APPENDICES

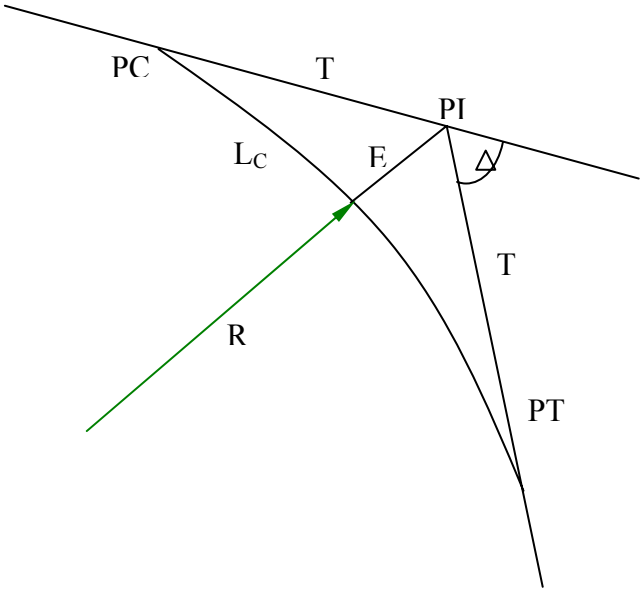
Appendix A

Forest Road Alignment and Geometric Design Limitations

FOREST ROAD ALIGNMENT

Horizontal Alignment

Circular Curve



1. Δ = deflection angle in degree
2. $Dc = \frac{572.9578}{R}$ degree
3. $R = \frac{T}{\tan\frac{\Delta}{2}}$ degree
4. T = Tangent meter
5. $Lc = 100\left(\frac{\Delta}{D_c}\right)$ meter
6. $E = T\tan\frac{\Delta}{4}$ meter
7. $V = 11.2795\sqrt{R(e+f)}$ Km/hr.(KPH)
8. S.E or e Max. = 0.10 meter/meter
9. PI STA = Point of Intersect
10. PC STA = PI STA – T

11. PT STA = PC STA + Lc

12. Coefficient of friction for aggregate surfacing material f = 0.06 -0.10

Limitations

A. Minimum Turning Radius

Flat terrain	75 – 110	meters
Hilly terrain	40 – 75	meters
Mountain	25 – 35	meters

B. Height of road bed above HWL. not less than 0.50 meters

C. Crown Slope not less than 4%

D. Design Speed 30 – 60 Km/hr.(KPH)

E. Carriage width 3.50 – 6.00 meters

F. Maximum gradient not exceed 16%.

G. For unpaved road, if the vertical alignment grade greater than 12%, road surface must be improve to paved surface by soil cement, asphaltic, concrete pavement, or other durable surfacing material by approval of NPD for erosion protection and safety purpose.

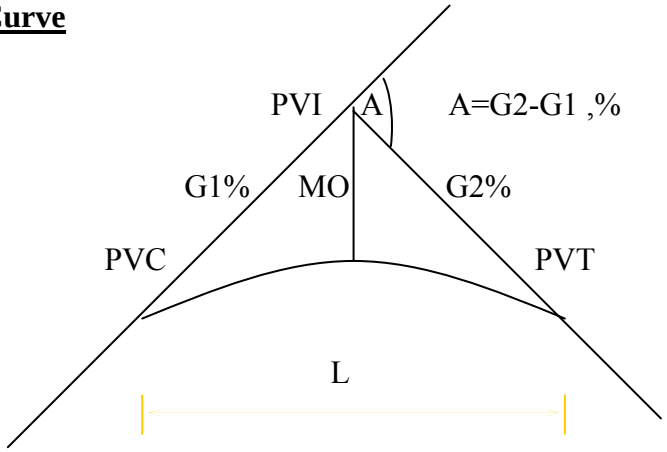
H. Tree within right of way which diameter at breath height(DBH) greater than 30 centimeter shall be transfer to road side or given places. Tree cutting and felling within right of way is prohibited.

I. Carriage width included shoulder not greater than 7.00 meters

J. The vertical alignment grade greater than 12% shall not continuously longer than 500 meters of road length and not shorter than 50 meters of road length.

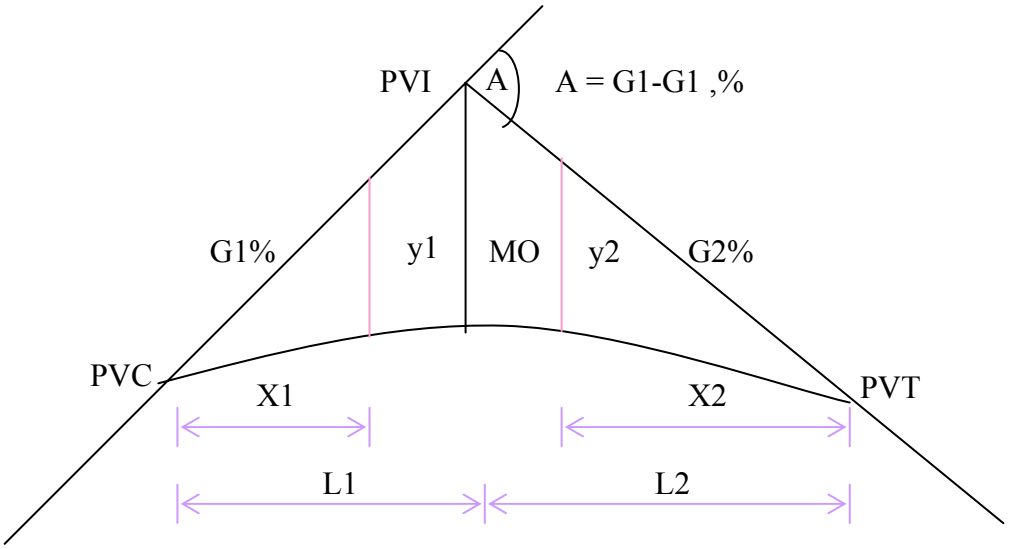
Vertical Alignment

Symmetrical Vertical Curve



1. Stopping Sight Distance
   - A. Hilly and Mountain terrain Lvc. not less than 30 meters
   - B. Flat terrain Lvc. not less than 110 meters
2. Maximum Gradient
   - A. Flat terrain not greater than 6%
   - B. Hilly terrain not greater than 10%
   - C. Mountain terrain not greater than 16%
3. $MO = \frac{L(G_2 - G_1)}{800}$ meters
4. PVC Elev = PVI $- \frac{LG1}{200}$ meters
5. PVT Elev = PVI $- \frac{LG2}{200}$ meters

