Master of Arts (1970)
Dept. of Geography

McGill University
Montréal, Quebec

ENTROPY CHANGES IN URBAN SYSTEM EVOLUTION

A Case Study of Malaysia

Liang-huew Wang

ABSTRACT

This thesis investigates the interrelationships of economic development, urban system evolution, and the associated inter-urban transportation network complexity of Malaysia. Economic development is studied in the context of Rostow's stages of growth. Information theory is utilized to discover trends in the development of the urban system and the related inter-urban transportation networks with reference to central place theory. It is found that, due to disparity in economic development, the Malaysian urban system possesses a spatial concentration characteristic.

WANG : ENTROPY CHANGES IN URBAN SYSTEM EVOLUTION

A Case Study of Malaysia.

ENTROPY CHANGES IN URBAN SYSTEM EVOLUTION

A Case Study of Malaysia

by

Liang-huew Wang

A Thesis Submitted to the Faculty of
Graduate Studies and Research
In Partial Fulfillment of the Requirements for the
Degree of Master of Arts

Department of Geography
McGill University
Montréal

May, 1970

ACKNOWLEDGEMENTS

I would like to acknowledge
my debt to:
Dr. R.K. Semple for his intellectual stimulation,
untiring interest, advice,
support and encouragement.
Dr. B.H. Massam and Mr. K.E. Haynes
for their constructive criticisms,
concerns and helpful suggestions.
Dr. L.J. King for his initial inspiration.
The Department of Statistics of Malaysia
for providing part of the data
for the present research.
My late parents who had sacrificed so much
for my early education.
Phooileng, my wife, for her tolerance and sacrifices,
10,000 miles away at home,
alone.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF MAPS AND ILLUSTRATIONS

All things began in order,
so shall they end,
and so shall they begin again;
according to the ordainer of order
and mystical mathematics
of the city of heaven.

-- Sir Thomas Browne
The Garden of Cyrus
Chapter 5

INTRODUCTION

This thesis investigates the development of the Malaysian[1] economy and the parallel development of urbanization. The economic development is studied with reference to the Rostovian stages of economic growth,[2] and the parallel urban development is examined by the use of information statistics, a branch of probability theory. The aim is to provide a link between the processes involved in economic development and urbanization.

Chapter I examines the economic development of Malaysia, highlighting only those cultural, political and economic factors which the author assumes are relevant to an explanation of the stages of growth.

Chapter II presents an analysis of the evolution of

i) the urban settlement pattern, ii) the city-size distribution pattern, iii) the urban population distribution pattern, and iv) the structure of connectivity of the Malaysian urban system by means of information theory.

Chapter III establishes the linkages between urbanization and economic development utilizing the results of Chapters I and II.

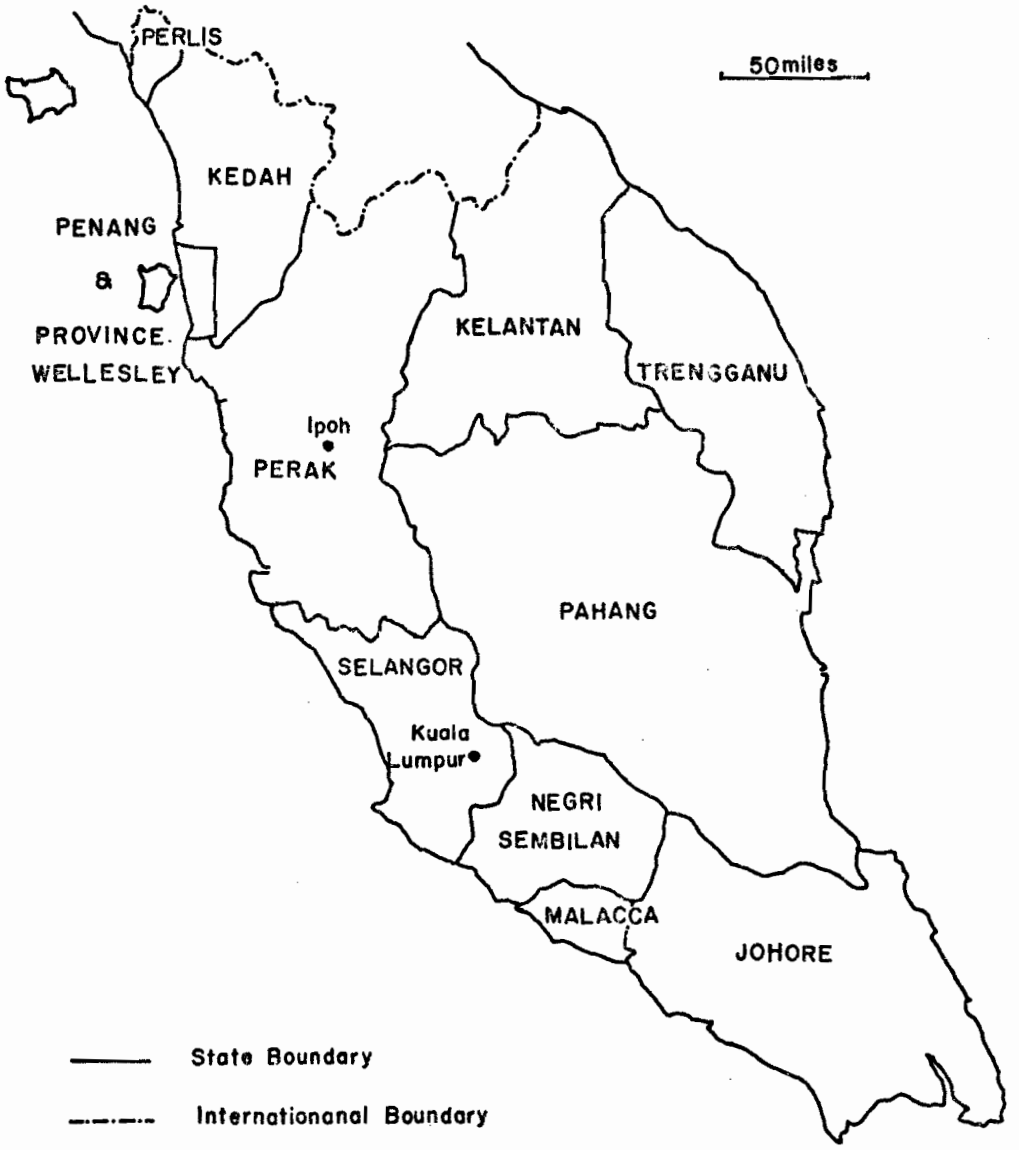
Chapter IV provides a summary and conclusion of the findings and suggests possible future research.

Footnotes:

1 The Federation of Malaysia consists of two political regions, Malaya and former British North Borneo. In the present study the term 'Malaysia' is used to refer to the territory of the former Federation of Malaya which in the state of Malaysia is called West Malaysia.

2 W.W. Rostow, The Stages of Economic Growth (London: Cambridge University Press, 1960).

FIGURE I : MAP OF MALAYSIA



CHAPTER I

SOME GENERAL COMMENTS ON MALAYSIAN DEVELOPMENT IN THE CONTEXT OF ROSTOW'S STAGES OF GROWTH[1]

According to W.W. Rostow, economic development normally follows five sequential stages: i) the traditional society, ii) the precondition for take-off, iii) the take-off, iv) the drive to maturity, and v) the age of high mass consumption. Today only a few highly industrialized countries have reached the fifth stage of development. Not all countries pass through all stages, nor do they necessarily pass through the stages in the exact sequential order outlined by Rostow. The time required for the evolving through the stages varies tremendously from country to country. By borrowing the scientific and technical innovations, designed and developed by mature nations, the developing countries today are able to accelerate their development transition, provided these innovations meet with the social needs and the cultural values held by the society of the developing countries. Further, most developing countries

today were previously integral parts of large colonial empires. Their resources were exploited to the benefit either of large international interests or a single colonial power. Consequently, the economies of ex-colonies tended to be unbalanced. Typically, primary raw materials were directly exploited and the home country was denied the advantages of processing plants; and not infrequently secondary and tertiary sectors of the economy suffered. This situation has existed in Malaysia since the middle of the last century.

I

The Traditional Society of Malaysia Previous to 1900: Before the close of the last century, the peninsula was divided into many sultanates. The hierarchical social structure was simple, consisting of a ruling class and the peasant class. Due to limited technology, attainable output per head was low and the value system was geared to long-run fatalism. The society, with slow economic and social improvement, was primitive in nature. The economic exploitation of British colonization brought the peasants into inevitable contact with a new set of social and economic values. The British initiated their 'Umbrella Policy'[2] which led to the formation of the Federated Malay States in 1895. The federation provided stability which in turn encouraged the inward flow of capital and Chinese and Indian labors. It was the direct implementation of this political

and economic structure that led to the establishment of the precondition for take-off.

The Precondition for Take-Off (1900 - 1962): According to Rostow, three preconditions are required for a successful take-off. First, technological revolution must occur in extractive industry and agriculture. Second, social overhead capital must be established. Third, an expansion of the human resources must take place. This implies not only technical training but the creating of an attitude of willingness to accept new changes and values. In Rostow's own words, 'the society must be able to prepare itself for sustained growth.'

The development in Malaysia in this stage was oriented toward the modernization of tin mining and the commercialization of rubber production. Chinese and Indians were in the forefront of this economic development since the Malays were culturally tied to their land.

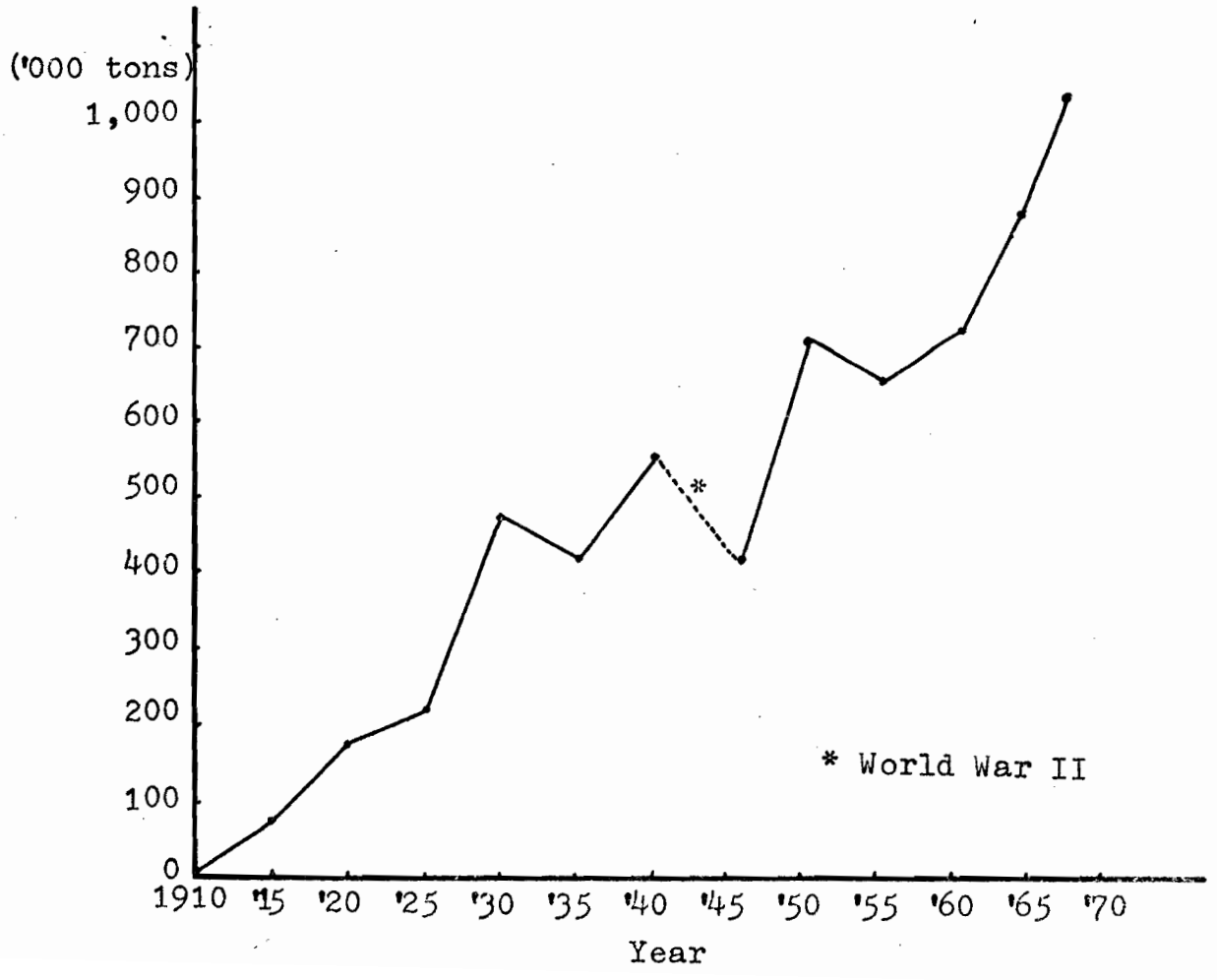
Tin mining has been an important industry in Malaysia. Traditionally the industry was purely a Chinese enterprise. However, by 1928 European[3] interests became dominant due to the introduction of advanced technology in the form of the dredge. See Table 1. The influence of this technological innovation was twofold. First, it forced the Chinese to improve their mining methods in order to compete with the more efficient

Table 1: Percentage of tin production under European Enterprise in Malaysia.

Year	Percent	Year	Percent	Year	Percent
1910	22	1925	44	1930	63
1913	26	1928	50	1937	68
1919	32	1929	61	1953	62
				1961	66

Sources: J.J. Puthucheary, Ownership and Control in the Malayan Economy, 1960; T.H. Silcock, ed. Readings in Malayan Economics, 1961; etc.

Fugire 2: Rubber production of Malaysia.



European expertise.[4] Second, it reduced the number of Chinese laborers from 225,000 in 1931 to 73,000 in 1939.[5] Production continued to increase despite this labor reduction. The unemployed labors then returned to China, turned to farming or became urban dwellers.

While tin mining became the chief mining activity, rubber production dominated the cash agricultural sector. The successful introduction of rubber into the agricultural economy marked the end of the search for a profitable cash crop for Malaysia. Spices, sugar cane and coffee had been introduced without success. The great demand for rubber caused by the development of the automobile industry assured a sound economic future for the rubber planation agriculture. See Figure 2.

As the production of tin attracted Chinese immigrants, the production of rubber created a massive inflow of cheap Indian laborers. Unlike the Chinese immigration, the Indian immigration was organized. Indians came to Malaysia under contracts and returned home after completing their services. Chinese laborers were not welcomed in the early days.[6] Further, rubber growing was initially a Western enterprise as opposed to tin mining which was initially a Chinese venture. This was partly due to the experience of the British colonial slave plantation enterprise prior to rubber planting in Malaysia.

However, after the depression of the 1930s, small-holdings became important. Today, smallholders produce as much as forty percent of the total output. A majority of them are Chinese and Malay planters.

As a result of the extensive exploitation, the foreign trade of tin and rubber soared rapidly during the boom years of the 1920s, reaching a peak value of £264 million in 1926. Though badly hurt by the depression of the early thirties, recovery was fast.

The growth of primary industries and overseas trade was accompanied by the development of social overhead capital, and political as well as economic institutions. Social overhead capital was used to construct roads and railways for further exploitation. It was also used to establish medical facilities, and to encourage the spread of sanitary and hygenic techniques. As a consequence, the death rate was reduced and health standard improved.[7] An improvement in the quality of food and the importation of luxury goods helped to improve further the standard of living. The higher consumption was a direct result of economic growth. Education and communication facilities were developed, although the development was not at the same level among the ethnic groups. People in the urbanized areas were advantageously located to derive the maximum benefit from the changes. The development of

institutions saw the establishment of an ordered government and a stable monetary system. These institutions created stability which continued to attract capital for investments.

Through time growth poles developed in areas with above average deposits of raw materials or in densely populated parts of the country. The economic prosperity was further concentrated among ethnic groups in the population. In toto the impact was to transform a traditional society into one which could compete in the international market, albeit to a limited extent.

Unfortunately the growth trend was disrupted by both World War II and the 'Emergency Period'. During the Japanese Occupation (1942-1945), tin and rubber production ceased entirely. Mining facilities were damaged, and rubber workers were forced to construct railroads along the Burma-Thailand border. The 'Emergency Period', a time of Communist uprising that broke out in 1948, delayed the economic recovery after World War II. Without the subsequent Korean War (1950-1953) that artificially inflated tin and rubber prices, the entire economy would have been jeopardized. However, the price increases enabled Malaysia to enjoy the highest per capita income among East Asian countries in the early fifties.[8]

During the 'Emergency Period' a resettlement scheme[9]

was established to relocate Chinese farmers. Since 1950 over a half-million have been withdrawn from their pioneer farms in the jungle to towns and other newly built defensive roadside villages.[10] About 500 'new villages' were built under the scheme, with the largest accommodating over 16,000 people. One in every five Chinese in the country was at least twice shifted by events from 1941 to 1954.[11]

Due to this prolonged and widespread disruption, the overall growth in physical output in the primary industries slowed down in comparison with the pre-war period.[12] The manufacturing sector, however, showed an increase in activity. This was partly due to rural-urban migration and forced urbanization. The increase of industrial enterprise in limited sectors together with the export trade caused the emergence of a new class of commercial elite, the increase of investments and the establishment of additional institutions for mobilizing savings. Politically, the war and the Emergency stimulated a new phase of nationalism that led the country to independence.

After independence in 1957, the previous economic pattern was criticized. The raw material oriented export economy proved of little resistance to world price fluctuations. The internal pattern of production and distribution was unbalanced; it was concerned with primary industries only. Regional inequality was great, and much of the capital accumulated by the export

trade went back to foreign shareholders.[13]

In order to diversify the one-crop economy, to develop local industrial activity and to create a local infrastructure larger than the export trade, economic plans were initiated. The Federal Land Development Authority[14] was established to promote and assist projects for the development and settlement of the land. Campaigns were geared to encourage small holdings and large scale productions in a variety of cash crops. Industrial estates were planned through public expenditure. These efforts to provide good 'working' atmosphere, in Rostow's words, led to a 'necessary condition for the take-off.'

The Take-Off since 1963: According to Rostow, during the take-off, the forces making for economic progress expand and come to dominate the society. Growth in this stage becomes its normal condition. One key manifestation of the take-off is the ability of the society to sustain an annual rate of net investment of the order of, at least, 10 percent of the national income. In non-economic terms, the take-off witnesses a definitive social, political and cultural victory of those who wished to modernize the economy over those who wanted to maintain the traditional society. However, victory can assume forms of mutual accommodation rather than the destruction of the traditional groups by the more modern.

Development in Malaysia since independence has been encouraging. This was partly due to proper planning and partly due to social enthusiasm toward rapid economic improvement. During the period of the First Five-Year Development Plan (1956-1961), public development expenditure totaled M$1,150 million or 12.0 percent of gross national product. The figures were doubled in the Second Five-Year Plan. During the three fiscal years 1963-1965, investment expenditure was 34.0 percent of total expenditure and 10.3 percent of national incomes.[15] Expenditures on social and economic services covered over 37.0 percent of the total current expenditure for 1963-1965.[16]

New Industries expanded rapidly in this period, in response to the Government's offer of specially prepared industrial sites complete with services, liberal company taxation consessions and tariff protection. Ten industrial estates of this kind were in operation in 1965.[17] Consequently, there has been a sharp increase in domestic products. Further, investment patterns tended to favor long-lived assets in preference to short-lived productive investment.[18] Savings became more elastic as income grew.[19]

The contribution of rubber and tin to income growth was discounted under the First Malaysia Plan (1966-1970). Emphasis was instead placed on a new range of i) agricultural products for exports and substitution of food imports, and

ii) mineral exploitation, including iron ore and bauxite. Oil palm, cocoa and rice growing have been improved substantially, by means of new techniques and management. The attitude of willingness of the smallholders in participating in the rubber replanting scheme caused rubber production to increase rapidly in recent years.[20] The improvement in rice growing, as a result of extensive governmental assistance, tended to raise the living standard of the comparatively backward peasant agricultural sector. It is hoped that this improvement will create a more uniform economic structure in the future.

