Studies on the Forest Road System

— Preliminary report on the road density —

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Acknowledgement

Importance of good road system has been widely recognized in recent few years in accordance with rapid progress in mechanized logging operations, as well as with improved management of forestry in general and remarkable rationalization of enterprises for timber production.

Among numerous problems relating to the forest road system, the most basic one is considered to be the standardization of forest road construction. There have been previously suggested no reasonable figures for the standard or optimum road density, by which any adequate orientation to the construction of forest road network could be given.

Therefore, the first step of our study was concentrated to the task of finding out the most reasonable and reliable figures for road density. For this purpose, a working group was organized in April of 1964. The following members, who are all active researchers in the field of Logging, Forest Engineering and Forest Management, are the collaborators of this study.

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On behalf of the members of the working group, the writer highly appreciate the Scientific Research Subsidy of total amount ¥3,000,000 allocated to this study by the Ministry of Education, by which they have been so much encouraged.

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Prof. Dr. Seihei KATO
Chairman of the working group

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1. Modern Forestry Depends upon the Forest Roads.

1-1. The Aim of Modern Forestry.

From the view point of national economy and policy, our forestry should be an activity to utilize our forest rosources most efficiently for the common welfare of mankind in permanence. Therefore, our modern forestry should open the way aiming at the least to the following four goals:

(1) Timber Production

(2) Water Production, Errosion and Flood Control

(3) Recreation and Nature Conservation

(4) Development of Local Communities

In the past, timber production was the only purpose of the traditional forestry. But, our modern forestry has three more purposes at least. Even timber production, usually the main purpose of forestry, is not allowed to prevent the achivement of other purposes. And if these four purposes could be successfully achieved, surely it would keenly appeal to the public sentiment. Then, we can expect more prospective forestry sustained by stronger public opinion.

1-2. Timber Production

According to the rapid increase of population, and to the remarkable development of our national economy, the demand for timber supply is ever increasing. Forestry is originally an industry to produce and supply timber for human demand. It is also a free enterprise under the economic structure of capitalism. Forestry enterprisers may necessarily seek for any reasonable profit by execution of various forest operations. But, it is most dangerous to attempt mere exploitation of the existing natural resources without adequate planning for reforestation, because the world forest resources, i.e. the timber producing potentialities of the accessible economic forests, are ever decreasing.

In Japan (1965), about 25% of the total timber demand was supplied by the imported timber from U.S.A., Canada, U.S.S.R. and South-east Asian countries. The author thinks it is difficult to expect that the Japanese wood industries depend upon the imported materials in larger percentage, because timber shortage will attack these overseas countries in future and no longer be able to export timber to Japan.

Our modern forestry should not be a timber plundering forestry. It must be the forestry of sustained yields and ever increasing timber production. Every effort should be paid for increasing soil productivity, increasing annual increments, increasing total timber storage of the forests. More intensive forest management is necessarily required. On the other hand, our forestry must be a profitable enterprise on the long time range basis, at least thirty to fourty years. To realize such ideal forestry, we must at first reform the forests themselves.

Logging (felling, assembling, processing, transport, etc.) is the main process of timber production. Cost control in the logging operation may be achieved by the mechanized methods of logging. In this case, considerable amounts of investments for the most suitable machines are necessary. And such mechanized operation depends on the existence of an adequate road system. Without good road system, minimum cost and maximum profit logging could not be expected.

Therefore, Forest Road System is the most fundamental facility of the economic forests. The first step of forest reformation is the road construction. Possibilities of more intensive management and every improvement in the silvicultural operations could be gained also by this permanent road system. For this reason, more investment for road construction is the most important task of the forestry enterprisers from the view point of forest economy.

1–3. Water Production, Errosion and Flood Control

Problems of water are much characteristic in Japan owing to the unique topography and climate of the land. Agriculture, which is characterized by ricefield cultivation, hydroelectric powerstations, industrial factories, as well as the human living in the towns and big cities, depend upon well controled water supply and public utilities.

Warm temperature and plenty of precipitation are most favourable for growing of trees and water production. But, very steep topography is the source of rapid run off of water, soil errosion and flood of rivers, especially at the time of heavy rain fall brought by the Typhoon storm in summer and fall every year.

In Japan, the problems of water production should be solved simultaneously with the problems of errosion and flood control. Multi-purpose damms, canals and other hydrologic structures, soil consolidation and reforestation works are the inevitable needs. Without good road system, such construction works and watershed management might be very difficult and expensive.

1–4. Recreation and Nature Conservation

Leisure in the modern world is the new product of social progress. Average people gains more money and more time, which are being spent for recreation activities. On the contrary, population is concentrated in the big cities. Urbanization and industrialization of the country sides are quickly spreading. Most people is living in the noisy, unhealthy, unnatural environment. Outdoor recreation is the ardent need in the modern life. From the view point of physical sanitation and mental moral, the best places for the outdoor recreation activities are the forests with rich nature.

Recreation and nature conservation should be more carefully considered in the management of modern forestry. We tentatively call it the "Third Utilization" of forests.

