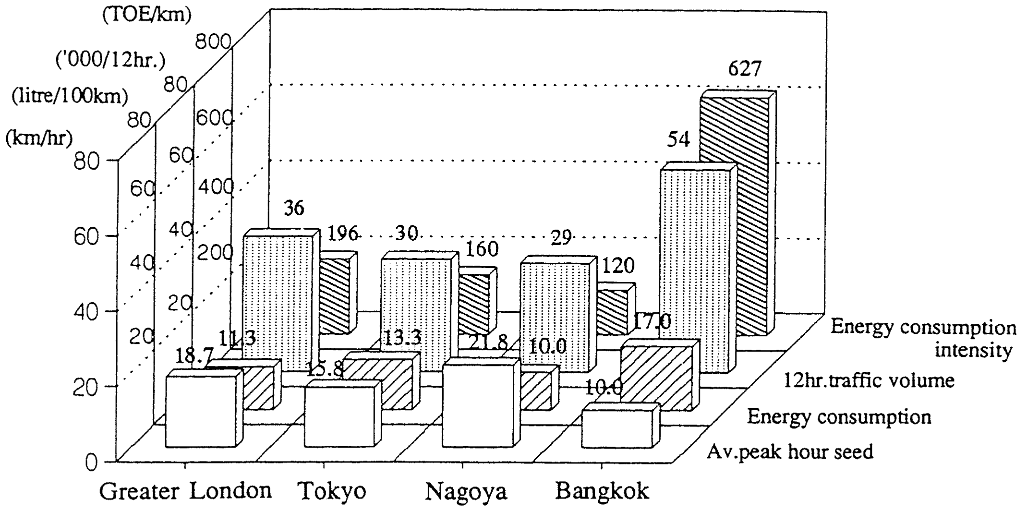


Fig. 28 Average peak hour travel speed and traffic volume and energy consumption
Sources: Ref. 5, 14, 24, 26, 41, 43

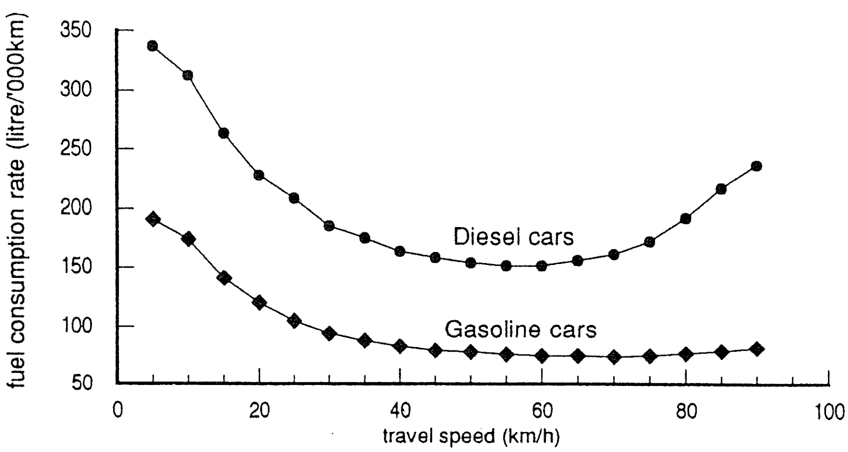


Fig. 29 Changes in efficiency in fuel consumption according to travel speed
Sources: Ref. 15, 39

increase rate to increase rate of urban radius is the highest in Bangkok (1.96 between 1972 and 1987) and then 1.69 in Tokyo between 1960 and 1980, 1.35 in London between 1960 and 1980 and the lowest in Nagoya (1.09 between 1971 and 1988).

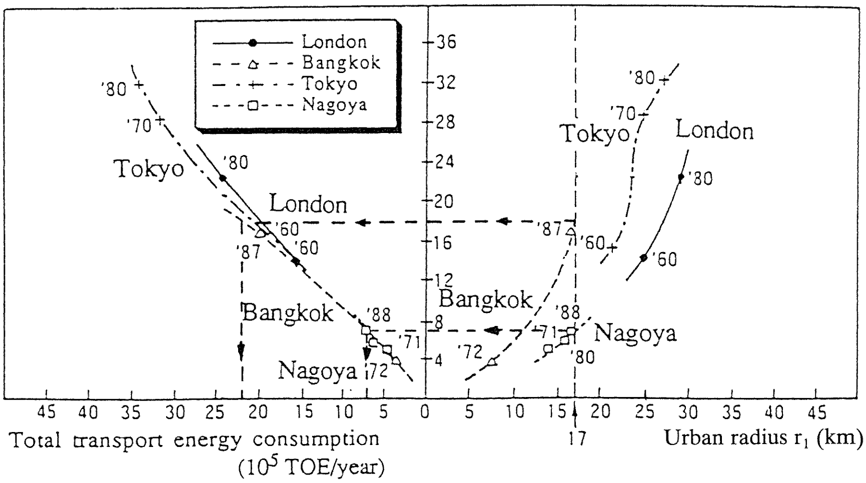


Fig. 30 Change in urban radius, car trip length and energy consumption
Sources: Ref. 17, 28