Though slightly disturbed by the Indonesian Confrontation[21] in the early 1960s, economic growth was consistent in this stage. Faced with a population growth rate of over three percent per annum, output has grown in the years 1960-1965 at 6.3 percent per annum, which compares favorably with a rate of about five percent for the non-communist world, and slightly less than five percent for the developing countries of a similar population growth rate. Consequently, both per capita income and gross national product (GNP) per head have increased steadily. The GNP rose by nine percent to M$11,305 million in 1969 . The GNP increase in 1968 was 6.4 percent, and the average annual growth in the five years preceding 1969 was 6.8 percent. The GNP per capita was M$963 in 1969 as compared to M$713 in 1963.[22] The share in agriculture in the origin of the GNP has declined while that of manufacturing has increased. The manufacturing

sector expanded by an estimated ten percent in 1969.[23] The country had a trade surplus of M$1,000 million in the first nine months of 1969.[24]

II

From many perspectives, the Malaysian economy represents a typical example of colonial development, with extremes in racial and functional pluralism and specialization in plantation and mining, superimposed on an isolated, tradition-bound, subsistance economy. The formation of the plural society was due to the arrival of Chinese and Indians during the stage for precondition for take-off. It has resulted in a violent disturbance of social and economic balance of the country. Under the British 'divide and rule' policy, a cleavage developed among the ethnic groups. On the one hand the new economic forces tended to cause disintegration of the traidi-tional life and customs of the old society; on the other hand the same forces generated new communities who were uprooted from their homeland and also out of place in their adopted country. All this created an imbalanced plural society with a lack of social cohesion and common purpose.

The plural society was further strengthened by the resettlement scheme under the 'Emergency'. As the Chinese were relocated in towns and nucleated settlements, urban

facilities became accessible. Consequently, living standard among the ethnic groups became more uneven than before. Although the resettlement scheme has done little in altering the basic regional distribution of the ethnic groups,[25] it has intensified the existing regional outlines and communal boundaries.[26] Consolidation after independence would have been greatly facilitated if these ethnic groups had been brought together to form a single community under the resettlement scheme.

Today, economically, the Malays occupy the rice and squatter farms, situated mainly in the North and East, and along the jungle fringes. The Malay community, isolated and shielded by British policy and administration before independence, failed to participate widely in the process of economic growth. Even today, they remain essentially rural and self-sufficient. In contrast, the Chinese are commercially oriented and make up the majority of the urban middle class, and they dominate the management of tin mines and rubber plantations. The Indian community has been associated with plantation agriculture as estate workers, in urban mercantile services and the lower civil service. Associated with this basic economic structure, there has been substantial Western interests in mines, plantations and in the network of large trading and financial enterprises.

Rostow states that although the overall pattern of

economic development might improve substantially, regional inequalities could exist. This is particularly true in Malaysia where a distinct east-west differential structure is noticeable. This east-west dichotomy is a 'carry-over' from the colonial period. In the past, only the accessible west coast states were developed, especially those states that were rich in resources. Consequently, the free play of market forces led to distinct regional differences in economic opportunity.

The commerce and induatry associated with the western states were concentrated in ports and mining areas, which in turn created prosperity in the west, both in wealth and in living standard. Today, Kuala Lumpur, the federal capital, and Ipoh, the largest tin mining city, have associated with them many smaller urban centres. Together these centres form two regional conurbations that enjoy a prosperity and level of development normally associated with Rostovian mature economy. Compared to those advanced western states, the east coast countryside is relatively underdeveloped.

The economic inequality among states is further reflected in the evolution of urban population. Even before World War II Malaysia had a high proportion of urban population as compared to her neighbors. Since the War the growth of rural population has been more rapid than the rural economy

could absorb. Such a surplus resulted in rural-urban migration.[27] Together with the forced migration of Chinese population, the rural-urban migration accelerated urban growth. It is significant that during the post-war period practically the whole of the country's population increase was absorbed by urban centres.[28] Nevertheless, the marked change in ethnic proportions in the rural areas due to the 1947-1957 rural-urban movements did not change the corresponding pattern in the towns.[29] It could be noted at the same time that there was very little population movement across the Main Range. Inter-state migration has not been significant. However, increasing rural-urban migration of the Malays, especially youths, has been noted.[30] The greater the rural-urban migration, the faster is the urban growth and consequently the greater is the regional inequality.

Though Malaysia showed a comparatively high rate of urbanization, its industrial occupations have been essentially primary. In 1957, primary industry accounted for more than 50 percent of the economically active population. This characteristic also existed in the later years. For the two census periods of 1947 and 1957, there was an increase in the urban population of 88.34 percent and a total increase of approximately 28 percent, while the number economic active only increased by 13.3 percent in manufacturing. Obviously, the expansion of manufacturing industries has not played a major role than

other forces in post-war urbanization. The rapid urban growth in the post-war period was mainly the result of the resettlement campaign and the rapid extension of governemnt adminstration and buildings which were concentrated heavily in the Federal capital and the state capitals. The concentration of urban population in capital cities is another feature in the Malaysian urban system.

As it has been noted, Chinese have been the major urban dwellers. Ethnic difference in rural and urban population distribution reflects the difference in their economic status. See Table 3. However, poverty, as well as exploitation, is basically a class problem rather than a communal problem.[31] Development in the future must penetrate into the countryside to solve the poverty of all the people, regardless of ethnic groups, as well as reducing regional inequality rather than just raising national production.

III

Some general comments on development in Malaysia in the context of Rostow's stages of growth have been outlined. The economy, after a rather long period of pre-condition for take-off, is now developing substantially. Nevertheless, a characteristic of severe inequality exists. It is believed that this characteristic may also be shown in the evolution

Table 2: Malaysian urban population distribution by locality size, 1957.

Urban Centres	Malays	Chinese	Indians	Others	Total
Over 100,000	93,708	451.386	101,698	30,111	676,903
50,000 - 100,000	77,088	192.417	41,089	14,818	325,412
20,000 - 50,000	121,793	244,900	44,838	10,875	422,406
10,000 - 20,000	57,016	153,965	26,238	5,029	242,248
5,000 - 10,000	78,036	210,726	24,445	4,751	317,958
2,000 - 5,000	101,135	300,292	33,155	5,634	440,216
Total	528,776	1,553,686	271,463	71,218	2,425,143

Source: Federation Year Book, 1961, (Kuala Lumpur), pp. 452-457.

Table 3: Distribution of individual Incomes under M$12,000 per annum, between urban* and rural districts and between ethnic groups, 1957.

	Malays		Chinese		Indians	
	Urban	Rural	Urban	Rural	Urban	Rural
Total population ('000)	350	2,800	1,050	1,300	200	500
Av. family income per month	$229	$128	$285	$260	$216	$212
Av. family size	5.7	5.0	6.1	6.6	5.1	5.1
Annual income per head	$482	$307	$561	$473	$513	$499
Est. total of indiv. incomes	$169m.	$860m.	$589m.	$615m.	$103m.	$249m.
Approx. division by ethnic (nearest $25m.)		1,025		1,200		350

* Urban centres of 2,000 people and over.

Sources: Household Budget Survey of the Federation of Malaya, 1957-8 (Kuala Lumpur: Department of Statistics), pp. 9, 14, 19, 24, 34, 39; Census of Malaya, 1957.

process of the Malaysian urban system. An attempt will be made to discuss the evolution of the system of cities by means of information theory in the following chapter.

Footnotes:

1 The Rostovian theory is utilized in this study to reveal only the trend of economic development in Malaysia, with the express purpose of explaining the trend of urbanization of the country.

2 K.G. Tregonning, A History of Modern Malaya (New York: David Mckay, 1964), pp. 136-185.

3 The term 'European' includes also inhabitants of North America, Australia, New Zealand and South Africa.

4 Many mining methods have been adopted by the Chinese miners, including dredging, gravel-pumping, hydraulic ing , 'dulang' washing, etc. See Ooi Jin-bee, Land, People and Economy in Malaya (London: Longmans, 1963), pp.299-303.

5 K.G. Tregonning, ibid. pp. 189-190.

6. Reports of the Commissioners of Enquiry into the State of Labour in the Straits Settlements and the Protected Malay States, 1890 (Singapore, 1890), para. 451, cited by Ooi Jin-bee, ibid. p. 115.

7 Malaysia has been enjoying a lowest crude death rate in Southeast Asia since the beginning of this century. See C.A. Fisher, Southeast Asia (London: Methuen, 1964), p. 173.

8 G.C. Allen and A.G. Donnithorne, Western Enterprise in Indonesia and Malaya, (London: G. Allen & Unwin, 1962, pp. 264-265).

9 See, for example, Hamzah Sendut,""The Resettlement Villages in Malaya", Geography, Vol. 47, 1962, pp. 41-46.

10 E.H.G. Dobby, "Recent Settlement Changes in South Malaya", The Malayan Journal of Tropical Geography, Vol. 1, 1953, pp. 2-8.

11 ibid.

12 R.A. Bilas, "Growth of Physical Output in the Federation of Malaya: 1930-1960", Malayan Economic Review, Vol. 8, No. 2, 1963, pp. 81-90.

13 G. Hunter, Southeast Asia: Race, Culture and Nation, (London: Oxford University Press, 1960), p. 89.

14 Ooi Jin-bee, ibid. pp. 143-144.

15 F.H. Colay et al. eds. Underdevelopment and Economic Nationalism in Southeast Asia, (Ithaca: Cornell University Press, 1969), p. 388.

16 ibid.

17 M. Ward, "A Review of Problems and Acheivements in the Economic Development of Independent Malaya", Economic Geography, Vol. 44, 1968, pp. 326-342.

18 D.R. Snodgrass, "Capital Stock and MAlayan Economic Growth", Malayan Economic Review, Vol. 11, No.2, 1966, p. 84.

19 Lee Soo Ann, "Financial Planning of Investment in Malaya", Malayan Economic Review, Vol. 14, No. 1, 1969, p. 64.

20 T.R. McHale, "Rubber Smallholdings in Malaya: Their Changing Nature, Role and Prospects", Malayan Economic Review, Vol. 10, No. 2, 1965, pp. 35-48.

21 A confrontation was enforced by the Indonesian Government against the establishment of the Federation of Malaysia in 1963. The confrontation was brought to an end following the abortive coup of September 30, 1965 in Indonesia.

22 Malaysian Digest (Kuala Lumpur: Federal Department of Information, April 14, 1970), p. 7; and The Mirror (Singapore: Ministry of Culture, December 15, 1969), p. 8.

23 Malaysian Digest, ibid.

24 Straits Times, Singapore, October 17, 1969.

25 W.D. McTaggart, "The Distribution of Ethnic Groups in Malaya", Journal of Tropical Geography, Vol. 26, 1968, p. 8.

26 Hamzah Sendut, ibid. p. 45.

27 J.C. Caldwell, "The Demographic Background" in The Political Economy of Independent Malaya, ed. by T.H. Silcock and E.K. Fisk (Caneberra: Australian National University, 1963), p. 83.

28 ibid. p. 83.

29 ibid. p. 84.

30 T.G. McGee, "An Aspect of the Urban Geography of Malaysia: The Movement of Malays to Kuala Lumpur City", Record, New Zealand Geographical Society, No. 39, 1965, pp. 7-9.

31 J.J. Puthucheary, Ownership and Control in the Malayan Economy, (Singapore: Eastern Universityies Press, 1960), p. 174, citing U.A. Aziz, Straits Times, Singapore, June 4, 1957.

CHAPTER II

INFORMATION THEORY, ENTROPY CHANGE AND URBAN SYSTEM EVOLUTION

Information theory, which was originally developed in communication engineering, has recently been adapted for use in the social sciences. Important works can be found in economics, sociology, psychology and geography.[1] The stimulus came primarily from the work of C.E. Shannon.[2]

According to Shannon, if the probabilities of occurrence of the events $x_1, x_2, \cdots, x_n$ of a complete system are $p_1, p_2, \cdots, p_n$ ($p_i \geqslant 0$; $\sum_{i=1}^{n} p_i = 1$), and if the amount of uncertainty is denoted by H, then

$$H(p_1, p_2, \cdots, p_n) = \sum_{i=1}^{n} p_i \log_2 \frac{1}{p_i}$$

$$= - \sum_{i}^{n} p_i \log_2 p_i \quad . \qquad (1)$$

The quantity H is called the 'entropy'[3] of the finite set (X). The concept of entropy makes the best possible unbiased inference of p_i in any finite data set. This makes it a good measure of uncertainty. Uncertainty is the lack of information and as a consequence, entropy is often used synonymously with uncertainty.

I

Entropy is a measure of selection, and the magnitude of the entropy is described by a set of probabilities. The entropy of a system will vanish if and only if all the occurrences of an event are zero except one which is unity. In this case the situation is completely determined as there is no choice. In other cases the entropy will be positive and reaches its maximum when all occurrences of the event are equally likely. Therefore, the value of entropy gives the information of a system. In practical applications, however, one is interested only in the amount by which the entropy of the system changes in the transition from one state to another. Every self-organizing system has a tendency to move toward equilibrium, i.e. order tends to increase through a process of 'feeding' upon energy inputs from the environment, thereby causing a local decrease in the entropy of the system at the expense of ever increasing entropy of the environment. However, for the purpose of calculating experimental results, some conventional point must

be chosen, not necessarily the maximum entropy, as the standard state of the system under study. The deviation of the existing entropy to the standard entropy, i.e. its entropy change, both over time and through space, yields the changes in the pertinent information of the system. Any single value of the entropy of a particular state bears no significant meaning in explaining the system.

Due to the difference in characteristics of different experimenta, the standard state of a theoretical system can be set in a number of ways. Suppose a system is specified in which the output variable can assume certain equi-probable states regardless of the initial input, its theoretical system can either be specified in which its H is maximized or minimized, depending on the nature of the system. Any deviation between this theoretical system and that of an observed system is then used to indicate the degree of regularity in the observed system, which in turn, may be used to infer the degree of organization in the observed system. In this content the entropy function is used as a random expectation model with which observed phenomena are compared. It should be noted that different interpretations can be made to suit the particular need of the system concerned when dealing with its entropy function. In some cases an optimized entropy value instead of the extreme values is chosen for the theoretical system. Although the criteria for specifying the theoretical

system may be different the basic concept for either choice is the same, i.e. to measure the amount of order or organization (as opposed to randomness) in the system.

II

Information statistics are utilized to investigate the patterns of i) the urban settlement distribution, ii) the city-size distribution, iii) the urban population distribution, and iv) the inter-urban transport linkages of the Malaysian urban system in order to establish an explanatory link with the rise of the present level of economic development. These features are examined for the census periods 1911, 1921, 1931, 1947 and 1957.[4]

The Urban Settlement Pattern: Christaller and Lösch[5] postulate that under the assumptions of an isotropic surface, i.e. under the conditions of a uniform terrain and resource localization, uniform distribution of population and purchasing power, and equal transport facility in all directions, the theoretical tendency for settlement distribution is toward uniform arrangement. However, in the real world the tendency is less evident. King[6] concludes that the settlement of the United States is not regular, though examination of a sample of states showed that the three classical patterns, regular, clustered and random, could be identified. Dacey[7] suggests

that even in an area of planned land-division the dominant pattern of settlement appears to be random, but the smallest show more vestiges of regular arrangement than do the higher-order settlement. Haggett[8] points out that this failure of the regular lattice as a model for actual settlement arrangements is hardly surprising because the hexagonal lattice is a purely theoretical concept and in practice one would expect it to be distorted by other relevant considerations. Clearly, the actual development of regional settlement patterns is the product of a set of cultural, economic, political and terrain variables in which social conventions play as big a part as environments.

A question is raised by Semple and Golledge[9] recently. If in theory settlements should be located in some regular pattern, and in reality they are not, is it possible to discover whether the irregular settlement patterns are in fact tending toward the postulated orderly equidistant patterns.

The theoretical settlement models postulated by Lösch and Christaller are essentially static and extremely simple. In reality settlement patterns evolve within the context of dynamic processes and as a consequence become more complicated. This is particularly evident of the Malaysian urban system. The first settlements in the Malaysian case were located along the west coast in response to contacts with the 'outside' world.

Later pioneering settlements began to move inland in response to the internal development of the economy,[10] which was being oriented toward mining and plantation agriculture. As it has been noted in Chapter I, urbanization in Malaysia has been accelerated by political factors as well as economic factors. The Resettlement Scheme in the early 1950s, for example, has created more urban centres than all the economic forces in previous years. This forced urbanization not only changed the distribution pattern but also greatly altered the structure of the urban system.

It is evident that the number of urban centres in Malaysia is increasing as the country develops. In order to trace the evolution process of the urban settlement pattern, two hypotheses are presented. First, the distribution of urban places in Malaysia has tended toward a more uniform pattern over time. Second, the Resettlement Scheme has significantly accelerated the evolution. These hypotheses will be tested for the period 1911 -1957 inclusive using a technique first developed by Yu. Medvedkov.[11] The sequences of calculation are as follows:

1). The map of settlements is reduced to a field of points and partitioned into Q equal quadrats. The side of each quadrat should be greater than the mean spacing of the points.

2). By counting the number of points in each quadrat,

n levels of density, d_i ($i = 1, 2, \cdots, n$), are obtained where $1 \leq n \leq Q$.

3). The number of occurrences for each level of density, m_i ,is noted. Given that

$$\sum_{i=1}^{n} m_i = Q \qquad (2)$$

and the probability or frequency of occurrence of each level of density d_i is expressed as a fraction of the total occurrences such that

$$p_i = m_i \,/\, \sum_{i=1}^{n} m_i \quad (i = 1, 2, \cdots, n) \qquad (3)$$

and

$$\sum_{i=1}^{n} p_i = 1 \; . \qquad (4)$$

4). The entropy H_s or the uncertainty for the system follows the Shannon's Formula:

$$H_s = - \sum_{i=1}^{n} p_i \log_2 p_i \qquad (5)$$

where p_i is the frequency of occurrence of events.

Past point pattern analysis has attempted to classify urban place distributions as regular, clustered or random.[12] The present analysis ignores clustered patterns as the aim of the experiment is to filter out the percentage of regularly distributed points on the map. Furthermore, a clustered pattern suggests that all points are located in one quadrat and all other quadrats are empty. In this case, since the uncertainty is predetermined, the H_s is zero. As Yu. Medvedkov has suggested, a point pattern may possess more than one component. Medvedkov's technique provides a method for the

separation of the random component from the regular component. The main feature of the separation process is the recognition of the similarities that regular settlement pattern on maps have in common with the signal transmission process when the random component is treated as analogous to the 'noise' of the communication system. For separation purpose, the properties of the entropy values for the two components, i.e. regular and random respectively, should be specified.

a). The Regular Lattice (R): This lattice is the one postulated by Christaller and Lösch for ideal settlement patterns. In this pattern $H_r = 0$ and complete certainty is reached since $n = 1$; d_i = constant and $m_i = Q$. In other words the amount of additional information needed in order to locate points on a hexagonal lattice is zero.

b). The Random Lattice (P): This field of points is antipode to the regular lattice, for the distribution follows the Poisson expansion. The H_p can be approximated as:

$$H_p \doteq 0.193(\log_{10} a_p)^2 + 1.461 \log_{10} a_p + 1.952 \qquad (6)$$

where a_p is the mean density of points per quadrat in the field.

