MATERIALS AND METHODS

Materials

The materials and equipments needed for this study in collecting field data and analysis, and establishing mathematical models were listed as following;

1. Topographic Maps with Scale 1:50,000
2. Theodolite Instruments, tripods, and accessories
3. Leveling Instruments, tripods, leveling staff rod, and accessories
4. Metal Tape 50 m.
5. Global Positioning System (GPS)
6. Note Book Computer
7. Desktop Computer
8. Digitizer
9. Tally Counter for Traffic Volume counting
10. Computer Softwares for Mathematical Modeling
11. Laser Printer
12. Plotter
13. Drawing Sets, Calculators
14. Four wheel drive light truck

Methods

The forest roads characteristics, designing, and constructing data were investigated and studied at Khao Yai National Park. These information were road width, road shoulder, line and profile, horizontal and vertical curve alignment, stopping sight distance, drainage structures, soil erosion protection structures, traffic signs and facilities, and traffic volume. The procedure in collecting field data and analysis, and developing park road standard in National Park of Thailand for tourism purposes were summarized step by step as listed following;

1. Literature review of all previous work of forest road standards including laws, Acts, regulations, limitations, announcements of the Royal Forest Department, etc.

2. Collecting and study secondary data for all road construction in forest area such as tourist statistics, traffic volume, climatic data, topographic data, forest and vegetation type, soil type, stream flow data, geology data, etc.

3. Field data collecting of existing park road in Khao Yai National Park all data concerning road density, location and position, road type, roadway width, and other road characteristics data.

4. Traffic volume collecting, speed, type and quantity of vehicle per day at study points.

5. Route location survey, horizontal and vertical alignment, maximum gradient.

6. Data collecting of road geometric design such as typical section, carriage width, surfacing design, surfacing materials, road structures, super elevation.

7. Data collecting of road drainage structures, type and quantity checking, capacity evaluation, and adequate number of structure checking.

8. Traffic sign and safety checking.

9. Road Density calculation

$$\text{Road Density} = \frac{\text{Length of road in km.}}{\text{Area of forest region in km}^2}$$

10. Data analysis and computer simulation.

11. Develop and establishing mathematical modeling of park road by using multi-goal programming.

The hybrid schematic diagram for problem solving of park roads standard modeling in Khao Yai National Park was shown on Figure 11.

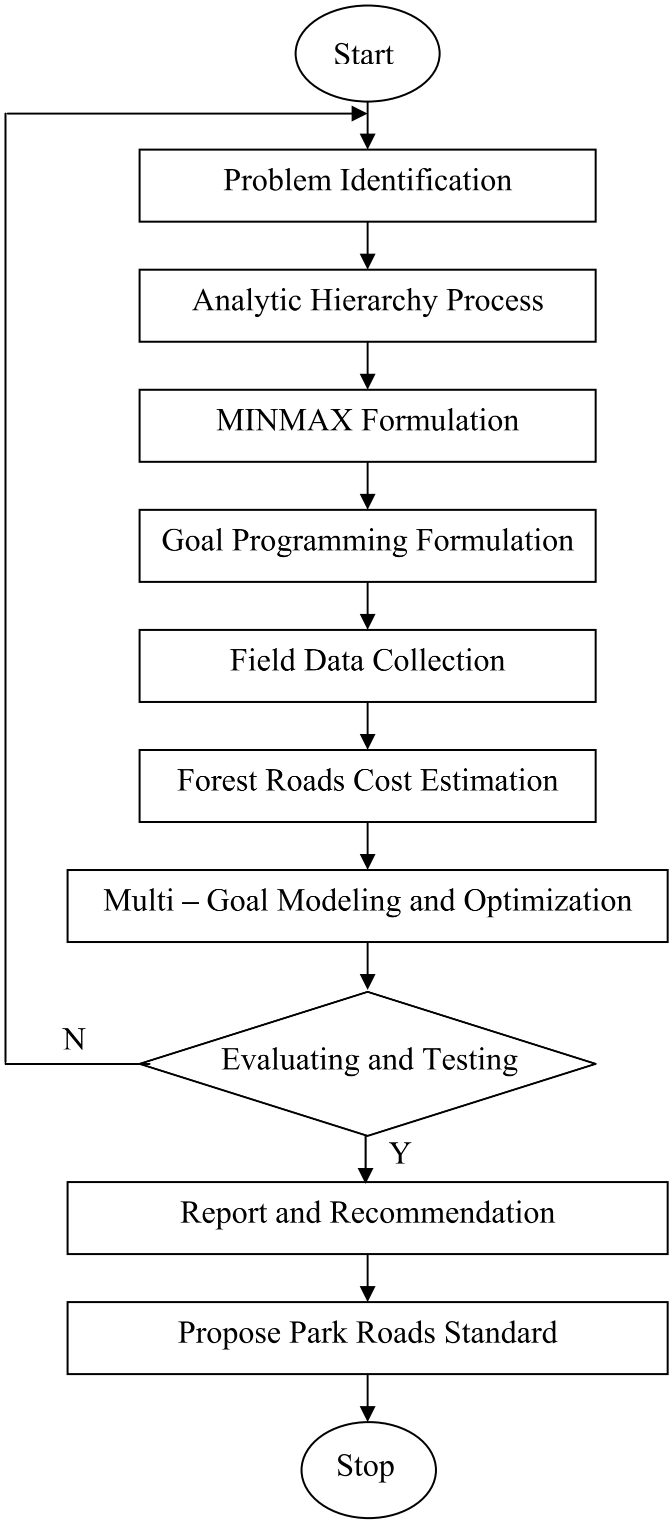

Figure 11 Hybrid schematic diagram for problem solving of park roads standard modeling.

Cost Estimation of Forest Road Construction

In developing mathematical models of forest road in this study, existing park road designing and cost data were used to derive the relationships of mathematical models. These relationships used to formulate multi-objective mathematical programming models to obtain optimal values for park road design in National parks.

The forest road cost estimation data can be determined by each type of work done. The forest road dimensions and unit cost data in cost estimation were defined as decision variables X_1, X_2, X_3,…, X_{37} and the coefficients a_1, a_2, a_3,…., a_{20} as shown in the Appendix B. The details of cost estimation in forest road construction were listed as followings.