The forests in the National Parks and in other Natural Parks or some parts of the National Forests are, no doubt, the subjects of this third utilization. Even in the private forests, the forest owners and managers must take care of visitors. They must pay more sensitive attension to the conservation of primitive wildness, preservation of wild lives, protection and restoration of natural beauty and quietness of the forests.

But, nowadays, the visitors' impact is observed to be too strong sometimes. Overuse or overdevelopment for the third utilization will destroy the precious nature of the forests. At the same time, public use may disturb the normal operation of the forestry, and sometimes even the growing trees may be damaged by visitors. This tendency is very often accelerated by the commercial tourist industries. In this case, forestry should withstand the external pressure of commercialism.

The only way to solve these complicated problems is the establishment of an autonomous plan for the third utilization from the side of the managing authorities. In this plan, any adequate distribution of the mass-visitors and smooth flow of traffic must be attempted. Therefore, here also a good road system plays an important role.

1–5. Development of Local Communities

It is obvious that forestry has close relation with local communities in the neighbouring areas. Even in the highly mechanized forestry, it is said that more than 60% of the total cost of timber production is occupied by the wages of the forest workers. This fact means that forestry depends on the labor force of the local communities.

On the contrary, forest enterprisers must be helpful for the development of local communities instead of being a mere labour sweater.

Based on the increase of average income of the villagers, their living standard must be raised. Also good facilities for education, for sanitation, and for all other social welfare and civilization, must be given to the local communities.

Without any road system, such development of the local communities could not be achieved.

2. Forest Road System

2-1. Network of Forest Roads

The whole area of the forest, which is the subject of any modern forestry, should be covered by a complete network of forest roads. Such road network is often compared with the circulating system of blood in our body, which consists of various vessels, from the major artery to the minor capillary. Similarly a good road system might be composed of various kinds of forest roads.

2-2. Classification of Forest Roads

There are many kinds of forest roads according to their types and functions. In the Forest Road Provision, issued by the Forestry Agency of Japan in 1955, forest roads were classified in seven kinds: (1) Forest railway, (2) Cableway, (3) Motor vehicle road, (4) Wagon road, (5) Kiuma-sled skidway (6) Bridle or cattle way, and (7) Floating or rafting waterway. But, nowaday, automobiles and motor trucks are the most popular kind of traffic even in the forests. So that the forest road system must generally consist of motor vehicle roads only, other traditional kinds of roads are better to be eliminated. Therefore, here we are considering motor vehicle roads only. Nevertheless, the motor vehicle roads have to be classified according to their functions.

Thus the forest roads, which are now under consideration, are classified in following three kinds:

(1) The access road.
(2) The primary road in the forest.
(3) The secondary road in the forest.

These classes of forest road were also seen in the historical development of forestry. In the first stage of forest exploitalion, the access road were built for the purpose of timber extraction from the forest. In the second stage of development, the network of forest roads were built within the forest area for the purpose of permanent forest management and continuous timber production. In the third stage, the network of the primary forest roads were supplemented by the secondary minor roads which gave better trafficability of machines and possibilities for more profitable logging, more intensive management and more careful treatment of individual forest stands.

3. Road Density

3-1. Definition and Meaning of the Forest Road Density

In general, road density is used for a measure, by which the degree of road net development is estimated relating to the judgement of the intensity of management of a certain forestry project. In this case, forest road density is defined as the length of the forest road per unit area of the forest, and expressed by the unit m/ha, for instance. In other words, the numerical figure obtained, when the total length in m of the forest roads being devided by the total area in ha of a forestry project, shows the road density.

Following to this definition, and if we want to estimate the justified intensity of forest management by road density, it is obviously incorrect if the distance of any access road is included in the total length of roads. The length of an access road depends more on the local development of land use and existence or absence of public highway and other roads. Therefore, as far as we discuss about the forest road density, we have to consider the roads in the forests only. Even then, there are two kinds of forest roads, the primary and the secondary.

In the forest road net planning, at first we must decide macro-layout of the primary roads, which may cover the whole area of a project, and then it could be supplemented by micro-layout of the secondary road net, case by case. Hence, in this study, only the macro-network of the primary roads is selected for the main subject of investigations. And we are required to find out the standard road density for this primary road net.

Prof. Hafner[1], Wien, suggested the standard density of 30~40 m/ha for the mountain forests of Austria, while Prof. Pestal[9] suggested 500 m road spacing (ca. 20 m/ha). Density of more than 40 m/ha up to 100 m/ha is commonly seen in West Germany, Switzerland, Austria, Sweeden and Norway.

For the secondary forest roads, Prof. Steinlin[10] suggested a standard density of 100~150 m/ha (30 m spacing). But, no one else showed any figure, because the problem of the secondary road (Erschliessungsgasse) seems to be quite new.

3-2. Density of the Primary Forest Roads and the Overall Forest Road System

It is true that the economic effect of the forest roads reaches far beyond a certain limit of merits in timber production. Forest roads are very useful for construction works of water production and control, for recreation and local development. But monetary estimations of such merits are very difficult. Therefore, the first procedure in the road net planning might be carried out by the standard density of the roads for logging connected to the access roads. And then the road system might be completed by adding all other necessary road lines case by case. According to this plan, the primary roads, which are more or less permanent, could be gradually realized by actual road construction. And then the intermediate spaces of the primary road network might be fulfilled by the minor secondary road nets following to the proceeding of primary road construction. Thus the overall forest road system could be completed.

