A Study on the Road Planning in Hokkaido

Hideo IGARASHI*
Hirozo OGAWA*

Abstract

This study was undertaken to provide an answer to the question as to how many roads are required in Hokkaido. The authors made thirteen series of correlation formulae by using data available at prefectural levels of Japan for 1960.

It was revealed that the following formulae provided the most satisfactory answer to the question.

The proposed formulae are

$$L = a(I/P) \cdot A + b \qquad \text{(for trunk roads)}$$

$$L = a(I/P) \cdot A' + b \qquad \text{(for branch roads)}$$

where

L: length of road, I: prefectural domestic production, P: population, A: area, A': inhabitable area, a, b: constants are determined by the classification of the roads.

Next, applications to determine the fitness of these formulae for 1965 based on data for that year.

From a viewpoint of trunk roads, the twelfth formula was found to be appropriate. Also for the planning of a freeway network, some calculations including railways and the results were found to be satisfactory.

1. Purpose of this study

In this chapter, an attempt was made to estimate how many roads should be expanded in Hokkaido. Such studies as expansion of roads by means of road density have been under way since 1950 when Masumi Fujii presented a paper entitled *On the Land Coefficient and the Density of Roads*[1] in the Journal of the Society of Civil Engineers. Later, the society presented a series of lectures on roads in 1952. Nobutaka Katahira mentions road density in the Journal Vol. 37 No. 5[2].

At the First Road Conference of Japan, Mitsuma Onaka[3], Isamu Imai[4], Masaaki Seto[5], Bunjiro Miura[6], Akio Okuda and Yoshitomo Oguri[7] gave reports concernig road density. At the Second Conference, reports on this subject were given by Isamu Imai and Yukichi Yamada[8]; at the Third Conference, by Hideo Tsujikawa[9], Yasushi Endo, Noboru Miura[10] and Yoshi Nanpo[11].

Some of those reports seem somewhat inconsistent in their style of expressions as well as in the selection of the raw material; some are on the density of roads of the world based upon data from each nation, some are from Japan based on prefectural data. Others are of a specific prefecture based on city, town and village. Still others are on the density of roads of Japan based on areal blocks

* Department of Civil Engineering, Faculty of Engineering, Hokkaido University, Sapporo, Japan.

which consist of several prefectures chosen at random. Also there are some unreliable papers as far as their management of data, ambiguity of the resourses and the epoch are concerned. Some statements remain too abstract. Nevertheless we may obtain good suggestions from all of these papers to improve our thinking on the present theme.

In this section, the essence of theories proposed on the density of roads will be discussed as a first step.

The notations are as follows:

L: Length of roads
A: Area
A': Inhabitable area, excluding "the whole area" namely "mountains, forests, lakes and other impossible-to-dwell areas"
1 : L/A=density of roads
P: Population
I : Income
V: Number of vehicles
$a, b, m, n,$: Coefficients or indexes

$$\frac{L}{A}=a\left(\frac{P}{A}\right)^b$$

This was adopted by Seto and Nanpo.

From the above the following may be led forth,

$$\frac{L}{A}=a\left(\frac{P}{A}\right)^{\frac{1}{2}}$$

This was adopted by Fujii, Katahira, and Miura.

According to Okuda and Oguri, the product of density of population by the income standard is interrelated with the density of roads, thus they tried to formulate the interrelation.

However, the results remained without a practical coefficient.

The following expression was used,

$$\frac{P}{A}\cdot\frac{I}{P}=a\left(\frac{L}{A}\right)^b$$

$$\frac{L}{A}=aV^{\frac{1}{4}}$$

This formula appears in one of Katahira's papers.

Suggested by the above formula, Endo and Miura deduced the following:

$$\frac{L}{A}=a\left(\frac{I}{A}\cdot V\right)^{\frac{1}{8}}$$

According to Imai, the whole area is divided into mountanious areas and flat areas, thus he set forth the following formula,

$$\frac{L}{A}=a\left(\frac{P}{A}\right)^b$$

in the flat area $0<b<1$

in the mountanious area $b=1$

The report presented by Imai and Yamada at the Second Road Conference gives the ratio of expansion of the trunk roads, which is related to $\frac{P}{A}$ and $\frac{I}{A}$.

$$L = A^m P^n$$

was introduced by Tsujikawa. All these formulae with some individualities are, as a whole, concerned with the relations between L, A, P, I, V, and their variations. Statistical management with these indexes will indicate how many roads there should be in a certain area at a certain period.

Needless to say, the statistical management should be applied only to natural phenomena and not to an artificial state of affairs.

Roads, though man-made, have causal relations with population, income, area, etc., thus these causal relations are worthy of consideration. This consideration is fundamentally based upon the concept that human behavior as well as those of animals are subject to the law of nature, In this sense, statistical management in regional planning has some significance; e. g. how many roads are required at a certain period in a certain region by 1980 in Hokkaido.

2. The Methods and the Data

As it has already been mentioned in Section 1, a statistical method will be adopted. That is to say, various combinations of length of roads per area, namely the density of roads, and some indexes which seem to be related to it, will be used to determine whether any correlations exist among the combinations. And if such correlation exist, they may be formulated as linear lines or curves. These will indicate the requisite length of roads in a given region at a certain period.