Unsymmetrical Vertical Curve)



$L1 \neq L2$

1. $MO = \frac{L_1 L_2 (G_2 - G_1)}{200(L_1 + L_2)}$ meters

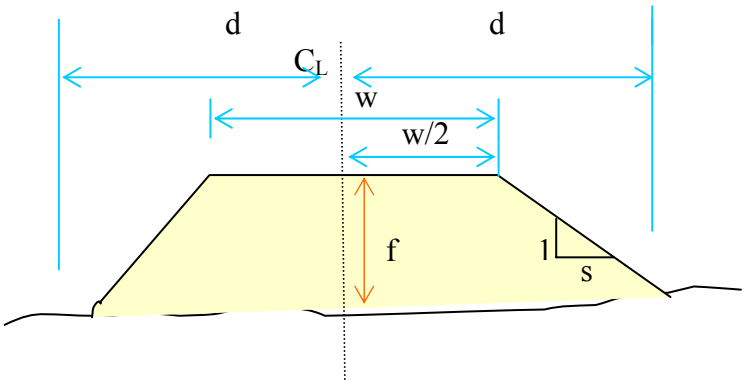
2. $Y1 = MO\left(\frac{X1}{L1}\right)^2$ meters

3. $Y2 = MO\left(\frac{X2}{L2}\right)^2$ meters

4. Elevation at any point on curve

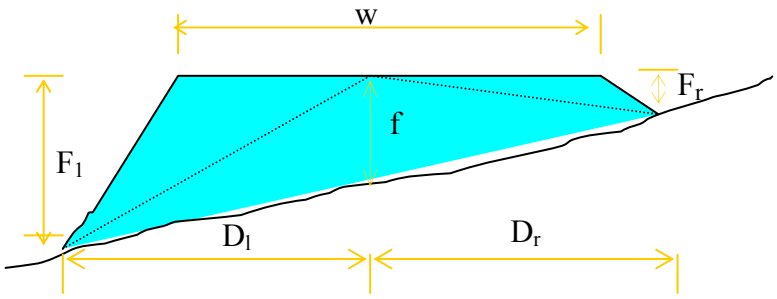
$$Elev = PVC\ Elev + \frac{G_1 X_1}{100} - Y1$$ meters

X-Section



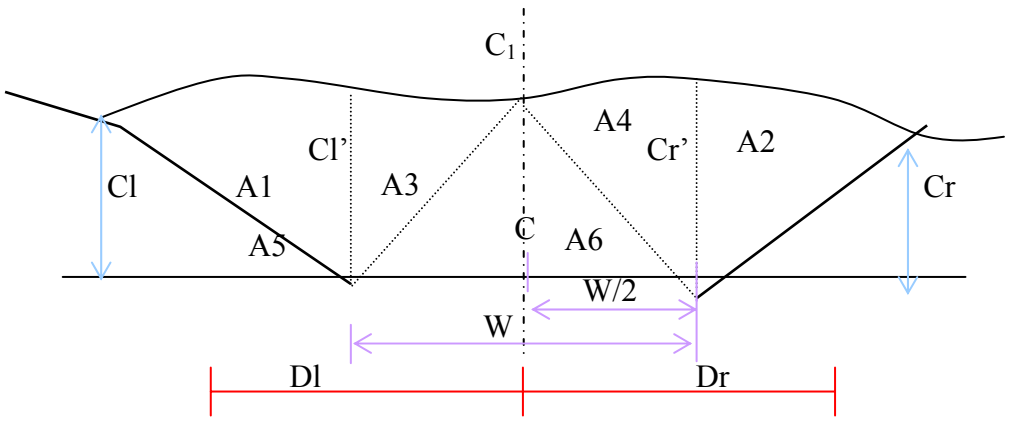
Section Area A = f (w+sf)

Level Section



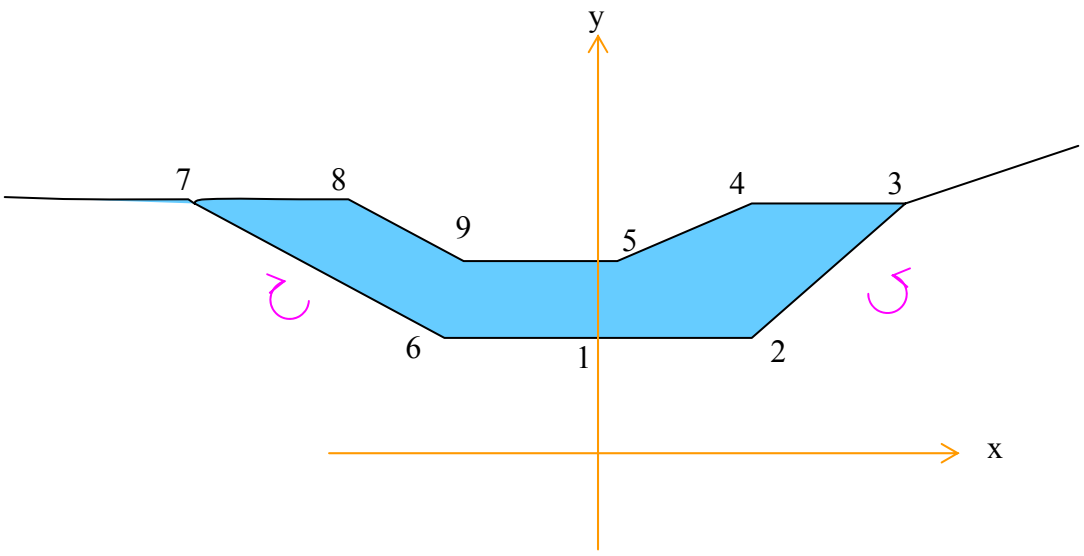
Section Area A = 0.5f (Dl+Dr)+0.25w (Fl+Fr)

Three – Level Section



Section Area A = 0.5(Cl' Dl + Cr' Dr +cw)

Five – Level Section



Irregular Section

Total sectional area A = Ar + A1

$$A = \frac{1}{2}\,[(Y1(X2-X8)+Y2(X3-X1)+Y3(X4-X2)+\ldots.+Y6(X7-X5)+Y7(X1-X6))]$$