The position of the primary road network, which is the main subject of our study, in the total scheme of forestry is shown in Fig. 1.

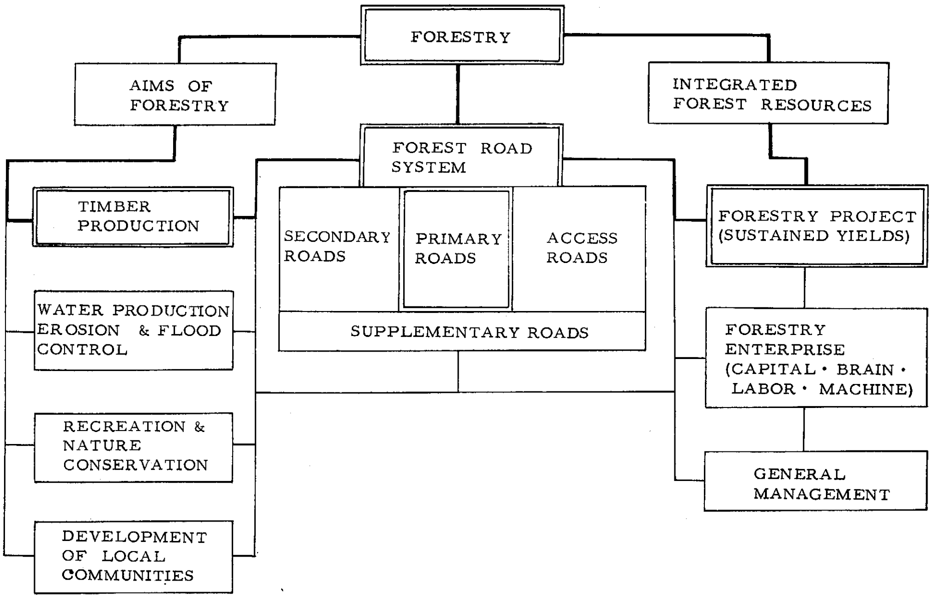


Fig. 1. Forest road system in the total scheme of the modern forestry.

3-3. Ideologies about the Forest Road Density.

As to the ideologies about the forest road density, we found three kinds of logic in the previous studies.

(1) Road spacing determined by the method of prehauling.

Prehauling means hauling timber from the felling site to the roadside. This process is considered to be most important in logging operation. In middle-european countries, especially in Austria, Switzerland and West Germany, the most suitable method of prehauling, not only from the view point of logging technique, but also from that of production costs, is usually selected at first and then the optimum road spacing corresponding to such prehauling method is determined. The most representative opinion on such idea has been explained by Pestal[9]. Although the optimum road spacing concept by such idea may be much useful and practical within a certain limit of application, it could be theoretically not always logical.

(2) Minimum cost idea[4)6)].

Matthews' optimum road spacing theory has been widely known already. The theory have been often successfully applied for practical cases, especially for logging on the flat terrain. This theory is based on the minimum cost idea, that the distance of road spacing should be such one as to make the total sum of prehauling cost, truckhauling cost and road construction cost to the minimum. Matthews derived a series of mathematical cost-functions from assumed theoretical models of the forest road nets, which was given by somewhat simplified geometrical expression. Then the optimum road spacing formulae were derived by the conditions which may give the minimum values of the cost-functions. Therefore, the form of the formula varies more or less according to the nature of the assumed geometrical models.

Sundberg[12], Larsson[5], Kamiiizaka[3], Okawara[8] and some other researchers followed up to this ideology, though the theoretical models and assumptions were modified. For instance, Sundberg introduced the idea of "Rectification coefficient" to have better application of the basic formula.

(3) Allowable maximum density idea.

The optimum road density mentioned above is the road density by which the timber production cost might be reduced to the minimum. It is not related to the amount of probable profit gained by the production. The difference between the sales price of timber and the cost of hauling operation, including road construction cost, is the gross profit gained by the hauling enterprise. But we have to pay more expenditure for timber production as a whole. The probable amount of the expenditure for stampage cost, for felling and log making, for planting and silviculture, for forest protection, for depreciation and maintenance of machines, equipments and installations, for interest of investment, for general management and business of the whole forestry enterprise, and finally for enterpriser's normal overhead, which would be estimated at a certain percentage of the invested capital, could be calculated.

The cost per unit volume of timber, corresponding to the sum of such expenditures, is also considered to be a part of the timber production cost. Therefore, the difference between the gross profit and this part of the production cost is the real net profit gained by the enterprise as a whole.

Of cause, it is left for free selection by the enterpriser how to use this net profit. But it is desirable that the net profit is spent for the basic improvement of the forest, especially for forest road construction.

When we assume that a certain amount of money, corresponding to the net profit, is completely reinvested for the road network, we could have a certain density, which is reflecting the level of profitability of the forestry enterprise under consideration.