5). The next step involves the break down of the actual pattern into a completely random and a completely regular component (P and R). If the map of existing pattern

is treated as the superimposition of two maps consisting of regular and random components respectively, its entropy can be expressed as

$$H_s = H_r + H_p \qquad (7)$$

but $H_r = 0$, hence $H_s = H_p$. Similarly, the mean density of the existing pattern a_s also equals to the sum of the mean density of the two respective original maps, i.e.

$$a_s = a_r + a_p \ . \qquad (8)$$

By using equation 6 the mean density of points per quadrat for the random system can be obtained. Since a_p is known, a_r is also known. By subsituting the value of a_r to the following equation:

$$B = a \cdot Q \ , \qquad (9)$$

where B is the number of points, the percentage of regular component within the system is obtained. The remainder is then treated as random component.

6). Repeat the sequences of calculation for each of the time periods chosen to measure the entropy changes in the process of evolution.

Experimental Results: Malaysia is divided into ten quadrats of equal area for the present analysis. Urban centres of more than 5,000 people are plotted. This criterion of 5,000 people is important as it eliminates a large number of settlements of 1,000 - 5,000 which are no more than overgrown

villages in plantations or mining areas.[13] These settlements are mainly not service oriented with regard to central place theory and hence should be eliminated. For a list of urban centres and their populations see Table 4.

For each of the five time periods the entropy of the resulting field of points is measured. The result of the analysis is shown in Table 5. It is found that the percentage of regularly distributed urban centres decreases from 60.8 percent in 1911 to 53.3 percent in 1921 and 34.2 percent in 1931. However, the trend begins to move upwards in the later periods, from 62.1 percent to 72.6 percent in 1947 and 1957 respectively. In other words, the overall trend does not confirm the hypotheses. Nevertheless, the tendency of moving toward regularity emerges at the later time periods.

Although the experimental results are conclusive and in favor of the central place theory at the later stages, one is aware that the results are based on two important assumptions that the land surface of Malaysia is homogeneous and the chances of occurrence of urban centres in the spatial distribution follow the Poisson expansion. It is evident that the land surface of the country is not uniform. As a consequence, the chance of occurrence of each urban settlement may not be the same. Thus, modification of some kind has to be made when using the results in Table 5 to explain the urban settlement evolution process of Malaysia.

Table 4: Urban Centres of 5,000 people and over in Malaysia.

		Population in Thousands				
	Urban Centres :	1911	1921	1931	1947	1957
1	Kuala Lumpur	47.6	80.4	111.4	176.0	316.2
2	Georgetown	101.2	123.1	149.4	189.1	234.9
3	Ipoh	24.0	36.9	53.2	80.9	125.8
4	Klang	7.7	11.7	20.9	33.5	75.6
5	Johore Baru	9.4	15.3	21.5	38.8	75.1
6	Malacca	21.2	30.7	38.0	54.5	69.9
7	Alor Star	6.3	11.6	18.6	32.4	52.9
8	Seremban	8.7	17.3	21.5	35.3	52.0
9	Taiping	19.6	21.1	30.1	41.4	48.2
10	Butterworth			13.5	21.3	42.5
11	Batu Pahat		6.4	13.3	26.5	40.0
12	Muar	5.0	13.3	20.3	32.2	39.1
13	Kota Baru	12.5	10.8	14.8	22.8	38.1
14	Telok Anson	6.9	10.9	14.7	23.1	37.0
15	Kluang			6.5	16.0	31.2
16	Kuala Trengganu	14.0	12.5	14.0	27.0	29.4
17	Bukit Mertajam			5.3	12.3	24.7
18	Kampar	11.6	12.3	15.3	17.5	24.6
19	Kuantan				8.1	23.1
20	Sungei Patani			7.7	13.2	22.9
21	Ayer Itam				13.5	22.4
22	Bentong				7.1	18.8
23	Segamat				7.3	18.5
24	Kulim				9.5	17.6
25	Jinjang					16.7
26	Petaling Jaya					16.6
27	Raub					15.4
28	Sungei Siput				6.0	15.3
29	Kuala Kangsar				8.4	15.3
30	Guntong					15.1
31	Pasir Pinji					14.0
32	Dungun					12.5
33	Temerloh				5.2	12.3
34	Kuala Pilah				7.3	12.0
35	Pangkat Kalang					11.2
36	Chukai					10.8
37	Batu Gajah				7.5	10.1
38	Serdang Baru					10.0
39	Ampang					9.7
40	Kajang					9.6
41	Tapah					9.6
42	Peringat					9.6
43	Tangkak					9.0

Table 4: Continued

	Urban Centres :	1911	1921	1931	1947	1957
44	Tumpat					8.9
45	Kuala Lipis					8.8
46	Pontian Kechil					8.5
47	Bidor					8.2
48	Pokok Assam					8.0
49	Pasir Mas					7.9
50	Kulai					7.8
51	Kota Tinggi					7.5
52	Mersing					7.2
53	Kadoh					7.2
54	Pekan Nanas					7.1
55	Tanjong Malim					7.0
56	Pusing					7.0
57	Labis					6.7
58	Kuala Kubu Baru					6.7
59	Sungei Lembing					6.5
60	Yong Peng					6.4
61	Tanjong Tokong					6.2
62	Mambang di-Awan					6.2
63	Kampong Koh					6.1
64	Bukit Merah					6.1
65	Kangsar					6.1
66	Kampong Simee					6.0
67	Ayer Tawar					5.9
68	Jinjaram					5.8
69	Malim Nawar					5.7
70	Batu Tiga					5.7
71	Kapar					5.6
72	Salak South					5.6
73	Aulong					5.5
74	Semenyih					5.5
75	Bahau					5.4
76	Bagan Serai					5.4
77	Batu Arang					5.4
78	Nibong Tebal					5.4
79	Kuala Kurau					5.3
80	Guar Chempedak					5.2
81	Sungei Chua					5.2
82	Jelapang					5.2
83	Tanjong Sepat					5.0
84	Gunong Rapat					5.0

Source: Federation Year Book, Government Printers, Kuala Lumpur, Malaysia, 1961.

FIGURE 3

MALAYSIAN URBAN SETTLEMENT DISTRIBUTIONS

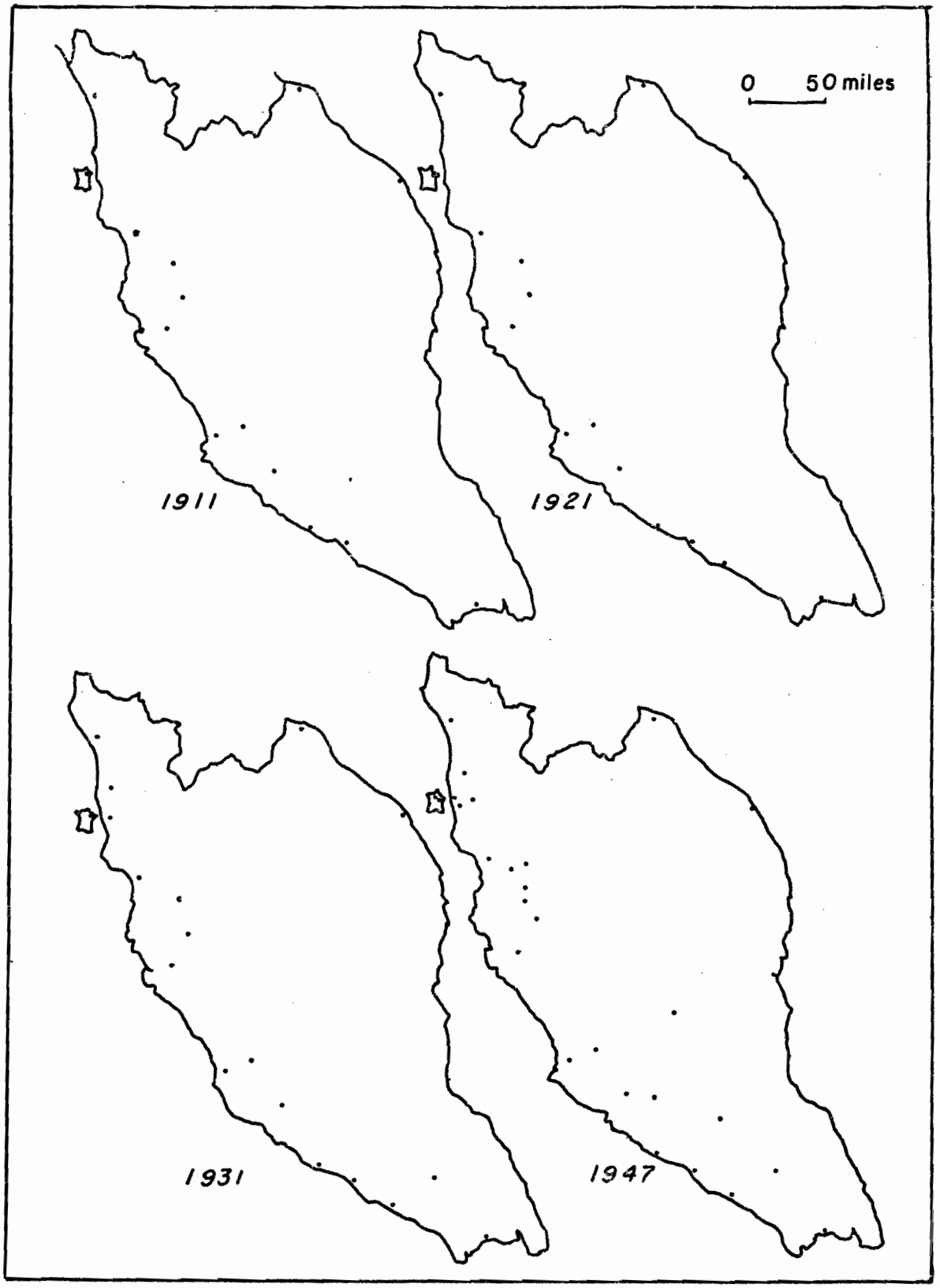
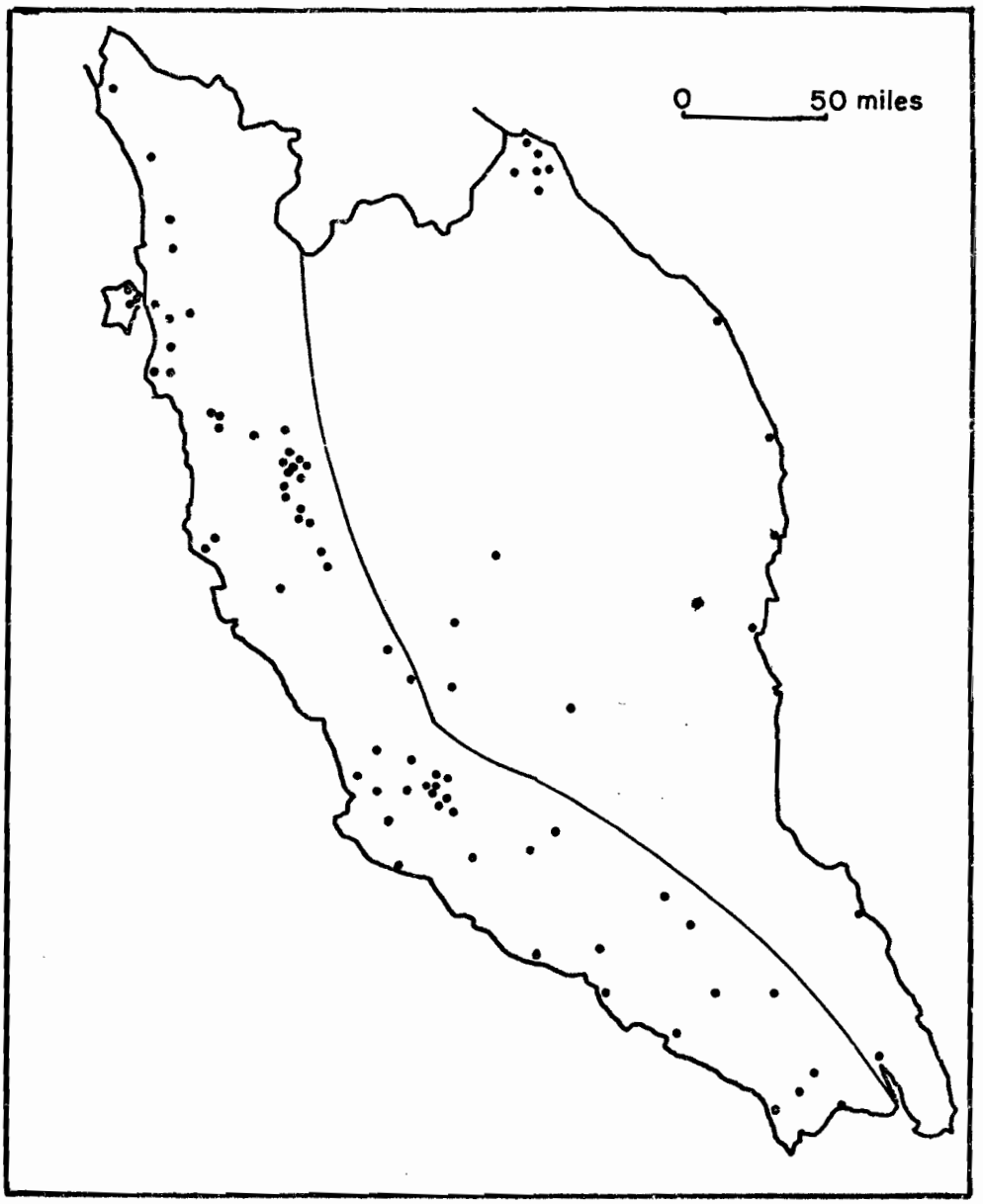


FIGURE 4

MALAYSIAN URBAN SETTLEMENT DISTRIBUTION 1957



A method is employed here to provide a measure of the degree of geographical differentiation in the urban settlement distribution of Malaysia. The indices obtained will show the nature of the distribution pattern, whether geographically concentrated or evenly distributed. The sequence of calculations is as follows:

1). As the entropy H_s of an urban settlement pattern is a function of Q, the number of quadrats, equation 5 can be rewritten in the following forms:[14]

$$H_s = - \sum_{i=1}^{n} p_i \log_2 p_i$$

$$= \log_2 Q - \frac{1}{Q} \sum_{i=1}^{n} m_i \log_2 m_i \qquad (10)$$

$$= \log_2 (\lambda Q) \qquad (11)$$

where $$\lambda = \frac{1}{\prod_{i=1}^{n} (p_i)^{p_i/Q}} \quad . \qquad (12)$$

Thus $$\lambda = \frac{1}{Q}(2)^{H_s} \qquad \left(\frac{1}{Q} \leqslant \lambda \leqslant 1 \right). \qquad (13)$$

The entropy H_s would assume a maximum value, $H_{max} = \log_2 Q$, in the case, and only in the case, when $\lambda = 1$, i.e. when all frequencies of occurrence $m_i = 1$ ($i = 1, 2, \cdots, n$). H_s would be minimum, $H_s = H_{min} = 0$, when and only when $\lambda = 1/Q$, i.e. when all frequencies of occurrence are zero except one which is unity.

2). Let L be the index of areal differentiation of urban settlement distribution of the system, where

$$L = 1 - \lambda \qquad \left(0 > L > \frac{Q-1}{Q} \right). \qquad (14)$$

If $L = 0$, a maximum differentiation occurs within the system as $H_s = H_{max} = \log_2 Q$. If $L = (Q-1)/Q$, a minimum differentiation is reached since $H_s = H_{min} = 0$. For all other possible values of L, the degree of areal differentiation is intermediate.[15] In other words, when L approaches zero, the difference of occurrence of urban settlements among quadrats is tending toward maximum. The opposite also holds.

Therefore, it can be concluded that the index L has a direct bearing on the criteron of regularity of a settlement lattice. The lattice is said to be regular when, and only when $L = (Q-1)/Q$ and $H_s = 0$.

Experimental Results: The results of the analysis show that urban settlement distribution in Malaysia tends toward sectorial concentration over time. See Table 6. The L value decreases from 0.7432 to 0.5541 for 1911 and 1957 inclusive except 1947. The decrease in L values indicates the increase of areal differentiation in distribution. Urban settlements are concentrated in the western half of the country where most of the economic activities exist. See Figure 4. As a result, it is to be emphasized that

Table 5 : Entropy changes in urban settlement evolution of Malaysia.*

Year	B	a_s	a_r	a_p	H_s	%R	%P
1911	14	1.40	0.85	0.55	1.3608	60.8	39.2
1921	15	1.50	0.80	0.70	1.7216	53.3	46.7
1931	19	1.90	0.65	1.25	2.1215	34.2	65.8
1947	29	2.90	1.80	1.10	1.9506	62.1	37.9
1957	84	8.40	6.10	2.30	2.5214	72.6	27.4

Note : Q = 10

Table 6 : Areal differentiation in urban settlement distribution of Malaysia.*

Year	H_s	λ	L
1911	1.3608	0.2568	0.7432
1921	1.7216	0.3298	0.6702
1931	2.1215	0.4353	0.5647
1947	1.9506	0.3865	0.6135
1957	2.5214	0.4559	0.5441

Note : Q = 10

Table 7: Entropy changes and areal differentiation in urban settlement evolution in the western region of Malaysia.*

Year	B	a_s	a_r	a_p	H_s	%R	%P	λ	L
1911	12	1.20	1.00	0.20	0.7218	83.3	26.7	0.1649	0.8351
1921	13	1.30	1.05	0.25	0.8812	80.8	29.2	0.1842	0.8158
1931	17	1.70	1.10	0.60	1.3608	64.7	35.3	0.2568	0.7432
1947	24	2.40	1.25	1.15	1.8951	52.0	48.0	0.3718	0.6282
1957	67	6.70	3.65	3.05	2.7213	54.5	45.5	0.6594	0.3406

Note : Q = 10

* Indices calculated by the author.

Table 8 : Regional distribution of urban settlements of Malaysia.

Year	total number of urban settlements	western region	eastern region
1911	14	12	2
1921	15	13	2
1931	19	17	2
1947	29	24	5
1957	84	67	17

the significance of the previous point pattern analysis is the tendency of the distribution of urban settlements toward regularity in the later stages, but the pattern is associated with increasing sectorial concentration.

Since 67 out of 84 of the urban centres in 1957 are located in the western half of the country, (See Table 8) an analysis for the western region alone is performed in order to give a more detailed information about the arrangement. However, the results show little departure from the overall pattern. See Table 7 . The distribution pattern becomes less and less regular from 1911 to 1947 inclusive but a reverse trend begins in 1957. The L value shows a sharp decrease from 0.8351 in 1911 to 0.3406 in 1957 inclusive. This means that a sectorial characteristic also occurs in the western region of the country.

In summary, the first hypothesis is rejected as the urban settlement pattern does not move toward regularity in the early three time periods. The second hypothesis, however, is accepted conditionally as regularity emerges in parallel with increasing areal differentiation. The analysis now proceeds to examine the population arrangement of the urban system.

