Planning method for circular road networks considering geographical features

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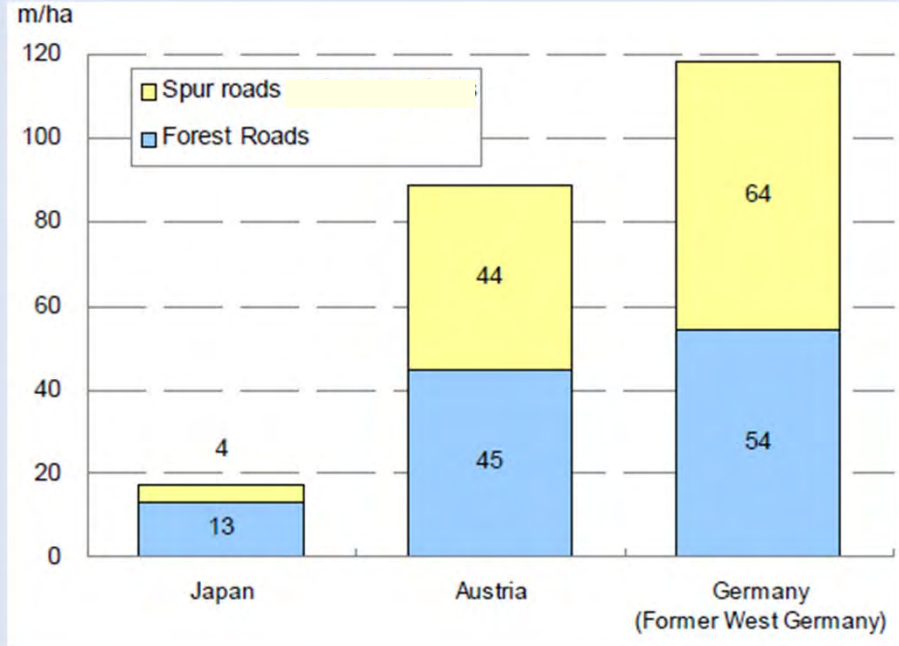
Introduction

- For sustainable forest management and low-cost forestry operation, forest road networks must be developed in Japan.



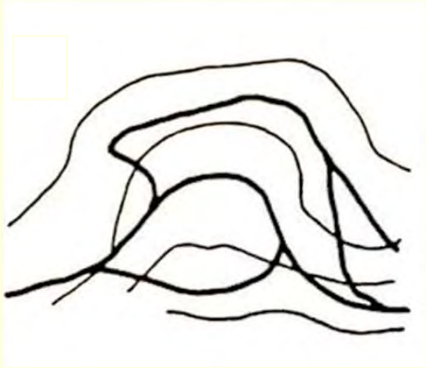
Source: BFW "Österreichische Waldinventur,"
BMELV| "Bundeswaldinventur(BWI),
"Forestry Agency

Notes: Figures are of Österreichische Waldinventur 1992/96 for Austria, of Bundeswaldinventur 1986/1989 for Germany and of accumulating total in 2007 of prefectural report for Japan.

Fig 1-11: Forest Road Network in Europe and Japan

Road network

- Arborescent network
- Mountainous area
- Shorter skidding/yarding distance
- Longer migration pathway
- No alternative route

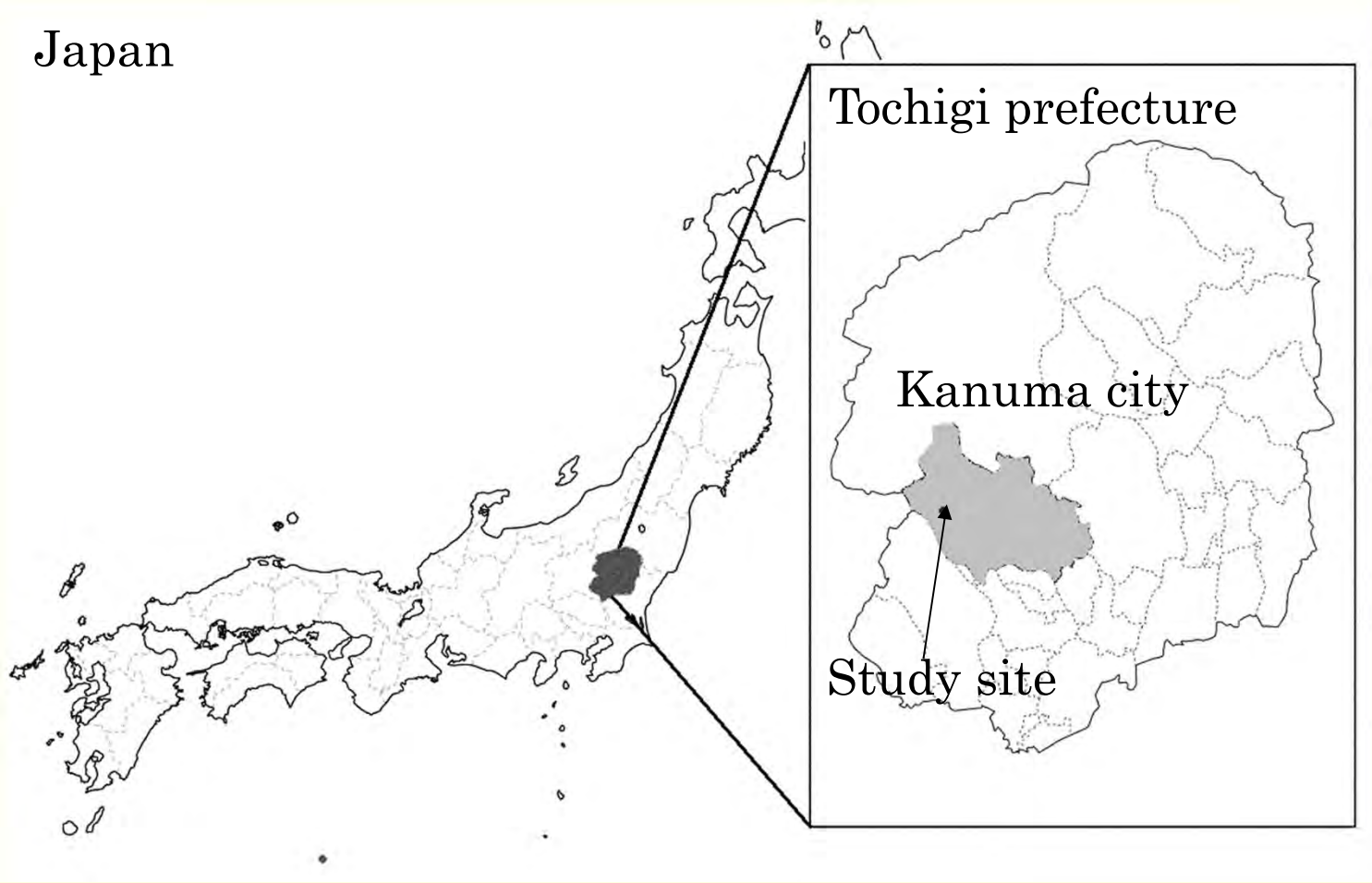


- Circular network
- Gentle slope area
- Longer skidding/yarding distance
- Shorter migration pathway
- Multiple alternative routes