1. Construction Survey in Kilometer (Km)

Quantity of work done	$= X_1/1000$	km.
Cost of work	$= a_1 X_1 /1000$	Baht
	$= 3{,}000 X_1 /1000$	Baht
Total cost	$= 3 X_1$	Baht

2. Clearing and Grubbing in Rai unit

Quantity of work done	$= X_1(X_2+2 X_{13}) /1600$	Rai
Cost of work done	$= a_2 X_1(X_2+2 X_3)/1600$	Baht
	$= 1000 X_1(X_2+2 X_3)/1600$	Baht
Total Cost of work done	$=0.625 X_1(X_2+2 X_3)$	Baht

3. Top soil removal in m^3.

Quantity of work done	$= X_1(X_2+2 X_3)0.15$	cu.m.
Cost of work done	$= 0.15a_3 X_1(X_2+2X_3)$	Baht
	$= 0.15x4.37 X_1(X_2+2X_3)$	Baht
Total Cost of work done	$= 0.6555 X_1(X_2+2X_3)$	Baht

4. Excavation in m^3

The grade line of road center line(CL.) profile of finished forest as shown in the Figure 12 can be formulated as the equation of grade line (Gieck, 1979; Tuma, 1979).

$$Y_1 = a + bx \quad (1)$$

Where " a " is y-axis intercept, b is a slope of the line.
Substitute b, slope of the line, with G, percent grade. Then, the equation is.

$$Y_1 = a+G_1x/100$$

then $$Y_{grade} = a+G_1x/100 \quad (2)$$

From the general parabolic vertical curve equation (Wylie and Barrett, 1985; Davis *et.al.*,1981), the expression is

$$Y_2 = ax^2+bx+c \quad (3)$$

Therefore, the parabolic curve equation can be obtained in term of grade line relation (Meyer and Gibson, 1980; Husain and Nagrai, 1975).

$$Y_2 = (G_2-G_1)x^2/200L+G_1x/100+c \quad (4)$$

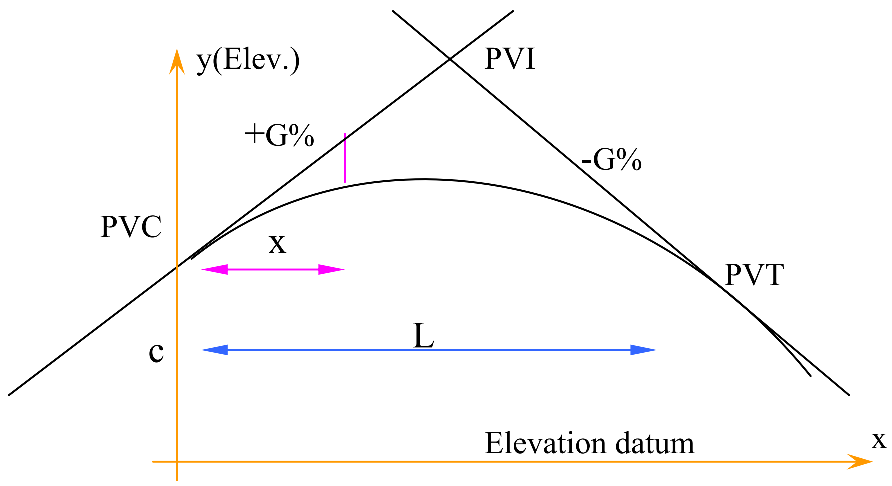

Figure 12 Depict the parabolic vertical curve alignment of road center line.

Source: Meyer and Gibson (1980)

Where: y is elevation of any point on the vertical curve

x is the horizontal distance from point of curvature to the point being computed.

G_1 is the incoming grade in percent

a = $(G_2-G_1)/200L$, is one-half the rate of change of grade in percent

c is y-axis intercept

L is the length of vertical curve.

Finally, the general equation of the vertical curve of forest road can be obtained.

$$Y_{Lvc} = (G_2-G_1)x^2/200L_{vc} + G_1x/100+c \quad (5)$$

The cut and fill volume in road construction can determine from the different of subgrade elevation and grade line of road as shown in the section end area in Figure 13. The other type of road cross section was shown in Appendix A.

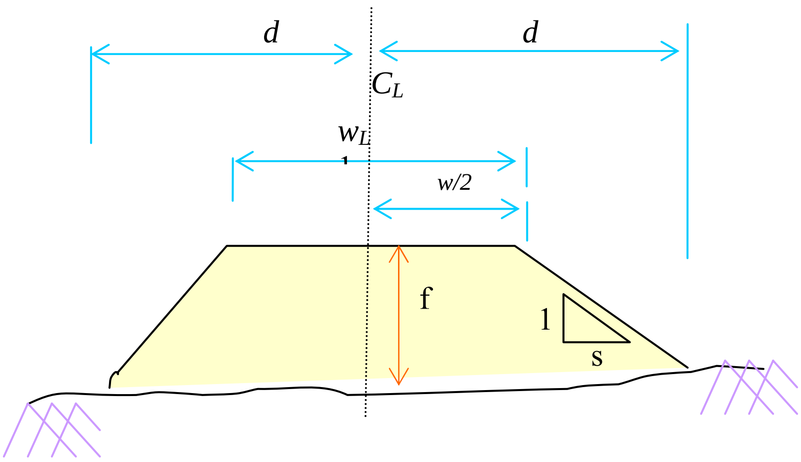

Figure 13 Portray the end area section of embankment in forest road construction.
Sources : Meyer and Gibson (1980); Davis *et.al.*, (1981)

f = elevation of road construction – elevation of original soil surface or subgrade

$f = Y - Y_{subgrade}$

where : f = + ; in case of soil filling

$f = -$; in case of soil cutting

The f value at any point on grade line can calculate from equation

$$f = a+G_1x/100 - Y_{subgrade}$$

Therefore f value at any point on vertical curve can depict as

$$f = (G_2-G_1)x^2/200L_{vc}+G_1x/100+c - Y_{subgrade} \quad (6)$$

<u>End area computation</u>

The area of road section as shown in Figure 11 is found from

Area of section, $A = f\,(w+sf)$ (7)

$= f\,(x_2+sf)$

side slope for soil filling 1:2 hence $s = 2$

side slope for soil cutting 1:1.5 then $s = 1.5$

Determine the road section end area at every Sta. of 25 meters A_1, A_2 , A_3, Then calculate soil cutting volume or soil filling volume by Average End Area technique (triangular prism)