The following data were used.

Area: October 1, 1960. Statistics Bureau of the Prime Minister's Office.
Inhabitable Area: the same as the above.
Population: October 1, 1960, and of 1965.
Economic Planning Board.
Production: the same as above.
Number of Vehicles: Annual Report for 1961, and for 1966.
Ministry of Construction.
Road: March 31, 1960. The same as above.
Railway: 1959. Annual Report on Statistics of National Railways.

The principles of the management of these data are as follows.

(1) Hokkaido was excluded from the data; the nature of the data of Hokkaido are so different from that of other prefectures that they may not be compared with the others on the same level. The differences consist of such facts as the largeness of area, the history of the development, its population, etc. The surface area of Hokkaido is twelve times as large as that of other prefectures. Hokkaido has a history of development of only a hundred years while even the least developed districts of the remainder of Japan has more than ten centuries of developmental history.

Yet the population of Hokkaido is only two and half times that of other prefectures on the average.

Excluding Hokkaido, the average area of a prefecture is 6,470 km^2; the smallest

prefecture Osaka is a mere 28% of the average, and the largest one Iwate, occupies 236% of the average, while Hokkaido with 1213% of the average, can not be equally treated. Since highways are so closely connected to the problems surrounding them, the theory on the requisite roads should be deduced from data excluding Hokkaido; in other words, for Hokkaido to become as prosperous as other prefectures, how many roads are required. This is by no means planning based on what Hokkaido is today, but upon what it should be.
(2) The forty five prefectures which are all prefectures of Japan except Hokkaido were not handled indiscriminately. In the regional study, the summing up or dividing into of prefectures without much thought happens to result in a collection of statistics which hardly reflect the true state of affairs. Thus, we believe that the credible unit at present is a prefecture.

Prefectures are dealt with as units in books of statistics. We are of the opinion that a prefecture is not only a unit of administration but also a unit people and communities or society. Such a unit seems to have been broken down hither to in and around large urban communities, however, the prefectures actually as a whole form a unit of social, cultural and in a sense an economical unit of human life. Thus, prefectures are used as a unit in this study.

3. The Correlation formulae

Followed by the preparations mentioned in Section 2, indexes such as area, population, etc., and nine classifications of roads such as national roads, prefectural roads, etc. The expressions shown on the tables were aquired from those data.

For formulae expressed with linear lines, the correlation coefficient r is indicated; for formulae expressed with exponential curves, these are expressed with logarithms, using the tentative correlation coefficient $\bar{r}$.

Which formula on the table best expresses the status-quo? Which formula, in other words, is most suitable and accurate in order that we may obtain the quantities of the requisite roads at a certain period in a certain prefecture? The following should be noted for deriving the answer.
(1) Among 45 prefectures, there are some prefectures which are especially greatly influenced by others. And if the influential factors of other prefectures are ignored, the results will not give a true picture. Formulae which give varying results are not suitable for deducing the quantities of requisite roads at a certain period in a certain area.

As for the formulae expressed with exponential curves, the results will become completely different if some prefectures with the large values are neglected, and some of which will not show the true correlations. As a result, these require different handling.
(2) The same applies to some formulae expressed with linear lines.
(3) Concerning a new formula expressed with a linear line, aquired by excluding the factors of the influential prefectures: although it may show high values of correlation coefficients, it may not still be very credible if this proposed formula and the former one which includes the factors of influential prefectures, show defferent tendencies. In other words, writing the two formulae as

$Y=aX+b$ (in the case of 45 prefectures)

$Y=a'X+b'$ (in the case of 39 prefectures)

TABLE 1. Correlation Formulae between the Density of Roads and Indexes (in the case of 45 prefectures)