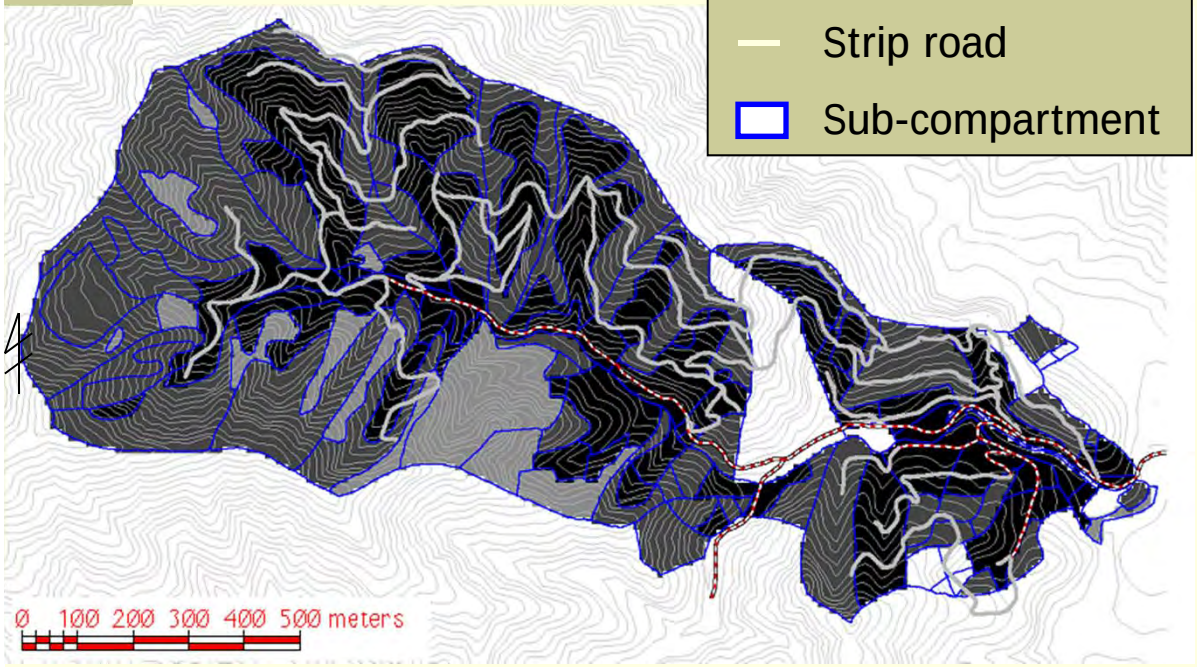
Objects

- This study developed a program for planning circular road networks from arborescent road networks on a mountainous area in Japan considering geographical features.
- Then, the road network planned by the program were compared with the existing road network constructed by the forest owner and examined using operational and traffic benefits as indexes.

Study site



Study site



Forest road

Strip road

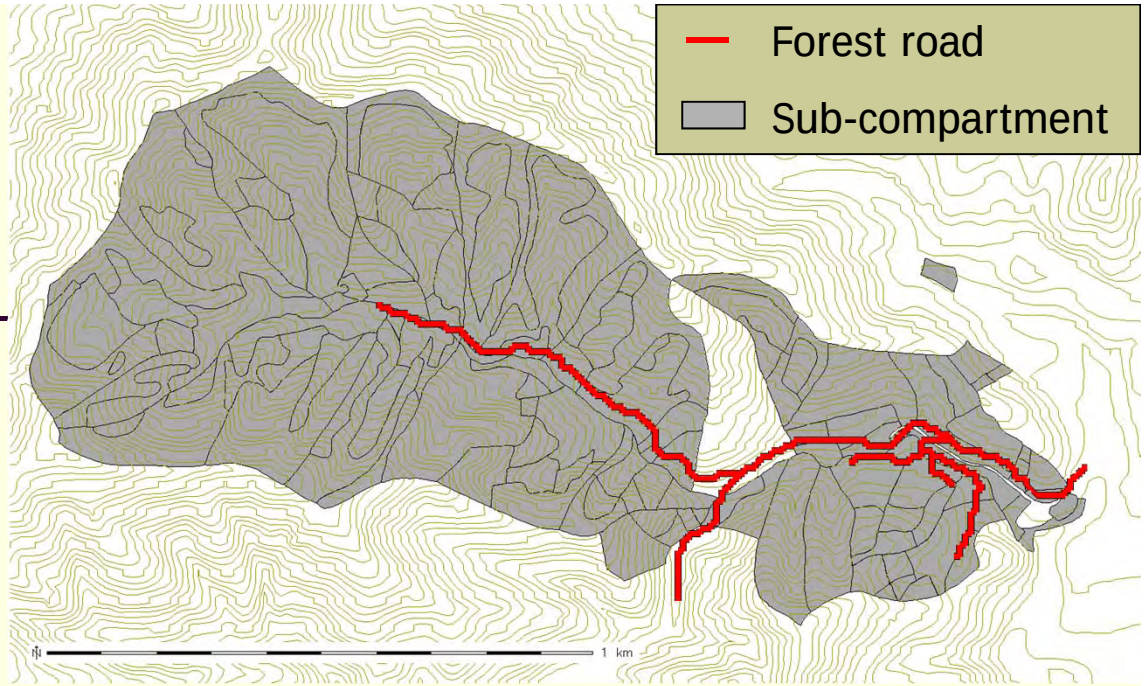
- Area: 97 ha
- Road density: 130 m/ha

- Japanese cedar 50%
- Japanese cypress 40%
- Broad-leaved tree 10%

Operation system

- Chainsaw felling and processing
- Grapple-loader with winch pre-yarding
- Forwarder forwarding.