III

City-Size Distribution Pattern: The rank-size rule

proposed by Zipf[16] to study city-size distribution has been examined in detail in the geographic literature.[17] The rule specifies that

$$P_r = p_i \cdot r^{-x} \qquad (15)$$

where r is the number of cities greater than or equal to size p_r, i.e. the rank of the city of size p_r; P_i is the population of the i^{th} city and x is an exponent. The rank-size rule simply states that the distribution of cities by population size class within countries is truncated lognormal.[18] However, it has been shown that not all the countries follow the rule in city-size distribution.[19]

Three kinds of city-size distribution are recognized: lognormal,[20] primate,[21] and intermediate type.[22] Berry extents a possible trend of movement of city-size distribution from primate to lognormal over time.[23] However, Curry is the first to attempt a comprehensive formulation of the organizational feature of urban systems in terms of cybernetics. Both Berry and Curry argue that rank-size distribution is the result of an entropy maximizing process. Nevertheless, Berry is not always clear and consistent in this respect. He fails to distinguish between unconstrained maximized entropy and constrained optimized entropy. Curry, on the other hand, is unable to define explicitly how order comes into existence in urban systems.[24] Simon suggests that lognormal distributions are produced as limiting cases by stochastic growth process, based on the notion of a general systems theory.[25] According to Simon, the rank-size

distribution is simply an average condition of a steady state of the system, i.e. a condition of entropy.

Recently, by borrowing the analogy of income distribution treated by Champernowne, Fano suggests that rank-size distribution of cities, for a given system of cities, may be conceived as generated by a constrained Markov chain process.[26]

Taking the theoretical lognormality postulated by Zipf as given, a method is derived to measure the entropy of the city-size distribution pattern of Malaysia. The measure indicates the degree of deviation of the existing pattern from lognormal. The procedure of calculations is illustrated as follows:

1) Let n be the number of urban centres of the existing system. Each urban centre i consists of a fraction of the total urban population of the system which is denoted as y_i ($y_i > 0$ and $i = 1, 2, \cdots, n$). It is obvious that

$$\sum_{i=1}^{n} y_i = 1 \quad . \tag{16}$$

2) As the distribution of the city-size is an outcome of a simple probabilistic process, the entropy, H_R , of the system can be calculated such that

$$H_R = - \sum_{i=1}^{n} y_i \log_2 y_i \tag{17}$$

where y_i is the probability of a given number of people

occurs in urban centre i ($i = 1, 2, \cdots, n$), expressed as a fraction of the total urban population. H_R is simply the entropy of the urban population shares of the system. When the shares of all the urban centres within the system are equal, i.e. when $y_i = 1/n$, ($i = 1, 2, \cdots, n$), a completed homogeneity is reached and $H_R = H_{max} = \log_n n$.

When all the y_i are zero except one which is unity, a minimum entropy occurs, $H_R = H_{min} = 0$, as there is only one urban centre within the system. There are the two extreme theoretical states of the equilibrium of the city-size distribution systm.

3) According to the theoretical rank-size rule, the urban population shares are in the form of a sequence of ratios, such as

$$P_r : \frac{P_r}{2} : \frac{P_r}{3} : \cdots : \frac{P_r}{n}$$

where P_r is the population of the largest urban centre and n is the number of the total urban centres. The entropy of this theoretical system, H_L , can also be calculated by means of equation 17 provided, for comparision purpose, the total number of urban centres and the total urban population are correspondent to the existing pattern and the shares within the theoretical system follows the above sequence of ratios. In this theoretical system, the probability density

function of each size class of urban centres is the same, and it represents an average state of equilibrium, i.e. state of lognormality. Obviously $H_{min} < H_L < H_{max}$ and $H_L / H_{max} = \text{Cos } 45^\circ = 0.7071$.

4) A ratio of the entropy measures of the existing pattern to the theoretical lognormal pattern can be calculated such that

$$R_r = \frac{H_R}{H_L} \quad . \tag{18}$$

When the two measures are alike, $R_r = 1$, the existing system is of a lognormal distribution. If $R_r < 1$, the greater is the tendency toward primate distribution. On the other hand, if $R_r > 1$, the greater is the tendency toward a distribution in which the medium size urban centres dominated.

5) To compare the R_r ratios over time, the trend of movement of the city-size distribution pattern of a country can be traced.

Experimental Result: The analysis shows that the Malaysian urban system approaches to lognormal in city-size distribution over time.[27] See Table 9. From 1911 to 1947 inclusive the R_r indices approach to one and in 1957 it is slightly greater than one. This implies that at the latest stage the number of medium size urban centres are increasing. A closer examination shows that the second largest city in Malaysia has a population share which is always larger than

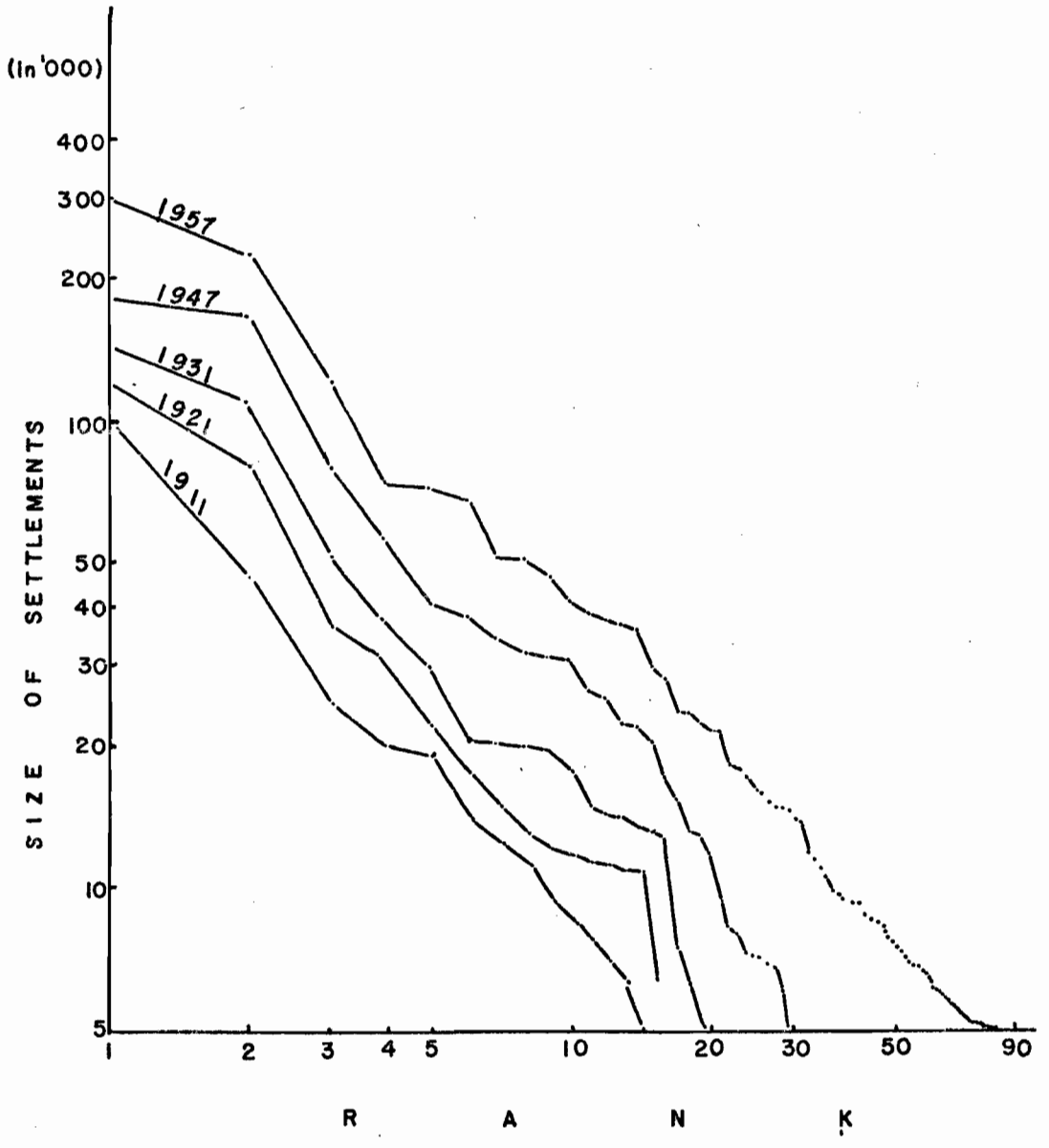
Table 9 : Entropy changes in city-size Distribution of Malaysia.*

Year	H_R	H_L	$R_r = \frac{H_R}{H_L}$
1911	3.1454	3.2590	0.9651
1921	3.1946	3.2982	0.9685
1931	3.5780	3.5930	0.9958
1947	3.9500	4.0414	0.9777
1957	5.3227	5.1356	1.0364

* Indices calculated by the author.

FIGURE 5

MALAYSIAN CITY-SIZE DISTRIBUTIONS



half of the largest city over time except 1911. This means that the first city has not been as large as expected when comparing to its theoretical equilibrium state.

As the R_r indices suggest that the Malaysian urban system has been at an average state of equilibrium in city-size distribution, it will be useful to examine whether this equilibrium also exists in the spatial distribution of the urban population, on which the analysis now proceeds.

IV

Urban Population Distribution: As it has been noted, distribution of urban centres in Malaysia possesses an areal differentiation or regional concentration character. This implies that the same situation may occur in the spatial urban population distribution pattern, i.e. region of more urban centres will obtain a larger share of urban population.

An attempt is made to measure the entropy change in the spatial distribution of urban population of Malaysia over time. Since the problem is an inter-state as well as a within-state one, the concept of between-set and within-set entropies is introduced.[28] The between-set entropy measures the differentiation among the states while the within-set entropy measures the differentiation within each of the individual state.

The derivation of the measurements is illustrated in outline as follows:

1) Let y_i be the probability of urban population share of urban centre i (i = 1, 2, ···, n), expressed as a fraction of the total urban population of the country. Then the entropy of all the shares, H_o , of the urban centres, n of them, will follow this expression:

$$H_o = \sum_{i=1}^{n} y_i \log_2 \frac{1}{y_i} \qquad (i = 1, 2, \cdots, n) \quad (19)$$

which can be regarded as the inverse measure of concentration. If the shares of all the urban centres are equal, i.e $y_i = \frac{1}{n}$ (i = 1, 2, ···, n), a complete homogeneity occurs and $H_0 = H_{max} = \log_2 n$. If all the shares are zero except one which is unity, a complete concentration of urban population occurs as there is only one city remains in the system. Thus, the higher the entropy as compared to its maximum state of equilibrium, the lower is the degree of concentration in its distribution pattern. The opposite holds.

2) Let all the urban centres, n , of Malaysia be grouped into G sets, each set represents a state in this case. The urban population of each set S_g (g = 1, 2,···, G) is then the summation of all the urban population of the particular set, expressed as a fraction of the total urban population of the system, such as

$$Y_g = \sum_{i \in S_g} y_i \qquad (g = 1, 2, \cdots, G) \tag{20}$$

and equation 19 can then be expressed in the following form:

$$H_o = \sum_{i=1}^{n} y_i \log_2 \frac{1}{y_i}$$

$$= \sum_{g=1}^{G} \left[\sum_{i \in S_g} y_i \log_2 \frac{1}{y_i} \right] \tag{21}$$

$$(i = 1, 2, \cdots, n, \text{ and } g = 1, 2, \cdots, G)$$

$$= \sum_{g=1}^{G} Y_g \log_2 \frac{1}{Y_g} +$$

$$\sum_{g=1}^{G} Y_g \sum_{i \in S_g} \frac{y_i}{Y_g} \log_2 \frac{Y_g}{y_i} \tag{22}$$

$$= H_B + \sum_{g=1}^{G} Y_g \cdot H_W \tag{23}$$

where $$H_B = \sum_{g=1}^{G} Y_g \log_2 \frac{1}{Y_g} \tag{24}$$

is the between-set entropy and

$$H_W = \sum_{i \in S_g} \frac{y_i}{Y_g} \log_2 \frac{Y_g}{y_i} \tag{25}$$

is the individual within-set entropy, which is calculated for each of the individual state. In words, the total national entropy, H_o, is the summation of the national between-set entropy and the total national within-set entropy. The total

national within-set entropy is also known as the 'regional heterogeneity',[29] because it measures the general difference in concentration within the individual set. The between-set entropy, H_B, measures the difference in concentration among the sets. The larger the between-set entropy, the less is the distribution difference among the sets. Similarly, the smaller the total within-set entropy will mean a greater differentiation among the urban centres within the sets.

3) Two ratios are now derived for the between-set and within-set entropies respectively as compared to their corresponding theoretical maximum entropies. The indices will then supply information of the degree of departure the existing patterns are away from their corresponding theoretical systems. For the between-set entropy, denoted the ratio be R_B, which is expressed as

$$R_B = H_B / H_{B_{max}}$$

$$= H_B / \log_2 G \qquad (0 \leq R_B \leq 1) \qquad (26)$$

where G is the number of sets, which is 11 in the Malaysian case. The nearer the R_B approaches to 1, the smaller is the degree of concentration, i.e. the urban population is said to be evenly distributed among the states. The opposite holds.

For the within-set entropy, H_W, the ratio R_W is then expressed as

$$R_W = H_W / H_{W_{max}}$$

$$= H_W / \log_2 V \qquad (0 \leqslant R_W \leqslant 1) \qquad (27)$$

where V is the number of urban centres within each individual state. The nearer the R_W approaches to zero, the greater is the concentration, i.e. urban population are concentrated in a few centres within the particular state. The opposite also holds.

4) Repeat the analysis through the five time periods to examine the entropy changes in the Malaysian urban system.

Experimental Result: An analysis is performed over time according to the above derivation. See Table 10. The entropy measurement for the country as a whole is increasing over time because the number of urban centres and the total urban population are increasing. The between-set entropy increases slightly over time, reflecting a slow tendency toward even distribution. From 1911 to 1931, the R_B index increases from 0.77 to 0.79 . In 1947, it drops to 0.77 again, but shoots up to 0.83 in 1957. The increase in R_B ratio suggests that more and more states are having a better share of the total urban population. The 1957 index is the highest among all, which implies that urban growth has become a phenomenon for the whole country. The difference among states is proportionally less than the previous periods. This is confirmed by the fact that most of the states enjoy a rapid

Table 10: Entropy changes in urban population distribution of Malaysia.*

	1911	1921	1931	1947	1957
H_R	3.1454	3.1946	3.5780	4.1020	5.3227
H_B	2.6489	2.7050	2.7475	2.6727	2.8773
$Y_g \cdot H_W$	0.4965	0.4896	0.8305	1.4293	2.4454
$H_{B_{max}}$	3.4594	3.4594	3.4594	3.4594	3.4594
R_B	0.77	0.78	0.79	0.77	0.83

* Indices calculated by the author.

increases in urban centres and urban population in 1957.

The rapid increase can also be traced by examining the within-set entropy changes among the states. See Table 11. The indices show that there is a striking difference in distribution pattern among the states. In some states the number of urban settlements remains unchanged over time, and in others the number increases rapidly. None of the states has a decrease in numbers. If all the urban population concentrates in one centre, the H_W is zero. Otherwise, the H_W is positive. The nearer the R_W ratio approaches to 1, the better is the even distribution pattern. A systematic interpretation of the results is given below:

1) Perlis and Malacca: These two states are both small in size and less urbanized. Malacca, though having the longest history of development. has only one centre throughout the five time periods. In Perlis, the first urban settlement of more than 5,000 people only occurs in the 1957 period. Consequently, the indices are equal to zero for these two states respectively. A complete concentration appears.

2) Kedah: This state possesses only one urban centre in 1911 and 1921. The number increases steadily since then. Nevertheless, after an increase in 1931, the R_W ratio drops rapidly for 1947 and increases again for 1957. It is 0.7077

Table 11: Within-set entropy changes in urban population distribution of Malaysia.**

	1911	1921	1931	1947	1957
1) Perlis:					
total centres	0	0	0	0	1
H_W	-	-	-	-	0
R_W	-	-	-	-	0
2) Kedah:					
total centres	1	1	2	3	4
H_W	0	0	0.8753	0.8680	0.4154
R_W	0	0	0.8753	0.8680	0.4154
3) Penang*:					
total centres	1	1	3	4	6
H_W	0	0	0.7406	0.7547	1.4824
R_W	0	0	0.4673	0.3773	0.5734
4) Perak:					
total centres	4	4	4	7	25
H_W	1.8550	1.8232	1.7921	2.2481	3.7724
R_W	0.9225	0.9058	0.8960	0.8008	0.8123
5) Selangor:					
total centres	2	2	2	2	16
H_W	0.7488	0.5492	0.6284	0.6097	2.0919
R_W	0.7488	0.5492	0.6284	0.6097	0.5227
6) Negri Sembilan:					
total centres	1	1	1	2	3
H_W	0	0	0	0.6902	1.0369
R_W	0	0	0	0.6902	0.6542
7) Malacca:					
total centres	1	1	1	1	1
H_W	0	0	0	0	0
R_W	0	0	0	0	0

Table 11 Continued

	1911	1921	1931	1947	1957
8) Johore: total centres	2	3	4	5	13
H_W	0.9314	1.5004	1.8774	2.1454	3.1366
R_W	0.9314	0.9466	0.9387	0.9239	0.9028
9) Pahang: total centres	0	0	0	3	6
H_W	-	-	-	1.5615	2.4657
R_W	-	-	-	0.9852	0.9538
10) Trengganu: total centres	1	1	1	1	3
H_W	0	0	0	0	1.4075
R_W	0	0	0	0	0.8870
11) Kelantan: total centres	1	1	1	1	6
H_W	0	0	0	0	1.9873
R_W	0	0	0	0	0.7685

* Including Province Wellesley.
** Indices calculated by the author.

in 1957, as compared to 0.8753 in 1931 and 0.5476 in 1947 respectively. The faster growth of Alor Star, the largest town in the state in 1947 changes the index for that period. During the last period, Kulim grows so rapidly that it balances out the concentration pattern, showing an increase of R_W value.

3) Penang and Province Wellesly: In 1911 and 1921, this state has only one centre, Georgetown ., which has been the largest city in the country until 1957 when Kuala Lumpur of Selangor overtakes. As Georgetown has most of the population shares, the R_W index is reasonably low, which is especially true for 1947 when the total population of Georgetown is almost four times larger than all the other towns combined. The R_W value is only 0.3773 in 1947, as compared to the slightly higher indices of 0.4673 and 0.5734 for 1931 and 1957 respectively.

4) Perak: This state has the largest number of urban centres over time. About 30 percent of the urban centres are found in this state in 1957. Consequently, the state is associated with a larger within-set entropy value over time. It is also found that the R_W indices are large throughout the five time periods, which indicates that a less concentration pattern exists in this state. However, due to the steady growth of Ipoh, the R_W indices show a gradual decrease over time, from 0.9225 in 1911 to 0.8008 in 1947. Until 1957 when more urban centres are springing up, the R_W index increases to 0.8123 .

5) Selangor: This is another state that has rapid urbanization since 1957. From 1911 to 1947 inclusive there are only two urban settlements in this state, i.e. Kuala lumpur and Klang. The first has been much larger than the second. Therefore, the R_W indices are rather low for these periods. In 1957, though the number of urban centres increases rapidly, the R_W index drops to 0.5227 when Kuala Lumpur becomes the first city and the capital of the country.