X \ l	railways l_0	national roads l_1	national roads + first class prefectural roads $l_6(=l_1+l_2)$	national roads + prefectural roads $l_7(=l_1+l_4)$	prefectural roads: first class prefectural roads l_2	prefectural roads: second class prefectural roads l_3	prefectural roads: summings $l_4(=l_2+l_3)$	county roads l_5	national roads + prefectural roads + county roads $(l_8=l_1+l_4+l_5)$
(1) P/A $\left(\frac{\text{person}}{\text{km}^2}\right)$	$l_0=8.580x^{0.3359}$ $\bar{r}=0.6818$	$l_1=2.305x^{0.2097}$ $\bar{r}=0.6039$	$l_6=2.307x^{0.3555}$ $\bar{r}=0.9125$	$l_7=44.15x^{0.4291}$ $\bar{r}=0.8822$	$l_2=6.850x^{0.4617}$ $\bar{r}=0.8615$	$l_3=25.140x^{0.4515}$ $\bar{r}=0.8036$	$l_4=31.13x^{0.4601}$ $\bar{r}=0.8583$	$l_5=11.93x^{0.5358}$ $\bar{r}=0.7108$	$l_8=159.4x^{0.5198}$ $\bar{r}=0.7568$
(2) $\sqrt{P/A}$ $\left(\frac{\text{person}}{\text{m}^2}\right)$	$l_0=1.7465x+29.4265$ $r=0.7200$	$l_1=1.0547x+58.6914$ $r=0.5236$	$l_6=5.1239x-85.1935$ $r=0.8966$	$l_7=25.4090x+72.4237$ $r=0.8701$	$l_2=4.0692x+26.5004$ $r=0.9024$	$l_3=20.2922x-12.9441$ $r=0.8756$	$l_4=24.3612x+13.5598$ $\gamma=0.8746$	$l_5=116.4024x+815.6423$ $r=0.6145$	$l_8=141.8184x+887.8913$ $r=0.6879$
(3) I/A $\left(\frac{\text{million yen}}{\text{km}^2}\right)$	$l_0=23.15x^{0.2631}$ $\bar{r}=0.6635$	$l_1=4.204x^{0.1697}$ $\bar{r}=0.6635$	$l_6=1.8192x^{0.2783}$ $\bar{r}=0.8900$	$l_7=154.8x^{0.3397}$ $\bar{r}=0.8701$	$l_2=27.36x^{0.3554}$ $\bar{r}=0.8430$	$l_3=93.67x^{0.3589}$ $\bar{r}=0.7958$	$l_4=12.01x^{0.3627}$ $\bar{r}=0.8430$	$l_5=589.5x^{0.4154}$ $\bar{r}=0.6868$	$l_8=748.4x^{0.4038}$ $\bar{r}=0.7325$
(4) I/P $\left(\frac{\text{thousand yen}}{\text{person}}\right)$	$l_0=0.5140x+3.6492$ $r=0.6036$	$l_1=0.5140x+34.7735$ $r=0.5431$	$l_6=1.5344x+6.5773$ $r=0.7649$	$l_7=7.3754x-290.9197$ $r=0.7356$	$l_2=1.1504x-282.023$ $r=0.7266$	$l_3=5.8462x-298.1373$ $r=0.6794$	$l_4=6.9965x-326.3246$ $r=0.7155$	$l_5=30.1209x-432.9169$ $r=0.4529$	$l_8=37.5015x-724.4776$ $r=0.5181$
(5) V/A $\left(\frac{\text{thousand vehicles}}{\text{km}^2}\right)$	$l_0=35.89x^{0.2250}$ $\bar{r}=0.5938$	$l_1=54.28x^{0.1582}$ $\bar{r}=0.5924$	$l_6=99.79x^{0.2619}$ $\bar{r}=0.8738$	$l_7=25.52x^{0.3225}$ $\bar{r}=0.8619$	$l_2=46.57x^{0.3332}$ $\bar{r}=0.8082$	$l_3=15.80x^{0.3433}$ $\bar{r}=0.7943$	$l_4=20.46x^{0.3450}$ $\bar{r}=0.8365$	$l_5=101.00x^{0.4291}$ $\bar{r}=0.7400$	$l_8=1.2750x^{0.4128}$ $\bar{r}=0.7813$
(6) V (thousand vehicles)	$l_0=0.1566x+51.1591$ $r=0.5523$	$l_1=0.0771x+73.0208$ $r=0.3274$	$l_6=0.4922x+146.6915$ $r=0.7369$	$l_7=2.9838x+339.9373$ $r=0.8939$	$l_2=0.4159x+73.6121$ $r=0.7885$	$l_3=2.4917x+193.1900$ $r=0.8698$	$l_4=2.9070x+266.8489$ $r=0.5490$	$l_5=12.1566x+2145.4792$ $r=0.5490$	$l_8=15.1411x+2485.3177$ $r=0.6283$
(7) $4\sqrt{V}$ (vehicle)	$l_0=4.4104x-3.8644$ $r=0.5571$	$l_1=2.3319x+43.5350$ $r=0.3456$	$l_6=13.4318x+19.8266$ $r=0.7202$	$l_7=68.2439x-47.28311$ $r=0.7317$	$l_2=11.1007x-63.3734$ $r=0.7542$	$l_3=54.8121x-453.0029$ $r=0.6852$	$l_4=65.9116x-516.3583$ $r=0.7250$	$l_5=409.3261x-3125.1332$ $r=0.6620$	$l_8=477.5701x-3597.9645$ $r=0.7097$
(8) $8\sqrt{(I/A)\cdot V}$ $\left(\frac{\text{thousand yen vehicle}}{\text{km}^2}\right)$	$l_0=4.8339x-7.872$ $r=0.6765$	$l_1=2.9611x+35.9799$ $r=0.4991$	$l_6=14.4609x-26.2179$ $r=0.8590$	$r_7=70.4953x-462.7155$ $r=0.8374$	$l_2=11.5002x-62.2044$ $r=0.8657$	$l_3=56.0369x-436.5318$ $r=0.7761$	$l_4=67.5336x-498.6872$ $r=0.8230$	$l_5=368.3312x-2284.8741$ $r=0.6600$	$l_8=438.8265x-2747.5900$ $r=0.7225$

l: density of roads, A: area, A': inhabitable area, P: population, I: prefectural domestic product, V: number of vehicles
r: correlation coefficient, $\bar{r}$: correlation coefficient of formulae with logarithms.