Method

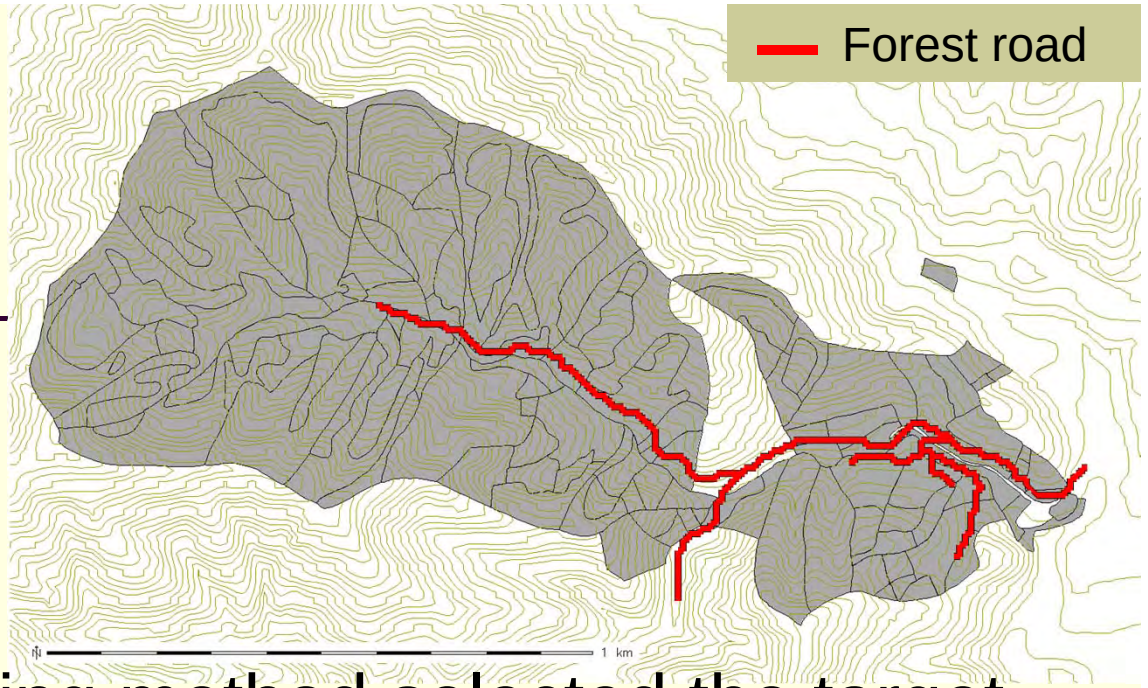


- The road network planning program was developed based on sub-compartments, which are the traditional operational units in Japan.
- The study site had a hundred sub-compartments.

Method

- The developed method first planned main strip road, then planed branch strip roads.
- Main strip roads orthogonal to the contour lines that reach the stand were planned along geographic features such as ridges or valleys to form the arborescent road network.
- Then, branch strip roads along the contour lines for operations were planned at regular intervals to form the circular road network.

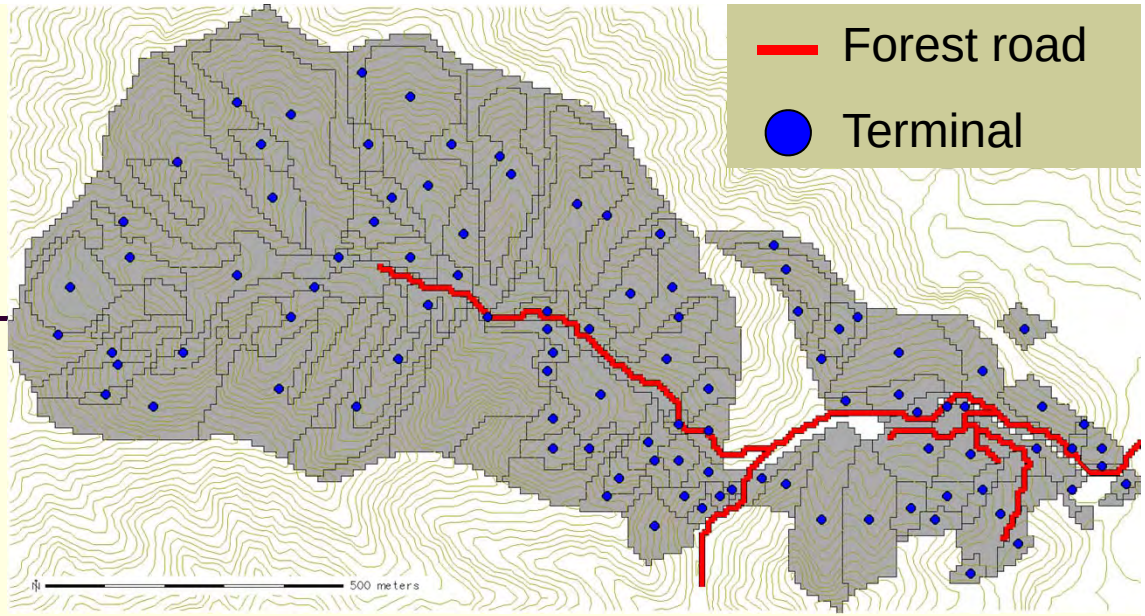
Main strip road



- First, the planning method selected the target sub-compartment that had the highest revenue among all sub-compartments.
- The revenues were estimated from
  - yield tables with the species and forest age
  - log prices: 13,500 yen/m^3 for Japanese cedar
    28,700 yen/m^3 for Japanese cypress.

€1 = 114 yen on June 27, 2011

Terminal point



- Then, the program determined the terminal point of the main strip road in the target sub-compartment.
- The terminal point was the point to which the total distance from all grids in the target sub-compartment was minimized.