Right hand side sectional area $Ar = \frac{1}{2}\left[\frac{Y_1}{X_1} \times \frac{Y_2}{X_2} \times \frac{Y_3}{X_3} \times \ldots \frac{Y_5}{X_5} \times \frac{Y_1}{X_1}\right]$

Left hand side sectional area $Al = \frac{1}{2}\left[\frac{Y_1}{X_1} \times \frac{Y_6}{X_6} \times \frac{Y_7}{X_7} \times \ldots \frac{Y_5}{X_5} \times \frac{Y_1}{X_1}\right]$

Appendix B

Decision variables and coefficient of variables in park roads mathematical modeling

DECISION VARIABLES

Variables in park roads mathematical modeling

The variables were defied as follows;

X_1 = road length in meters

X_2 = carriage width included shoulder in meters

X_3 = clearing and grubbing width in meters

X_4 = side slope ratio(H:V) for soil cutting

X_5 = side slope ratio(H:V) for soil filling

X_6 = subgrade level in meters

X_7 = percentage of grade G from PVC.STA. to PVI.STA.in %

X_8 = percentage of grade G from PVI.STA. to PVT.STA. in %

X_9 = Length of vertical curve(Lvc) in meters

X_{10} = Subbase thickness in meters

X_{11} = Base thickness in meters

X_{12} = traffic surfacing thickness in meters

X_{13} =number of culvert installation points

X_{14} = number of rows of culvert installation in each point

X_{15} = number of culvert in each row

X_{16} = culvert diameter in meters

X_{17} = rip rap thickness in meters

X_{18} = length of earth side ditch in meters

X_{19} = length of concrete side ditch in meters

X_{20} = number of guide post, milestone post

X_{21} = number of traffic sign

X_{22} = number of place in slope protection construction

X_{23} = number of trip in machine and equipment mobilization

X_{24} = embankment depth in meters

X_{25} = width of earth side ditch in meters

X_{26} = number of places in retaining wall construction

X_{27} = width of concrete side ditch in meters

X_{28} = depth of road bed in meters

X_{29} = rip rap thickness in meters

X_{30} = length of guard rail in meters

X_{35} = number of Ø 1.0 RCP in meters

X_{36} = number of Ø 0.80 RCP in meters

X_{37} = number of Ø 0.60 RCP in meters

Coefficient of Variables in Park Road Analysis

a_1 = unit price of construction survey in Baht/km.

a_2 = unit price of clearing and grubbing in Baht/sq.m.

a_3 = unit price of top soil removal in Baht/sq.m.

a_4 = unit price of soil cutting in Baht/cu.m.

a_5= unit price of soil filling in Baht/cu.m.

a_6 = unit price of aggregate material for subbase in Baht/cu.m.

a_7 = unit price of crushed stone in Baht/cu.m.

a_8 = unit price of surfacing materials in Baht/ sq.m.

a_9 = unit price of rip rap in Baht/ cu.m.

a_{10} = unit price of culvert opening protection in Baht/ cu.m.

a_{11} = unit price of culvert + culvert bed + concrete mortar in Baht/ m.

a_{12}= unit price of earth side ditch in Baht/ m.

a_{13} = unit price of concrete side ditch in Baht/ m.

a_{14} = unit price of sodding in Baht/ sq.m.

a_{15} = unit price of guide post in Baht/ post.

a_{16} = unit price of traffic sign in Baht/ piece.

a_{17}= unit price of slope protection in Baht/ sq.m.

a_{18} = unit price of retaining wall construction in Baht/ place.

a_{19} = unit price of guard rail in Baht/ m.

a_{20} = unit price of machine and equipment mobilization in Baht/ trip.

Appendix C

Goal mathematical programming models and results of analysis

model : Z1

!File : KY_G1_1.LG4

Last Update : 31/05/05 time :14:40

Determine the road width(x2) which Minimize Construction Cost Model, Z1

Mr.Nathakitt Puangchit Civil Engineer 8, CE 5432;

```
min=  21045 !route layout and survey construction;
      +14030*x2+28060*x3 !clearing and grubbing;
      +4598.33*x2+9196.66*x3 !top soil removal;
      +1036263.963*x2 !soil cutting..... updated;
      +769322.16*x2 !embankment                    updated;
      +327677.76*x2 !surplus embankment            updated;
      +1087325*x2*x10 !laterite soil subbase;
      +1613450*x2*x11 !sand cushion;
      +18940500*x2*x12 !surfacing materials;
      +69799.25+2683254.08*x2 !wire mess for concrete pavement;
      +2500*x35+1100*x36+950*x37 !RCP;
      +141750 !inlet and outlet concrete masonry;
      +117222 !rip rap;
      +150*x18+470*x19 !side ditches;
      +1500*x20 !guide post and distance post;
      +524500 !traffic sign and facilities;
      +10000*x22 !soil protection structures;
      +36000*x26 !retaining wall;
      +300000 !sodding;
      +1400*x30 !guard rail;
      +20000 !miscellaneous cleaning and machine moving out;
```

```
!total road length = 7,015 m.;
!min. laterite soil subbase thickness = 0.15 m.;
!min. sand cushion thickness = 0.05 m.;
!min. concrete pavement surfacing thickness= 0.10 m.;
!min. RCP = 601 m.;
!min. earth side ditch and concrete gutter length = 2,130 m.;
!min. guide post and distance post = 500 posts;
!number of soil protection structures = 10 sta.;
!number of retaining wall = 6 sta.;
!min. sodding cost = 300,000 Baht;
!min. guide rail and guard rail = 650 m.;

!subject to;
    x2>=3.0;!road width x2 greater than or equal to 3.0 m. but less than 7.0 m.;
    x2<=7.0;
    x3>=x2;!clearing and grubbing x3 must be greater than or equal to road width
            x2;
    2*x3+x2>=3*x2;!2 times of clearing and grubbing width x3 must be greater
                    than or equal to 3 times of road width x2;
    x10>=0.15;!subbase thickness must be greater than or equal to 0.15 m.;
    x10<=0.25; !subbase thickness must be less than or equal to 0.25 m.;
    x11>=0.05;!sand cushion thickness must be greater than or equal to 0.05 m.;
    x11<=0.10; !sand cushion thickness must be less than or equal to 0.10 m.;
    x12>=0.10;!concrete pavement surfacing thickness x12 must be greater than
            or equal to 0.10 m;
    x12<=0.25;!concrete pavement surfacing thickness x12 must be less than or
            equal to 0.25 m;
    x35+x36+x37>=601;!total number of RCP from blue print;
    x35+x36+x37<=650;! min. total number of RCP;
```

```
x35>=400;!min. RCP Ø1.0 m.(x35) must be greater than or equal to 400
        pipes;
x35<=536; !min. RCP Ø1.0 m.(x35) must be less than or equal to 536 pipes;
x36>=12;!min. RCP Ø0.80 m.(x36) must be greater than or equal to 12
        pipes;
x36<=41; !min. RCP Ø0.80 m.(x36) must be less than or equal to 41 pipes;
x37>=102;!min. RCP Ø0.60 m.(x37) must be greater than or equal to 102
        pipes;
x37<=160;!min. RCP Ø0.60 m.(x37) must be less than or equal to 160 pipes;
x18>=1;!earth side ditch x18 (m.) must be greater than or equal to 1 m.;
x18<=14030;!earth side ditch x18 (m.) must be less than or equal to 14,030
        m.;
x19>=1;!concrete gutter x19 (m.) must be greater than or equal to 1 m.;
x19<=14030;!concrete gutter x19 (m.) must be less than or equal to 14,030
        m.;
(x18+x19)>=2130;!earth side ditch x18 and concrete gutter x19 must be
        greater than or equal to 2,130 m.;
x18+x19<=14030;!earth side ditch x18 and concrete gutter x19 must be less
        than or equal to 14,030 m.;
x20>=500;!guide post and distance post must be greater than or equal to 500
        posts;
x22>=10;!soil protection structures x22 must be greater than or equal to 10
        sta.;
x26>=6;! Retaining walls x26 must be greater than or equal to 6 sta.;
x30>=650;!guard rail x30 must be greater than or equal to 650m.;
x30<=14030; !guard rail x30 must be less than or equal to 14,030 m.;
end
```