Thus, such road density might be called "The allowable maximum density" or "The marginal density". Recently, Minamikata[7] gave a series of formulae for forest road density based on this idea. Results of some trial calculation showed in most cases much higher density than the optimum density based on the minimum cost idea.

This theory is rather logical and very interesting. But, it seems to be not yet practical at present to apply such formulae for our road net planning, because the density of the existing forest road nets are too poor when compared with such theoretical density.

Our comparative study on the basic idea of road density leads us to the decision that we might preferably follow up to the minimum cost idea, in which the idea of prehauling methods concept being introduced.

4. Terrain Classification and Types of Logging Operation

4-1. Road Density Closely Related to Terrain Condition

Actually, the density of the existing forest road net is observed to be more or less influenced by many factors: Topography, Geology, Soil, Climate, Vegitation, Method of road construction, logging organization and technic, tree species, amount of timber stock, method of regeneration, annual increment of stands, machines and labor supply, etc. Also the social and economic structure of the local communities, type of enterprise, method of management and other various complicated factors are affecting indirectly on the road density. These numerous factors could be classified into;

(1) Factors relating to the difficulty of road construction and consequently to the construction costs.
(2) Factors relating to the methods of prehauling.
(3) Factors relating to the amount of timber out put.

Among them, terrain condition is the most predominant factor. It must be quite true when we recognize the assumptions;

(1) The total area of the logging project is big enough for sustained yields concept, generally from several hundreds hectares up to several thousands hectares.
(2) Annual timber out put is limited within the volume equivalent to the annual increment of the standing trees in the forest.
(3) Usual mechanized methods of logging are applied.

In Japan, forestry takes place on the level low land, on the hilly land, on the mountain sides, and even on the very steep mountains higher than 2,000 m in elevation. Consequently, technical difficulties and costs of road construction are closely related to the terrain conditions or topography of the land.

4-2. "Terrain-Index"

If the forest road density is most closely related to the nature of terrain, we have to at first investigate how to classify the different kind of terrain, on which a certain kind of logging operation could be carried out most economically. And then we have to find out the optimum road density the most suitable for each kind of terrain and respective method of logging, especially of prehauling operation.

Gradient of terrain surface is the most basic factor as far as difficulty in prehauling and road construction is concerned. Also other factors, such as unevenness and obstacles on the surface, valleys and streams, swampy spots, erosive spots, rocks and stumps on the ground, undergrowth of shrubs and bomboos, etc. may give considerable influence to road construction. But, when we consider any larger area of the forest for sustained yields and rational rotation of cutting site, minor ground factors can be neglected. Therefore, three big factors were taken into account for our purpose. These are

(1) Gradient. (2) Unevenness.
(3) Density of valleys and streams.

And then, the difference in these environmental factors were most objectively given be the numerical values of the "Terrain-Index". This index formula have been recently derived by Hori[2].

Denoting that;

I = Terrain-Index

I_i = Index for gradient

I_r = Index for unevenness of ground and density of valleys and streams

Then, the "Terrain-Index" is calculated by the formula;

$$I=\frac{3I_i+I_r}{4}. \tag{1}$$

To find out the values of I_i and I_r, the standard contour maps (1:50000) published by the Bureau of Geographical Survey, which are always available for every place in Japan, should be utilized. In this map, topography is shown by the contour lines of every 20 m vertical height difference.

As to the procedure of calculation, at first the boundary of the forest under consideration is drawn on the map. Then the whole area within the boundary is covered by any sufficient number of circles, each of which having 500 m diameter. In other words, circles of such diameter are evenly distributed on the whole area of the project. (Fig. 2–a). In each circle, another circle of 250 m diameter is drawn, co-ordinated to the same center point. Thus, the contour lines of the map may be intersected by the circumferences of these two kinds of circles. (Fig. 2–b). Then, for each circumference, numbers of such intersecting points are counted respectively. Now denote that,

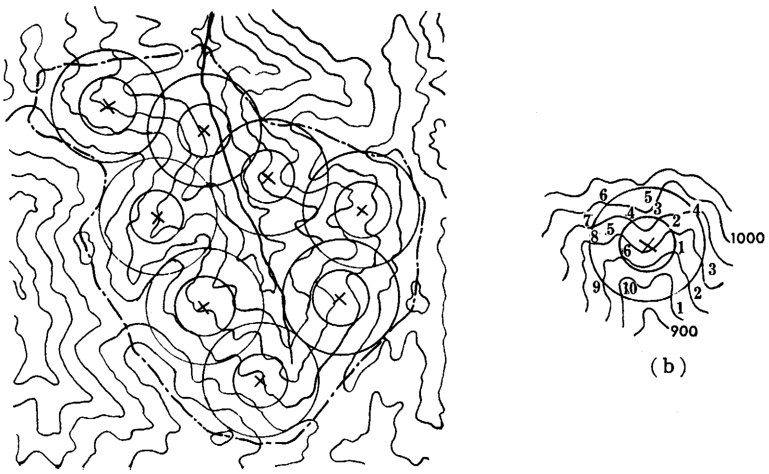
n_1 = Number of intersecting points on a bigger circle (diameter 500 m)

n_2 = Number of intersecting points on a smaller circle (diameter 250 m)

N_1 = Average value of n_1 for all bigger circles

N_2 = Average value of n_2 for all smaller circles

Then the "Index for gradient" (Average gradient in %) is given by



(a) (b)

Fig. 2.

$$I_i=\frac{2}{3}(N_1+N_2). \tag{2}$$

Unevenness of the ground within each bigger circle (diameter 500 m) is given by the absolute difference of ground height within the circle. Such height difference is simply read by the contour lines on the map. So that the mean value of the unevenness for all bigger circles is mathematically calculated. This mean value R shows the average unevenness of the ground.