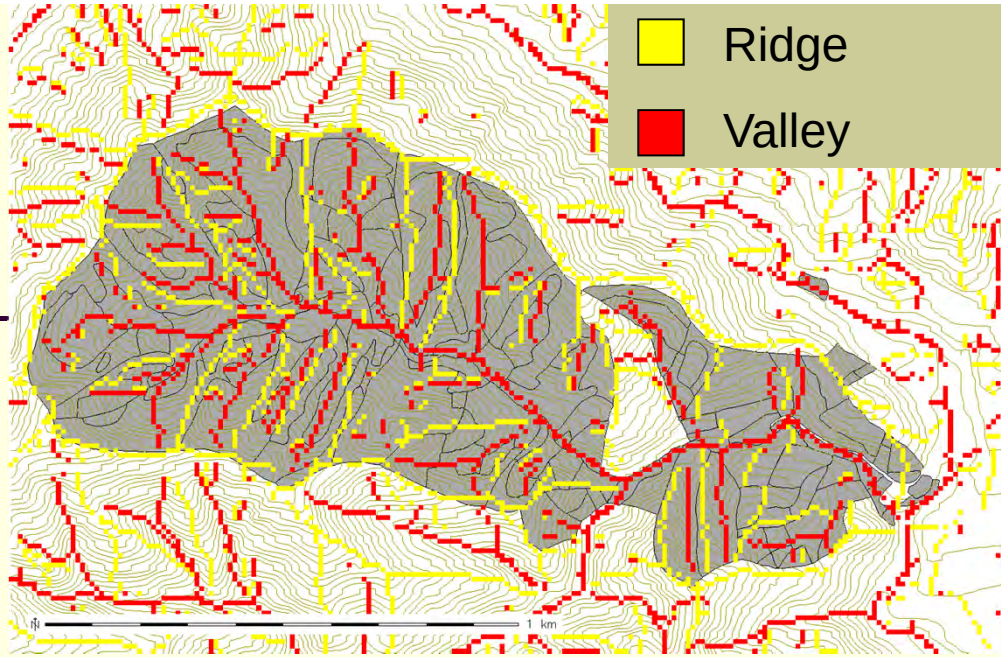
Main strip road

- The program determined the main strip road route from the terminal point to the existing roads or pre-planned roads using the Dijkstra method with the minimum earthwork volumes.
- The gradient of the main strip road was limited to below 50%.
- Values of limitation for road gradients were set to be larger than those for existing roads because of the grid-based program.

Earthwork volume

- The earthwork volumes were estimated from the slope angles of cross-sections, road width (2.5 m), right cut slope angles, and no fillings.

Geographical features

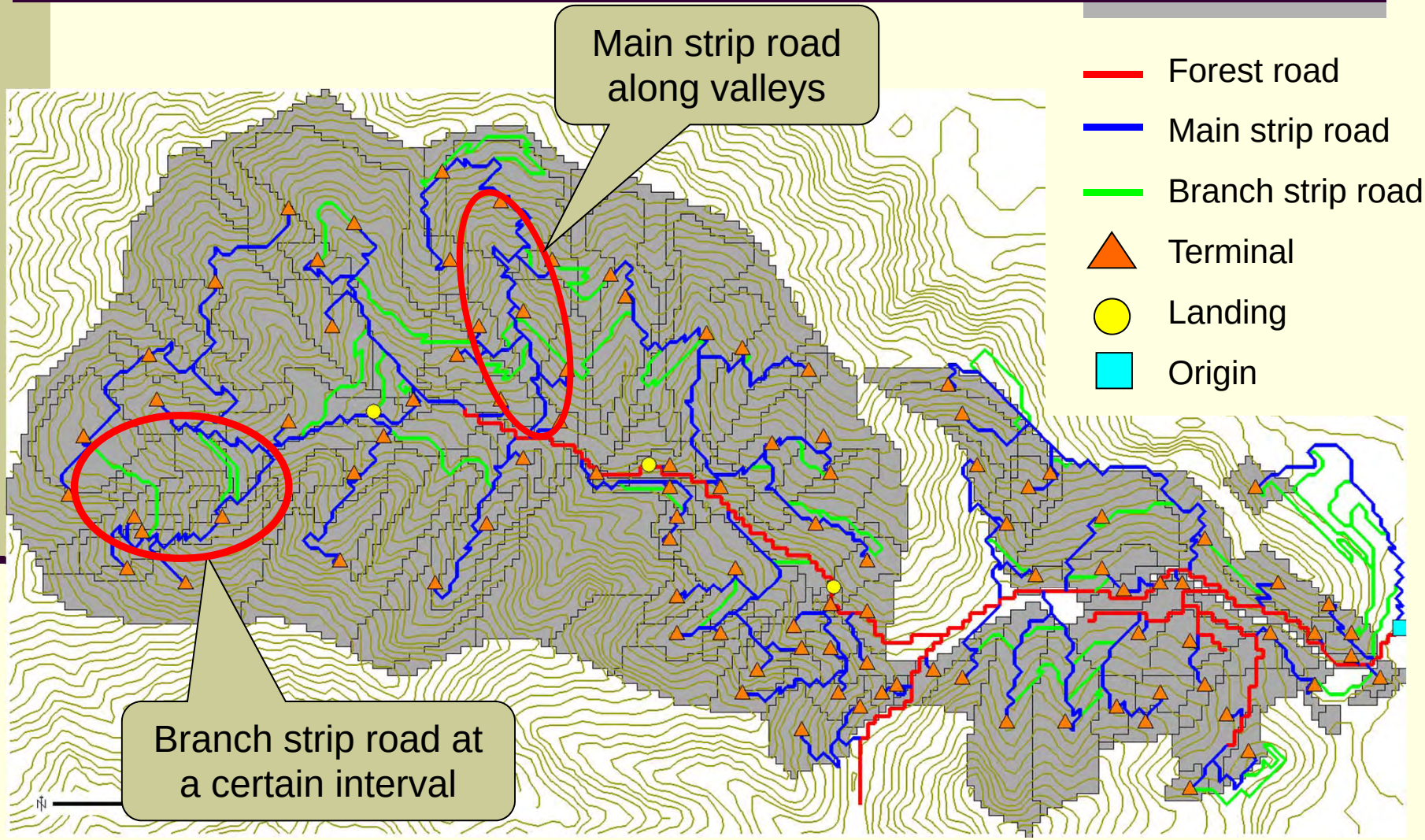


- Forest roads were traditionally constructed along the valleys in Japan.
- Nowadays, forest roads tend to be constructed on ridge tops that do not collapse easily.
- The program determined the route by estimating earthwork volumes as zero when the route of the main strip road passed over ridges or along valleys.
- Thus, the program selected the route of the main strip road preferentially, based on geographical features.