Average end area, where f_1, f_2 are the same sign

$$V = ½\,(A_1+A_2)L$$

Triangular prism method, where f_1, f_2 are not the same sign

$$V = ½AL$$

Then, at Sta.1 and Sta.2 that 25 meters apart, and the elevation at subgrade are $Y1_{subgrade}$, $Y2_{subgrade}$, the end section area A_1, A_2 are

$$A_1 = f_1\,(x_2+sf_1)$$

$$A_2 = f_2\,(x_2+sf_2)$$

The earth volume by Average End Area Method in case of f_1 and f_2 are the same sign (both +, or -) are

$$V = (A_1+A_2)L/2$$

$$V = (f_1\,(x_2+sf_1) + f_2\,(x2+sf_2))\,L/2$$

$$V = ½L\,(x_2\,(f_1+f_2) + s(f_1^2 + f_2^2)) \quad (8)$$

Case f_1 and f_2 are same sign

from(8), if f_1 and f_2 are both minus sign (-) indicate that the soil volume is excavation. Therefore, s =1.5 and L= 25 meters, then

$$V = 12.5 (x_2 (-f_1 - f_2) + 1.5 (f_1^2 + f_2^2))$$

$$V = -12.5x_2(f_1 + f_2) + 18.75(f_1^2 + f_2^2) \quad (8a)$$

from(8), if f_1 and f_2 are both plus sign (+), the soil volume is embankment. Then, s =2.0 and L= 25 meters, the expressions became as follows;

$$V = 12.5 (x_2 (f_1 + f_2) + 1.5 (f_1^2 + f_2^2))$$

$$V = 12.5x_2(f_1 + f_2) + 18.75(f_1^2 + f_2^2) \quad (8b)$$

Case f_1 and f_2 are different sign

Determine the soil volume by triangular prism method (Parmly, 1981), if f_1 and f_2 are different sign, the –v is excavation and +v is embankment.

$$V_1 = ½A_1L_1 \quad (9)$$

$$V_2 = ½A_2L_2 \quad (10)$$

and $$L = L_1 + L_2 \quad (11)$$

substitute f in (9), (10) assume $f_1 = – f_1$, cutting section s =1.5, and $f_2 = + f_2$, filling section s =2, therefore

$$V_1 = -f_1(x_2-1.5f_1)L_1/2$$

$$V_2 = f_2 (x_2+2f_2)L_2/2$$

and $$25 = L_1 + L_2$$

So, V_1 and V_2 can be obtained, if V is –, cutting volume, V + for filling volume.

Relation of L_1, L_2 and f_1, f_2

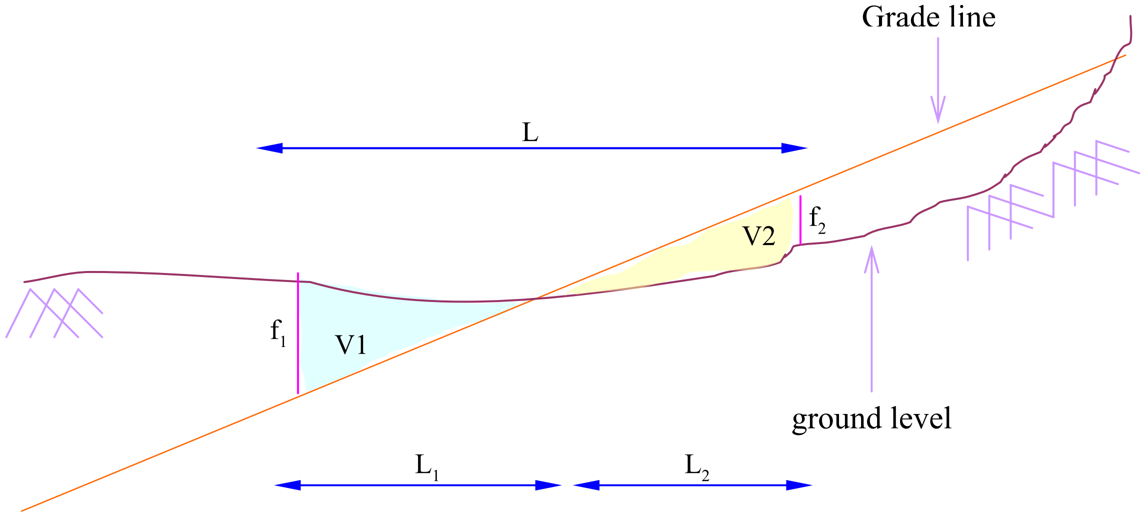

Figure 14 Portray cut and fill section at the same station.

As shown in Figure 14, from the rule of similar triangles, the expression can be formulated as;

$$\frac{f_1}{L_1} = \frac{f_2}{L_2} \Rightarrow L_2 = \frac{f_2}{f_1} L_1 \qquad (12)$$

and

$$L_1 + L_2 = L$$

$$L_1 = L - L_2 \qquad (13)$$

Substitute (12) in (13)

$$L_1 = L - \frac{f_2}{f_1} L_1$$

Then

$$L_1 + \frac{f_2}{f_1} L_1 = L$$

$$L_1 \left(\frac{f_1 + f_2}{f_1}\right) = L$$

Therefore

$$L_1 = \frac{f_1 L}{f_1 + f_2} \qquad (14)$$

Substitute L_1 from (14) in (12), to determine L_2

$$L_2 = \frac{f_2 L}{f_1 + f_2} \tag{15}$$

from $$v_1 = \frac{1}{2}AL_1 \Rightarrow \frac{1}{2}(x_2 + sf_1)f_1L_1 = \frac{1}{2}(x_2 + sf_1)f_1(\frac{f_1L}{f_1 + f_2})$$

the value of soil cutting volume V_1 can be found, as

$$v_1 = \frac{Lf_1^2}{2}\frac{(x_2 + sf_1)}{(f_1 + f_2)} \tag{16}$$

To simplify, therefore, replace L = 25 m

$$v_1 = 12.5f_1^2\frac{(x_2 + 1.5f_1)}{(f_1 + f_2)} \tag{16a}$$

And from $$v_2 = \frac{1}{2}AL_2 \Rightarrow \frac{1}{2}(x_2 + sf_2)f_2L_2 = \frac{1}{2}(x_2 + sf_2)f_2(\frac{f_2L}{f_1 + f_2})$$

Also, the value of soil filling volume V_2 can be found, as

$$v_2 = \frac{Lf_2^2}{2}\frac{(x_2 + sf_2)}{f_1 + f_2} \tag{17}$$

replaced L = 25 m $$v_2 = 12.5f_2^2\frac{(x_2 + 2f_2)}{f_1 + f_2} \tag{17a}$$

Then, the total volume of earthwork $V = \sum V$ m^3

The procedures in obtaining the total volume of soil cutting and soil filling were depicted in Figure 15.