6) Negri Sembilan: This state has only one centre, Seremban, from 1911 to 1931. However, the R_W indices for 1947 and 1957 are also low, showing that Seramban has most of the population shares.

7) Johore: This state has a different pattern. Most of the urban centres are of medium size throughout the five time periods. The R_W indices approach to 1 all the time, ranging from 0.9028 to 0.9466 . This state also has a most steadily increase of urban centres and population, showing by the increase of the within-set entropy.

8) Pahang, Trangganu and Kelantan: These three states in the east are less urbanized and less developed. Pahang has no urban centre before 1947, while the other two states have only one respectively before 1957. Most of the urban centres are small in size. Hence, the population shares are more or

less similar, reflecting in the high R_W indices. Kelantan has the lowest value of 0.7683 among the three states in 1957 as Kota Baru is larger than other centres.

The analysis indicates that the urban system has an areal differentiation characteristic, both in point arrangement and in urban population distribution. It is, therefore, desirable to know whether these urban centres are all efficiently linked. Inter-urban transportation linkage pattern suggests the external structure of the urban system. The analysis now proceeds to investigate this external structure.

V

The importance of transportation to economic development has been extensively noted in geographic literature.[30] There are at least two major reasons for emphasizing the role of transport in regional development. Firstly, it is the key to pioneer settlement. Secondly, the improved and extended transport facilities widen the market in areas already settled, and stimulate further production for internal and external trade and so in encouraging the growth of urban places and a modern exchange economy.

Since transport network is such an important indicator to urban growth, a measurement for the network complexity is

required.[31] It is difficult to state the type of transport network that is the best, though urban theorists have suggested two ways of efficiently linking centres within a system of central places. The first, proposed by Christaller[32] is derived from the hexagonal central place hierarchical structure and consists of six radical links oriented toward the nearest service centre of any given central place. Each link is of equal length and is the shortest route. The second, proposed by Lösch[33] is derived from the square central place hierarchical structure and consists of four perpendicular links with the nearest neighbors. This linkage arrangement is less efficient than the first one. Assumption is made here to denote these two linkage arrangements as the two ideal theoretical network systems. The complexity of the Malaysian transport network system is studied by comparing existing patterns to theoretical patterns.

A method is derived to measure the complexity, based on the concept of a Markovian approach in information theory.[34] The Markov chain moves one step ahead, starting from the initial state. The indices derived by this method will provide the information about the Malaysian transportation system. The indices can be obtained by means of the following sequence of calculations:

1). Reduce an inter-urban transportation network to a series of nodes and associated links, i.e. a graph or graphs.

2) Record any node i ($i = 1, 2, \cdots, n$) that is linked directly to any node j ($j = 1, 2, \cdots, k$) in an adjacency matrix A_{ij} . Use nominal measures to indicate the number of links.[35] Calculate row totals for A_{ij} .

3) Construct a matrix of conditional probabilities by expressing each element a_{ij} as a proportion of its corresponding row total. Call this probability $P_{j.i}$; read, the probability of j, given i. Calculate row totals for this probability matrix. Each total should equal 1 indicating that every node is connected by at least one link out of a total possible of k , to other nodes in the system. If any row totals equal zero, the corresponding node is not linked with any other node.

4) Calculate the level of uncertainty or entropy, a surrogate for complexity, for any node i in the system in the following manner:

$$H_n = - \sum_{j=1}^{k} p_{j.i} \log_2 p_{j.i} \qquad (28)$$

5) The level of uncertainty associated with the n nodes of the entire network can be obtained as follows:

$$H_s = - \sum_{i=1}^{n} \sum_{j=1}^{k} p_{j.i} \log_2 p_{j.i} \ . \qquad (29)$$

For the two theoretical networks, such as those formulated

by Lösch and Christaller, equation 29 reduces to:

$$H_k = - nk \left(\frac{1}{k} \log_2 \frac{1}{k} \right) \qquad (30)$$

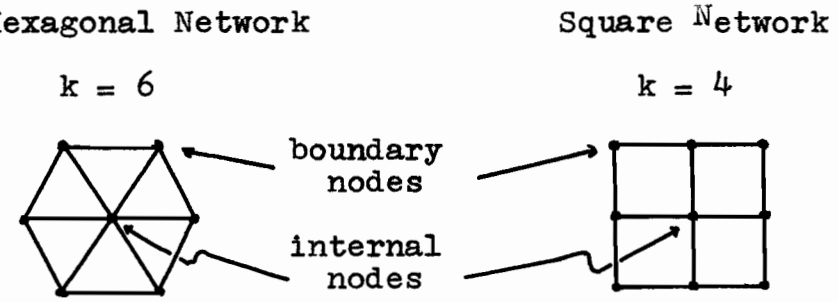
where n is the number of nodes and k is the number of links associated with each node.[36] It is to be noted that equation 30 is only applicable to networks found in unbounded plains, i.e. on the isotropic surface. This implies that n tends to infinity. However, in real world n is finite and the network is encompassed by a boundary, either physical or a political one. Consequently, in order to compare the entropy change in real world networks, boundaries must be placed on ideal networks such that they correspond to their real world counterparts.

6). Boundaries can be placed on ideal 6-link and 4-link networks as in Figure 6. A strategy is presented which insures that the bounded ideal models conform to the real world model.

7). Construct the ideal bounded model in such a way that the number of the nodes and network configuration conforms to its real world counterpart. Insure that the arrangement of the nodes for the hexagonal 6-link model are offset and for the square model are aligned perpendicular to each other. Also insure that the ideal model has the same number of boundary nodes as does the real world model.[37] A boundary node is one that is not encircled by linkages. Figure 6, for example, is constructed in such a way that all nodes are on boundaries

except for a single 'internal' node. Use equation 29 to

Figure 6: Ideal Networks



calculated the entropies in the bounded ideal model as well as the bounded real model. Denote these entropies by H_{ideal} and H_{real}, respectively.

8) Calculate the index of redundancy, R_k, for the real world network by using the following equation:

$$R_k = \left(1 - \frac{H_{real}}{H_{ideal}} \right) \times 100\% \quad . \qquad (31)$$

If $R_k > 0$, the existing transportation network is less complex than the ideal. If $R_k < 0$, the opposite holds. If $R_k = 0$, the two networks are identically complex.

9) Repeat the above procedure over time to measure the entropy change in the system.

Experimental Results: For the Malaysian transportation network system, two different analyses are performed to measure the railway complexity and the highway complexity respectively. Railway transport has proved important to early development and urban growth. In the later stage, however, highway transport dominates. As there has been no major railway construction after 1931, the analysis for the railway network is performed for only the 1911, 1921 and 1931 periods. On the other hand, highway network analysis is performed throughout the five time periods.

Railway Network: The analysis shows that the railway network structure of Malaysia is far from ideal. See Table 12. It consists of 10 links in 1911, 14 links in 1921 and 18 links in 1931. One fifth to a third of the nodes are not linked. All the nodes are on the boundary. The graph resembles a simple Y tree. See Figure 7. The redundancy indices show that the network is 53.80 percent less complex than the ideal 4-link network and 65.75 percent less complex than the corresponding 6-link network in 1911. The situation improves in 1921, with 39.41 percent and 53.61 percent less complex than the two respective ideal models. However, the indices increase to 41.08 percent and 54.42 percent respectively in 1931. This implies that the 1931 network is less efficient than the 1921's as far as complexity is concerned. The overall extremely high percentages indicate that the railway network of Malaysia is

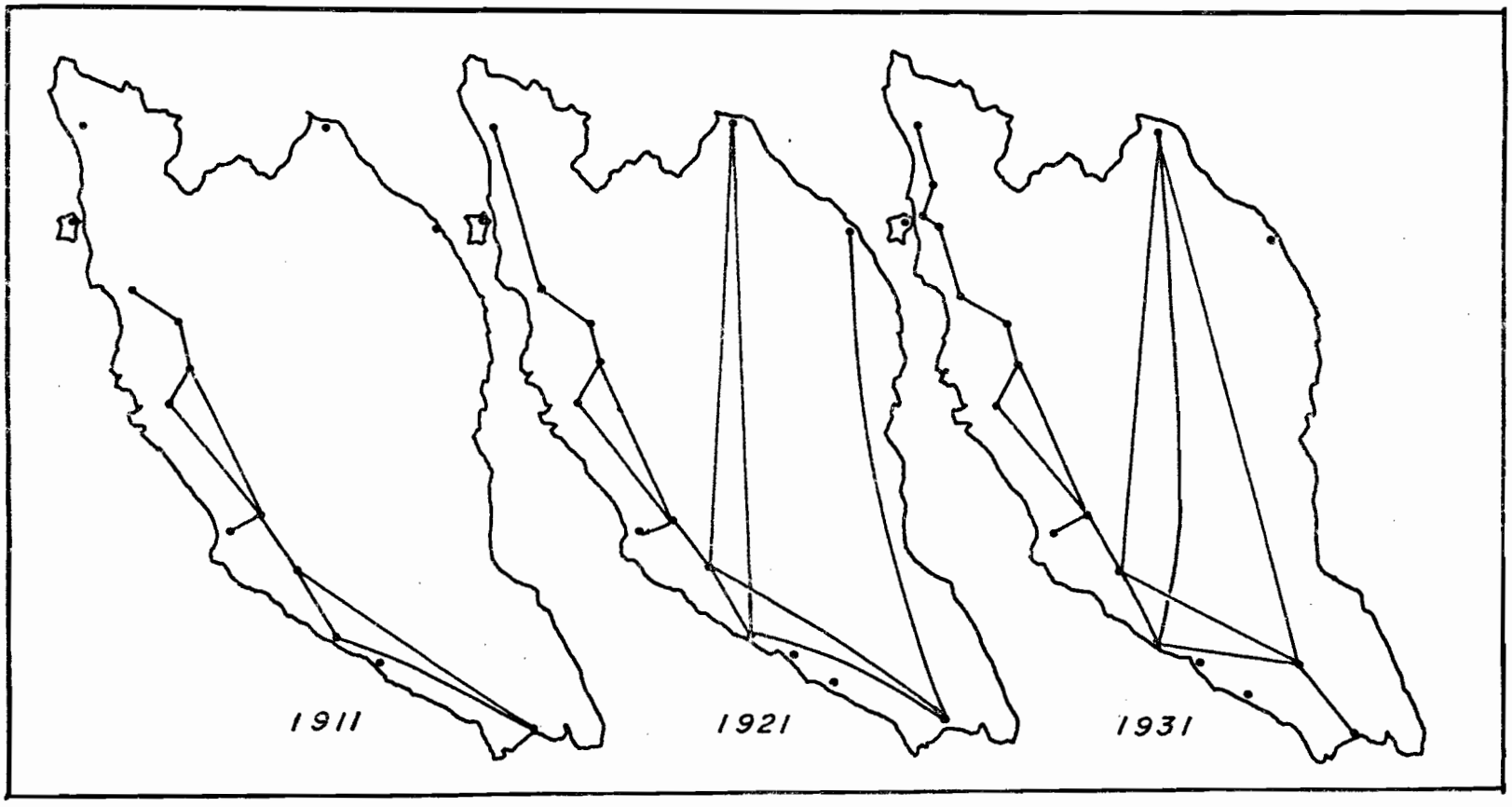


FIGURE 7 : MALAYSIAN RAILWAY NETWORKS

Table 12 : Entropy changes in inter-urban railroad network of Malaysia.**

	1911	1921	1931
Total towns	14	15	19
Nonlinked towns	5	4	4
Total linkages	10	14	18
H_t	9.1692	13.3384	16.7538
H_4	19.8460	22.0152	28.4336
H_6	26.7538	28.7538	36.7538
R_4^*	53.80	39.41	41.08
R_6^*	65.73	53.61	54.42

* Redundancy expressed in percentage.
** Indices calculated by the author.

at an extremely elementary level of complexity.

Highway Network: For highway network analysis, only principle roads [38] are selected. The analysis shows that highway network has been improved greatly since 1931. See Table 13. The redundancy indices indicate that the existing pattern is 56.73 percent less complex than the ideal 4-link network and 65.89 percent less complex than the theoretical 6-link model in 1911. The indices decrease rapidly in the later years. For example, they are 23.14 percent and 37.86 percent respectively in 1931. In 1947, the complexity of the Malaysian network has shown a tendency toward the ideal 4-link model, reflecting by the low 7.31 percent index. In 1957, the existing pattern is far more complex, by 26.01 percent, than the ideal 4-link network. It is also nearly identical to the 6-link network in complexity, with an index of 0.26 percent. The sharp decrease in redundancy indices coincides with the rapid increase of urban centres, implying that the highway system has been improving over time.

However, a closer examination of the graphs reveals the fact that the network system is made up of several almost isolated groups of circuits and trees, joining each other by only a single link. This fact, together with the large number of bounday nodes, suggests that the Malaysian transportation system is also subject to the characteristic of regional

FIGURE 8 : MALAYSIAN HIGHWAY NETWORKS

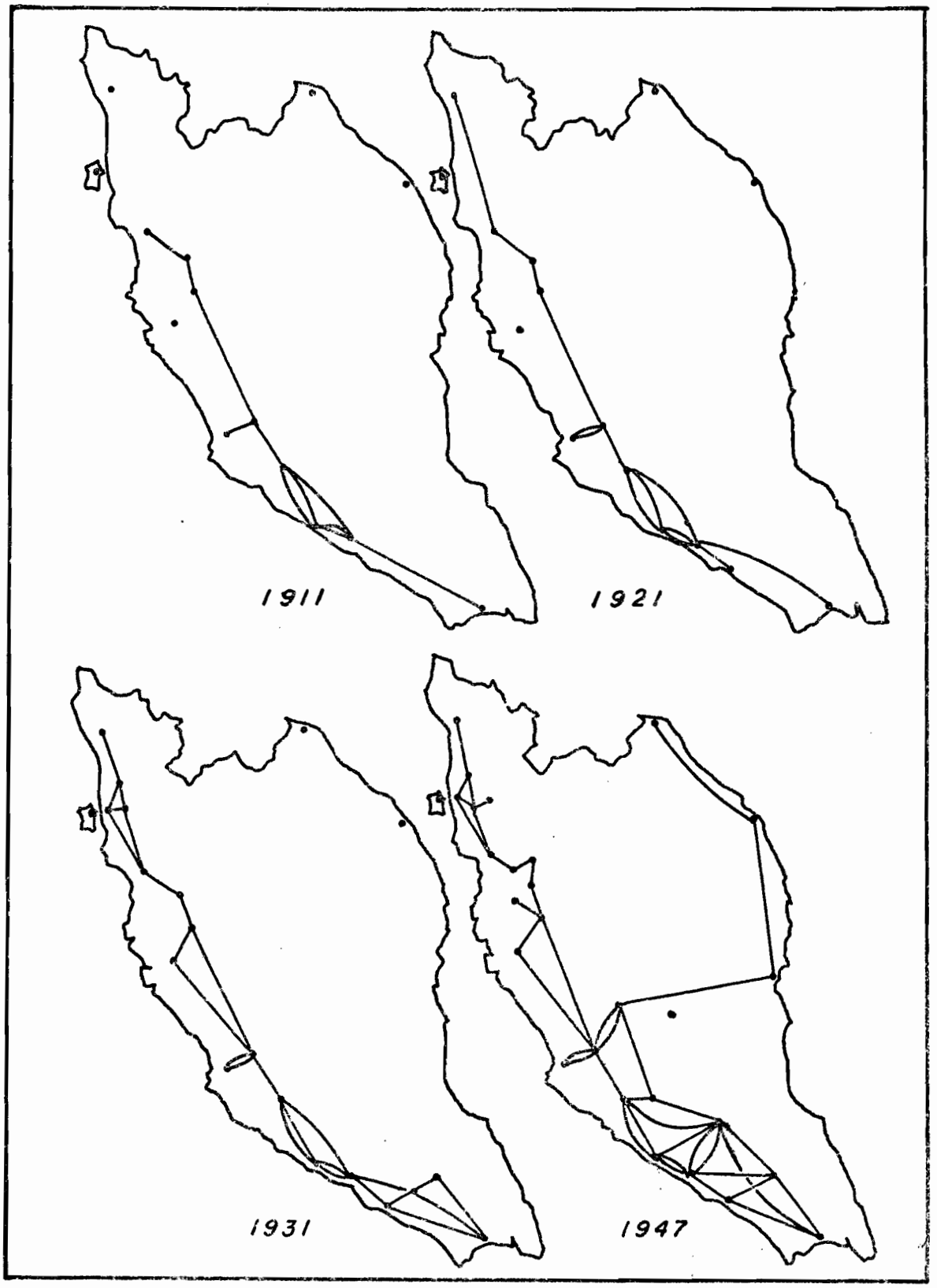


FIGURE 9 : MALAYSIAN HIGHWAY NETWORK 1957

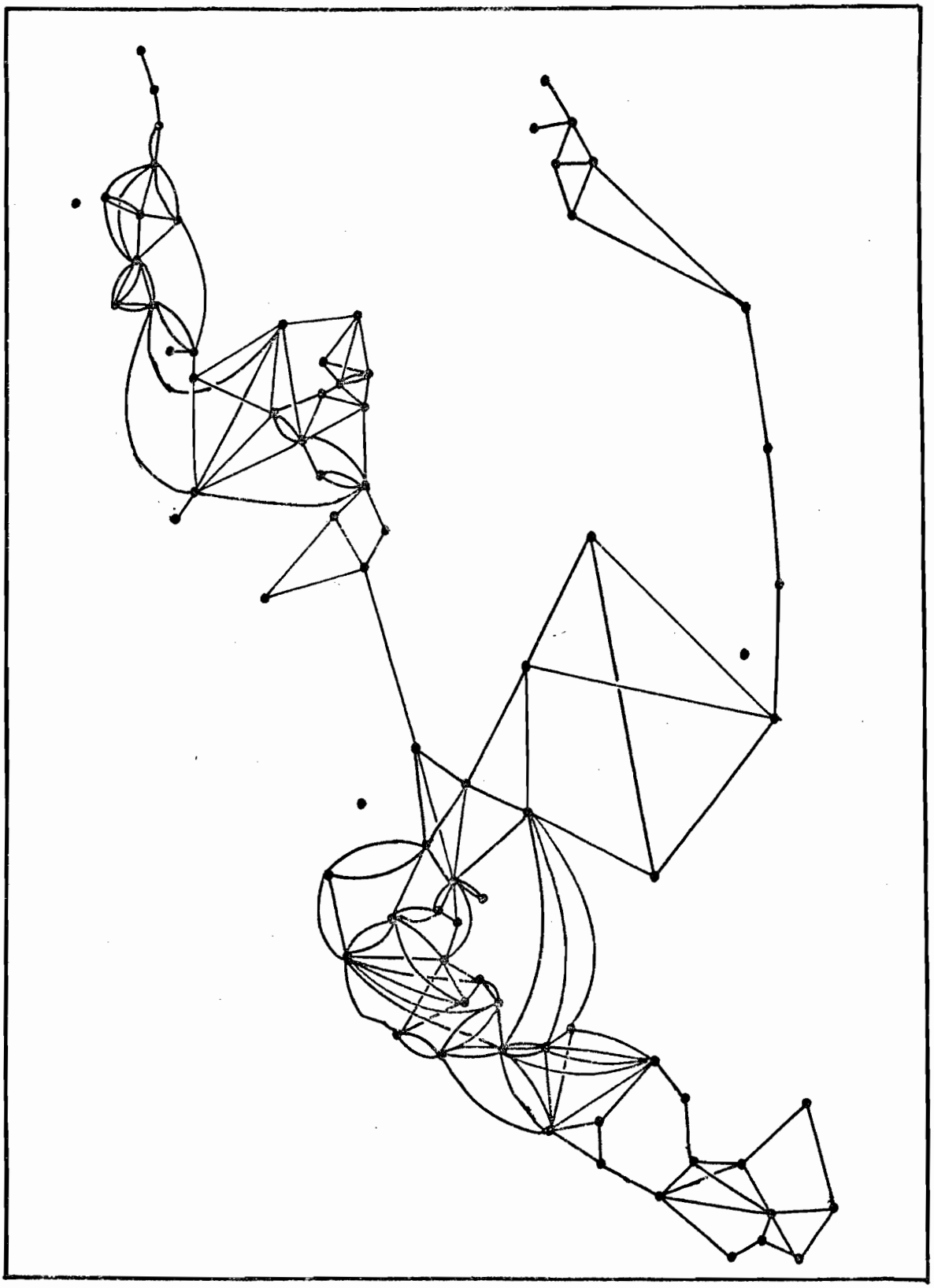


FIGURE 10

MALAYSIAN BOUNDED IDEAL NETWORKS (1957)