The Optimization Result of Goal Z1

Minimize Construction Cost Model

Local optimal solution found.

Objective value: 0.3501717E+08

Total solver iterations: 12

Variable	Value	Reduced Cost
X2	3.000000	0.000000
X3	0.5000000	0.000000
X10	0.1500000	0.000000
X11	0.5000000E-01	0.000000
X12	0.2500000	0.000000
X35	536.0000	0.000000
X36	41.00000	0.000000
X37	160.0000	0.000000
X18	8008.000	0.000000
X19	1.000000	0.000000
X20	500.0000	0.000000
X22	10.00000	0.000000
X26	6.000000	0.000000
X30	650.0000	0.000000

Row	Slack or Surplus	Dual Price
1	0.3501717E+08	-1.000000
2	0.000000	-9545515.
3	4.000000	0.000000
4	0.000000	-18628.33
5	0.000000	-3261975.
6	0.1000000	0.000000
7	0.000000	-4840350.

8	0.5000000E-01	0.000000
9	0.000000	-0.5682150E+08
10	87.00000	0.000000
11	0.000000	-2500.000
12	0.000000	-1100.000
13	0.000000	-950.0000
14	8007.000	0.000000
15	6022.000	0.000000
16	0.000000	-320.0000
17	0.000000	-150.0000
18	14029.00	0.000000
19	6021.000	0.000000
20	0.000000	-1500.000
21	0.000000	-10000.00
22	0.000000	-36000.00
23	0.000000	-1400.000
24	13380.00	0.000000

model : Z2

!File : KY_G2.LG4

Last Update : 31/05/05 time :14:40

Determine the road width(x2) which Minimize Maintenance Cost Model , Z2

Mr.Nathakitt Puangchit Civil Engineer 8, CE 5432;

```
min=  21045 !route layout and survey construction;
      +14030*x2+28060*x3 !clearing and grubbing;
      +4598.33*x2+9196.66*x3 !top soil removal;
      +1036263.963*x2 !soil cutting;
      +769322.16*x2 !Embankment;
      +327677.76*x2 !surplus embankment;
      +1087325*x2*x10 !laterite soil subbase;
      +1613450*x2*x11 !sand cushion;
      +18940500*x2*x12 !surfacing materials;
      +69799.25+2683254.08*x2 !wire mess for concrete pavement;
      +2500*x35+1100*x36+950*x37 !RCP;
      +141750 !inlet and outlet concrete masonry;
      +117222 !rip rap;
      +150*x18+470*x19 !side ditches;
      +1500*x20 !guide post and distance post;
      +524500 !traffic sign and facilities;
      +10000*x22 !soil protection structures;
      +36000*x26 !retaining wall;
      +752905.92 !sodding;
      +1400*x30 !guard rail;
      +20000 !miscellaneous cleaning and machine moving out;
```

```
!max. surface pavement = 0.25 m.;
!max. RCP = 626 m.;
!max. side ditches = 5070 m.;
!max. soil protection structures = 10 sta.;
!max. retaining walls = 6 sta.;
!max. sodding works = 752905.92 Baht;

!subject to;
1647222.17+4961033.44*x2+37256.66*x3+1087325*x2*x10+1613450*x2*x
11+18940500*x2*x12+2500*x35+1100*x36+950*x37+150*x18+470*x19+1500*x2
0+10000*x22+36000*x26+1400*x30=35575200+407710;
x2>=3;!road width x2 greater than 3.0 m. but less than or equal to 7.0 m.;
x2<=7;
x3>=x2;!clearing and grubbing x3 must be greater than or equal to road width
x2;
2*x3+x2>=3*x2;!2 times of clearing and grubbing width x3 plus road width
x2 must be greater than or equal to 3 times of road width
x2;
x10>=0.15;!subbase thickness must be greater than or equal to 0.15 m. but
less than or equal to 0.25 m.;
x10<=0.25;
x11>=0.05;!sand cushion thickness must be greater than or equal to 0.05 m.
but less than or equal to 0.010 m.;
x11<=0.10;
x12>=0.25;!surface pavement thickness must less than or equal to 0.25 m.;
x35+x36+x37>=626;!RCP Ø1.0 m.(x35) plus RCP Ø0.8 m. plus RCP Ø0.6
m. must be greater than or equal to 626 pipes;
x35>=400;!min. RCP Ø1.0 m.(x35) must be greater than or equal to 400
pipes but less than or equal to 536 pipes;
x35<=536;
```

```
x36>=12;!min. RCP Ø0.80 m.(x36) must be greater than or equal to 12
        pipes;
x36<=41;
x37>=102;!min. RCP Ø0.60 m.(x37) must be greater than or equal to 102
        pipes but less than or equal to 160 pipes;
x37<=160;
x18>=1;!earth side ditch x18 (m.) must be greater than or equal to 1 m. but
        less than or equal to 14,030 m.;
x18<=14030;
x19>=1;!concrete gutter x19 (m.) must be greater than or equal to 1 m. but
        less than or equal to 14,030 m.;
x19<=14030;
x18+x19>=5070; !earth side ditch x16 plus concrete gutter x19 must less
        than or equal to 5,070 m. but less than or equal to 14,030
        m.;
x18+x19<=14030;
x20>=500;!guide post and distance post must be greater than or equal to 500
        posts;
x22>=10;!soil protection structures x22 must be greater than or equal to 10
        sta.;
x26>=6;!Retaining walls x26 must be greater than or equal to 6 sta. ;
x30>=650;!guard rail x30 must be greater than or equal to 650m. but less than
        or equal to 14,030 m.;
x30<=14030;
end
```