Table 5 Influence of suburbanization on car trip length and energy consumption
Source: Fig. 30

	increase rate of urban radius (A)	increase rate of total car trip length (B) [B/A]	increase rate of car energy consumption (C) [C/A]
London (1960-1980)	1.16	1.57 [1.35]	1.51 [1.30]
Tokyo (1960-1980)	1.26	2.13 [1.69]	2.12 [1.68]
Nagoya (1971-1988)	1.18	1.29 [1.09]	1.52 [1.29]
Bangkok (1972-1987)	2.27	4.46 [1.96]	4.75 [2.00]

This implies that the total trip length in Bangkok increases at a rate two times higher than that in Nagoya. Comparing Bangkok in 1987 and Nagoya in 1988, although the urban radius is the same (17 km), the total car trip length in Bangkok is about 16 billion vehicle km per year which is almost three times higher than 6 billion in Nagoya. This may come from the following reasons:

1) the total number of cars in Bangkok is larger than that in Nagoya by 30%,

2) in Bangkok almost all trips depend on road traffic in the extended suburban areas because urban rail transit systems are far from sufficient.

3) as the road length per car is only 3.9 metres in Bangkok (JICA, 1990), which is less than half of 8.1 metres in Nagoya (Nagoya City, 1990), car traffic is obliged to detour especially in the suburban areas where the road network is far from sufficient.

b) Contribution of Increase in Car Trips Length to Energy Consumption

The left hand side of Fig. 30 shows that the relationship between the total transport energy consumption and the total trip length has progressed almost proportionately. But only Bangkok's tangent in the graph has declined which means that its efficiency has also declined. By following the arrows in the figure, it is easy to understand the influence of suburbanization on transport energy consumption through trip length.

As shown in the brackets in Table 5, the ratio of increase rates of urban radius to transport energy consumption is 1.29 in Nagoya at minimum, 1.30 in London, 1.68 in Tokyo and 2.00 in Bangkok at maximum. This implies that marginal energy consumption to unit suburbanization is about 60% higher in Bangkok than in Nagoya. The main causes would be a) the car dependent transport system, b) higher aged unhealthy cars because of a loose car inspection system and consequently c) inefficient fuel use under very serious traffic congestion (Hayashi, *et al.*, 1993a).

4.3.5 Contribution of Road Traffic to Air Pollution

Fig. 31 and 32 show the average pollution levels of CO in background areas and the road side. Although the comparison of absolute numbers of pollution level between cities is not accurate because of different measurement methods, we can grasp the contributions of traffic to pollution by comparing the difference in pollution levels between the background and the road side.

The difference is 0.4 ppm in Nagoya at minimum, 1.8 ppm in Tokyo, 2.4 ppm in London and 6.0 ppm in Bangkok at maximum. This means that traffic caused pollution is extremely high in Bangkok. This corresponds to the order of the amount of transport energy consumption intensity alone the road: 120 TOE (ton oil equivalent)/km in Nagoya at minimum, 160 TOE/km in Tokyo, 196 TOE/km in London and 627 TOE/km in Bangkok at maximum.

NOx pollution can be analyzed in the same way. The emission rates of CO and NOx of diesel vehicles are 5 to 10 times higher than those of gasoline ones.

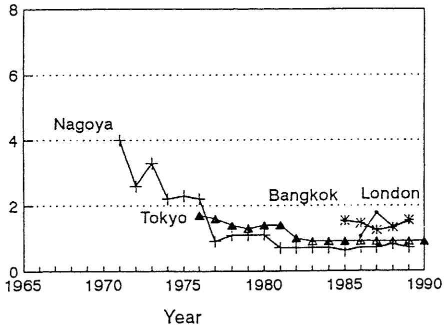


Fig. 31 Changes in annual mean concentration of CO

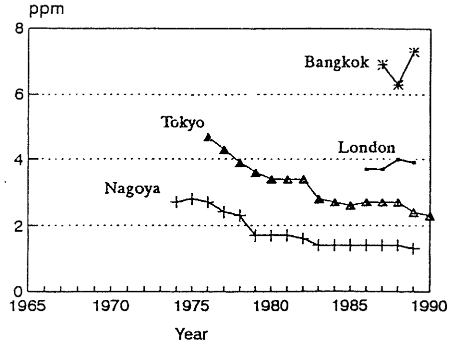


Fig. 32 Changes in annual mean concentration of CO (roadside)

Sources: Ref. 1, 19, 29, 36, 37, 38

5. Conclusions

5.1 General Findings and Results of Analysis in the Study

According to the phenomenal nexus of urbanization, motorization and the environment, we may summarize some major findings and results of analysis as follows:

—Similar processes of economic development, urbanization, motorization and environmental degradation are found in common, especially among the cases of Bangkok, Tokyo and Nagoya.