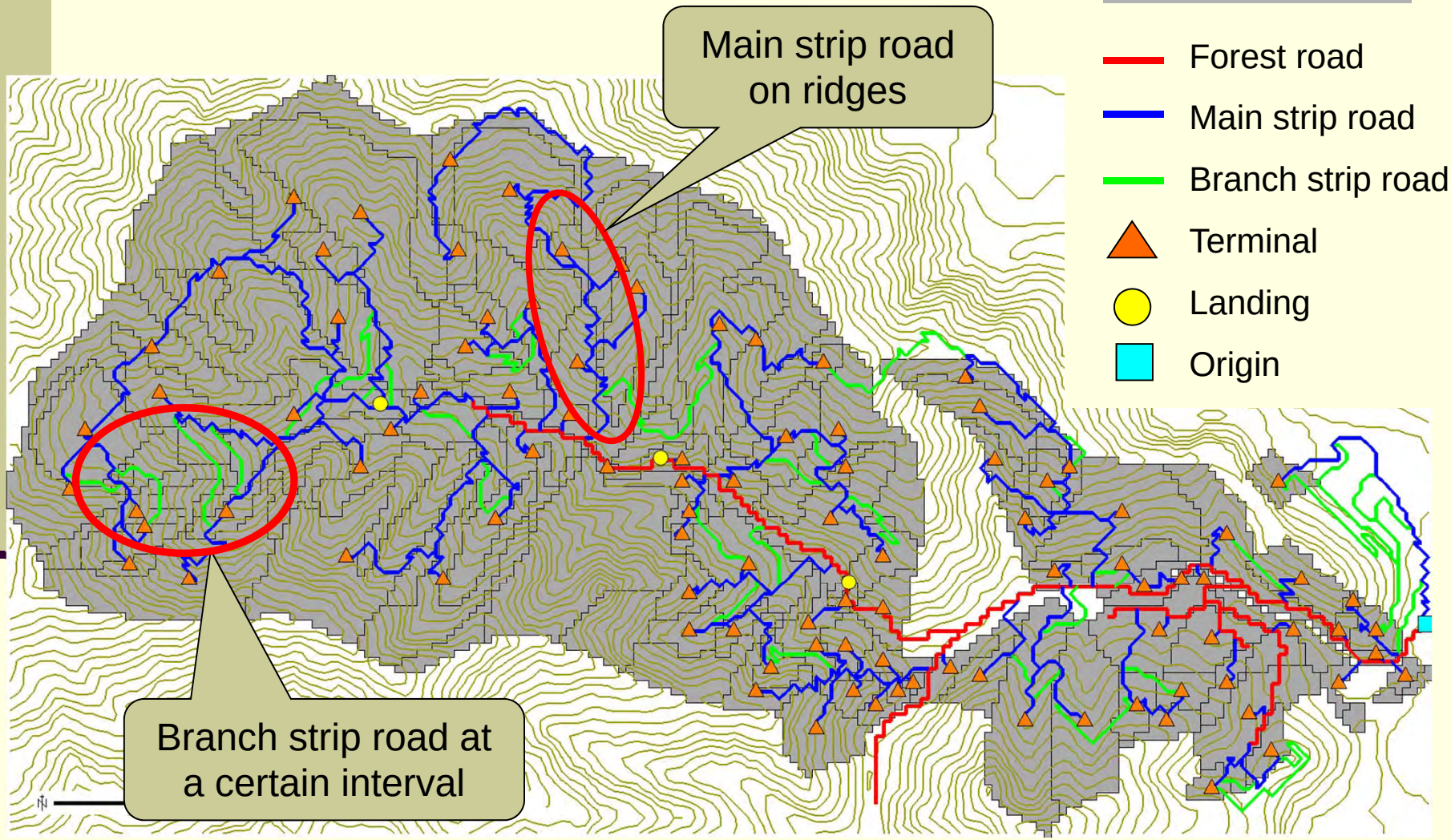
Branch strip road

- The program checked whether a branch strip road could be planned along the contour lines at 100-m intervals along the main strip roads to the existing roads or pre-planned roads using the Dijkstra method to minimize distances.
- 100-m intervals were estimated from 60 m, which is double the maximum pre-yarding distance of this site and the detour of the main strip road.
- The gradient of the branch strip road was limited to below 30%.

Road network with main strip road along valleys



Road network with main strip road on ridges



Optimizing

- Main strip roads were sequentially planned from the sub-compartments that had the highest revenues.
- However, the order of the planning of main strip roads may not be the best.
- Therefore, the order of planning of main strip roads was changed at random while revenues and expenditures were estimated.
- Then, the road network with the largest benefit was planned.

€1 = 114 yen on June 27, 2011

Revenues

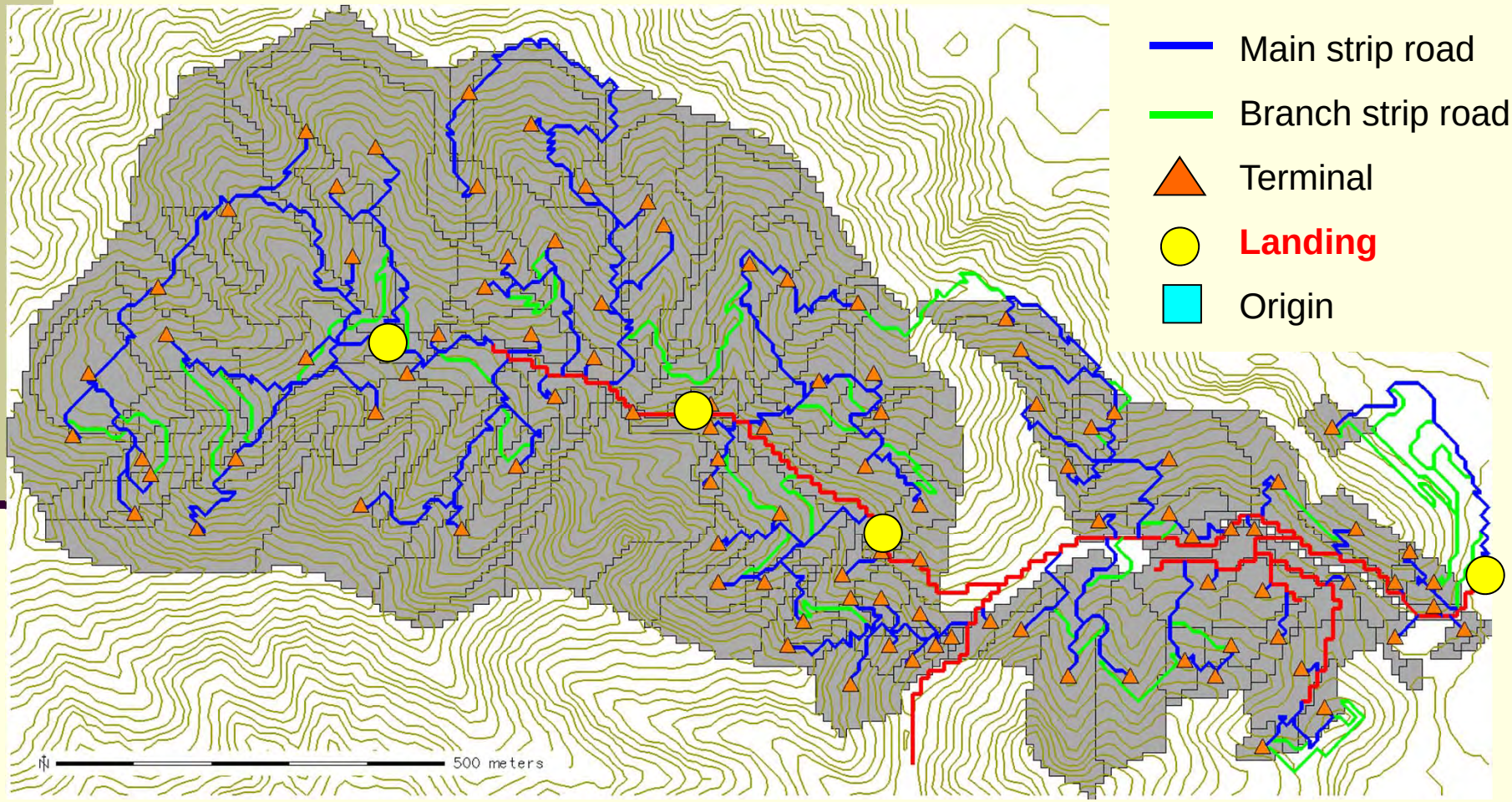
- Thinning operations with a 20% thinning rate of stocks were assumed to be conducted on both 30-m sides along the existing or planned roads.
- All thinned woods were assumed to be extracted.
- The revenues were estimated from
  - volume of extracted thinned woods
  - log prices: 13,500 yen/m^3 for Japanese cedar
    28,700 yen/m^3 for Japanese cypress.