TABLE 2. Correlation Formulae between the Length of Roads and Indexes
(in the case of 45 prefectures)

L / X	railways L_0	national roads L_1	national roads + first class prefectural roads $L_6(=L_1+L_2)$	national roads + prefectural roads $L_7(=L_1+L_4)$	prefectural roads: first class prefectural roads L_2	prefectural roads: second class prefectural roads L_3	prefectural roads: summings $L_4(=L_2+L_3)$	county roads L_5	national roads + prefectural roads + county roads $L_8(=L_1+L_4+L_5)$
(9) P (thousand persons)	$L_0=0.0001x+3.3883$ $r=0.1233$	$L_1=0.000085x+4.7761$ $r=0.0791$	$L_6=0.00034x+9.6706$ $r=0.1557$	$L_7=0.0028x+24.6535$ $r=0.4331$	$L_2=0.00043x+4.8946$ $r=0.3049$	$L_3=0.0025x+14.9828$ $r=0.5103$	$L=_40.0029x+19.8774$ $r=0.4935$	$L_5=0.0186x+134.6828$ $r=0.2557$	$L_8=0.0214x+159.3363$ $r=0.2785$
(10) $(I/P)\sqrt{A\cdot P}$ $\left(\frac{10^5\text{ yen/person}}{\times\sqrt{10^8\text{ km}^2\cdot\text{person}}}\right)$	$L_0=0.1260x+2.1661$ $r=0.4275$	$L_1=0.0919x+3.5206$ $r=0.3225$	$L_6=0.3007x+6.7765$ $r=0.5205$	$L_7=1.1760x+16.2438$ $r=0.6861$	$L_2=0.2088x+3.2561$ $r=0.5658$	$L_3=0.8750x+9.4705$ $r=0.6774$	$L_4=1.0839x+12.7257$ $r=0.6982$	$L_5=8.6376x+68.8714$ $r=0.4491$	$L_8=9.8146x+85.1035$ $r=0.4813$
(11) $(I/P)\sqrt{A'P}$ $\left(\frac{10^5\text{ yen/pepson}}{\times\sqrt{10^8\text{ km}^2\cdot\text{person}}}\right)$	$L_0=0.0972x+2.9651$ $r=0.2506$	$L_1=0.0328x+4.3751$ $r=0.0875$	$L_6=0.2557x+8.5165$ $r=0.3359$	$L_7=1.1979x+21.6369$ $r=0.4308$	$L_2=0.2139x+4.2055$ $r=0.4401$	$L_3=0.9422x+13.1208$ $r=0.5540$	$L_4=1.1600x+17.2982$ $r=0.5676$	$L_5=10.3008x+97.7782$ $r=0.4068$	$L_8=11.4995x+119.4091$ $r=0.4283$
(12) $(I/P)A$ $\left(10\frac{\text{million yen}}{\text{person}}\cdot\text{km}^2\right)$	$L_0=0.450x+0.5493$ $r=0.7983$	$L_1=0.0482x+1.2764$ $r=0.8860$	$L_6=0.0962x+3.6835$ $r=0.8710$	$L_7=0.2417x+13.4629$ $r=0.7376$	$L_2=0.0481x+2{\cdot}4070$ $r=0.6812$	$L_3=0.1454x+9.7794$ $r=0.5892$	$L_4=0.1935x+12.1865$ $r=0.6519$	$L_5=1.8899x+40.5092$ $r=0.5140$	$L_8=2.1318x+53.9578$ $r=0.5486$
(13) $(I/P)A'$ $\left(\frac{\text{million yen}}{\text{person}}\cdot\text{km}^2\right)$	$L_0=0.0119x+0.9417$ $r=0.6652$	$L_1=0.010x+2.3080$ $r=0.5827$	$L_5=0.0385x+3.8220$ $r=0.8134$	$L_7=0.0767x+12.6145$ $r=0.7392$	$L_2=0.0184x+1.5141$ $r=0.6170$	$L_3=0.0482x+8.7925$ $r=0.6170$	$L_4=0.0667x+10.3066$ $r=0.7090$	$L_5=0.8792x-30.0378$ $r=0.7549$	$L_8=0.9559x-17.4242$ $r=0.7765$

L: length of roads, A: area, A': inhabitable area, P: population, I: prefectural domestic product, V: number of vehicles.

TABLE 3. Correlation Formulae between the Density or Roads and the Indexes (in the case of 39 prefectures)