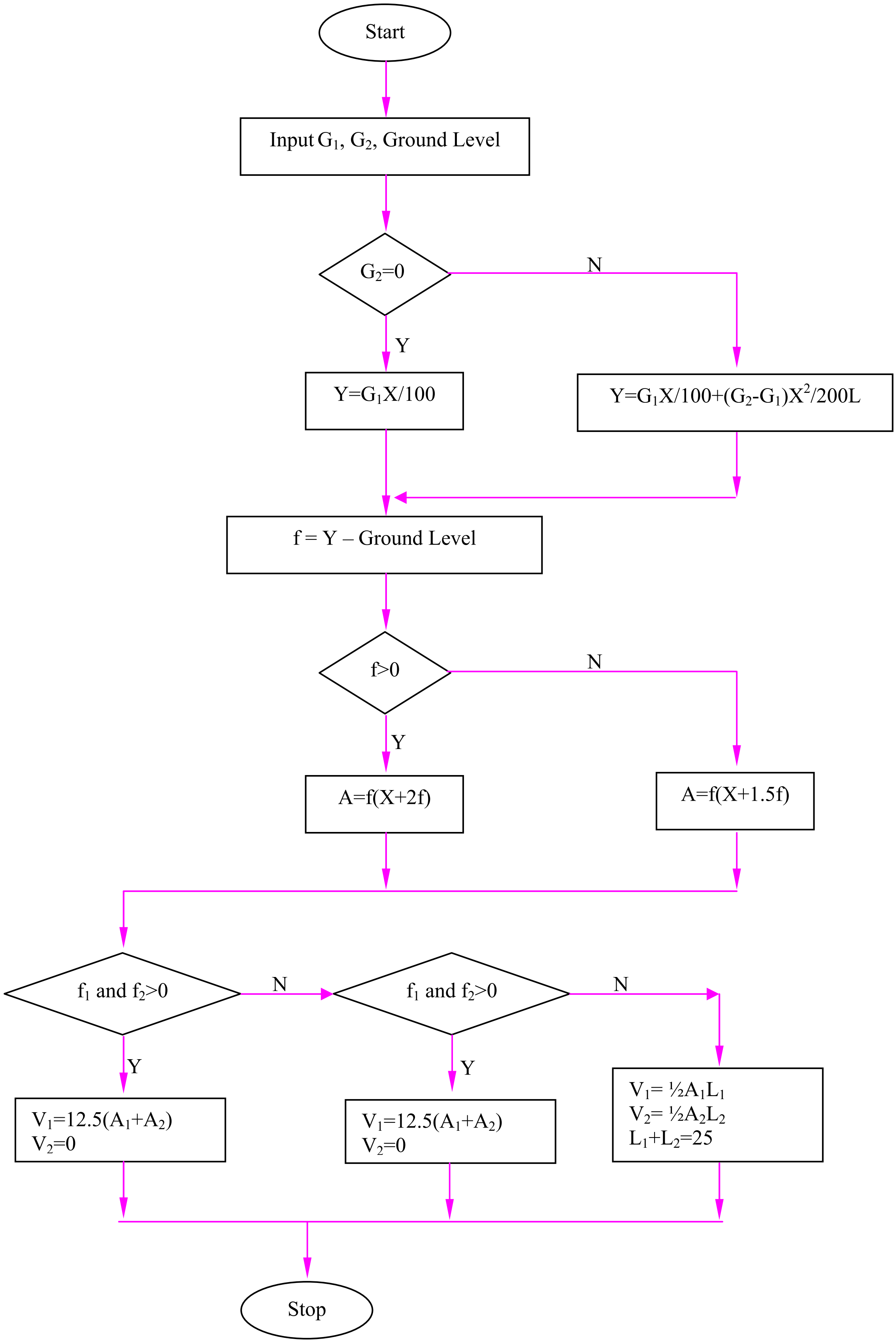

Figure 15 Soil Cutting and Soil Filling Flow Chart.

Calculate the total volume of soil cutting

Quantity of work done	$V = \sum V_{cut}$	m^3
Cost of work done	$= a_4 \sum V_{cut}$	Baht
	$= a_4(659.0029 - 306.653X_2)$	Baht
	$= 34(659.0029 - 306.653X_2)$	Baht
Total cost of work done	$= 22{,}406 – 10{,}426.202X_2$	Baht

5. Embankment, calculate soil embankment in m^3.

Quantity of work done	$V = \sum V_{fill}$	m^3
Cost of work done	$= a_5 \sum V_{fill}$	Baht
	$= a_5(34.79370+46.607X_2)$	Baht
	$= 139(34.79370+46.607X_2)$	Baht
Total cost of work done	$= 4{,}836.3246 +6{,}478.373X_2$	Baht

6. Road surfacing, base, and sub base works in m^3.

6.1 sub base course, laterite soil or weathering rock in cu.m.

Quantity of work done	$= X_1X_2X_{10}$	m^3
Cost of work done	$= a_6X_1X_2X_{10}$	Baht
Total cost of work done	$= 214X_1X_2X_{10}$	Baht

6.2 Base course, crushed stone or gravel in m^3.

Quantity of work done	$= X_1X_2X_{11}$	m^3
Cost of work done	$= a_7 X_1 X_2X_{11}$	Baht
Total cost of work done	$= 300X_1 X_2X_{11}$	Baht

6.3 Road surfacing course in m^2.

Quantity of work done	$= X_1X_2X_{12}$	m^3
Cost of work done	$= a_8 X_1X_2X_{12}$	Baht

Case I : Asphaltic concrete pavement thickness of 0.05 m.(Withayakul, 1985).

	$= 108X_1X_2$	Baht
Total cost of work done for case I	$= 108X_1X_2$	Baht

Case II : Reinforced Concrete pavement thickness of 0.15 m.(Charoenpao, 1994).

$= 304X_1X_2$ Baht

Total cost of work done for case II $= 304\ X_1X_2$ Baht

7. Pipes and Culvert

The amount of work depends on terrain characteristics, and the numbers of crossing stream which may effects the forest road bed during rainy season. (US. National Park Service, 1979; U.S. Forest Service, 1979)

7.1 Pipes, Reinforced Concrete Pipes(RCP) in numbers of RCP

The under pass RCP requirement can be estimated from road section as shown in Figure 16.

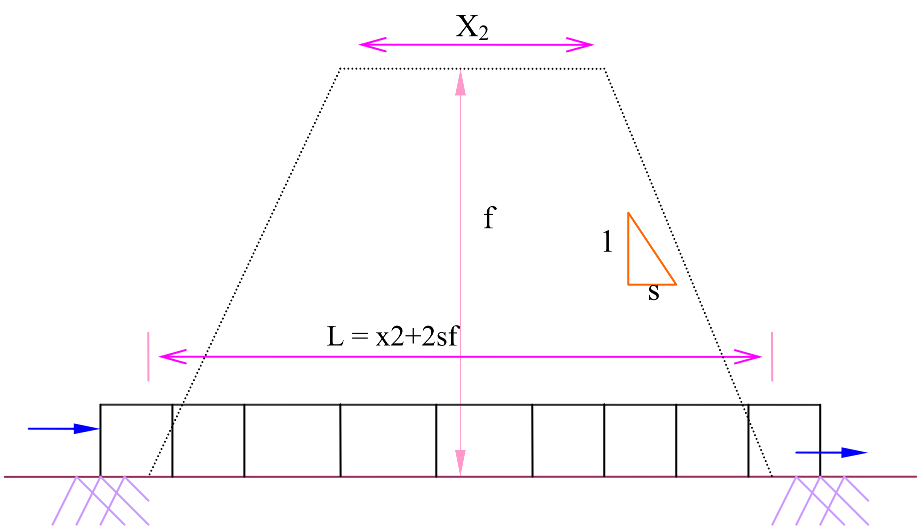

Figure 16 The RCP installation in forest road section.