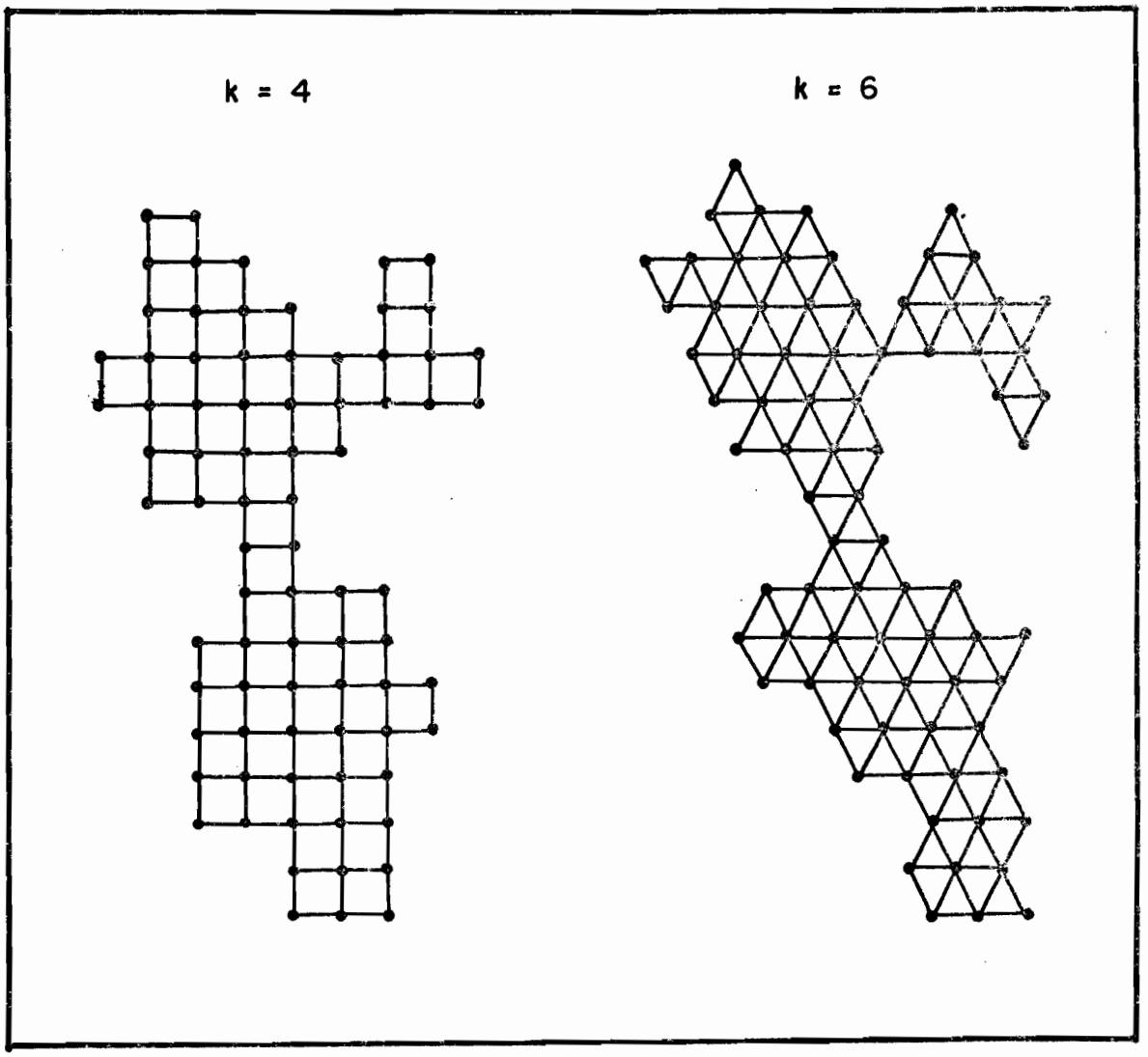


Table 13: Entropy changes in inter-urban highway network of Malaysia.***

	1911	1921	1931	1947	1957
Total towns	14	15	19	28*	79*
Nonlinked towns	5	4	3	2	2
Total linkages	11	14	23	42	174
H_t	8.5846	11.4503	21.8529	38.9590	162.5863
H_4	19.8460	22.0152	28.4336	42.0304	129.0304
H_6	25.1692	27.1692	35.1692	53.1692	163.0087
R_4**	56.73	47.99	23.14	7.31	-26.01
R_6**	65.89	57.85	37.86	26.73	0.26

* Urban centres less than one mile apart are treated as single node.
** Redundancy expressed in percentage.
*** Indices calculated by the author.

concentration, in parallel with the urban settlement distribution and economic development. In order to confirm this hypothesis, an analysis for several selected regions is repeated. This analysis covers the two most highly developed states, Perak and Selangor, and the three less developed east coast states, i.e. Kelantan, Trengganu and Pahang. The calculation is only performed for the 1957 period. See Table 14. The analysis shows that the west coast states have a far more complex network system than the east coast counterparts. In Selangor, there are 16 nodes and 11 of them are boundary nodes. The redundancy indices indicate that the Selangor network is 33.93 percent and 10.28 percent more complex than the ideal 4-link and 6-link network models respectively. However, one node in the system is not linked. In Perak, out of the 23 nodes, 16 of them are boundary nodes. The indices suggest that the network is 14.26 percent and 5.79 percent more complex than the ideal models respectively. On the other hand, the less developed east coast states have an index of 16.70 percent less complex than the 4-link ideal structure and 28.82 percent less complex than the 6-link theoretical pattern. This sharp difference between the two regions confirms the hypothesis of areal imbalance.

VI

An attempt has been made to investigate the evolution

Table 14: Entropy changes in inter-urban highway network for selected regions in Malaysia (1957).**

	Selangor	Perak	Pahang, Kelantan and Trengganu
Total towns	16	23	15
Nonlinked towns	1	0	1
Total Linkages	41	45	19
H_t	35.7289	41.9083	19.3384
H_4	26.6768	36.6768	22.0152
H_6	32.4286	44.4858	27.1692
R_4*	- 33.93	- 14.26	16.70
R_6*	- 10.18	5.79	28.82

* Redundancy expressed in percentage.
** Indices calculated by the author.

of the Malaysian urban system and the associated transport networks by means of entropy measures. The four separate experiments yield favorable results for explaining the growth process of the Malaysian urban system. The indices give a measure of the areal imbalances and further, they show precisely the rapid growth changes which have occurred since the end of World War II.

Footnotes:

1 H. Thiel, Economics and Information Theory, (Amsterdam: North-Holland, 1967); J.L. van Soest,"A Contribution of Information Theory to Sociology", Synthese, Vol. 9, 1954, pp. 265-273; H. Quastler, ed. Information Theory in Psychology, (Glencoe: The Free Press, 1955); V. Yu. Medvedkov, "Concept of Entropy in Settlement Pattern Analysis", Papers, Regional Science Association, Vol. 18, 1967, pp. 165-168; etc.

2 C.E. Shannon,"A Mathematical Theory of Communication", Bell System Technical Journal, Vol. 27, 1948, pp. 379-423, 623-656.

3 The term 'entropy' can be loosely translated from Greek as 'evolution'. As the base of the logarithm is 2 in

equation 1, the entropy value is expressed in 'binary digits', or for short, bits. When natural logarithms are used, the information unit is expressed in nits. Throughout the present study, entropy values are measured in bits.

4 More recent informations are not available. The latest census survey was held in 1957.

5 W. Christaller, Central Places in Southern Germany, trans. by C.W. Baskin (Englewood-Cliffs: Prentice-Hall, 1966); A. Lösch, The Economics of Location, trans. by W.H. Woglom (New Haven: Yale University Press, 1954).

6 L.J. King, "A Multivariate Analysis of the Spacing of Urban Settlements in the United States", Annals of the Association of American Geographers, Vol. 51, 1961, pp. 222-233.

7 M.F. Dacey, "Analysis of Central Place and Point Patterns by a Nearest Neighbor Method", Lund Studies in Geography, Series B, Human Geography, No. 24, 1962, pp. 55-75.

8 P. Haggett, Locational Analysis in Human Geography, (London: E. Arnold, 1965), pp. 92-93.

9 R.K. Semple and R.G. Golledge, "An Analysis of Entropy Changes in a Settlement Pattern Over Time", Economic Geography, Vol. 46, 1970, pp. 157-160.

10 E.J. Taaffe; R.L. Morril and P.R. Gould, "Transport Expansion in Underdeveloped Countries: A Comparative Analysis", Geagraphical Review, Vol. 53, 1963, pp. 503-529.

11 V. Yu. Medvedkov, "The Regular Component in Settlement Patterns as Shown on a Map", Soviet Geography, Vol. 8, 1967, pp. 150-168.

12 L.J. King, Statistical Analysis in Geography, (Englewood-Cliffs: Prentice-Hall, 1969), chaps. 3 and 5.

13 Ooi Jin-bee, Land, People and Economy in Malaya, (London: Longmans, 1963), pp. 135-141.

14 B.L. Gurevich, "Measures of Features-Based and Areal Differentiations and Their Use in City Services", Soviet Geography, Vol. 10, 1969, pp. 383-386.

15 The relationship may not be necessarily in linear function.

16 G.K. Zipf, Human Behaviour and the Principle of Least Effort, (New York: Hafner, 1965), p. 359.

17 C.T. Stewart, "The Size and Spacing of Cities", Geographical Review, Vol. 48, 1958, pp. 222-245; B.J.L. Berry and W.L. Garrison, "Alternate Explanations of Urban Rank-size Relationships", Annals of the Association of American Geographers, Vol. 48, 1958, pp. 83-91; E.N. Thomas, "Additional Comments on Population-Size relationships for Sets of Cities", Quantitative Geography, Northwestern Studies in Geography, 1965; M.J. Beckmann, "City Hierarchies and the Distribution of City-Size", Economic Development and Cultural Change, Vol. 9, 1958, pp. 243-248; B.J.L. Berry, "City Size Distribution and Economic Development", Economic Development and Cultural Change, Vol. 9, 1961, pp. 573-588; P.L. Fano, "Organization, City-Size Distribution and Central Places", Papers, Regional Science Association, Vol. 22, 1969, pp. 29-38; etc.

18 The rank-size rule appears as a straight line on a double-log paper.

19 B.J.L. Berry, 1961, ibid.

20 This distribution follows the rank-size rule.

21 The pattern is said to be primate when a marked gap in distribution between the leading city (or cities) and the smaller cities exists.

22 Intermediate type of distribution includes three sub-types: i) the primate cities grafted on top of a complete lower log-normal distribution, ii) smaller cities are missing from the log-normal curve, and iii) curiously 'bevelled' distribution with a log-normal middle section.

23 B.J.L. Berry, 1961, ibid.

24 L. Curry, "The Random Spatial Economy: An Explanation in Settlement Theory", Annals of the Association of American Geographers, Vol. 54, 1964, pp. 145.

25 H.A. Simon, "On a Class of Skew Distribution Functions", Biometrika, Vol. 42, 1955, pp. 425-440.

26 P.L. Fano, ibid., pp. 32-35.

27 B.J.L. Berry's finding states that the Malaysian city-size distribution is of a primate type. See B.J.L. Berry, 1961, ibid. and B.J.L. Berry, "Research Frontiers in Urban Geography" in The Study of Urbanization, ed. by P.M. Hauser and L.F. Schnore (New York: John Wiley & Sons, 1967), p. 427 footnote No. 38. The present finding coincides with the conclusion of Hamzah Sendut's study of the distribution pattern of the Malaysian cities. See Hamzah Sendut, "Town Distributions

in Malaya", unpublished paper presented to the I.G.U. conference on Southeast Asia held at Kuala Lumpur, 1962.

28 H. Thiel, ibid., pp. 290-302.

29 H. Thiel, ibid.

30 W.L. Garrison, et al. Studies of Highway Development and Geographic Change (Seattle: University of Washington, 1959); K. Kansky. Structure of Transportation Networks, The University of Chicago, Department of Geography Research Paper No. 84, 1963; P. Haggett and R.J. Chorley, Network Analysis in Geography (London: E. Arnold, 1969), etc.

31 Various ways of measuring network complexity are available in geographic literature. The most common one is the application of graph theory.

32 W. Christaller, ibid. pp. 27-83.

33 A. Lösch, ibid., pp. 124-134.

34 R.K. Semple and L.H. Wang. "A Geographical Analysis of Redundancy in Inter-Urban Transportation Links". University of Toronto, Department of Geography Discussion Paper Series No. 5, 1970.

35 Each link need not necessarily have an equal weighting. Links may be weighted where weighting is proportional to the capacity of the links and/or their length. In the present study each link was weighted as if it was of equal length and capacity as any other link.

36 The entropy associated with the unbounded hexagonal, 6-link and unbounded square, 4-link, networks is respectively $H_6 = 2.5842n$ and $H_4 = 2n$, where n is the number of nodes. For a special 2-link,linear model, $H_2 = n$.

37 Any node (town) that lies on an external linkage circuit is treated as a boundary town.

38 According to the Ministry of Transport, Malaysia, principle roads refer to the first class paved highways.

CHAPTER III

ANALYTICAL LINKS BETWEEN URBAN SYSTEM EVOLUTION AND ECONOMIC DEVELOPMENT

This chapter emphasizes the interrelationships of urban system evolution, inter-urban transportation networks and economic development in Malaysia.

Modern industrial nations in general have highly developed urban systems together with complex communication links. These links may be in the form of telecommunication, or simply highway and railroad connections. Nevertheless, in many countries, poorly developed urban systems exist, quite often dominated by one large city with limited linkages to its surrounding hinterland. This is particularly evident of countries with colonial background, where the transportation linkages were initially developed in order to exploit natural resources. Consequently, railways and highways originating in the interior simply linked the trading ports, in order to establish connections with an international oriented

market. At later stages of development this pattern often hinders uniform internal development of the country. Malaysia provides an excellent example of this form of colonial exploitation. An account of the interconnections of urban and transportation systems and economic development of Malaysia is established below based on the findings of Chapters I and II.

I

Initially the discussion brings into focus the urban settlement pattern and economic growth. The development of the spatial distribution of urban settlements is a result of a long and complex interplay of social and economic forces. According to central place theory, hexagonal pattern of places should emerge. In reality, numerous forces tend to counteract this arrangement. As a consequent, it is pertinent to investigate these forces so as to understand the orientation of the urban settlement pattern. The pattern analysis for Malaysia concludes that the arrangement of urban centres first moved from regularity toward randomness and then back toward regularity. It is suggested that this trend is related to economic development in the following way.

Urban settlements were regularly distributed along the coast initially and were associated with interior development especially tin mining and later rubber plantation. Given

a set of random locations of resource and a set of settlers, the pattern of settlement represents the intersection of these two sets. In this early stage, economic exploitation was not systematic, but occurred in a random fashion. Gradually urban settlements sprang up inland, functioning as collecting and distributing centres for the nearby mines and plantations. Their location was dependent upon the random occurrence of resources and this in turn was partly dependent upon the random decision made by miners and planters who ventured from the coast. As these interior centres became more numerous, the overall random component of the settlement pattern grew, at the expense of the uniform distribution of the coastal urban centres.

This first economic boom reached its peak just before the depression of 1930s. During and after the depression a period of consolidation took place in which economic development was stablized and foreign immigration was prohibited. A readjustment of the urban system took place, reflecting a need for internal development. This internal development led to a more comprehensive system of central places. As a result, the regular component increased to 62.1 percent in 1947 as compared to the low figure of 34.2 percent in 1931. The uniform component continued to grow due to the effect of the resettlement scheme in the 1950s. Not only did the number of urban settlements increased substantially during this period, but

also the natural central place system within the country was intensified. This new development now dominated the random component which was initially associated with the raw material exploitation.

As it was noted in Chapter I, early economic development in Malaysia was mainly externally oriented. Urban centres were found to coincide with those regions which were either accessible to the 'outside' world, like ports, or in close proximaty to the 'resource' areas, based on mining and plantation agriculture. Hence, although there was a tendency for the enlargement of the regular component in the urban settlement arrangement, this did not imply perfect uniformity. On the contrary, the arrangement possessed some local characteristics of regional concentration due to economic inequality. The second phase of the analysis thus concerned with areal differentiation and indicated that as the number of urban centres increased in the western region of the country, the characteristic of regional concentration was then intensified. This concentration was reflected by the decrease of the L index which measures areal differentiation.

The increase in urban concentration in the western region of the country presumed the necessity of a detailed analysis for this particular region in order to relate better and understand the urban settlement pattern and economic

development. It was found that, however, within this west coast region, certain states tended to have a high concentration of urban centres as well. This result could be explained by the rapid growth of Kuala Lumpur and Ipoh, the two largest cities of the mainland. These two cities caused the establishment of many smaller urban centres arround them, creating an areal imbalance in the overall arrangement pattern.

II

So far the analysis has treated cities as points and analyzed the spatial relations of these points. In order to add another dimension to this spatial analysis, the urban hierarchy was investigated, by means of an information analysis of the city-size distribution.

Berry has discussed the complex interrelationships between urbanization, type of city-size distribution and economic development.[1] Berry suggested that countries with either a condition of complex economic and political structure, a long history of urbanization, or larger than average size tended toward a lognormal distribution of city-size versus number of cities. This distribution indicated a steady state or a condition of equilibrium. On the other hand, city-size distribution tended toward primate type, dominated by one large centre.[2]

The analysis of the city-size distribution of the Malaysian system indicated that the basic pattern approached to lognormal. The pattern has not changed greatly over time. This fact was illustrated by the R_r ratios which tended toward unity for the five time periods. These results, however, did not coincide with the hypothesis postulated by Berry that in a small country like Malaysia which has also a short history of urbanization and economic development a primate distribution should exist.

There are two special features that must be taken into consideration in the Malaysian case. The first involves the existence of Singapore to the south of the federation. If Singapore had been included in the analysis, it appeared that Berry's hypothesis might have been confirmed. Economically Singapore has been an excellent out port for a large proportion of the Malaysian export trade. On the other hand, whether the lognormal distribution is a result of the complex Malaysian plural society remains to be investigated.

An additional finding of the analysis concerned the peculiar pattern for the 1957 period. The R_r ratio for this time period was greater than one, indicating that superabundant medium size centres existed in the arrangement. This was related to the resettlement scheme when a large proportion of Chinese were relocated in the nearby centres. The forced

migration gave this rather unusual index value and complicated any explanation of the 'normal' rank-size distribution.