X \ l	railways l_0	national roads l_1	national roads + first class prefectural roads $l_6(=l_1+l_2)$	national roads + prefectural roads $l_7(=l_1+l_4)$	prefectural roads			county roads l_5	national roads + prefectural roads + county roads $l_8(=l_1+l_4+l_5)$
					first class prefectural roads l_2	second class prefectural roads l_3	summings $l_4(=l_2+l_3)$		
(2)′ $\sqrt{P/A}$ $\left(\frac{\text{person}}{\text{km}^2}\right)$	$l_0=3.3653x$ $+4.6594$ $r=0.6284$	$l_1=2.4022x$ $+36.7095$ $r=0.5222$	$l_6=8.5624x$ $+31.1370$ $r=0.8673$	$l_7=27.5822x$ $+47.5822$ $r=0.8482$	$l_2=6.2409x$ -5.5725 $r=0.8268$	$l_3=18.9874x$ $+16.8649$ $r=0.7536$	$l_4=25.1798x$ $+10.7914$ $r=0.8264$	$l_5=328.3726x$ -2412.9305 $r=0.6716$	$l_8=355.9548x$ -2365.4326 $r=0.7014$
(4)′ I/P $\left(\frac{\text{thousand yen}}{\text{person}}\right)$	$l_0=0.3021x$ $+25.6081$ $r=0.1976$	$l_1=0.3315x$ $+39.6995$ $r=0.2524$	$l_6=0.5724x$ $+104.6961$ $r=0.2031$	$l_7=3.2663x$ $+137.5578$ $r=0.3519$	$l_2=0.2409x$ $+64.9967$ $r=0.1132$	$l_3=2.6940x$ $+32.8618$ $r=0.3746$	$l_4=2.9348x$ $+97.8627$ $r=0.3374$	$l_5=16.2731x$ $+994.3417$ $r=0.1166$	$l_8=19.5395x$ $+1131.8894$ $r=0.1349$
(6)′ V (thousand vehicles)	$l_0=0.2864x$ $+44.6198$ $r=0.3521$	$l_1=0.0537x$ $+71.6431$ $r=0.0769$	$l_6=0.4510x$ $+144.6204$ $r=0.3002$	$l_7=1.5182x$ $+410.2831$ $r=0.3074$	$l_2=0.3972x$ $+72.9774$ $r=0.3510$	$l_3=1.0672x$ $+265.6643$ $r=0.2789$	$l_4=1.4645x$ $+338.6390$ $r=0.3164$	$l_5=45.4612x$ $+741.4830$ $r=0.6121$	$l_8=4.6979x$ $+1151.7660$ $r=0.6095$
(7)′ $\sqrt[4]{V}$ (vehicle)	$l_0=2.9908x$ $+15.1036$ $r=0.2732$	$l_1=0.0276x$ $+74.3130$ $r=0.0293$	$l_6=4.8865x$ $+95.6742$ $r=0.2421$	$l_7=17.3912x$ $+232.3863$ $r=0.2616$	$l_2=4.9147x$ $+21.3517$ $r=0.3227$	$l_3=12.5044x$ $+136.7173$ $r=0.2428$	$l_4=17.4191x$ $+158.0683$ $r=0.6071$	$l_5=606.8603x$ -5785.7913 $r=0.6071$	$l_8=624.2515x$ -5553.4044 $r=0.6017$
(8)′ $\sqrt[8]{I/A\cdot V}$ $\left(\frac{\text{thousand yen vehicle}}{\text{km}^2}\right)$	$l_0=6.4505x$ -28.0395 $r=0.4856$	$l_1=3.2832x$ $+30.7466$ $r=0.2877$	$l_6=14.5360x$ -27.3831 $r=0.5936$	$l_7=4.9757x$ -179.6090 $r=0.6169$	$l_2=11.2529x$ -58.1311 $r=0.6089$	$l_3=35.2239x$ -152.2274 $r=0.5636$	$l_4=46.4760x$ -210.3490 $r=0.6149$	$l_5=844.2588x$ -8429.2001 $r=0.6961$	$l_8=894.0185x$ -8608.8083 $r=0.7102$

l_1: density of roads, A: area, A': inhabitable area, P: population, I: prefectural domestic product, V: number of cars vehicles.

TABLE 4. Correlation Formulae between the Length of Roads and the Indexes (in the case of 39 prefectures)