€1 = 114 yen on June 27, 2011

Operation cost

- 3,000 yen/m^3 for chainsaw felling and processing and grapple-loader with winch pre-yarding
- 0.32 yen/m^3/m for forwarder forwarding.

Forwarding distance



Construction cost

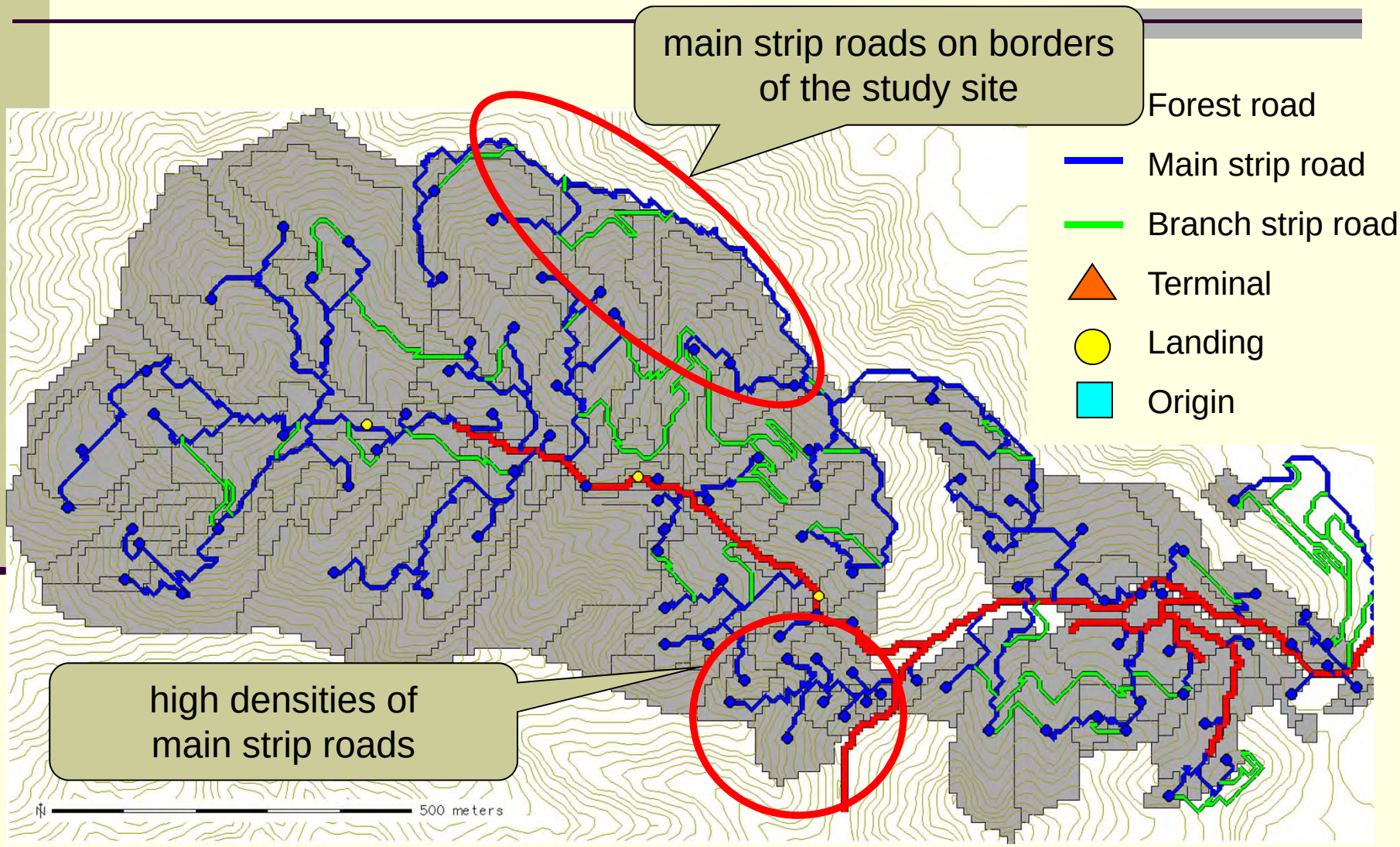
€1 = 114 yen on June 27, 2011

- Strip road construction cost *C* (yen/m) was estimated using the following equation:

$$C = \frac{\tan\theta \times W^2}{2} \times C_a + W \times C_b$$

- where, θis the slope angle of cross-sections (°), *W* is the road width (2.5 m), C_a is the cutting and filling cost (437 yen/m^3), and C_b is the clearing and grubbing cost (203 yen/m^2).