The Optimization Result of Goal Z_2

Minimize Maintenance Construction Cost Model

Local optimal solution found.

Objective value: 0.3560010E+08

Total solver iterations: 16

Variable	Value	Reduced Cost
X2	3.040864	0.000000
X3	3.040864	0.000000
X10	0.1500000	0.000000
X11	0.5000000E-01	0.000000
X12	0.2500000	0.000000
X35	425.0000	0.000000
X36	41.00000	0.000000
X37	160.0000	0.000000
X18	5069.000	0.000000
X19	1.000000	0.000000
X20	500.0000	0.000000
X22	10.00000	0.000000
X26	6.000000	0.000000
X30	650.0000	0.000000

Row	Slack or Surplus	Dual Price
1	0.3560010E+08	-1.000000
2	-0.9894571	-0.9873825
3	0.4086400E-01	0.000000
4	3.959136	0.000000
5	0.000000	0.000000
6	0.000000	-235.0430
7	0.000000	-41718.60

8	0.1000000	0.000000
9	0.000000	-61905.01
10	0.5000000E-01	0.000000
11	0.000000	-726711.0
12	0.000000	-31.54375
13	25.00000	0.000000
14	111.0000	0.000000
15	29.00000	0.000000
16	0.000000	17.66450
17	58.00000	0.000000
18	0.000000	19.55712
19	5068.000	0.000000
20	8961.000	0.000000
21	0.000000	-4.037600
22	14029.00	0.000000
23	0.000000	-1.892625
24	8960.000	0.000000
25	0.000000	-18.92625
26	0.000000	-126.1750
27	0.000000	-454.2300
28	0.000000	-17.66450
29	13380.00	0.000000

model : Z3

!File : KY_G3_1.LG4

Last Update : 31/05/05 time :14:40

Determine the road width(x2) which Minimize Environmental Impact Cost Model , Z3,

Mr.Nathakitt Puangchit Civil Engineer 8, CE 5432;

```
min= 21045 !route layout and survey construction;
     +14030*x2+28060*x3 !clearing and grubbing;
     +4598.33*x2+9196.66*x3 !top soil removal;
     +913333.9*x2 !soil cutting;
     +482203.763*x2 !embankment;
     +469198.863*x2 !surplus embankment;
     +1087325*x2*x10 !laterite soil subbase;
     +1613450*x2*x11 !sand cushion;
     +18940500*x2*x12 !surfacing materials;
     +69799.25+2683254.08*x2 !wire mess for concrete pavement;
     +2500*x35+1100*x36+950*x37 !RCP;
     +141750 !inlet and outlet concrete masonry;
     +117222 !rip rap;
     +150*x18+470*x19 !side ditches;
     +1500*x20 !guide post and distance post;
     +524500 !traffic sign and facilities;
     +10000*x22 !soil protection structures;
     +36000*x26 !retaining wall;
     +752905.92 !sodding;
     +1400*x30 !guard rail;
     +20000 !miscellaneous cleaning and machine moving out;
```

```
!min. clearing and grubbing = x2+1m. ;
!max. surface pavement thickness = 0.25 m.;
!max. RCP = 650 m.;
!max. side ditches = 8009 m.;
!max. soil protection structures = 10 sta.;
!max. retaining wall = 6 sta.;
!max. sodding works = 752905.92 Baht.;

!subject to;
x2>=3;!road width x2 greater than 3.0 m. but less than or equal to 7.0 m.;
x2<=7;
2*x3+x2>=x2+1;!2 times of clearing and grubbing width x3 plus road width
                x2 must be greater than or equal to road width plus one;
x10>=0.15;!subbase thickness must be greater than or equal to 0.15 m. but
          less than or equal to 0.25 m.;
x10<=0.25;
x11>=0.05;!sand cushion thickness must be greater than or equal to 0.05 m.
           but less than or equal to 0.10 m.;
x11<=0.10;
x12>=0.25;!concrete pavement surfacing thickness x12 must be greater than
          or equal to 0.25 m.;
x35+x36+x37>=650;!total number of RCP must less than or equal to 650
                 pipes;
x35>=536;!RCP Ø1.0 m.(x35) must be greater than or equal to 536 pipes;
x36>=41;!RCP Ø0.80 m.(x36) must be greater than or equal to 41 pipes;
x37>=160;!RCP Ø0.60 m.(x37) must be greater than or equal to 160 pipes;
x18>=1;!earth side ditch x18 (m.) must be greater than or equal to 1 m. but
       less than or equal to 14,030 m.;
x18<=14030;
```

```
        x19>=1;!concrete gutter x19 (m.) must be greater than or equal to 1 m. but
                less than or equal to 14,030 m.;
        x18+x19>=8009;!earth side ditch x18 and concrete gutter x19 must be greater
                than or equal to 8,009 m. but less than or equal to 14,030
                m.;
        x18+x19<=14030;
        x20>=500;!guide post and distance post must be greater than or equal to 500
                post;
        x22>=10;!soil protection structures x22 must be greater than or equal to 10
                sta.;
        x26>=6;!Retaining walls x26 must be greater than or equal to 6 sta.;
        x30>=650;!guard rail x30 must be greater than or equal to 650m. but less than
                or equal to 14,030 m.;
        x30<=14030;
end
```

The Optimization Result of Goal Z_3

Minimize Environmental Impact Construction Cost Model

Local optimal solution found.