Where: x_{13} is the number of RCP installation STA.

x_{14} is the number of row in RCP installation

x_{15} is the number of pipes in each row of RCP installation

L is the length of toe of embankment

s is the side slope of embankment

X_2 is the road width

f is the height of embankment

Quantity of RCP installation $= X_{13}X_{14}\, X_{15}$ pipes

$= X_{13}X_{14}(2+X_2+2sf)$ pipes

Cost of work done $= a_{11}\, X_{13}\, X_{14}(2+X_2+4f)$ Baht

Total cost of work done $= a_{11}\, X_{13}\, X_{14}(2+X_2+4f)$ Baht

Use RCP Ø 0.80 m., X_{14} rows @ 10 pipes at X_{13} STA, f = 2.0 m. and hauling distance at 100 km. from pipe factory (Budget Bureau, 2004).

Therefore $= 1{,}119\, X_{13}\, X_{14}(2+X_2+4x2)$ Baht

$= 1{,}119\, X_{13}\, X_{14}(10+X_2)$ Baht

Total cost of work done $= 1{,}119\, X_{13}\, X_{14}(10+X_2)$ Baht

7.2 RCP inlet and outlet concrete masonry bed in cu.m.

Concrete bed under RCP at least 0.15 m. thick and 2.0 m. long.

Quantity of work done $= 2(0.15x2(2x0.8+0.5(X_{14}-1)+ X_{14}X_{16}))\, X_{13}$ m^3

$= 0.60X_{13}(1.60+0.5(X_{14}-1)+ X_{14}X_{16})$ m^3

Cost of work done $= 0.60\, a_{10}X_{13}(1.60+0.5(X_{14}-1)+X_{14}X_{16})$ Baht

$= 0.60\, x960X_{13}(1.60+0.5(X_{14}-1)+ X_{14}\, X_{16})$ Baht

$= 576\, X_{13}(1.60+0.5(X_{14}-1)+ X_{14}\, X_{16})$ Baht

Total cost of work done $= 633.6X_{13} +288\, X_{13}X_{14} +X_{14}\, X_{16}$ Baht

7.3 Rip Rap in cu.m.

Stone work at least 0.30 m. thick along side slope both inlet and outlet of RCP.

Length of riprap $L =(2x0.80+0.5(X_{14}-1)+X_{14}X_{16})$ m

Height along side slope $Hs = ((X_{16}+0.5/\sqrt{5})-\frac{\pi}{4}X_{14}\, X^2_{16})\sqrt{5}$ m

Area of riprap $LxHs = (2x0.80+0.5(X_{14}-1) +X_{14}X_{16})((X_{16}+0.5/\sqrt{5})$

$- \frac{\pi}{4}\, X_{14}\, X^2_{16})\sqrt{5}$ m^2

Volume of riprap $= 0.3(2x0.80 + 0.5(X_{14}-1) + X_{14}X_{16})$

$((X_{16}+0.5/\sqrt{5}) - \frac{\pi}{4}\, X_{14}\, X^2_{16})\sqrt{5}$ m^3

$= 0.3\sqrt{5}\, (1.1+0.5X_{14}+X_{14}X_{16})$

$(X_{16} +0.5/\sqrt{5} - \frac{\pi}{4} X_{14} X^2_{16})$ m^3

$= 2X_{13}x0.3\sqrt{5} \, (1.1+0.5X_{14}+X_{14}X_{16})(X_{16}+0.5/\sqrt{5}$

$- \frac{\pi}{4} X_{14} X^2_{16})$ m^3

$= 1.342X_{13}(1.1+0.5X_{14}+X_{14}X_{16})(X_{16} +1.118$

$- 3.1416X_{14} X^2_{16})$ m^3

Total quantity of work done $= (1.4762 X_{13}+0.671X_{13}X_{14} +1.342X_{13}X_{14}X_{16})$

$(X_{16} +1.118 - 3.1416X_{14} X^2_{16})$ m^3

Cost of work done $= a_9 (1.4762 X_{13}+0.671X_{13}X_{14} +1.342X_{13}X_{14}X_{16})$

$(X_{16} +1.118 - 3.1416X_{14} X^2_{16})$ Baht

Total cost of work done $= 1,200 (1.4762 X_{13}+0.671X_{13}X_{14}$

$+1.342X_{13}X_{14}X_{16})(X_{16} +1.118 - 3.1416X_{14}$

$X^2_{16})$ Baht

8. Side Ditch in meters

8.1 Earth side ditch

Use earth side ditch at any excavation Sta. where a percentage of grade less than 8 %. (RFD, 1983)

Quantity of work done	$= X_{18}$	m
Cost of work done	$= a_{12}X_{18}$	Baht
	$= 100 X_{18}$	Baht
Total cost of work done	$= 100 X_{18}$	Baht

8.2 Concrete, and masonry side ditch, or gutter

Concrete, and masonry side ditch are suitable at any excavation or embankment sta. where a percentage of grade more than 8 %. (RFD, 1983)

Quantity of work done	$= X_{19}$	m
Cost of work done	$= a_{13}X_{19}$	Baht
	$= 500 X_{19}$	Baht
Total cost of work done	$= 500 X_{19}$	Baht

9. Guide Post and Distance Post

Install guide posts at any horizontal and vertical curve Sta., and the critical places or special attention driving care spots. The distance post or mile stone is installed at each 1 km. distance.

Quantity of work done	= X_{20}	posts
Cost of work done	= a_{15} X_{20}	Baht
	= 1,000 X_{20}	Baht
Total cost of work done	= 1,000 X_{20}	Baht

10. Traffic Sign and Facilities

Install traffic sign, tourist information sign, and facilities at any Sta. on sharp curve and any attraction points.

Quantity of traffic sign	= X_{21}	pieces
Cost of work done	= a_{16} X_{21}	Baht
	= 3,500 X_{21}	Baht
Total cost of work done	= 3,500 X_{21}	Baht

11. Retaining Wall and Slope Protection Structures

Number of works	= X_{22}	places
Cost of work done	= a_{17} X_{22}	Baht
	= 10,000 X_{22}	Baht
Total cost of work done	= 10,000 X_{22}	Baht

12. Miscellaneous, Cleaning, Moving in and out

The miscellaneous, cleaning, moving in and out costs are the lump sum expense for starting and ending construction project. The heavy machine equipments need for construction work usually move in at the beginning of the project and move out after finish the duty work.