L \ X	railways L_0	national roads L_1	national roads + first class prefectural roads $L_6(=L_1+L_2)$	national roads + prefectural roads $L_7(=L_1+L_4)$	prefectural roads			county roads L_5	national roads + prefectural roads + county roads $L_8(=L_1+L_4+L_5)$
					first class prefectural roads L_2	second class prefectural roads L_3	summings $L_4(=L_2+L_3)$		
(10)′ $(I/P)\sqrt{A\cdot P}$	$L_0=0.3479x+0.1522$	$L_1=0.2942x+1.6843$	$L_6=0.7043x+3.1345$	$L_7=1.9214x+9.9478$	$L_2=0.4003x+1.5495$	$L_3=1.2172x+6.8133$	$L_4=1.6175x+8.3629$	$L_5=19.6984x-30.9508$	$L_8=21.5863x-r20.6038$
$\left(\frac{10^5\text{ yen/person}}{\times\sqrt{10^8\text{ km}^2\cdot\text{person}}}\right)$	$r=0.7786$	$r=0.7141$	$r=7.8399$	$r=0.8318$	$r=0.7450$	$r=0.7418$	$r=0.7941$	$r=0.6653$	$r=0.6932$
(11)′ $(I/P)\sqrt{A'\cdot P}$	$L_0=0.4855x+0.8730$	$L_1=0.3557x+2.6151$	$L_6=0.9860x+0.7410$	$L_7=2.6842x+13.9105$	$L_2=0.5978x+2.1500$	$L_3=1.6991x+9.3307$	$L_4=2.3109x+11.3985$	$L_5=35.1899x-35.2117$	$L_8=37.8254x-20.9603$
$\left(\frac{10^5\text{ yen/person}}{\times\sqrt{10^8\text{ km}^2\cdot\text{person}}}\right)$	$r=0.6846$	$r=0.5439$	$r=0.7410$	$r=0.7323$	$r=0.7540$	$r=0.6525$	$r=0.7150$	$r=0.7490$	$r=0.7657$
(12)′ $(I/P)\cdot A$	$L_0=0.0459x+0.5235$	$L_1=0.0448x+1.4432$	$L_6=0.0931x+3.8723$	$L_7=0.2339x+13.3545$	$L_2=0.0463x+2.4287$	$L_3=0.1408x+9.4821$	$L_4=0.1871x+11.9113$	$L_5=1.9010x+38.4732$	$L_8=2.1323x+52.1315$
$\left(10\cdot\frac{\text{million yen}}{\text{person}}\ \text{km}^2\right)$	$r=0.7960$	$r=0.8802$	$r=0.8606$	$r=0.7850$	$r=0.6679$	$r=0.6653$	$r=0.7121$	$r=0.4979$	$r=0.5309$
(13)′ $(I/P)\cdot A'$	$L_0=0.0142x+0.5890$	$L_1=0.0115x+2.1754$	$L_6=0.0301x+3.7387$	$L_7=0.075x+13.1382$	$L_2=0.0186x+1.5630$	$L_3=0.0450x+9.3995$	$L_4=0.0636x+10.9628$	$L_5=0.9504x-37.9355$	$L_8=1.0238x-24.3830$
$\left(\frac{\text{million yen}}{\text{person}}\ \text{km}^2\right)$	$r=0.7607$	$r=0.6656$	$r=0.8570$	$r=0.7761$	$r=0.8270$	$r=0.6546$	$r=0.7455$	$r=0.766$	$r=0.7855$

L: length of roads, A: area, A': inhabitable area, P: population, I: prefectural domestic product, V: number of vehicles.

TABLE 5. Stability Ratio $(k=a'/a)\times 100$

		railways	national roads	national roads + first class prefectural roads	national roads + prefectural roads	prefectural roads			county roads	national roads + prefectural roads + county roads
						first class prefectural roads	second class prefectural roads	summing total		
li	(1) P/A									
	(2) $\sqrt{P/A}$	192.7	227.8	167.1	108.6	151.4	93.6	103.4	282.1	251.0
	(3) I/A									
	(4) I/P	58.8	86.3	37.3	44.3	20.9	46.1	41.9	54.0	52.1
	(5) V/A									
	(6) V	182.9	69.6	91.6	50.9	95.5	42.8	50.4	374.0	310.3
	(7) $4\sqrt{V}$	67.8	− 1.2	36.4	25.5	44.3	22.8	26.4	148.3	130.7
Li	(8) $2\sqrt{(I/A)\cdot V}$	133.4	110.9	100.5	70.6	97.8	62.9	68.8	229.2	203.7
	(9) P									
	(10) $(I/P)\sqrt{A\cdot P}$	276.1	320.1	234.2	163.4	191.7	139.1	149.2	228.1	219.9
	(12) $(I/P)\sqrt{A'\cdot P}$	499.5	1.084.5	385.6	224.1	279.5	180.3	199.2	341.6	328.9
	(12) $(I/P)\cdot A$	102.0	97.1	96.8	96.8	96.3	96.8	96.7	100.6	100.0
	(13) $(I/P)\cdot A'$	119.3	113.9	105.6	97.9	101.1	93.4	95.4	108.1	107.1

The numerical values on the table are those of $k=(a'/a)\times 100$ when the correlation formulae in case of 45 prefectures are expressed as

$$l\,(\text{or } L)=ax+b$$

and the correlation formulae in case of 39 prefectures are expressed as

$$l\,(\text{or } L)=a'x+b'$$

thus $(a'/a)\times 100$ are obtained.

the ratio $k=(a'/a)\times 100$ would not be much further from 100. We call k the stability ratio.
(4) The formulae which meet the conditions in (1), (2), and (3) and those with a high correlation coefficient are required. The influential prefectures mentioned here are Tokyo, Osaka, Kanagawa, Aichi, Hyogo and Kyoto.

Viewing the statistics of the prefectural distributed income per capita in 1955 and 1960, these six prefectures show exceptionaly high quantities. As for the rate of the population growth from 1955 to 1960, the first five prefectures show the highest values. These facts indicate that the six prefectures by themselves form the cores of the socio-economic activities of Japan, and they can hardly be compared with the other prefectures at the same level. Then, we obtained eight methods for producing the formulae of road density 1, and five methods for road length L. The formulae which were obtained are summarized in Table 1–2 (in the case of 45 prefectures), and in Table 3–4 (in the case of 39 prefectures). The stability ratio k are as shown in Table 5.

4. A Theoritical View of expansion of roads

The following statement is our theoritical view of the how roads should be placed.