Density of valleys and streams means the numbers of valleys and streams per unit area in km^2 of the project. Consequently, the number (n) of all valleys and streams within the boundary of the project must be counted, and the area (A) of the project measured by a planimeter. Then, the density;

$$V=n/A. \tag{3}$$

The "Index for unevenness of ground and density of valleys and streams" is calculated by

$$I_r=R(0.1+0.01V). \tag{4}$$

4-3. Standard Types of Logging Operation

There are various types of logging operation practiced in Japanese forestry[4]. Among them, following four types are considered to be most suitable and desirable for modern forestry not only from the view point of mechanized organization of operation, but also from that of rationalization of forestry as a whole. Hence, we call them here the standard types of logging operation.

Type I [*Truck hauling type*] on even terrain:

(Very short distance prehauling)+(Truck transport)

Type II [*Tractor hauling type*] on hilly terrain:

(Very short distance prehauling by tractor-winch)+(Medium distance skidding by tractor)+(Truck transport)

Type III [*Medium distance skyline type*] on steep terrain:

(Medium distance prehauling by skyline cable-crane)+(Truck transport)

Type IV [*Long distance skyline type*] on very steep terrain:

(a) (Long distance prehauling by skyline cable-crane)+(Truck transport) or (b) (Short to medium distance prehauling by skyline cable-crane)+(Cable-way transport)+(Truck transport).

The common machines and installations, which are required for these standard types of operational organization, are listed on the Table 1.

4-4. Types of Logging Operation Related to the Terrain Class

Each type of logging operation is closely related to the terrain conditions. A certain method of logging is most suitable for a certain class of the terrain. From the results of our field investigations, we confirmed the relation shown in the Table 2.

Therefore, if we want to find out the standard density of the forest road network, at first we must calculate the average value of the "Terrain-Index". By this value, we

Table 1. Machines and Installations Required.

Standard type of logging operation	Terrain	Machines required	Installations required
Type I (Truck-hauling type)	Even	Trucks, Log loaders or Loading Cranes.	Primary forest roads, Secondary forest roads for truck transport.
Type II (Tractor-hauling type)	Hilly	Trucks, Tractors, Loading machines.	Primary forest roads. Secondary forest roads for trucks. Secondary forest roads for tractors. Timber landing yards.
Type III (Skyline type, Medium distance)	Steep	Trucks, Cable yarders, Loading machines.	Primary forest roads. Secondary forest roads for trucks. Skyline cable system. Landing decks.
Type IV (Skyline type, Long distance)	Very Steep	Trucks, Loading machines, Cable yarders, (Cableway machines).	Primary forest roads. Secondary forest roads for trucks. Skyline cable system. Landing decks.

Table 2. Terrain Class and Types of Logging Operation.

Terrain Class	I (Even)	II (Hilly)	III (Steep)	IV (Very Steep)
Value of the Terrain-Index (I)	0～19	20～39	40～69	>70
Type of Logging Operation	Type I (Truck hauling)	Type II (Tractor hauling)	Type III (Medium distance skyline)	Type IV (Long distance skyline)
Difficulty in Road Construction	Easy	Moderate	Difficult	Very Difficult

can confirm the terrain class by Table 2. And then, the standard density could be calculated by the theoretical formula on the basis of the assumed standard type of the logging operation corresponding to the terrain class.

5. Formula for the Standard Road Density

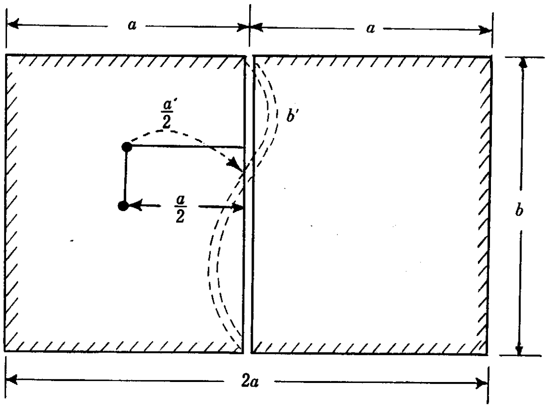
5-1. The Theoretical Model

The standard or optimum density formula may be derived from a theoretical model. Investigation on such models previously studied by several researchers showed that a simple model might be good enough for our practical purpose. So that we employed a new and simplified theoretical model shown in Fig. 3.

5-2. Relation between Road Density and Width of Logging Site.