—The later a metropolis starts to urbanize, the faster the urbanization cycle will be, due to advanced technological progress, particularly increasing availability of automobiles. It is also found from the study that urbanization-cycle speed in Bangkok is 4, 2 and 1.5 times higher than those in London, Nagoya and Tokyo, respectively.

—Serious recognition of air quality control occurred when per-capita product level in a metropolis reached the amount of US$ 1000–3000 approximately. Meanwhile a strict emphasis on transport-based air pollution impact appeared at a per-capita product level beyond US$ 3000. It is found that severe air pollution issues can exist at any stage of development but a lately urbanized metropolis may experience environmental problems at an earlier stage than those of the other preceding metropolises.

—Presumably, the economic development patterns in Bangkok has followed the same path as those in Tokyo and Nagoya by about 20–30 years of time lag. In contrast, London led the two metropolises by about 10 years.

—The close relationships between per-capita product and car ownership are quite similar to each other among metropolises, even though the normalized car prices in Bangkok are about 10 times greater than those of the others.

—Since the transport infrastructure supply of road and rail in Bangkok is far behind those of the other metropolises, it is estimated that every 1 km growth of urban radius will increase the average trip length by 0.3 km in return.

—The lack of radial rail mass transit system encourages car use and increases trip length extensively. Moreover, the lack of transport infrastructure also causes intensive energy consumption and associated air pollutants along the road side in Bangkok much more than those of the other metropolises.

—Evidently, transport energy consumption decreases significantly as development density (population density in the urbanized area) increases owing to the high concentration of economic activities.

5.2 Discussion on Economic Development Cycle

Intuitively, suburbanization enlarges the boundaries of human activities by shortening travel times between the regions thus encouraging people to live in a distant suburb. However, when most houses are located in a sprawling manner and therefore effective or adequate public transport cannot be provided, mobility of population through available transport modes in suburbs is forced to depend heavily upon car use. This definite obligation will further accelerate motorization. It is therefore detected by the comparative history of urban development study that *negative feedback* of suburbanization and motorization have a mutual or reverse multiplier effect thus boosting continuous increase in transport energy consumption.

The *associated residuals* or output discrepancies caused by different characteristics and unique features of individual metropolis are basically examined in this study as well.

5.3 A Scenario Analysis Method and its Phenomenal Interpretations

Through combining all the intuitive processes of analysis conducted in this study, a conceptual method for scenario analysis of environmental influences can be obtained as shown in Fig. 33 on the next page.

In short, the process of scenario analysis method consists of six consecutive components as described as follows:

1) observe the past trends and consolidate them to get likely scenarios of economic growth [Fig. 33 1), Fig. 1]
2) examine urbanization scenarios [Fig. 33 2), Fig. 13]
3) examine motorization scenarios [Fig. 33 3), Fig. 20]
4) examine road improvement policy scenarios in comparison with the expected increase of traffic demand [Fig. 33 4), Fig. 25]
5) examine the relationship among urban radius, vehicle-drive distance and the used transport energy [Fig. 33 5), Fig. 30]
6) forecast the environmental changes [Fig. 33 6), Fig. 31, 32]

The latter figure numbers in each bracket show the corresponding figure numbers which appeared in previous chapters.

At the moment it is still difficult to forecast the clear future conditions of land use, transport and the consequent environment in a changing development stage for each metropolis by simple empirical examination of the trend. One fundamental reason is that there are many unseen and non-linearly changing factors emerging in the real-world economic framework. For instance, these could be unstable economic growth patterns, inconsistent increasing rate of car ownership and traffic demand which is generally higher than that of income, the financial inadequacy to supply transport infrastructure or to support technological innovation for car emissions, and the shortage of funds to subsidize environmental improvement measures. In other words, such cases imply that it would be much useful to review the actual trends and to understand the development mechanism of elderly aged metropolises in the past, especially when comparing at the same economic development stage with another younger aged metropolis.

Thus fundamentally, the later metropolis can incorporate the fact findings and results of analysis from the earlier metropolises into its planning and evaluation process to accommodate future sustainable development and pleasant environment simultaneously. To a certain extent, this paper has explicitly pointed out the *common phenomena* under similar constraints that could take place again at *the same stages* of economic development, urbanization, motorization and the environment which are closely interrelated. Thus from learning the past experiences for future applications, we have tried to derive some guidelines for a late developing metropolis by appropriately shifting and/or accelerating the development cycles of preceding metropolises.