If the districts of a nation were the same in surface area with each other, such districts should have a expansion of roads proportional to the development of the district. Because a district which is more advanced has greater production activities and requires better traffic facilities. Whether one nation or area is advanced or not is indicated by the degree of high income of the people in that area. Denmark, or New Zealand, for example, are considered to be advanced countries along with the Great Britain or West Germany because of their high individual income, although they are primarily agricultural countries.

In short, the degree of the development in a region should be estimated by the standard of individual income.

Efforts towards regional development are indication of an attempt to raise the per capita income of people who live there.

Thus, the expansion of roads in the district should be considered as a function of the area and the per capita income of the district. Therefore, the expansion of roads are proportionate to the product of the individual income or per capita income (I/P) and the area A.

Now, let each formula of Table 1, 2, 3, 4 be examined from the correlation coefficient r and stability ratio k, then, the formula with $(I/P)\cdot A$, or $(I/P)\cdot A'$ as the argument is the best for obtaining a profitable expansion of roads in a district. Moreover, these two formulae are theoretically reasonable.

Figure 1 shows the interrelation between $(I/P)\cdot A$ and L_1. In this formula, I is the prefectural production income, P is the population, A is the entire area, and L_1 is the sum of the length (expansion) of national roads in the prefecture.

Here it may be noted that the idea that a positive correlation exists between the expansion of roads and the population is generally accepted. It follows that the larger a population one region has, the more road it requires. In a broad sense, this correlation is reasonable.

But the following questions may naturally be raised.

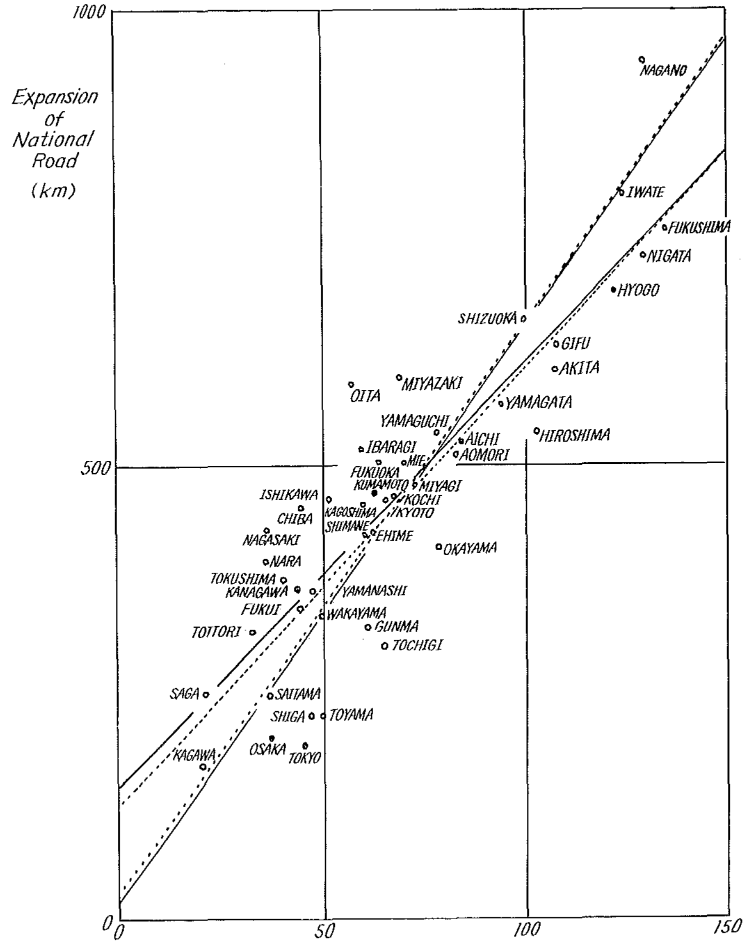

Fig. 1. $\frac{\text{Prefectural Production Income}}{\text{Population}} \times \text{Area}\left(10 \cdot \frac{\text{million yen}}{\text{person}} \times \text{km}^2\right)$

(1) Are there still more roads required in and around a large metropolitan area, and if so, is there enough space remaining where new roads may be constructed? In a extreme case, the question may be should all empty areas be roads in and around a big city?
(2) The general tendency of the population in each rural prefecture is that the population is on a decreasing trend with the exception of big cities where many people migrate to in. Could all the roads in a decentralization area be taken away? Or, would there be no need for further constructions?