It is known by the theoretical model that, the total length of the forest road in m is $b'=b(1+\eta)$ and the total area in square metre of the logging site is $2ab$. So that, the road density d m/ha is given by the equation.

$$d=\frac{b(1+\eta)}{2ab}\times 10^4=\frac{(1+\eta)}{2a}\cdot 10^4 \qquad (1)$$



$2a$=Width of Logging site (m)=Distance of road spacing (m)
b=Length of Logging site (m)=Straight distance of forest road (m)
$2a \times b$=Area of the logging site (m^2 or $1/10^4$ ha.)
$a/2$=Average straight distance of prehauling (m)
$b'=b(1+\eta)$=Distance of forest road (m)
$a'/2$=Average distance of prehauling (m)= $a(1+\eta')/2$
η, η'=Ratio of increment in distance of forest road and prehauling line respectively

Fig. 3. The theoretical model.

5-3. Cost Function

Cost of logging per unit volume of produced timber is the total sum of the cost components, such as felling cost, log making cost, prehauling cost, transport cost, loading and unloading cost, cost for construction and maintenance of forest roads and all other installations. Some of these cost components, for example the prehauling cost, are very sensitive to the road construction, while the amounts of some other cost components may be almost unchanged by the construction of new roads. Therefore, such insensitive components can be eliminated from the cost function when we discuss about the road density. Then the cost function K may be given by a very simple expression,

$$K=(\text{Cost of forest road construction (A)})+(\text{Cost of prehauling (B)}).$$

Usually, the long distance truck transport cost on the access road occupies a considerable high percentage of the total timber production cost, of course. But, transport distance on the forest roads in the forest is generally very short when compared with that on the access road, larger part of which is very often a public highway or a road of similar nature. The total cost for major truck transport operation from the logging site to the market changes very little according to the additional transport on the forest road in the forest. The cost of road maintenance may be also considerably high. But, it is almost proportional to the amount of traffic, and can be included in the transport operation cost. Consequently, we can reasonably assume that the effect of the forest road on the total transport operation cost is negligible. Therefore, only the cost components (A) and (B) were taken into account in this case.

Prehauling cost (B) is actually a kind of mixed cost. But, the timber volume to be hauled from a logging site may be within a certain limit, because the annual timber output does not change so much under the sustained yields concept and continuous production system. Also the prehauling distance may remain within a certain upper and lower limit, corresponding to the type of logging operation. Therefore, the prehauling cost (B) can be given by a function, proportional to the volume of timber and to the prehauling distance.

Thus, the cost function is simply derived from the theoretical model:

$$K = A + B$$

$$= r \cdot b(1+\eta) + x \cdot \frac{a}{2}(1+\eta')v\frac{2ab}{10^4} \tag{2}$$

where,

r=unit cost of road construction in ¥ per m,

x=unit cost of prehauling in ¥ per m and per m^3

v=volume of timber output per ha

5-4. Standard Density Formula

The condition for the minimum value of the cost function is obtained by

$$\frac{dK}{db}=0, \qquad \text{and from eq. (2)}$$

$$\frac{dK}{db} = r \cdot (1+\eta) - \frac{10^4 \cdot x \cdot v(1+\eta')}{4b^2} = 0$$

$$\therefore \quad a = 10^2 \sqrt{\frac{r(1+\eta)}{x \cdot v(1+\eta')}}$$

or

$$2a = 2 \cdot 10^2 \sqrt{\frac{r(1+\eta)}{x \cdot v(1+\eta')}} \tag{3}$$

eq. (3) gives the most economic width of the cutting area developed by the construction of a forest road. And also this $2a$ means the optimum road spacing led by the minimum cost principle.

Substituting eq. (3) into eq. (1), we obtain the optimum forest road density in m/ha.

$$d = \frac{10^2}{2} \sqrt{\frac{x \cdot v \cdot (1+\eta)(1+\eta')}{r}}. \tag{4}$$

If the economic effect of the invested capital for the road construction is taken into account, the unit cost r in the formula should be a corrected value of the technically estimated unit cost of construction. Therefore, in eq. (4),

$$r = \gamma \cdot r' \tag{5}$$

where

r'=technically estimated value of road construction in ¥ per m.

γ=correction factor

Denoting that,

n=Average period of depreciation (year)

I=Total investment for forest road construction (Yen)

α=Annual depreciation for the forest road.

p=Interest

Then,

$$\alpha = I \times \frac{1.0p^n \times 0.0p}{1.0p^n}$$

And the amount of total depreciation is $n \cdot \alpha$, hence, the correction factor should be

$$\gamma = \frac{n \cdot a}{I} = \frac{n(1.0p^n \times 1.0)}{1.0p^n - 1}. \qquad (6)$$

If we put, $n=10$ and $p=5\%$ in eq. (6),

$$\gamma = 1.3.$$

Which means the necessity of 30% surplus estimation.