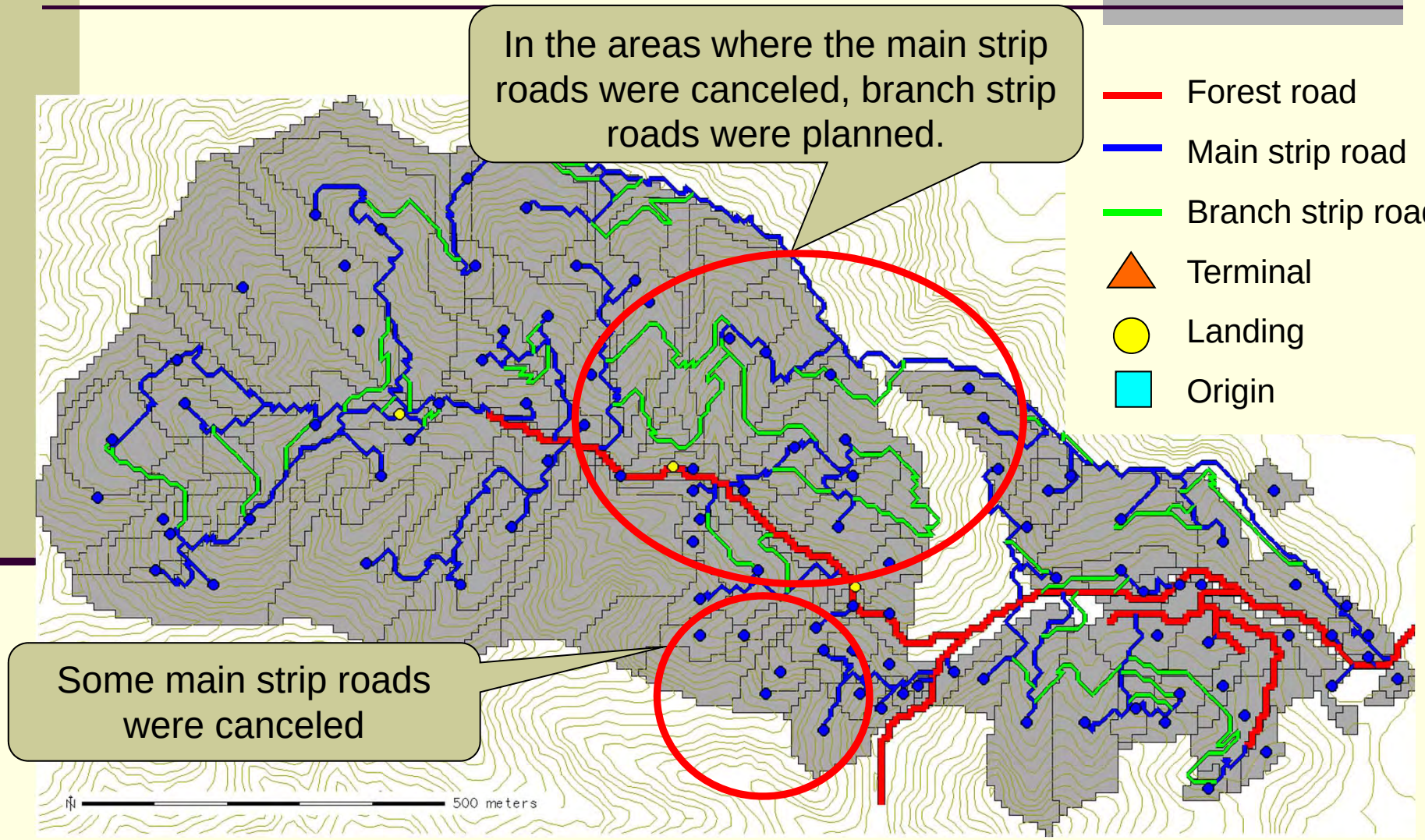
Optimized road network with main strip road on ridges



Decreasing the number of terminal points

- The terminal points in the sub-compartments were not evenly distributed.
- Consequently, some areas had high densities of main strip roads.
- Therefore, the density of the road network was adjusted by decreasing the number of terminal points of the main strip roads in order to eliminate overlap of the operational areas.