Objective value: 0.3501717E+08

Total solver iterations: 12

Variable	Value	Reduced Cost
X2	3.000000	0.000000
X3	0.5000000	0.000000
X10	0.1500000	0.000000
X11	0.5000000E-01	0.000000
X12	0.2500000	0.000000
X35	536.0000	0.000000
X36	41.00000	0.000000
X37	160.0000	0.000000
X18	8008.000	0.000000
X19	1.000000	0.000000
X20	500.0000	0.000000
X22	10.00000	0.000000
X26	6.000000	0.000000
X30	650.0000	0.000000

Row	Slack or Surplus	Dual Price
1	0.3501717E+08	-1.000000
2	0.000000	-9545515.
3	4.000000	0.000000
4	0.000000	-18628.33
5	0.000000	-3261975.
6	0.1000000	0.000000
7	0.000000	-4840350.

8	0.5000000E-01	0.000000
9	0.000000	-0.5682150E+08
10	87.00000	0.000000
11	0.000000	-2500.000
12	0.000000	-1100.000
13	0.000000	-950.0000
14	8007.000	0.000000
15	6022.000	0.000000
16	0.000000	-320.0000
17	0.000000	-150.0000
18	14029.00	0.000000
19	6021.000	0.000000
20	0.000000	-1500.000
21	0.000000	-10000.00
22	0.000000	-36000.00
23	0.000000	-1400.000
24	13380.00	0.000000

model : Z_4

!File : KY_G4.LG4

Last Update : 31/05/05 time :14:40

Determine the road width(x2) which Maximum Safety Cost Model , Z4

Mr.Nathakitt Puangchit Civil Engineer 8 CE 5432;

```
min= 21045 !route layout and survey construction;
     +14030*x2+28060*x3 !clearing and grubbing;
     +4598.33*x2+9196.66*x3 !top soil removal;
     +3385264.61*x2 !soil cutting;
     +1104302.5*x2 !embankment;
     +2013577.11*x2 !surplus embankment;
     +1087325*x2*x10 !laterite soil subbase;
     +1613450*x2*x11 !sand cushion;
     +18940500*x2*x12 !surfacing materials;
     +69799.25+2683254.08*x2 !wire mess for concrete pavement;
     +2500*x35+1100*x36+950*x37 !RCP;
     +141750 !inlet and outlet concrete masonry;
     +117222 !rip rap;
     +150*x18+470*x19 !side ditches;
     +1500*x20 !guide post and distance post;
     +524500 !traffic sign and facilities;
     +10000*x22 !soil protection structures;
     +36000*x26 !retaining wall;
     +752905.92 !sodding;
     +1400*x30 !guard rail;
     +20000 !miscellaneous cleaning and machine moving out;
```

```
!road width range = 3-7 m.;
!total road length = 7,015 m.;
!max. surface pavement thickness = 0.25 m.;
!max. RCP = 650 pipes;
!max. earth side ditches and concrete gutter = 8009 m. ;
!max. guide post and distance post = 1958 posts;
!max. soil protection structures = 10 sta.;
!max. retaining wall = 6 sta.;
!max. sodding works = 752905.92 Baht.;
!max.guid rails = 5305 m.;

!subject to;
x2>=3;
x2<=7;!road width x2 must be greater than or equal to 3.0 m. but less than or
      equal to 7.0 m.;
x3>=x2;!clearing and grubbing x3 must be greater than or equal to road width
       x2;
2*x3+x2>=3*x2;!2 times of clearing and grubbing width x3 must be greater
              than or equal to 3 times of road width x2;
x10>=0.15;!subbase thickness must be greater than or equal to 0.15 m.but
          less than or equal to 0.25 m.;
x10<=0.25;
x11>=0.05;!sand cushion thickness must be greater than or equal to 0.05 m.
          but less than or equal to 0.10 m.;
x11<=0.10;
x12>=0.25;!concrete pavement surfacing thickness x12 must be greater than
          or equal to 0.25 m;
x35+x36+x37>=650;!total number of RCP must be greater than or equal to
                 650 pipes;
```

```
x35>=536;! RCP Ø1.0 m.(x35) must be greater than or equal to 536 pipes;
x36>=41;! RCP Ø0.80 m.(x36) must be greater than or equal to 41 pipes;
x37>=160;!min. RCP Ø0.60 m.(x37) must be greater than or equal to 160
          pipes
x18>=1;!earth side ditch x18 (m.) must be greater than or equal to 1 m but
        less than or equal to 14,030 m;
x18<=14030;
x19>=1;!concrete gutter x19 (m.) must be greater than or equal to 1 m. but
        less than or equal to 14,030 m.;
x19<=14030;
(x18+x19)>=8009;!earth side ditch x18 and concrete gutter x19 must be
                 greater than or equal to 8,009 m. but less than or equal to
                 14,030 m.;
x18+x19<=14030;
x20>=1958;!guide post and distance post must be greater than or equal to
           1,958 posts;
x22>=10;!soil protection structures x22 must be greater than or equal to 10
         sta.;
x26>=6;!Retaining walls x26 must be greater than or equal to 6 sta.;
x30>=5305;!guard rail x30 must be greater than or equal to 5,305 m. but less
           than or equal to 14,030 m..;
x30<=14030;
end
```

The Optimization Result of Goal Z_4

Maximum Traveling Safety Construction Cost Model

Local optimal solution found.