Finally, the Standard Road Density Formula:

$$d = \frac{10^2}{2}\sqrt{\frac{x \cdot v \cdot (1+\eta)(1+\eta')}{r}} \qquad (7)$$

where,

d = The standard forest road density (m/ha)
x = Unit cost of prehauling (¥/m.m^3)
η = Ratio of increment in distance of forest road
η' = Ratio of increment in prehauling line
$r = \gamma \cdot r'$ = Unit cost of forest road construction (¥/m)
r' = Technically estimated unit cost of construction (¥/m)
γ = Correction factor, determined by eq. (6)
v = Volume of timber to be hauled in m^3 per ha

6. Practical Application of the Formula

6-1. Results of Calculated Road Density

Twenty-three logging projects were selected in Hokkaido, in Honshu (Main Island) and in Shikoku. In each project, the area of which is between 200 to 3583 ha, every needed datum, such as terrain class, forest type, amount of existing timber stock, proposed annual timber out put, average cost of road construction, average cost of prehauling, average ratio of increment in distance of truck hauling and prehauling in the forest, etc., were carefully investigated and provable standardized figures were obtained. By these estimated values of the factors, the standard density was calculated by the formula. The results are shown in the Table 3. But, they are now still under discussion. Though it seems difficut to have a definite conclusion, following tendencies were recognized.

(1) The optimum or standard forest road density, which means the least density of the forest road network, excluding the access roads, is calculated at the numerical value between 5~56 m/ha according to the terrain class and type of logging operation.

(2) The standard road density is almost proportional to the average timber out put per ha.

(3) The standard road density is not always reversely proportional to the unit cost of construction, especially in the cases of unit cost more than ¥10,000 per m. ($28.-/m)

(4) It seems to us that the standard road density must be higher for the planted forests of conifers than for the natural forests of native trees.

Table 3. Examples of the Standard Farest Road Densily.

No.	Terrain		Type of logging operation	Location of the investigated logging project	Ownership and characteristics of the forest in the investigated project	Total area of the forest ha	Estimated values of the factors					Standard forest road density (d) m/ha
	Class	Index (I)					Average timber production per unit area cbm/ha	Unit cost of road construction per linear meter. (r) ¥/m	Unit cost of prehauling per unit volume and per unit distance. (x) ¥/m³·m	Ratio of distance increment for Forest road (η)	Ratio of distance increment for Prehauling line (η')	
1	I	18	I	Uryu, Hokkaido.	Hokkaido University Forest. Natural mixed stands of fir, spruce and hardwoods. Natural regeneration by selection cutting.	1,119	80	3,900	2.02	0.17	0.50	13.5
2	I	13	I	Iwate, Honshu.	National Forest. Planted stands of conifers. Regeneration by clear cutting and planting.	890	106	3,000	1.18	0.29	0.50	12.5
3	II	26	II	Kamikawa, Hokkaido.	National Forest. Planted stands of conifers. Regeneration by clear cutting and planting.	747	242	3,600	1.70	0.16	0.22	20.0
4	II	31	II	Kamishihoro, Hokkaido.	//	916	242	2,200	1.53	0.47	0.42	30.0
5	II	35	II	Hombetsu, Hokkaido.	Private forest. Natural mixed stands of fir, spruce and hardwoods. Natural regeneration by selection cutting.	328	360	2,000	5.99	0.17	0.21	56.0
6	II	26	II	Furano, Hokkaido.	Tokyo University Forest. Natural mixed stands of fir, spruce and hardwoods. Natural regeneration by selection cutting.	1,620	240	5,200	2.67	0.13	0.50	25.0
7	II	38	II	Iwate, Honshu.	National Forest. Planted stands of conifers. Regeneration by clear cutting and planting.	1,050	100	2,000	1.51	0.22	0.50	16.1
8	II	36	II	Nagano, Honshu.	//	599	150	8,000	2.65	0.50	0.50	16.7
9	III	63	III	Iwate, Honshu.	National Forest. Natural stands of hardwoods. Regeneration by clear cutting and planting conifers.	860	90	3,000	0.93	0.30	0.20	9.1

10	III	48	III	〃	〃	1,013	110	3,000	0.93	0.30	0.20	10.1
11	III	65	III	〃	〃	1,002	83	9,000	0.84	0.36	0.20	4.9
12	III	66	III	〃	〃	1,004	181	6,000	0.84	0.33	0.20	8.9
13	III	69	III	Tochigi, Honshu.	National Forest. Natural mixed stands, conifers and hardwoods. Regeneration by clear cutting and planting conifers.	1,654	200	22,000	1.78	0.50	0.20	8.5
14	III	45	III	Gumma, Honshu.	National Forest. Planted stands of conifers. Regeneration by clear cutting and planting.	3,583	250	9,100	0.80	0.70	0.20	10.5
15	III	65	III	Nagano, Honshu.	National Forest. Natural mixed stands of conifers and hardwoods. Regeneration by clear cutting and planting conifers.	2,400	282	20,000	1.39	0.55	0.20	9.5
16	III	53	III	Shizuoka, Honshu.	National Forest. Planted stands of conifers. Regeneration by clear cutting and planting.	1,454	244	19,500	1.78	1.00	0.20	11.6
17	III	56	III	〃	〃	972	235	13,000	1.78	0.70	0.20	12.9
18	III	67	III	Mie, Honshu.	Private forest. Planted stands of conifers. Regeneration by clear cutting and planting.	920	200	15,600	3.00	0.30	0.20	12.3
19	III	62	III	〃	〃	200	350	11,700	0.97	0.30	0.20	10.5
20	III	61	III	〃	National Forest. Natural mixed stands of conifers and hardwoods. Regeneration by clear cutting and planting conifers.	1,440	121	11,700	1.25	0.39	0.20	8.0
21	III	61	III	Kochi, Shikoku.	Private forest. Planted stands of conifers. Regeneration by clear cutting and planting.	582	300	9,000	1.20	0.80	0.20	16.2
22	IV	77	IV	Niigata, Honshu.	National Forest. Planted stands of conifers. Regeneration by clear cutting and planting.	695	247	7,800	2.57	0.22	0.20	17.2
23	IV	87	IV	Tochigi, Honshu.	Private forest. Planted stands of conifers. Regeneration by clear cutting and planting.	1,004	286	13,000	1.49	0.80	0.20	13.3