Number of machine moving	= X_{23}	trips
Cost of work done	= a_{18} X_{23}	Baht

$= 150{,}000\ X_{23}$ Baht

Total Cost of work done $= 150{,}000\ X_{23}$ Baht

13. F Factor

The f factor is the multiply factor for cost estimation which included percentage of unexpected cost, management cost, operating cost, risk, profit, and tax. (Budget Bureau, 2004)

Total construction cost $= F \times Y$ Baht

Finally, the total cost of forest road construction can obtain by summation of all road construction cost details item number 1 to item number 12 as shown following;

The total (labor cost + material cost),Y = summation of item 1 to item 12

$$Y = 3X_1 + 0.625X_1(X_2 + 2X_3) + 0.6555X_1(X_2 + 2X_3) + 22{,}406 - 10{,}426.202X_2 + 4{,}836.3246 + 6{,}478.373X_2 + 214X_1X_2X_{10} + 300X_1X_2X_{11} + 304X_1X_2 + 1{,}119\ X_{13}X_{14}(10 + X_2) + 633.6X_{13} + 288\ X_{13}X_{14} + X_{14}\ X_{16} + 1{,}200(1.4762\ X_{13} + 0.671X_{13}X_{14} + 1.342X_{13}X_{14}X_{16})(X_{16} + 1.118 - 3.1416X_{14}\ X^2_{16}) + 100X_{18} + 500X_{19} + 1{,}000X_{20} + 3{,}500X_{21} + 10{,}000X_{22} + 150{,}000X_{23}$$

Simplified the equation, then

$$Y = 27{,}242.32 + 3X_1 + 16{,}904.58X_2 + 305.28X_1X_2 + 2.56\ X_1X_3 + 214.00X_1X_2\ X_{10} + 300.00X_1X_2\ X_{11} + 1{,}119.00X_2X_{13}\ X_{14} + 2{,}614.07X_{13} + 12{,}378.21X_{13}\ X_{14} + X_{14}\ X_{16} + 2{,}146.80X_{13}\ X_{14}\ X_{16} + 1{,}771.44X_{13}X_{16} + 7{,}175.56X_{13}X_{14}X^2_{16} + 2{,}529.62X_{13}X^2_{14}X_{16} + 5{,}059.23X_{13}X^2_{14}X^3_{16} + 100X_{18} + 500X_{19} + 1{,}000X_{20} + 3{,}500X_{21} + 10{,}000X_{22} + 150{,}000X_{23} \quad (18)$$

The steps in formulating mathematical models and multi-goal programming analysis were displayed in Figure 17.

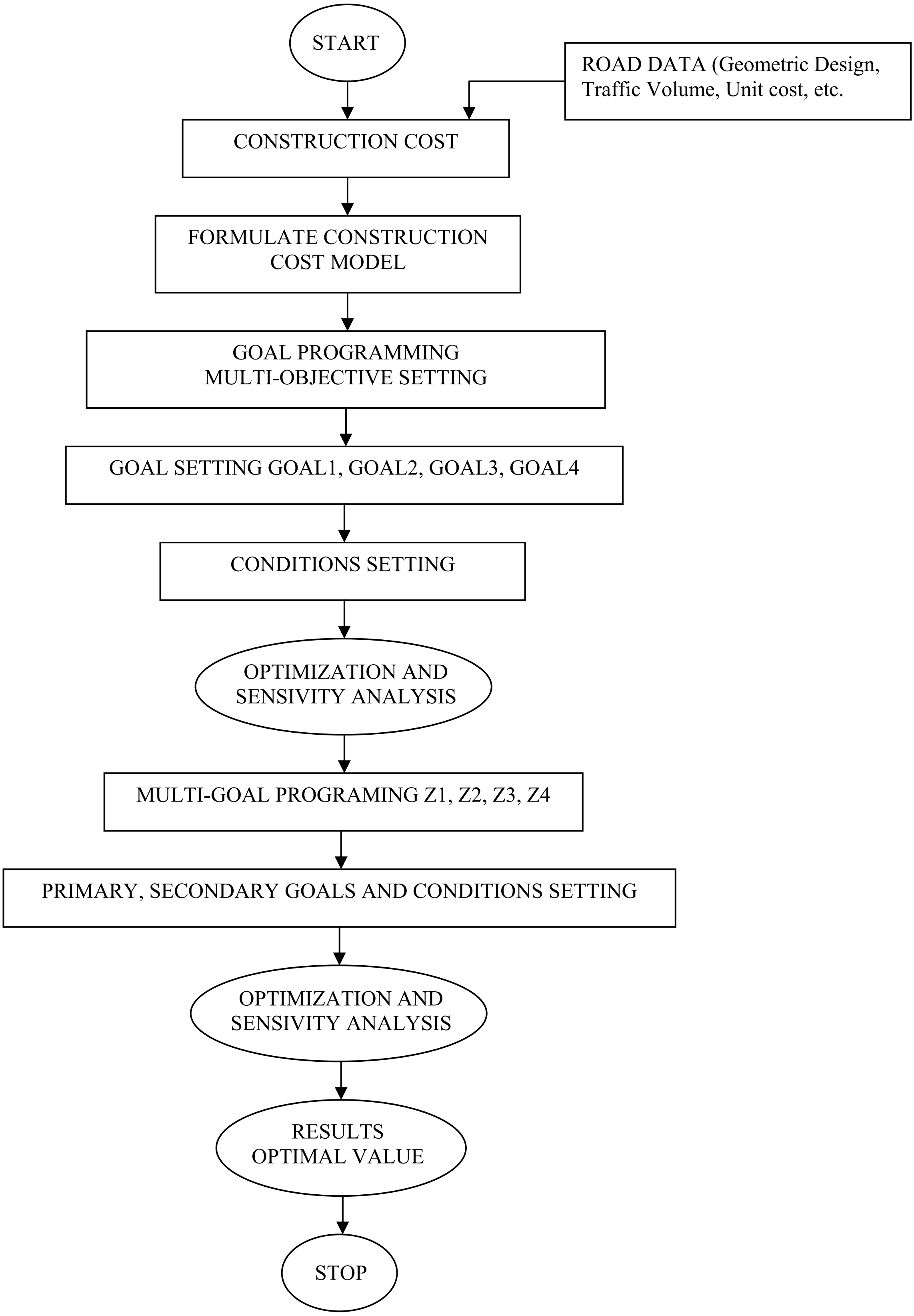

Figure 17 Mathematical Programming Models Formation Outline.