The expansion of roads in a region does not grow in accordance with the growth of the population in that area: the more the population grows, the less steadily the rate of the expansion increases. There is little room left today in or around a big city for the further construction of roads, and the conjunction roads to a trunk may have been so densely placed that there is no more need to shorten the distance between them. This is to say, the population is not a proper argument in the aquiring of a theory of the expansion of roads. Then, why has population

TABLE 6. Coefficients of the Formulae by Using Data of 1960 and of 1965

	1960	1965	
national roads L_1	$a_{60}=0.0482$ $b_{60}=1.2764$ $r_{60}=0.8850$ $a'_{60}/a_{60}=0.97$	$a_{65}=0.0280$ $b_{65}=1.3535$ $r_{65}=0.8579$ $a'_{65}/a_{65}=0.96$	$\frac{a_{60}}{a_{65}}=1.72$
national roads + first class prefectural roads $L_6(=L_1+L_2)$	$a_{60}=0.0962$ $b_{60}=3.6835$ $r_{60}=0.8710$ $a'_{60}/a_{60}=0.97$	$a_{65}=0.0595$ $b_{65}=3.7134$ $r_{65}=0.9015$ $a'_{65}/a_{65}=0.96$	$\frac{a_{60}}{a_{65}}=1.84$
national roads + prefectural roads $L_7(=L_1+L_4)$	$a_{60}=0.2417$ $b_{60}=13.4629$ $r_{60}=0.7376$ $a'_{60}/a_{60}=0.97$	$a_{65}=0.1317$ $b_{65}=11.8166$ $r_{65}=0.8116$ $a'_{65}/a_{65}=0.92$	$\frac{a_{60}}{a_{65}}=1.84$
first class prefectural roads L_2	$a_{60}=0.0481$ $b_{60}=2.4070$ $r_{60}=0.6812$ $a'_{60}/a_{60}=0.96$	$a_{65}=0.0315$ $b_{65}=2.3601$ $r_{65}=0.8088$ $a'_{65}/a_{65}=0.95$	$\frac{a_{60}}{a_{65}}=1.53$
second class prefectural roads L_3	$a_{60}=0.1454$ $b_{60}=9.7794$ $r_{60}=0.5892$ $a'_{60}/a_{60}=0.97$	$a_{65}=0.0722$ $b_{65}=8.1030$ $r_{65}=0.6900$ $a'_{65}/a_{65}=0.89$	$\frac{a_{60}}{a_{65}}=2.01$
first class and second class prefectural roads $L_4(=L_2+L_3)$	$a_{60}=0.1935$ $b_{60}=12.1865$ $r_{60}=0.6519$ $a'_{60}/a_{60}=0.97$	$a_{65}=0.1037$ $b_{65}=10.4631$ $r_{65}=0.7590$ $a'_{65}/a_{65}=0.91$	$\frac{a_{60}}{a_{65}}=1.87$
county roads L_5	$a_{60}=1.8899$ $b_{60}=40.5092$ $r_{60}=0.5140$ $a'_{60}/a_{60}=1.01$	$a_{65}=0.8746$ $b_{65}=51.6852$ $r_{65}=0.4802$ $a'_{65}/a_{65}=1.02$	$\frac{a_{60}}{a_{65}}=2.16$
national roads + prefectural roads + county roads $L_8(=L_1+L_4+L_5)$	$a_{60}=2.1318$ $b_{60}=53.9578$ $r_{60}=0.5486$ $a'_{60}/a_{60}=1.00$	$a_{65}=1.0063$ $b_{65}=63.5027$ $r_{65}=0.5229$ $a'_{65}/a_{65}=1.01$	$\frac{a_{60}}{a_{65}}=2.12$

$L=a_{60}(I/P)\cdot A+b_{60}$: formula of 1960
$L=a_{65}(I/P)\cdot A+b_{65}$: formula of 1965
r: correlation coefficient
(a'/a): stability ratio/100

been used as the argument to detect the expansion of roads?

The fact is that the population is a function of production. The population of a low-product or low-income region flows into another region with a high-product or high-income. The expression of the population pressure well explains this fact. Consequently, the per capita income, and not the population itself, is appropriate in the search of the expansion of roads.

5. The Examination of the formulae by using data of 1965

An equivalent fornulae using data of 1965 was made, and compared with each corresponding formula of 1960. Those are shown in Table 6 which concerns only compound variable $(I/P)\cdot A$.

Since the prefectural area A is constant, and the personal income (I/P) of 1965 increased to twice as that of 1960, it may be said that ratios (a_{65}/a_{60}) are approximately two, as shown in the last column of Table 6.

This fact proves that the formula with $(I/P)\cdot A$ or $(I/P)\cdot A'$ as the argument can be used to estimate the expansion of roads in Hokkaido for fair number of years.

References and Notes

1) Journal of the Society of Civil Engineers Vol. 35 No. 6.

2) the following ideas were introduced: $do=ko\sqrt{P}$ $do=kv\sqrt{N}$, when ko is land coefficient, kv is index of cars, do is the density of roads, P is the population, N is number of cars. Katahira mentions that this was suggested by Dr. Fujii's paper.

3) Onaka, M.: Road Conditions Viewed from Statistics and Their Future Placements.

4) Imai, I.: Road Networks Today and Future.

5) Seto, M.: The Relationship Between Density or Roads and Density of Requisite Roads and their Calculation Method.

6) Miura, B.: On the Trunk Road Network Settlement in Kyushu District.

7) Okuda, Oguri: On the Characteristics of Trunk Road Network in Chubu District.

8) Imai, Yamada: Some Problems Concerning First Class Prefectural Road Settlement.

9) Tsujikawa, H.: Re-composition of Prefectural Road Networks.

10) Endo, Miura: The same as the above.

11) Nanpo, Y.: Re-composition of Prefectural Road Network Especially Concerning the Density of Roads.