6-2. Forest Types and the Road Density

There are various forest types in Japan. Among them some types are very important for economic forestry. Such economic forests could be practically classified at least in ten types according to tree species, method of regeneration and forest forms.

Of these ten types, only five took place in our field investigations. Therefore, further investigations are expected for the different types of forests. Although more adequate figures will be obtained by the statistic treatment of the results of sufficient number of field investigations in future, here the auther is roughly sugesting the standard road density which might be useful for planning forest road network in Japan. Such figures are shown in the Table 4, in which the standard density means the density inevitable for the mechanized logging operations at present and in the near future in Japan.

Further supplementary forest roads for the purposes other than logging should be added to complete total forest road system of the forestry project.

Table 4. Standard Forest Road Density Suggested.

Terrain	Type of Logging Operation	Standard Density m/ha
Class I Even	Type I Truck hauling type	30 ～ 50
Class II Hilly	Type II Tractor hauling type	20 ～ 30
Class III Steep	Type III Medium distance skyline type	10 ～ 20
Class IV Very steep	Type IV Long distance skyline type	5 ～ 15

7. References

1) Hafner, F.: Zur forstlichen Wegenetzlegung in steilem Gebirgsgelände. Allgemeine Forstzeitung. 75 Jahrgang, folge 3/4, 1964.
2) Hori, T.: Judgement of topography on the map for road net planning. (Jap.), Journal of the Japanese Forestry Society, Vol. 47, No. 4, 1965.
3) Kamiizaka, M.: A study on the optimum density of Forest roads. (Jap.), Journal of the Japanese Forestry Society, Vol. 45, No. 9, 1963.
4) Kato, S.: Logging industry. (Jap.), 1954.
5) Larsson, G.: Studies on forest road planning. Transaction of the Royal Institute of Technology, 1959.
6) Matthews, D.M.: Cost control in the logging industry, 1942.
7) Minamikata, Y.: Optimum and marginal density of the forest road in the logging project. (Jap.) Bulletin of the Tokyo University Forest, No. 61, 1965.
8) Okawara, S.: Studies on the logging road density related to the distance of tractor hauling in Obihiro National Forest. (Jap.) Journal of the Japanese Forestry Society, Vol. 46, No. 7, 8, 9, 1964, Vol. 47, No. 6, 1965.
9) Pestal, E.: Kardinal Punkt 500 m, Rückungsmethode entscheiden Wegnetzdichte. Holz-Kurier, Nr. 51/52, 1963.
10) Steinlin, H.: Anfgabe des Erschliessungsnetzes und seine Answirkung auf die Führung eines Forstbetriebes. Schweizerlische Zeitschrift für Forstwesen, Nr. 9, 1963.
11) Sugihara, H. and Iwakawa, O.: Ratio of the increment in distance of the road alignment. (Jap.), Journal of the Japanese Forestry Society, Vol. 42, No. 7, 1960.
12) Sundberg, U.: A study of timbertransportation, SDA, 1960.

林 道 網 に 関 す る 研 究

——林道密度について——

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概　　要

この報告は昭和39·40年度文部省科学研究費の補助を受けて行った総合研究の結果を取りまとめたものである。まず近代林業における林道網の意義を明らかにし，林道の種別を検討した上で，新たに「林道密度」を定義し，研究の焦点をここにしぼった。次に林道の適正密度に関する既往の研究を吟味し，その根底の思想を明らかにした。本研究の主たる対象とした適正密度（標準密度）はマチュウスの木材生産コスト最小の密度という思想と，機械化された集材作業における最適集材距離の思想とを組合せた思想を出発点としている。このために新たに客観的な地形区分の方法を案出し，地形区分に対応する標準作業仕組みを想定した上で，木材の保続生産を前提とするいわゆる循環団地を経営の対象とした場合の標準林道密度算定公式を誘導した。

次いで全国的に 23 ヵ所の経営団地につき実地調査を行って公式の算定に必要な諸因子の適正値を把握し，これにより標準密度を試算した。その結果は第3表の通りである。これより直ちに結論を得ることは困難であり，研究分担者間に於てなお討議中であるが，一応達観的な方向付けをしてみると概ね第4表のようになるであろう。但し数値は今後の研究により若干の変更が予想されるものである。