Multi-Goal Mathematical Programming Model

$Z_0 \leq C'X_{ij}$ (1)

$AX_{ij} \leq b_0$ (2)

$X_{ij} \geq 0$ (3)

Goal Objective Functions

$$Optimal\_Z = \sum_{i=1}^{n}\sum_{j=1}^{m} A_i X_{ij}$$

In formulating the goal objective functions of forest road cost in national park, the goal objectives were aimed at minimum construction cost, minimize maintenance cost, minimize environmental Impact, and maximize traveling safety of tourist as the main purposes of this study. The goal objective functions were listed as following.

1. Minimize construction cost model (Z_1)

$$Minimal\_Z_1 = \sum_{i=1}^{n}\sum_{j=1}^{m} a_i X_{ij}$$

2. Minimize maintenance cost model (Z_2)

$$Minimal\_Z_2 = \sum_{i=1}^{n}\sum_{j=1}^{m} b_i X_{ij}$$

3. Minimize environmental impact model (Z_3)

$$Minimal\_Z_3 = \sum_{i=1}^{n}\sum_{j=1}^{m} c_i X_{ij}$$

4. Maximize traveling safety model (Z_4)

$$Minimal\_Z_4 = \sum_{i=1}^{n}\sum_{j=1}^{m} d_i X_{ij}$$

Constraints. Maximum gradient, appropriated width, horizontal and vertical alignment, drainage system, surfacing materials, traveling speed

1. The Minimize Construction Cost Goal (Z_1)

The minimize construction cost (Z_1) goal was subjected to;

1.1 minimal soil cutting
1.2 minimal soil embankment
1.3 minimal drainage structures
1.4 minimal soil protection structures
1.5 shortest route layout

Minimize Construction Cost Mathematical Model (Z_1)

The mathematical model of minimize construction cost was formulated as follows:

Objective functions:

$$Z_1 = 1{,}388{,}250.17 + 4{,}961{,}033.36X_2 + 37{,}256.66X_3 + 1{,}087{,}325X_2X_{10} + 1{,}613{,}450X_2X_{11} + 18{,}940{,}500X_2X_{12} + 45{,}500X_{13}X_{14} + 4{,}550X_{13}X_{14}X_2 + 1{,}782X_{13} + 810X_{13}X_{14} + 1620X_{13}X_{14}X_{16} + 23{,}192.24X_{13} + 19{,}384.35X_{13}X_{14} - 8{,}175.50X_{13}X^2_{14};$$

Decision variables and Constraints

In formulating the goal programming problem, the decision variables represent as follows.

Subject to;

$X_2+2X_3>=3X_2;$ (4)

$X_3>=X_2;$ (5)

$X_2>=3;$ (6)

$X_2<=7;$ (7)

$X_{10}<=0.25;$ (8)

$X_{10}>=0.15;$ (9)

$X_{11}<=0.10;$ (10)

$X_{11}>=0.05;$ (11)

$X_{12}<=0.25;$ (12)

$X_{12}>=0.10;$ (13)

$X_{13}>=0;$ (14)

$X_{14}>=0;$ (15)

$X_{16}>=0.60;$ (16)

$X_{16}<=1.00;$ (17)

2. The Minimize Maintenance Cost Goal (Z_2)

The minimize maintenance cost(Z_2) goal was subjected to;

2.1 maximum thickness of surfacing layer and adequate surfacing material
2.2 adequate drainage structures
2.3 maximum soil protection structures
2.4 adequate soil compaction
2.5 foreseen traffic intensity within the expectation range
2.6 adequate routine maintenance

Minimize Maintenance Cost Mathematical Model (Z_2)

The mathematical model of minimize maintenance cost was formulated as follows:

Objective functions:

$$Z_2 = 17{,}625{,}120.69 + 3{,}261{,}975X_{10} + 4{,}840{,}350X_{11} + 56{,}821{,}500X_{12} + 59{,}150X_{13}X_{14} + 1{,}782X_{13} + 810X_{13}X_{14} + 1{,}620X_{13}X_{14}X_{16} + 23{,}192.24X_{13} + 19{,}384.35X_{13}X_{14} - 8175.50X_{13}X^2_{14} + 150X_{18} + 470X_{19};$$

Decision Variables and Constraints

In formulating the goal programming problem, the decision variables represent as follows.

Constraints;
Subject to;

$X_{10}>=0.25;$ (18)
$X_{11}>=0.10;$ (19)
$X_{12}<=0.25;$ (20)
$X_{12}>=0.15;$ (21)
$X_{13}>=33;$ (22)
$X_{14}>1;$ (23)
$X_{16}>=0.60;$ (24)
$X_{16}<=1.00;$ (25)
$X_{18} +X_{19}<=14,030;$ (26)
$X_{18}>=0;$ (27)
$X_{18}<=14,030;$ (28)
$X_{19}>=2,130;$ (29)
$X_{19}<=14,030;$ (30)

3. The Minimize Environmental Impact Cost Goal (Z_3)

The minimize environmental impact cost (Z_3) goal was subjected to;

3.1 minimal clearing and grubbing
3.2 minimal soil cutting
3.3 minimal soil embankment
3.4 maximum soil protection structures
3.5 maximum drainage structures
3.6 adequate routine maintenance

3.7 maximum thickness of surfacing layer and adequate surfacing material

3.8 foreseen traffic intensity within or less than the expectation range

3.9 well design and construction process

Minimize Environmental Impact Cost Mathematical Model (Z_3)

The mathematical model of minimize environmental impact cost was formulated as follows:

Objective Functions:

$$Z_3 = 17{,}197{,}350.69 + 37{,}256.7X_3 + 3{,}261{,}975X_{10} + 4{,}840{,}350X_{11} + 56{,}821{,}500X_{12} + 59{,}150X_{13}X_{14} + 1{,}782X_{13} + 810X_{13}X_{14} + 1{,}620X_{13}X_{14}X_{16} + 23{,}192.24X_{13} + 19{,}384.35X_{13}X_{14} - 8{,}175.50X_{13}X^2_{14} + 150X_{18} + 470X_{19} + 10{,}000X_{22} + 3{,}600X_{26};$$

Decision variables and constraints

In formulating the goal programming problem, the decision variables represent as follows.