Objective value: 0.5772953E+08

Total solver iterations: 12

Variable	Value	Reduced Cost
X2	3.000000	0.000000
X3	3.000000	0.000000
X10	0.1500000	0.000000
X11	0.5000000E-01	0.000000
X12	0.2500000	0.000000
X35	536.0000	0.000000
X36	41.00000	0.000000
X37	160.0000	0.000000
X18	8008.000	0.000000
X19	1.000000	0.000000
X20	1958.000	0.000000
X22	10.00000	0.000000
X26	6.000000	0.000000
X30	5305.000	0.000000

Row	Slack or Surplus	Dual Price
1	0.5772953E+08	-1.000000
2	0.000000	-0.1422118E+08
3	4.000000	0.000000
4	0.000000	0.000000
5	0.000000	-18628.33
6	0.000000	-3261975.
7	0.1000000	0.000000

8	0.000000	-4840350.
9	0.5000000E-01	0.000000
10	0.000000	-0.5682150E+08
11	87.00000	0.000000
12	0.000000	-2500.000
13	0.000000	-1100.000
14	0.000000	-950.0000
15	8007.000	0.000000
16	6022.000	0.000000
17	0.000000	-320.0000
18	14029.00	0.000000
19	0.000000	-150.0000
20	6021.000	0.000000
21	0.000000	-1500.000
22	0.000000	-10000.00
23	0.000000	-36000.00
24	0.000000	-1400.000
25	8725.000	0.000000

model : Zall

!File : KY_multiAll_3A.gl4

Last Update : 4 April 2006 12:45

Forest Roads in Khao Yai National Park

The Construction Cost which min.Environment Impact, Road Width, and

min.Maintenance Cost, and max.Safety Construction Cost

Mr.Nathakitt Puangchit Civil Engineer 8 CE 5432;

min=d1m+d1p+d2m+d2p+d3m+d3p+d4m+d4p;

!subject to;

!min.construction cost Z1;

21045+14030*x2+28060*x3+4598.33*x2+9196.66*x3+1036263.963*x2+769322.16*x2+327677.76*x2
+1087325*x2*x10+1613450*x2*x11+18940500*x2*x12+69799.25+2683254.08*x2+2500*x35+1100*x36+950
*x37+141750+117222+150*x18+470*x19+1500*x20+524500+10000*x22+36000*x26+300000
+1400*x30+20000-d1m+d1p=25717910;

!min.maintenance cost Z2 ;

21045+14030*x2+28060*x3+4598.33*x2+9196.66*x3+1036263.963*x2+769322.16*x2+327677.76*x2
+1087325*x2*x10+1613450*x2*x11+18940500*x2*x12+69799.25+2683254.08*x2+2500*x35+1100*x36+950
*x37+141750+117222+150*x18+470*x19+1500*x20+524500+10000*x22+36000*x26+752905.92
+1400*x30+20000-d2m+d2p=35600100;

!min.environmental impact cost Z3;

21045+14030*x2+28060*x3+4598.33*x2+9196.66*x3+913333.9*x2+482203.763*x2+469198.863*x2

+1087325*x2*x10+1613450*x2*x11+18940500*x2*x12+69799.25+2683254.08*x2+2500*x35+1100*x36+950*

x37+141750+117222+150*x18+470*x19+1500*x20+524500+10000*x22+36000*x26+752905.92

+1400*x30+20000-d3m+d3p=35017170;

!min.safety cost Z4;

21045+14030*x2+28060*x3+4598.33*x2+9196.66*x3+3385264.61*x2+1104302.5*x2+2013577.11*x2

+1087325*x2*x10+1613450*x2*x11+18940500*x2*x12+69799.25+2683254.08*x2+2500*x35+1100*x36+950*

x37+141750+117222+150*x18+470*x19+1500*x20+524500+10000*x22+36000*x26+752905.92

+1400*x30+20000-d4m+d4p=57729530;

d1m*d1p=0;

d2m*d2p=0;

d3m*d3p=0;

d4m*d4p=0;

x2>=3;

x2<=7;

x3>=x2;

x10>=0.15;

x10<=0.25;

x11>=0.05;

x11<=0.10;

x12>=0.10;

x12<=0.25;

x35+x36+x37>=601;

x35+x36+x37<=650;

x35>=400;

x35<=536;

x36>=12;

x36<=41;

x37>=102;

x37<=160;

x18>=1;

x18<=14030;

x19>=1;

x19<=14030;

x18+x19>=2130;

x18+x19<=8009;

x20>=500;

x20<=1958;

x22>=10;

x26>=6;

x30>=650;

x30<=5305;

end

The Optimization Result of Multi-Goal Z_{all}

Minimize Construction Cost Goal,

Minimize Maintenance Construction Cost Goal,

Minimize Environmental Impact Construction Cost Goal,

Maximum Traveling Safety Construction Cost Goal.

Local optimal solution found.

Objective value: 0.1279991E+08

Total solver iterations: 36

Variable	Value	Reduced Cost
D1M	0.1003638E+08	0.000000
D1P	0.000000	2.000000
D2M	607096.7	0.000000
D2P	0.000000	2.000000
D3M	0.000000	1.391644
D3P	0.000000	0.6083562
D4M	0.000000	2.000000
D4P	2156432.	0.000000
X2	4.431678	0.000000
X3	4.431678	0.000000
X10	0.1500000	0.000000
X11	0.5000000E-01	0.000000
X12	0.1000000	0.000000
X35	400.0000	0.000000
X36	41.00000	0.000000
X37	160.0000	0.000000
X18	2129.000	0.000000
X19	1.000000	0.000000
X20	500.0000	0.000000
X22	10.00000	0.000000

X26	6.000000	0.000000
X30	650.0000	0.000000

Row	Slack or Surplus	Dual Price
1	0.1279991E+08	-1.000000
2	-0.2054345	1.000000
3	-0.2054345	1.000000
4	-0.2054345	-0.3916438
5	-0.2054345	-1.000000
6	0.000000	0.000000
7	0.000000	0.000000
8	0.000000	0.000000
9	0.000000	0.000000
10	1.431678	0.000000
11	2.568322	0.000000
12	0.000000	-22665.32
13	0.000000	-2931470.
14	0.1000000	0.000000
15	0.000000	-4349923.
16	0.5000000E-01	0.000000
17	0.000000	-0.5106432E+08
18	0.1500000	0.000000
19	0.000000	-1520.890
20	49.00000	0.000000
21	0.000000	0.000000
22	136.0000	0.000000
23	29.00000	0.000000
24	0.000000	851.6987
25	58.00000	0.000000
26	0.000000	942.9521
27	2128.000	0.000000

28	11901.00	0.000000
29	0.000000	-194.6740
30	14029.00	0.000000
31	0.000000	-91.25343
32	5879.000	0.000000
33	0.000000	-912.5343
34	1458.000	0.000000
35	0.000000	-6083.562
36	0.000000	-21900.82
37	0.000000	-851.6987
38	4655.000	0.000000

Appendix D

Glossary of selected road engineering terms

GLOSSARY OF SELECTED ROAD ENGINEERING TERMS

AASHTO - Abbreviation for American Association of State Highway and Transportation Officials.