III

The third stage in the analysis examined an additional aspect of the spatial structure of the Malaysian urban system. The distribution of urban population among states as well as within individual state was examined by utilizing the between-set and within-set entropies concept. As it has been noted in Chapter II, the total entropy of a system is the summation of the between-set entropy and the total within-set entropy of the system. Between-set entropy assesses the difference among sets (states) and within-set entropy reveals the difference among centres within each set in distribution pattern.

The analysis showed that the between-set entropy of the Malaysian urban population system has been relatively constant over time, ranging from 77 percent to 83 percent to the maximum state of equilibrium, reflecting by the the R_B ratios. This suggested that the overall pattern of arrangement has been improving over time. Urban population has been increasing in every state, though the rate and numbers were not in the same proportion. In the early stage, urban populaton was concentrated within a few states. Through time, the economy developed and thus urban population increased in every state. The rate

of increase depended upon the level of economic development. The R_B ratio was slightly higher in 1957, as a result of the substantial growth of urban population in every state under the resettlement campaign. This was identical to the sharp increase of urban centres as shown before.

The total within-set entropy, on the other hand, has increased over time since 1921. This suggested that, in general, the overall within-set difference has become less significant. At the early stage, many states had only one centre. The increasing urban centres in the latter stages divided the population among themselves within individual state, causing a proportional decrease of population shares of the larger centres within each state. This was again particularly evident during the resettlement period.

The overall within-set situation was much better than the between-set situation, as the between-set entropy increased less rapid than the total within-set entropy. However, the individual with-set entropy values for each of the eleven states indicated that distribution differed from state to state, ranging from complete concentration in Perlis and Malacca to almost complete equality in Pahang and Johore. See Table 11. The layout was partly due to the size of the states and partly due to the level of economic development within the states.

By examining the within-set entropy changes over time for the eleven states, the characteristic of the rate of development of each of these states could be revealed. Considering the four most prosperous states (Penang, Perak, Johore and Selangor) as an example, their within-set entropy changes were different.

At the early stage, Penang was dominated by a single centre, Georgetown. Since 1931 the number of towns increased. Nevertheless, the dominant position of Georgetown remained throughout the five time periods. This was shown by the low R_W ratios. Georgetown today remains the second largest city in the country.

The high indices for Perak showed not only a larger and comparatively even distributed urban population, but also an economic prosperity due to tin mining. However, there was a tendency toward inequality among the centres as the R_W ratio showed a decreasing tendency over time. This was due to the rapid growth of Ipoh at the expense of other centres.

Johore, on the other hand, possessed a most constant pattern over time. The importance of Johore has been mainly due to commercial agriculture. As economic opportunities were evenly distributed within the western half of the state where centres occurred, population among the centres grew simultaneously.

The Selangor pattern showed great departure from the three cases mentioned above. From 1911 to 1947, there were only two centres in the state. However, one of them, Kuala Lumpur, dominated the pattern. Until 1957, there were 16 centres. Nevertheless, the dominant position of Kuala Lumpur remained the same. The emergence of Kuala Lumpur as the largest city, the political, economic as well as financial centre of the country caused a severe concentration in the distribution pattern. Whether Kuala Lumpur will continue to grow into primate city is yet to be seen.

The great difference in the within-set entropy values among the states again strongly indicated the regional inequality of development of the Malaysian economy. Probably this pattern will remain for some time, as all the ten industrial estates, now in operation are located in the west coast states. Industries will continue to concentrate here and encourage an even higher level of immigration.

IV

The last stage in the analysis showed the connectivity in the urban system and related it to development in the Malaysian economy.

The main effect of transportation improvement on the

system of cities is to increase the competitive advantage of larger centres. At the same time, the more complex is the network, the more complex is the economic development. The complexity of the Malaysian transportation linkages was represented by the redundancy indices in the analysis. Two theoretical systems (i.e. the 4-link and the 6-link systems) have been suggested as the norm for comparison. The 4-link system postulated by Lösch indicated an efficient network, while the 6-link Christaller's network showed a higher level of development which was usually found in industrial regions where highly complexed linkages were needed.[3]

Malaysian railway and highway systems were investigated. Railway was an important mode of transport prior to highway development. The first north-south trunk line was completed parallel the west coast in 1910. Construction for the east coast railway was not completed until 1931. Since then no major construction occurred. As a result the analysis was only performed for the first three time periods. The redundancy indices indicated that the railway system of Malaysia has been less complexed than the two ideal patterns. During the first economic boom in the 1920s, railway transport proved to be extremely important, and most efficient. The redundancy index was lowest in 1921, showing a tendency toward the ideal structure.

The development of rail transport in place of rivers

was soon followed by the development of road transport. Ever since the 1920s, road transport has been gaining in importance at the expense of the rail transport. Road construction was rapid. During the stage of precondition for take-off, Malaysia witnessed an intensive investment of social capital on highway expansions. By 1947, the highway network was almost as complex as the 4-link ideal network. By 1957 the existing system was 26.01 percent more complex than the 4-link system and almost equal in complexity with the 6-link ideal system. The rapid increase in efficiency and complexity in the highway linkage structure was due to the great demand in economic development.

Since the economic development of the country consisted of a characteristic of areal imbalance, accompanied with a similar urban settlement distribution pattern, it should not by surprising if the same characteristic existed in transportation linkages. A closer examination of the layout of the highway system revealed this fact. See Figure 9. The spatial distribution of highway network pattern for 1957 comprised three almost isolated network graphs: i) Perak and the three states to the north, ii) Selangor and the three states to the south, and iii) the three east coast states. The first group was dominated by tin, followed by rubber and rice. The second group was concentrating in rubber planting, with tin mining as the second activity. Peasant farming, fishing and lumbering were among the chief activities for the east coast states.

A special analysis was performed for the selected regions for 1957. See Table 14. The results showed that Selangor had a most complexed network than the 4-link and 6-link ideal counterparts respectively. The well developed transportation network of Selangor resembled those in the industrial countries. The importance of Kuala Lumpur as the political centre, the existence of Port Swettenham as the chief port for central Malaysia, the rich in resources, and the longer history of development all added up for this complexity. Perak had a network which was 14.26 percent more complexed than the 4-link structure but 5.79 percent less than the 6-link system. An efficient transport linkage was necessary for tin mining. On the other hand, for the three east coast states, not only the redundancy indices were relatively low, there were few urban centres in these states as well. The significance of the indices was overshadowed. Actually this region has been less developed as reflected by the indices.

As it has been shown, economic development depended partly upon the existence of a well established transport linkage system. More routes have to be constructed in the less developed east coast region to stimulate economic change if the present inequality is to be eliminated.

V

The analysis has shown that urban system evolution was closely related to economic development in Malaysia. The spatial concentration of economic development resulted a similar pattern of urban settlement distribution and a similar pattern of transportation network structure. The west coast region has been much in advance in development than the east coast region. Unless efforts are made to uphold the less developed sector, the present pattern of spatial inequality will continue to hinder the total economic development of the country.

Footnotes:

1 Brian J.L. Berry, "City Size Distributions and Economic Development", Economic Development and Cultural Change, Vol. 9, 1961, pp. 573-588 .

2 ibid.

3 R.K. Semple and L.H. Wang, A Geographical Analysis of Redundancy in Inter-Urban Transportation Links, (Discussion Paper Series No. 5, Department of Geography, University of Toronto, 1970).

CHAPTER IV

CONCLUSION

This thesis has discussed and analyzed trends in the development of the Malaysian urban system, and the related transportation network. The trends tended to confirm that the development of the Malaysian economy conforms to Rostow's stages of economic growth.

The basis of the economic history of Malaysia has been one of external oriented involvements. As has been indicated, development was primarily due to the extensive exploitation of minerals and the establishment of commercial agriculture. As the economy was externally oriented in the beginning, development was concentrated in the most accessible west coast region, which resulted in a serious regional inequality. Associated with this regional imbalance was the creation of a plural society.

Economic development and urbanization have proceeded simultaneously in Malaysia. Today the country is one of the most rapidly urbanizing countries in Asia. This rate of urbanization was due mainly to economic forces. However, political factors, such as the resettlement scheme in the fifties, were important.

To investigate the evolution of the development in Malaysia, information theory was utilized to discover trends in the development of the urban system. Four separate analyses were performed in order to evaluate the evolution process of i) the urban settlement distribution, ii) the city-size distribution, iii) the urban population distribution, and iv) the associated inter-urban transportation linkages. It was found that the urban pattern possesses a regional concentration characteristic.

An attempt was made to establish the relationship between economic development and the evolution of the Malaysian urban system as well as between the associated transportation network.

In the initial stage, the low level of economic developments was reflected by few urban centres, a small urban population size and an extremely elementary transport network structure. However, areal differentiation was less pronounced.

During the first period of rapid economic exploitation, few restraints were placed on the orientation of exploitation. As a consequence of this land and mineral exploitation, the following phenomena occurred: i) a rapid increase of railway linkage, ii) a profound increase of random component in the urban settlement arrangement, and iii) an increasing regional concentration of urban centres. The boom reached its peak just before the depression of the 1930s.

Urban growth after the depression depended entirely upon internal population growth and rural-urban migration as immigrations from China and India were prohibited. Through time, economic development became stablized. This was reflected by the increase in the regular component of the urban settlement pattern, the expansion of the urban system as well as the improvement of the transportation network structure. The resettlement scheme has contributed substantially to the urbanization of the country.

Although overall economic development of Malaysia has been encouraging, the general tendency has been for greater regional disparity. This fact is common to most developing economies; nevertheless, it indicates that much planning still remains in order to achieve comparable levels of prosperity throughout the entire nation.

II

Results of application of information theory to problems of development geography found in this study indicate that future research may take the following directions.

First, information statistics may be utilized to construct a simulation model for development by means of a Markov chain analysis. This research would expand upon the simple Markovian approach used to analyse network complexity in the present study. In the Markovian context the average amount of information at each link in the chain could be utilized, for instance, to investigate stages of consumer behavior in the process of development.

A second approach may modify traditional measure of entropy to form measures of inequality. These inequality measures could be used to examine regional disparity in population growth and income change, both over space and through time.

Still another possibility would be the use of entropy measures to form the basis of similarity measures which would allow areas or regions of a given country to be classified. For example, economic regions could be formed such that individuals are assigned to regions with most similar entropy values.

And finally, information theory could be utilized to examine problems involving continuous flow of data. Unlike the discrete analysis performed in the present study, analysis involved economic, political, social and cultural aspects of development might better employ continuous functions found in more advanced information theory. For example, an information model utilizing differential equations could provide the dynamic basis of a simulation approach in development studies.

BIBLOGRAPHY

Abraham, W.I. and M.S. Gill, "New Measures of Economic Growth and Structural Change of the Malaysian Economy in the Post 1960 Period". Malayan Economic Review, Vol. XIV, 1969, pp. 65-79.

Adelman, I.G. "A Stochastic Analysis of the Size Distribution of Firms". Journal of the American Statistical Association, Vol. 53, 1958, pp. 893-904.

Anderson, N. ed. Urbanism and Urbanization. Leiden: E.J. Bril, 1964.

Allen, G.C. and A.G. Donnithorne. Western Enterprise in Indonesia and Malaya. London: G. Allen & Unwin, 1962.

Attneave, F. Application of Information Theory to Psychology. New York: Henry Holt, 1959.

Aziz, U.A. ed. Subdivision of Estates in MAlaya: 1951-1960. Kuala Lumpur: University of Malaya, 1962.

Baldwin, R.E. Economic Development and Growth. New York: John Wiley & Sons, 1966.

Barton, T.F. "Rural and Urban Dwellers of Southeast Asia". Journal of Geography, Vol. 64, 1965, pp. 113-122.

Beckmann, M. "City Hierarchies and the Distribution of City Size". Economic Development and Cultural Change, Vol. 6, 1958, pp. 243-248.

Beckmann, M. Location Theory. New York: Random House, 1968.

Berry, B.J.L. Geographic Aspects of the Size and Arrangement of Urban Centres. Unpublished M.A. Thesis, University of Washington, 1956.

Berry, B.J.L. "City Size Distribution and Economic Development". Economic Development and Cultural Change, Vol. 9, 1961, pp. 573-588.

Berry, B.J.L. "Cities as Systems Within Systems of Cities". Papers, The Regional Science Association, Vol. 13, 1964, pp. 147-163.

Berry, B.J.L. Geography of Market Centres and Retail Distribution. Englewood Cliffs: Prentice-Hall, 1967.

Berry, B.J.L. and W.L. Garrison. "Alternate Explanations of Urban Rank-Size Relationships". Annals of the Association of American Geographers, Vol. 48, 1958, pp. 83-91.

Berry, B.J.L. and P.J. Schwind. "Information And Entropy in Migration Flows". Geographical Analysis, Vol. 1, 1969, pp. 5-14.

Bilas, R.A. "Growth of Physical Output in the Federation of Malaya: 1930-1960". Malayan Economic Review, Vol. VII, 1963, pp. 81-90.

Bonifat'yeva L.I. "Some Characteristics of the Urban Network in the Countries of South and Southeast Asia". Soviet Geography, Vol. 7, 1966, pp. 60-70.

Breese, G. Urbanization in Newly Developing Countries. Englewood Cliffs: Prentice-Hall, 1966.

Breese, G. ed. The City in Newly Developing Countries. Englewood Cliffs: Prentice-Hall, 1969.

Brillouin, L. Science and Information Theory. 2nd ed. New York: Academic Press, 1962.

Brillouin, L. "Empirical Laws and Physical Theories: The Respective Roles of Information and Imagination" in Self Organizing Systems-1962. Edited by M.C. Yovits, G.T. Jacobi and G.D. Goldstein. Washington D.C.: Spartan, 1962.

Brown, L.A. "On the Use of Markov Chains in Movement Research". Paper prepared for the Regional Analysis Workship of the Development of Geography, University of Chicago, 1969-1970.

Buchanan, K. "Southeast Asia: Predeveloped or Underdeveloped?" Eastern Horizon, Vol. 3, 1964, pp. 6-16.

Bunting, B. "The Cultivation of Sugar Cane". Agricultural Bulletin of the Federated Malay States, Vol. 8, 1920, pp. 96-97.

Bunting, B. and J.N. Milsum. "Cultivation of Coffee in Malaya". Malayan Agricultural Journal, Vol. 18, 1930, pp. 481-482.

Cady, J.F. Southeast Asia: Its Historical Development. New York: McGraw Hill, 1964.

Caldwell, J.C. "Some Implications of Past Population Growth and Likely Future Trends in Malaya". Population Review, Vol. 7, 1963, pp. 43-52.

Caldwell, J.C. "New and Old Malaya: Aspects of Demographic Change in a High Growth Rate Multiracial Society". Population Review, Vol. 8, 1964, pp. 29-36.

Carney, D. Patterns and Mechanics of Economic Growth: A General Theoretical Approach. New York: The Antioch Press, 1967.

Champernowne, D.G. "A Model of Income Distribution". Economic Journal, Vol. 63, 1953, pp. 318-351.

Chan, K.W. "A Study of the Supply Response of Malayan Rubber Estates Between 1948-1959". Malayan Economic Review, Vol. VII, 1962, pp. 77-94.

Chang, S.D. "The Distribution and Occupation of Overseas Chinese". Geographical Review, Vol. 58, 1968, pp. 89-107.

Chatterjee, S.P. ed. Developing Countries of the World. Calcutta: 21st I.G.U. Congress, 1968.

Chisholm, M. "General Systems Theory and Geography". Institute of British Geographers, Transactions, Vol. 42, 1967, pp. 45-52.

Christaller, W. Central Places in Southern Germany. Translated by C.W. Baskin. Englewood Cliffs: Prentice-Hall, 1966.

Clark, C. "The Location of Industries and Population". The Town Planning Review, Vol. 35, 1964, pp. 195-218.

Colay, F.H. et al. eds. Underdevelopment and Economic Nationalism in Southeast Asia. Ithaca: Cornell University Press, 1969.

Corry, W. "The Present Picture in Malaysia". Royal Central Asian Journal, Vol. 52, 1965, pp. 249-259.

Courtenay, P.P. "Changing Patterns in the Tin Mining and Smelting Industry of Southeast Asia". The Journal of Tropical Geography, Vol. 25, 1967, pp. 8-17.

Curry, L. "The Random Spatial Economy: An Exploration in Settlement Theory". Annals of the Association of American Geographers, Vol. 54, 1964, pp. 138-146.

Dacey, M.F. "Two Dimensional Random Point Patterns: A Review and Interpretation". Papers, The Regional Science Association, Vol. 31, 1964, pp. 41-58.

Dacey, M.F. "A County-Seat Model for the Areal Pattern of an Urban System". Geographical Review, Vol. 56, 1966, pp. 527-542.

Davis, K. and H.H. Golden. "Urbanization and the Development of Pre-Industrial Areas". Economic Development and Cultural Change, Vol. 3, 1954, pp. 6-26.

Degani, A.H. Land Use Policy for Rubber and Rice in Malaya: 1947-1960. Unpublished M.A. Thesis, University of British Columbia, 1962.

Degani, A.H. "The Land Development Authority: An Economic Necessity?" Malayan Economic Review, Vol. IX, 1964, pp. 75-82.

Demas, W.G. The Economics of Development in Small Countries. Montréal: McGill University Press, 1965.

Dobby, E.H.G. "Resettlement Transforms Malaya". Economic Development and Cultural Change, Vol. 3, 1952, pp. 163-189.

Dobby, E.H.G. "Recent Settlement Changes in South Malaya". The Malayan Journal of Tropical Geography, Vol. 1, 1953, pp. 1-8.

Dobby, E.H.G. Southeast Asia. 5th ed. London, 1956.

Dwyer, D.J. "The Problem of In-Migration and Squatter Settlement in Asian Cities". Asian Studies, Vol. 2, 1964, pp. 145-169.

Dwyer, D.J. "Economic Development in Southeast Asia: Problems and Prospects". Journal of the Institute of Bankers, June, 1964, pp. 1-12.

Fano, P.L. "Organization, City-Size Distribution and Central Places". Papars, The Regional Science Association, Vol. 22, 1969, pp. 29-38.

Feinstein, A. Foundations of Information Theory. New York: McGraw-Hill, 1958.

Federation of Malaysia. First Malaysian Plan 1966-1970. Kuala Lumpur: Government Printer, 1965.

Fell, H. 1957 Population Censur of the Federation of Malaya, Report No. 14. Kuala Lumpur: Department of Statistics, Malaya, 1960.

Feller, W. An Introduction of Probability Theory and Its Application, Vol. I. New York: John Wiley, 1957.

Fisher, C.A. "The Malaysian Federation, Indonesia and the Philippines: A Study in Political Geography". The Geography Journal, Vol. 129, 1963, pp. 311-328.

Fisher, C.A. Southeast Asia. London: Methuen, 1964.

Fisher, C.A. "Malaysia: A Study in the Political Geography of Decolonization" in Essays in Political Geography. Edited by C.A. Fisher. London: Methuen, 1968.

Freedman, M. "The Growth of a Plural Society in Malaya". Pacific Affairs, Vol. 33, 1960, pp. 158-168.

Friedmann, J. and W. Alonso. eds. Regional Development and Planning. Cambridge: The M.I.T. Press, 1964.

Friedmann, J.R.P. "Locational Aspects of Economic Development" Land Economics, Vol. 32, 1956, pp. 213-227.

Friedmann, J.R.P. "Cities in Social Transformation". Comparative Studies in Society and History, Vol. 4, 1961, pp. 86-103.