Constraints;

Subject to;

$X_3>=3;$ (31)

$X_{10}>=0.25;$ (32)

$X_{11}>=0.10;$ (33)

$X_{12}<=0.25;$ (34)

$X_{12}>=0.15;$ (35)

$X_{13}>=33;$ (36)

$X_{14}> \quad 1;$ (37)

$X_{16}>=0.60;$ (38)

$X_{16}<=1.00;$ (39)

$X_{18} + X_{19} <= 14,030;$ (40)

$X_{18} >= 0;$ (41)

$X_{18} <= 14,030;$ (42)

$X_{19} >= 8,009;$ (43)

$X_{19} <= 14,030;$ (44)

$X_{22} >= 10;$ (45)

$X_{26} >= 6;$ (46)

4. The Maximize Traveling Safety Cost Goal (Z_4)

The maximize safety cost (Z_4) goal was subjected to;

4.1 maximum horizontal curve alignment
4.2 adequate vertical curve alignment
4.3 maximum stopping distance
4.4 adequate traffic sign and road sign facilities
4.5 maximum carriage width
4.6 maximum thickness of surfacing layer and adequate surfacing material
4.7 foreseen traffic intensity within or less than the expectation range
4.8 well design and construction process
4.9 maximum drainage structures
4.10 low gradient
4.11 adequate routine maintenance

Maximize Safety Cost Mathematical Model (Z_4)

The mathematical model of maximize safety cost was formulated as follows:

Objective functions:

$$Z_4 = 9{,}405{,}912.42 + 2{,}277{,}778.5X_2 + 37{,}256.7X_3 + 3{,}261{,}975X_{10} + 4{,}840{,}350X_{11} + 56{,}821{,}500X_{12} + 59{,}150X_{13}X_{14} + 1{,}782X_{13} + 810X_{13}X_{14} + 1{,}620X_{13}X_{14}X_{16} + 23{,}192.24X_{13} + 19{,}384.35X_{13}X_{14} - 8{,}175.50X_{13}X^2_{14} + 150X_{18} + 470X_{19} + 1{,}100X_{21} + X_{22} + 36{,}000X_{26} + 1{,}400X_{30}$$

Decision variables

In formulating the goal programming problem, the decision variables represent as follows.

Constraints;

Subject to;

$X_2 + 2X_3 >= 3X_2$; (47)

$X_3 >= X_2$; (48)

$X_2 >= 3$; (49)

$X_2 <= 7$; (50)

$X_{10} >= 0.25$; (51)

$X_{11} >= 0.10$; (52)

$X_{12} <= 0.25$; (53)

$X_{12} >= 0.15$ (54)

$X_{13} >= 33$; (55)

$X_{14} > 1$; (56)

$X_{16} >= 0.60$; (57)

$X_{16} <= 1.00$; (58)

$X_{18} + X_{19} <= 14{,}030$; (59)

$X_{18} >= 0$; (60)

$X_{18}<=14{,}030;$	(61)
$X_{19}>=8{,}009;$	(62)
$X_{19}<=14{,}030$	(63)
$X_{20}>=8;$	(64)
$X_{21}>=27;$	(65)
$X_{22}>=10;$	(66)
$X_{26}>=6;$	(67)
$X_{30}>=650;$	(68)
$X_{30}<=14{,}030;$	(69)

The Proposed Mathematical Model:

$$\mathbf{Y_{pw} = f(A,X)}$$

where:

Y_{pw} = dependent variable such as total cost in Baht

A = unit price of each variables

X = independent variables such as depth of soil cutting and filling, road width, surfacing thickness, road length, cut and fill slope, length of vertical curve, length of horizon curve, design speed, turning radius, superelevation rate, stopping sight distance, widening width, length and width of gutter or side ditch, pipe diameter, shoulder width, width of clearing and grubbing, grade or maximum gradient in percent, traffic volume in vehicles/day, number of lane, safety infrastructure type(guard rail, barrier, traffic sign), soil conditions, precipitation(rainfall intensity in mm.), vegetation cover condition, drainage condition, surfacing materials type(earth, gravel, surface treatment, asphalt conc., concrete), park road type (paved, unpaved road), etc.

Multi-Goal Mathematical Model

The multi-goal mathematical model was formulated as follows:

Objective functions:

Z=2,314,250.17 +4,961,033.43X_2 +37,256.7X_3 +1,087,325X_2X_{10} +1,613,450X_2X_{11} +1,8940,500X_2X_{12} +59,150$X_{13}X_{14}$ +1,782X_{13} +810$X_{13}X_{14}$ +1,620$X_{13}X_{14}X_{16}$ +23,192.24X_{13} +19,384.35$X_{13}X_{14}$ -8,175.50$X_{13}X^2_{14}$ +150X_{18} +470X_{19} +10,000X_{22} +36,000X_{26};

Decision variables and Constraints of Multi-Goal Mathematical Model

In formulating the multi-goal programming problem, the decision variables represented as follows.

Subject to;

1,388,250.17 +4,961,033.36X_2 +37,256.66X_3 +1,087,325X_2X_{10} +1,613,450X_2X_{11} +18,940,500X_2X_{12} +45,500$X_{13}X_{14}$ +4,550$X_{13}X_{14}X_2$ +1,782X_{13} +810$X_{13}X_{14}$ +1620$X_{13}X_{14}X_{16}$ +23,192.24 X_{13} +19,384.35$X_{13}X_{14}$ -8,175.50$X_{13}X^2_{14}$> = 22,796,600; (70)

17,625,120.69 +3,261,975X_{10} +4,840,350X_{11} +56,821,500X_{12} +59,150$X_{13}X_{14}$ +1,782X_{13} +810$X_{13}X_{14}$ +1,620$X_{13}X_{14}X_{16}$ +23,192.24X_{13} +19,384.35$X_{13}X_{14}$ - 8,175.50$X_{13}X^2_{14}$ +150X_{18} +470X_{19}>=31,653,800; (71)

9,405,912.42 +2,277,778.5X_2 +37,256.7X_3 +3,261,975X_{10} +4,840,350X_{11} +56,821,500X_{12} +59,150X13X_{14} +1,782X_{13} +810$X_{13}X_{14}$ +1,620$X_{13}X_{14}X_{16}$ +23,192.24X_{13} +19,384.35$X_{13}X_{14}$ -8,175.50$X_{13}X^2_{14}$ +150X_{18} +470X_{19} +1,100X_{21} +10,000X_{22} +36,000X_{26} +1,400X_{30} >=34,398,500; (72)

$X_2 >= 3;$ (73)

$X_2 <= 7;$ (74)

$X_3 >= 3;$ (75)

$X_{10} >= 0.25;$ (76)

$X_{11} >= 0.10;$ (77)

$X_{12} <= 0.25;$ (78)

$X_{12} >= 0.15;$ (79)

$X_{13} >= 33;$ (80)

$X_{14} > 1;$ (81)

$X_{16} >= 0.60;$ (82)

$X_{16} <= 1.00;$ (83)

$X_{18} + X_{19} <= 14{,}030;$ (84)

$X_{18} >= 0;$ (85)

$X_{18} <= 14{,}030;$ (86)

$X_{19} >= 8{,}009;$ (87)

$X_{19} <= 14{,}030;$ (88)