5.4 Limitations and Final Thought of the Study

Although in this study many attempts have been made mainly to compare and contrast the concurrent dynamic changes of urbanization, motorization and the influential environmental impact among the metropolises, one should keep in mind that our comparative study is typically based on '*cross-sectional analogous analysis*' of the output at various stages of development and at different points of time in order to characterize their common phenomena. It is then recommended that further meaningful research be also carried out through '*longitudinal homogeneous analysis*' of the chronological entity and compatible development mechanism for each metropolis in order to gain an insight into interactions and actual out-

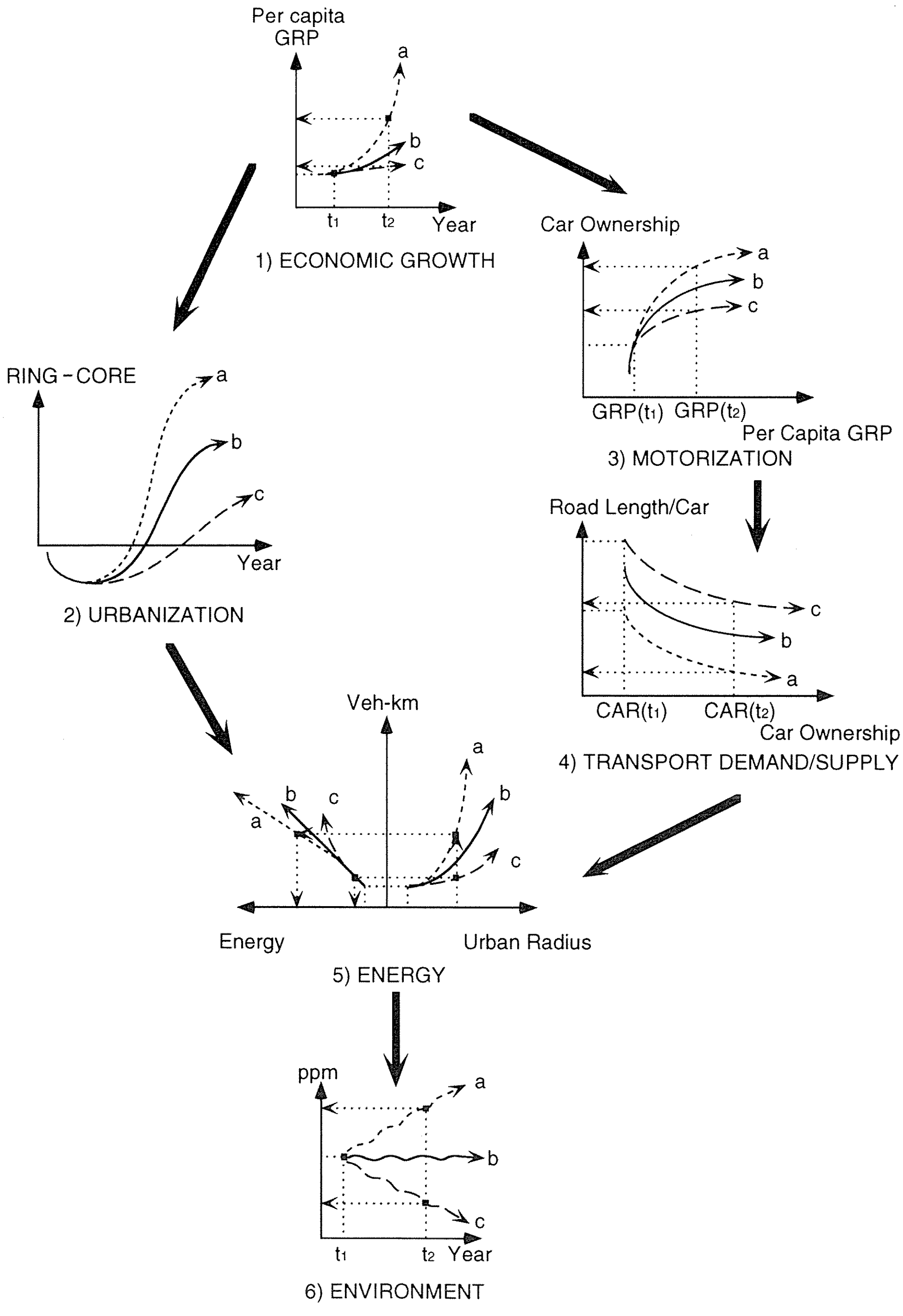


Fig. 33 Process of scenario analysis method

comes from these three study parameters. As a result of the relatively comprehensive analysis or integrated approach mentioned above, it would be possible to realize a deeper and broader perspective towards sustainability of how and when such comparable dynamic development process keeps changing under diverse conditions. Likewise, it would enable us to depict a more reasonable and reliable portrait of our future for the sake of advanced integrated planning purposes.

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