Fryer, D.W. "The Development of Cottage and Small-Scale Industries in Malaya and in Southeast Asia". Journal of Tropical Geography, Vol. 17, 1963, pp. 99-115.

Fryer, D.W. and J.C. Jackson. "Peasant Producers or Urban Planters? The Chinese Rubber Small-Holders of Ulu Selangor". Pacific Viewpoints, Vol. 7, 1966, pp. 198-228.

Furtado, C. Development and Underdevelopment. Translated by R.W. de Aguiar and E.C. Drysdale. Berleley: University of California Press, 1967.

Garner, B. "Models of Urban Geography and Settlement Location" in Models in Geography. Edited by R.J. Chorley and P. Haggett. London: Methuen, 1967.

Gatlin, L.L. "The Information Content of DNA". Journal of Theoretical Biology, Vol. 10, 1966, pp. 281-300.

Gibbs, J.W. Elementary Principles in Statistical Mechanics. New York: Dover, 1963.

Gill, R.T. Economic Development: Past and Present. Englewood Cliffs: Prentice-Hall, 1963.

Goh, K.S. Urban Incomes and Housing. Singapore: Government Printinf Office, 1956.

Goldman, S. Information Theory. Englewood Cliffs: Prentice-Hall, 1953.

Gosling, L.A.P. "The Location of 'Problem' Areas in Rural Malaya" in Chicago University, Department of Geography Research Paper No. 62, 1960, pp. 124-142.

Gurevich, B.L. "Measures of Feature-Based and Areal Differentiations and Their Use in City Services", Soviet Geography, Vol. 10, 1969, pp. 383-386.

Gurevich, B.L. "Geographical Differentiation and Its Measures in a Discrete System". Soviet Geography, Vol. 10, 1969, pp. 387-413.

Gurevich, B.L. "An Operator of Smoothing and Measures of Homogeneity of Linearly Ordered Geographical Structures". Soviet Geography, Vol. 10, 1969, pp. 413-420.

Haggett, P. Locational Analysis in Human Geography. London: Edward Arnold, 1965.

Haggett, P. and R.J. Chorley. Network Analysis in Geography. London: Edward Arnold, 1969.

Hanna, W.A. Sequel to Colonization: The 1957-1960 Foundations for Malaysia. New York: American Univ. Field Staff, 1965.

Harrison, B. Southeast Asia. London: Macmilan, 1966.

Hartley, R.V.L. "Transmission of Information". Bell System Technical Journal, Vol. 7, 1928, pp. 535-563.

Harvey, D. Ecplanation in Geography. London: Edward Arnold, 1969.

Hauser, P.M. ed. Urbanization in Asia and the Far East. Calcutta: UNESCO Reaearch Centre, 1957.

Hauser, P.M. and L.F. Schnore, eds. The Study of Urbanization. New York: John Wiley & Sons, 1967.

Ho, A.K. The Far East in World Trade: Development and Growth Since 1945. New York: F.A. Praeger, 1967.

Hodder, B.W. Man in Malaya. London: London University Press, 1959.

Hodder, B.W. Economic Development in the Tropics. London; Methuen, 1968.

Hooper, J.W. and H. Thiel. The Information Approach to the Measurement of Income Inequality. Report 6501 to the Econometric Institute pf the Netherlands School of Economics, 1965.

Hudson, J.C. "Pattern Recognition in Empirical Map Analysis". Journal of Regional Science, Vol. 9, 1969, pp. 189-199.

Hunter, G. Southeast Asia: Race, Culture and Nation. New York: Oxford University Press, 1966.

Jackson, J.C. "Population Changes in Selangor State, 1850-1891". The Journal of Tropical Geography, Vol. 19, 1964, pp. 42-57.

Jackson, J.C. Planters and Speculators: Chinese and European Agricultural Entreprise in Malaya: 1788-1921. Kuala Lumpur: University of Malaya Press, 1968.

Jefferson, M. "The Law of the Primate City". Geographical Review, Vol. 19, 1939, pp. 226-232.

Jones, G.W. "The Employment characteristics of Small Towns in Malaya". Malayan Economic Review, Vol. 10, 1965, pp. 44-72.

Jones, G.W. "Malaysia's Future Population". Pacific Viewpoint, Vol. 6, 1965, pp. 39-51.

Kansky, K. Structure of Transportation Networks. University of Chicago, Department of Geography Research Paper No. 84, 1963.

Keeble, D.E. "Models of Economic Development" in Models in Geography. Edited by R.J. Chorley and P. Haggett. London: Methuen, 1967.

Keyfitz, N. "The Ecology of Indonisian Cities". The American Journal of Sociology, Vol. 66, 1961, pp. 348-354.

Khinchin, A.I. Mathematical Foundations of Information Theory. New York: Dover, 1957.

Kinloch, R.F. "The Growth of Electric Power Production in Ma;aya". Annals of the Association of American Geographers, Vol. 56, 1966, pp. 220-235.

King, L.J. "A Multivariate Analysis of the Spacing of Urban Settlements in the United States". Annals of the Association of American Geographers, Vol. 51, 1961, pp. 222-233.

King, L.J. Statistical Analysis in Geography. Englewood Cliffs: Prentice-Hall, 1969.

Kolmogorov, A.N. Foundations of the Theory of Probability. Translated by N. Morrison. New York: Chelsea, 1956.

Koopman, B.O. and G.E. Kimball. "Information Theory" in Notes on Operation Research 1959. Assembled by the Operations Research Centre, M.I.T. Cambridege: The Technological Press, 1959.

Kullback, S. Information Theory and Statistics. New York: Johm Wiley & Sons, 1959.

Lampard, E.E. "The Evolving System of Cities in the United States: Urbanization and Economic Development" in Issues in Urban Economics. Edited by H.S. Perloff and L. Wingo, Jr. Baltimore: The Johns Hopkins Press, 1968.

Lee, S.A. "Financial Planning of Investment in Malaysia". Malayan Economic Review, Vol. 14, 1969, pp. 48-64.

Leopold, L.B. and W.B. Langbein. The Concept of Entropy in Landscape Evolution. Prof. Paper, 500A, U.S. Geological Survey, 1962.

Lewis, W.A. Theory of Economic Growth. London: G. Allen & Unwin, 1959.

Lösch, A. The Economics of Location. Translated by W.H. Woglom and W.F. Stolper. New Haven: Yale University Press, 1954.

Ma, R.and P.S. You. "The Economic Characteristics of the Population of the Federation of Malaya, 1957". Malayan Economic Review, Vol. 5, 1960, pp. 10-45.

Manning, N. "Southeast Asian Society: Dual or Multiple". Journal of Asian Studies, Vol. 23, 1964, pp. 420-422.

Martin, G.J. "'The Law of Primate Cities' Reexamined". The Journal of Geography, Vol. 60, 1961, pp. 165-172.

McGee, T.G. "The Cultural Role of Cities: A Case Study of Kuala Lumpur". The Journal of Tropical Geography, Vol. 17, 1963, pp. 178-196.

McGee, T.G. "An Aspect of the Urban Geography of Malaysia: The Movement of Malays to Kuala Lumpur City". Record, New Zealand Geographical Society, No. 39, 1965, pp. 7-9.

McGee, T.G. The Southeast Asian City. New York: F.A. Praeger, 1967.

McHale, T.R. "The Competition Between Synthetic And Natural Rubber". Malayan Economic Review, Vol. 6, 1961, 1961, pp. 23-31.

McHale, T.R. "Natural Rubber and Malaysian Economic Development". Malayan Economic Review, Vol. 10, 1965, No. 1, pp. 16-43.

McHale, T.R. "Rubber Smallholdings in Malaya; Their Changing Nature, Role and Prospects". Malayan Economic Review, Vol. 10, No. 2, 1965, pp. 35-48.

McTaggart, W.D. "The Distribution of Ethnic Groups in Malaya". The Journal of Tropical Geography, Vol. 26, 1968, pp. 69-81.

Medvedkov, Yu. V. "Application of Mathematics to Some Problems in Economic Geography". Soviet Geography, Vol. 5, 1964, pp. 36-53.

Medvodkov, Yu. V. "The Regular Component in Settlement Patterns as Shown on a Map". Soviet Geography, Vol. 8, 1967, pp. 150-168.

Medvedkov, Yu. V. "Concept of Entropy in Settlement Pattern Analysis". Papers, The Regional Science Association, Vol. 18, 1967, pp. 165-168.

Metha, S.K. "Some Demographic and Economic Correlates of Primate Cities: A Case for Revaluation". Demography, Vol. 1, 1964, pp. 136-147.

Middleton, D. An Introduction to Statistical Communication Theory. New York: McGraw-Hill, 1960.

Missen, G.J. "The Malay Village Two Case Studies of Peasant Economy" in New Viewpoints in Economic Geography, by J. Rutherford, M.I. Logan and G.J. Missen. Sydney: Martindale, 1966, pp. 115-136.

Missen, G.J. "Manufacturing in Malaya: A Survey with Special Reference to the Impact of Political Changes" in New Viewpoints in Economic Geography, by J. Rutherford, M.I. Logan and G.J. Missen. Sydney: Martindale, 1966, pp. 296-313.

Morrill, R.L. "The Development of Spatial Distribution of Towns in Sweden: A Historical Predictive Approach". Annals of the Association of American Geographers, Vol. 53, 1963, pp. 1-14.

Myint, H. The Economics of the Developing Countries. New York: F.A. Praeger, 1964.

Myrdal, G. Economic Theory and Underdeveloped Regions. London: Methuen, 1965.

Neville, W. "Singapore: Ethnic Diversity and It's Implications". Annals of the Association of American Geographers, Vol. 56, 1966, pp. 236-253.

North, D. "Locational Theory and Regional Economic Growth". Journal of Political Economy, Vol. LXIII, 1955, pp. 243-255.

Ooi, J.-B. "The Rubber Industry of the Federation of Malaya". The Journal of Tropical Geography, vol. 15, 1961, pp. 46-65.

Ooi, J.-B. Man, People and Economy in Malaya. London: Longmans, 1963.

O'reilly, J.M.H. "An Assessment of the malayan Tin Mining Industry of the Twentieth Century". The Journal of Tropical Geography, Vol. 17, 1963, pp. 72-79.

Parr, J.B. "City Hierarchies and the Distribution of City Size: A Reconsideration of Beckmann's Contribution". Journal of Regional Science, Vol. 9, 1969, pp. 239-253.

Pielou, E.C. "The Measurement of Diversity in Different Types of Biological Collection". Journal of Theoretical Biology, Vol. 13, 1966, pp. 131-144.

Pitts, F.R. ed. Urban Systems and Economic Development. Papers and proceedings of the Conference on Urban Systems Research in Underdeveloped And Advanced Economics, University of Oregon, School of Business Administration, 1962.

Puthucheary, J.J. Ownership and Control in the Malayan Economy. Singapore: Eastern Universities Press, 1960.

Quastler, H. ed. Information Theory in Biology. Urbana: University of Illinois Press, 1953.

Quastler, H. ed. Information theory in Psychology. Glencoe: The Free Press, 1955.

Quastler, H. "General Principles of Systems Analysis" in Theoretical and Mathematical Biology. Edited by T.H. Waterman and H.J. Morowitz. New York, 1965.

Rashevsky, N. "Contribution to the Theory of Human Relations: Outline of a Mathematical Theory of the Size of Cities". Psychometrica, Vol. 8, 1943, pp. 87-90.

Rostow, W.W. The Stages of Economic Growth. London: Cambridge University Press, 1962.

Sandhu, K.S. "The Population of Malaya: Some Changes in the Pattern of Distribution Between 1947 and 1957". The Journal of Tropical Geography, Vol. 15, 1961, pp. 82-96.

Sandhu, K.S. "Chinese Colonization of Malacca". The Journal of Tropical Geography, Vol. 15, 1961, pp. 1-26.

Sandhu, K.S. "Emergency Resettlement in Malaya". The Journal of Tropical Geography, Vol. 18, 1964, pp. 157-183.

Sandhu, K.S. "Indian in the Modern Malayan Economy". Indian Quaterly, Vol. 23, No. 2, 1967, pp. 106-126.

Schnore, L.F. "The Statistical Measurement of Urbanization and Economic Development". Land Economics, Vol. 37, 1961, pp. 229-245.

Schnore, L.F. "Urbanization and Economic Development: The Demographic Contribution". The American Journal of Economics and Sociology, Vol. 23, No. 1, 1964, pp. 37-48.

Semple, R.K. and R.G. Golledge. "An Analysis of Entropy Changes in a Settlemnt Pattern Over Time". Economic Geography, Vol. 46, No. 2, 1970, pp. 157-160.

Semple, R.K. and L.H. Wang. "A Geographical Analysis of Redundancy in Inter-Urban Transportation Links". University of Toronto, Department of Geography Discussion Paper Series No. 5, 1970.

Semple, R.K. and L.H. Wang. "A Geographical Analysis of Changing Redundancy in Inter-Urban Transportation Links". Geografiska Annaler, Forthcoming, 1971.

Sendut, H. "Problems of Rural-Urban Migration". Community Development Bulletin, Vol. 7, No. 3, 1961, pp. 86-90.

Sendut, H. "Rasah: A Resettlement Village in Malaya". Asian Survey, Vol. 1, No. 9, 1961, pp. 21-26.

Sendut, H. "Town Distribution in Malaya". Unpublished paper presented to the I.G.U. regional Conference on Southeast Asia held at Kuala Lumpur, 1962.

Sendut, H. "The Resettlement Villages in Malaya". Geography, Vol. 47, 1962, pp. 41-46.

Sendut, H. "Patterns of Urbanization in Malaya". The Journal of Tropical Geography, Vol. 16, 1962, pp. 114-136.

Sendut, H. "The Structure of Kuala Lumpur". The Town Planning Review, Vol. 36, 1965, pp. 125-138.

Sendut, H. "Contemporary Urbanization in Malaysia". Asian Survey, Vol. 6, No. 9, 1966, pp. 484-491.

Sendut, H. "Planning Resettlement Villages in Malaya". Planning Outlook, N.S. Vol. 1, 1966, pp. 58-70.

Shannon, C.E. "A Mathematical Theory of Communication". Bell System Technical Journal, Vol. 27, 1948, pp. 379-423, 623-656.

Shrestha, M. A Dynamic Analysis of Rural Market Area. Unpublished Ph.D. Dissertation, Department of Geography, University of Iowa, 1969.

Silcock, T.H. ed. Readings in Malayan Economics. Singapore: Eastern Universities Press, 1961.

Silcock, T.H. and E.K. Fisk. The Political Economy of Independent Malaya. Caneberra: Australian National University, 1963.

Simon, H.A. "On a Class of Skew Distribution Functions". Biometrika, Vol. 42, 1955, pp. 425-440.

Simms, G. "Malayan Tin: A Rich Endowment". Optima, Vol. 18, No. 2, 1968, pp. 74-79.

Singh, S. "An Evaluation of Three Land Development Schemes in Malaysia". Malayan Economic Review, Vol. 8, No. 1, 1968, pp. 89-100.

Sjoberg, G. The Preindustrial City, Past and Present. Glencoe: The Free Press, 1960.

Smelser, N.J. and S.M. Lipset. Social Structure and Mobility in Economic Development. Chicago: Aldine, 1966.

Snodgrass, D.R. "Capital Stock and Malayan Economic Growth: A Preliminary Analysis". Malayan Economic Review, Vol. 11, No. 2, 1966, pp. 63-85.

Soest, J.L. van. "A Contribution of Information Theory to Sociology". Synthese, Vol. 9, 1954, pp. 265-173.

Sovani, N.V. "The Analysis of 'Over-Urbainzation'". Economic Development and Cultural Change, Vol. 7, No. 2, 1964, pp. 113-122.

Spencer, J.E. The Cultural Factor in 'Underdevelopment': The Case of Malaya. The University of Chicago, Department of Geography Research Paper No. 62, 1960, pp. 35-48.

Stenton, J.E. "Rural Development in Malaysia". Canadian Geographical Review, Vol. 48, 1958, pp. 222-245.

Stone, K.H. "The Development of a Focus for the Geography of Settlement". Economic Geography, Vol. 41, 1965, pp. 346-255.

Swettenham, F. British Malaya. London: G. Allen & Unwin, 1948.

Taaffee, E.J.; R.L. Morrill and P.R. Gould. "Transport Expansion in Underdeveloped Countries: A Comparative Analysis". Geographical Review, Vol. 53, 1963, pp. 503-529.

Theil, H. Economics and Information Theory. Amsterdam: North-Holland, 1967.

Thomas, E.N. "Additional Comments on population Size Relationships for Sets of Cities" in Quantitative Geography. Edited by W.L. Garrison and D. Marble. Evanston: Northwestern University Press, 1967.

Trengonning, K.G. A History of Modern Malaya. New York: David McKay, 1964.

Ullman, E.L. "Regional Development and the Geography of Concentration". Papers and Proceeding, The Regional Science Association, Vol. 4, 1958, pp. 179-198.

UNESCO. Urbanization in Asia and the Far East. Proceedings of the joint UN/UNESCO Seminar, Bangkok, 1956.

von Foerster, H. "On Self-organizing Systems and Their Environments" in Self-Organizing Systems. Edited by M.C. Yovitts and S. Cameron. Oxford; Pergamon, 1960.

Walker, R. "The Problem of the Underdeveloped Countries". Australian Journal of Science, Vol. 26, 1964, pp. 335-342.

Ward, M.W. "Port Swettenham and Its Hinterland, 1900-1960". The Journal of Tropical Geography, Vol. 19, 1964, pp. 69-78.

Ward, M.W. "Major Port Hinterland in Malaya". Tijdschrift voor Economische en Sociale Geografie, Vol. 57, 1966, pp. 242-251.

Ward, M.W. "A Review of Problems and Achievements in the Economjc Development of Independent Malaya". Economic Geography, Vol. 44, 1968, pp. 326-342.

Ward, R.J. ed. The Challenge of Development Theory and Practice. Chicago: Aldine, 1967.

Wheatley, P. "Notes on the Historical Geography of the Malay Peninsula". Centre for Southeast Asia Studies, University of California, Berkeley, 1962. (Mimeographed).

Wheelwright, E.L. Industrialization in Malaysia. New York: Cambridge University Press, 1965.

Wilson, A.G. "A Statistical Theory of Spatial Distribution Models". Transportation Research, Vol. 1, 1967, pp. 253-269.

Wilson, A.G. "Notes on Some Concepts in Social Physics". Papers, The Regional Science Association, Vol. 22, 1969, pp. 159-193.

Wilson, A.G. "The Use of Entropy Maximizing Models in the Theory of Trip Distribution, Mode Split and Route Split". Journal of Transport Economics and Policy, Vol. 3, 1969, pp. 108-126.

Wilson, A.G. "Entropy in Urban and Regional Modelling". Centre For Environmental Sturies, London; Working Paper CES WP 26, January 1969.

Wong, L.K. "The Economic History of Malaysia". The Journal of Economic History, Vol. 25, 1965, pp. 244-262.

Yip, Y.H. "Malaya Under the Pre-War International Tin Agreement". Malayan Economic Review, Vol. 10, No. 1, 1963, pp. 81-97.

Yip, Y.H. "Recent Changes in the Ownership and Control of Locally Incoporated Tin Dridging Companies in Malaya". Malayan Economic Review, Vol. 8, No.1, 1968, pp. 70-88.

Zipf, G.K. Human Behaviour and the Principle of Least Effort. New York: Hafner, 1965.