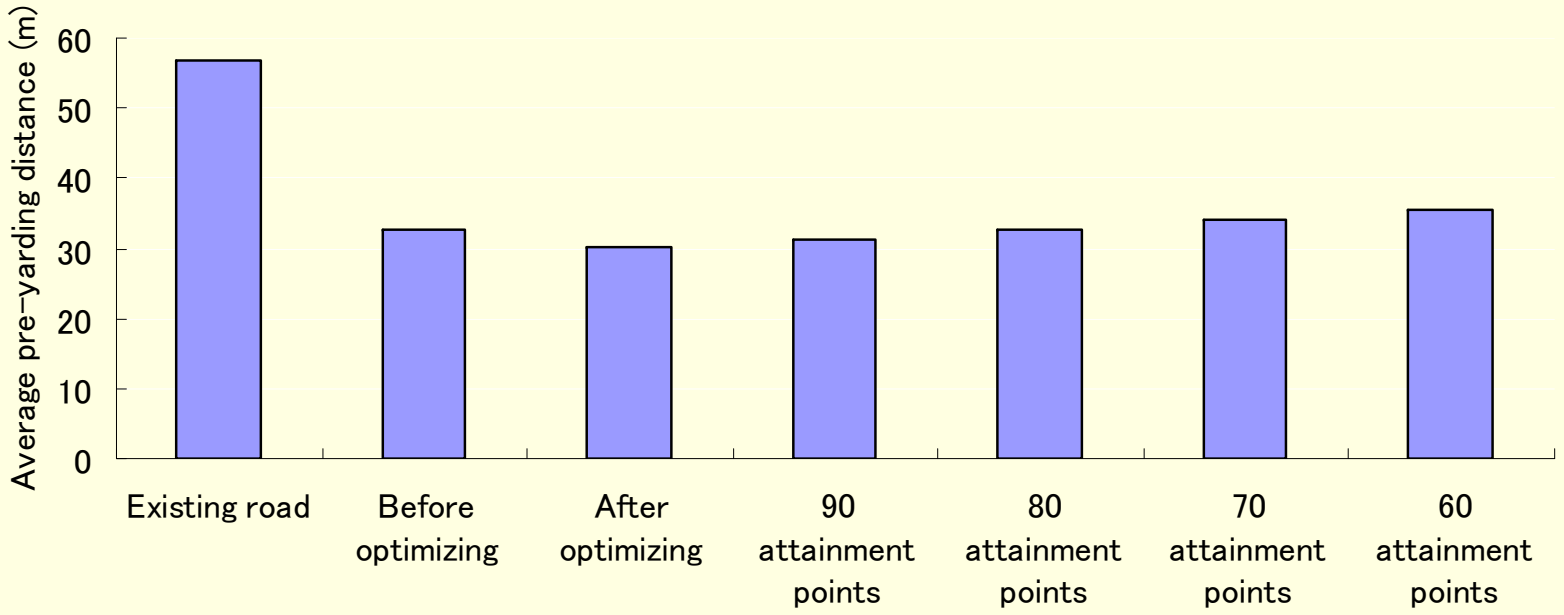
70 terminal points



Evaluatoin

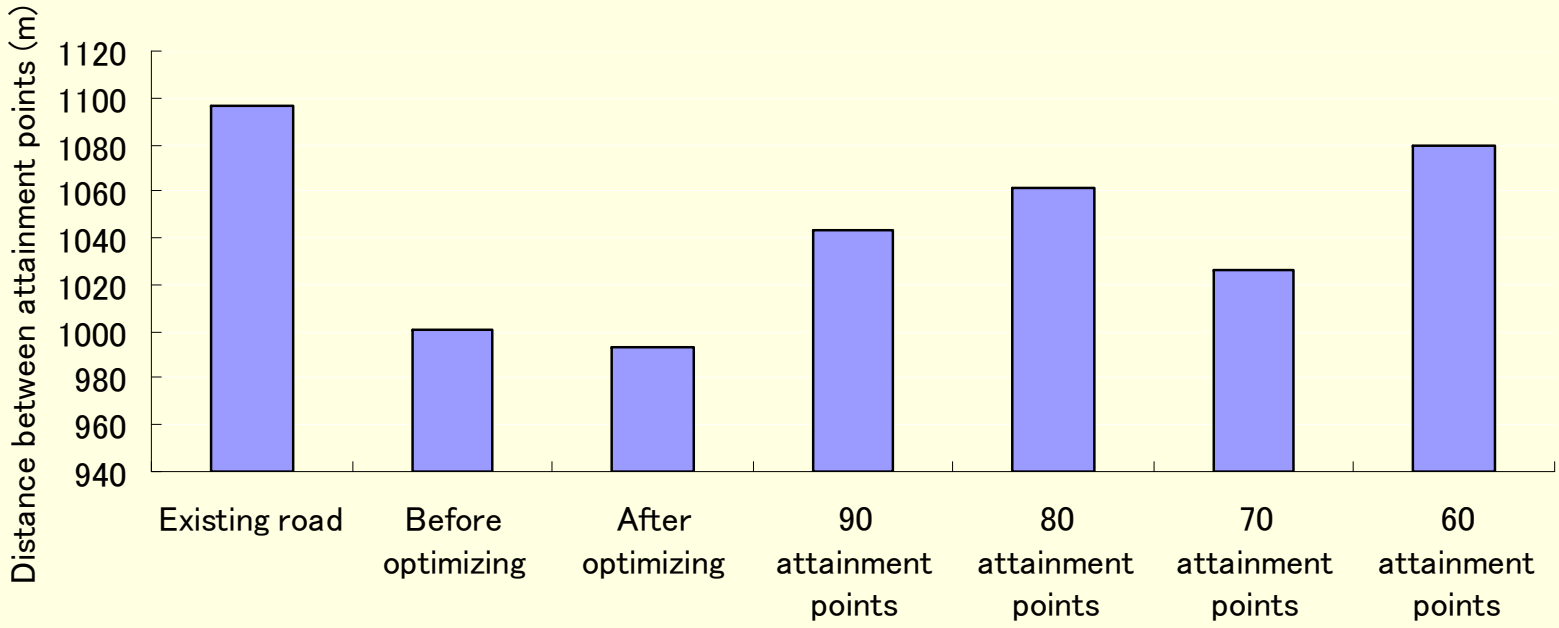
- Road density
- Ratio of branch strip road length to total road length
- Average pre-yarding distance
- Ratio of average pre-yarding distance to theoretical average pre-yarding distance
  - theoretical average pre-yarding distance = 2,500/road density
- Average distance between the terminal points of the main strip roads in all sub-compartments
- Economic balance

Average pre-yarding distance



The average pre-yarding distances of the road networks planned by the program were shorter than that on the existing road network and the average pre-yarding distance after optimizing was the shortest.

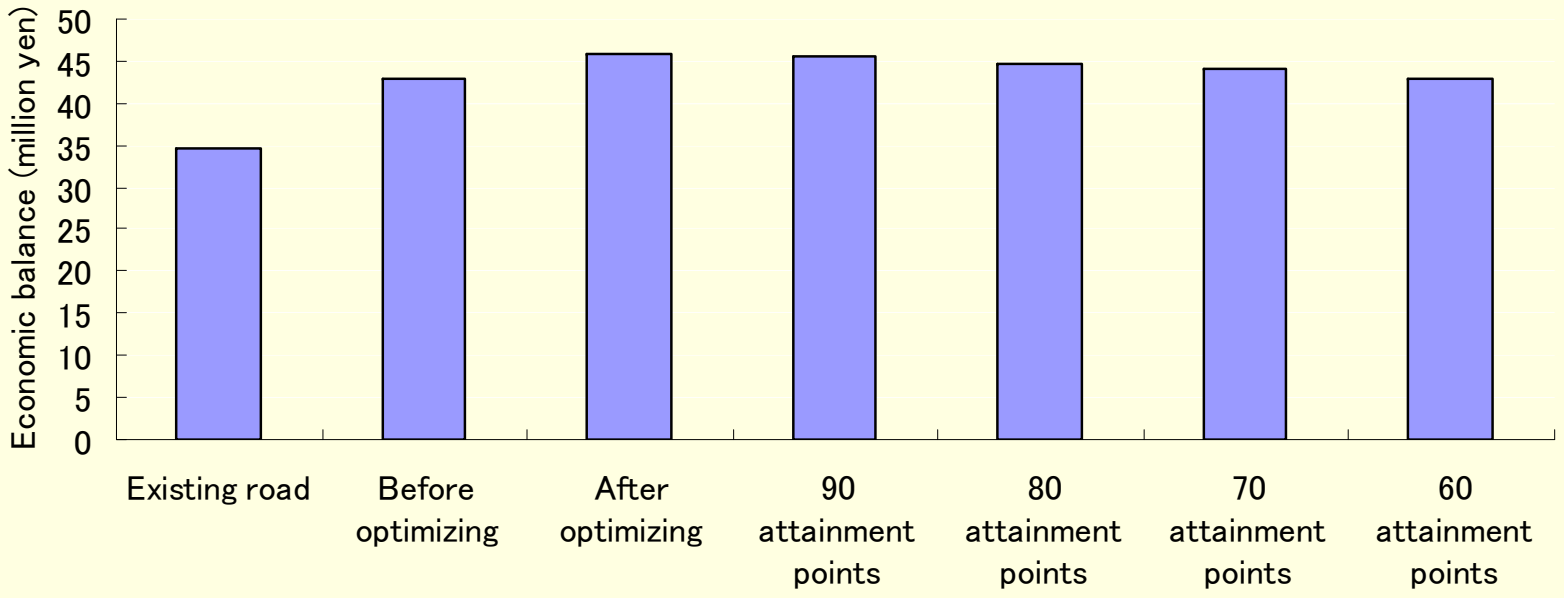
Average distance between the terminal points



The average distances between the terminal points of the road networks planned by the program were also shorter than that on the existing road network and the average distance after optimizing was the shortest.

Economic balance

€1 = 114 yen on June 27, 2011



The benefits of the road network planned by the program were larger than that on the existing road network and the benefit after optimizing was the largest.

Conclusions

- This study developed a program for planning circular road networks considering geographical features.
- The program optimized the road networks by changing the order of planning of the main strip roads and decreasing the number of terminal points.
- The average pre-yarding distance and the average distance between terminals on the road network after optimization were the shortest and the benefit was the largest.
- Therefore, the program successfully optimized circular road networks with the largest economical and operational benefits.