ADT - cf. "Average Daily Traffic".

Aesthetics - A branch of philosophy dealing with beauty and the beautiful and judgments of taste concerning them. In highway engineering, aesthetic judgments have to do primarily with the appearance of the highway or road as a whole, including the roadside and its relationship to the natural and cultural environment through which it passes.

Average Daily Traffic (ADT) - The average 24-hour volume, being the total volume during a stated period divided by the number of days in that pe riod, normally a year or the number of days the road is actually open to public travel.

Average Running Speed - For all traffic, or a component thereof, the summation of distances traveled divided by the summation of running times.

Backslope - In cuts, the slope from the bottom of the ditch to the top of the cut.

Bridge - A structure exceeding 20 feet clear span measured along the centerline of the roadway, which carries traffic over a watercourse or opening.

Broken Back Curve - An arrangement of curves in which a short tangent separates two curves in the same direction.

Capacity - The maximum number of vehicles which has a reasonable expectation of passing over a given section of lane or roadway during a given time period under prevailing roadway and traffic conditions.

Centerline - (1) For a two-lane road, the centerline is the middle of the traveled way; and for a divided road, the centerline may be the center of the median. For a divided road with independent roadways, each roadway has its own centerline. (2) The defined and surveyed line shown on the plans from which road construction is controlled.

Critical Length of Grade - That combination of gradient and length of grade which will cause a designated vehicle to operate at some predetermined minimum speed. A lower speed than this is unacceptable and usually requires that an

auxiliary climbing lane be provided for slow-moving vehicles.

Cross Section - The transverse profile of a road showing horizontal and vertical dimensions.

Cross Walk - Any portion of a roadway at an intersection or elsewhere distinctly delineated for pedestrian crossing by signs and by lines or other markings on the surface.

Culvert - Any structure under the roadway with a clear opening of 20 feet or less measured along the center of the roadway.

Curve Widening - The widening of the traveled way on sharp curves to compensate for the fact that the rear wheels of a vehicle do not follow exactly in the track of the front wheels.

Curvilinear Alignment - A flowing alignment in which the majority of its length is composed of circular and spiral curves.

Cut Section - That part of the roadway which, when constructed, is lower in elevation than the original ground.

Design Speed - A speed selected for purposes of design and correlation of the physical features of a road that influence vehicle operation. It is the maximum safe speed that can be maintained over a specified section of the road when conditions are so favorable that the design features of the road govern.

Design Vehicle - A selected motor vehicle, the weight, dimensions, and operating characteristics of which are used as a control in road design.

Design Vehicle Turning Radius - The turning radius of a Design Vehicle, used primarily to determine the minimum radius used in the design of turning and intersecting roadways.

Design Volume - A volume determined for use in design, representing the traffic expected to use the road.

Embankment - A raised earth structure on which the roadway pavement structure is placed.

Fill Section - cf. "Embankment".

Foreslope - The slope from the edge of the surfaced shoulder to the top of the subgrade, or the bottom of the ditch in cuts.

Functional Classification - The grouping of individual roads in a road system according to their purpose or function and the type of traffic or use they serve.

Geometric Design - The arrangement of the visible elements of a road, such as alignment, grades, sight distances, widths, slopes, etc.

Grade - (1) The profile of the center of the roadway, or its rate of ascent or descent. (2) To shape or reshape an earth road by means of cutting or filling. (3) Elevation.

Grade Separation - A structure which provides for traffic to pass over or under another road or railroad.

Horizontal Alignment - Horizontal geometries of the roadway.

Horizontal Curve - A curve or transitional by means of which a road can change direction to the right or left.

Hourly Volume - The number of vehicles passing over a given section of lane or roadway during one hour.

Intersection - The general area where two or more roads join or cross, within which are included the roadway and roadside facilities for traffic movements in that area.

Intersection Angle - The angle between two intersecting roads.

Lanes

Auxiliary Lane - The portion of the roadway adjoining the traveled way for parking, speed change, turning, storage for turning, weaving, truck climbing, or for other purposes supplementary to through traffic movement.

Median Lane - A speed-change lane within the median toaccommodate left-turning vehicles.

Parking Lane - An auxiliary lane primarily for the parking of vehicles.

Speed-Change Lane - An auxiliary lane, including tapered areas, primarily for the acceleration or deceleration of vehicles entering or leaving the through traffic lanes.

Turn Lane - A traffic lane within the normal surfaced width of a roadway, or an auxiliary lane adjacent to or within a median, reserved for vehicles turning left or right at an intersection.

Traffic Lane - The portion of the traveled way for the movement of a single line of vehicles in one direction.

Level of Service - A qualitative rating of the effectiveness of a road relative to the service it renders to its users, measured in terms of a number of factors, such as operating speed, travel time, traffic interruptions, freedom to maneuver and pass, driving safety, comfort, and convenience.

Median - The portion of a divided roadway separating the traveled ways for traffic in opposite directions.

Merging - The converging of separate streams of traffic into a single stream.

Multi-Lane Road - A road having two or more lanes for traffic in each direction, or four or more lanes for traffic in two directions. It may be one-way or two-way, divided or undivided.

Overlook (Scenic Overlook) - A roadside area provided for motorists to stop their vehicles beyond the traveled-way, primarily for viewing scenery in safety.

Passing Opportunity - A section of two-lane, two-directional road where sufficient clear sight distance exists to allow a safe passing maneuver to be performed.

Passing Sight Distance - The minimum sight distance that must be available to enable the driver of a vehicle to pass another safely and comfortably without interfering with the speed of an oncoming vehicle traveling at the design speed should it come into view after the overtaking maneuver is started.

Pavement Markings - Devices or paint placed on the roadway to mark pavement for vehicular and pedestrian traffic control.

Pavement Structure - The combination of subbase, base course, and surface course placed on a subgrade to support the traffic load and distribute it to the roadbed.

Base Course - The layer or layers of specified or selected material of designed thickness placed on a subbase or a subgrade to support a surface course.

Subbase - The layer or layers of specified or selected material or designed thickness placed on a subgrade to support a base course.

Subgrade - The top surface of a roadbed upon which the pavement structure and shoulders, including curbs, are constructed.

Subgrade Treatment - Modification of roadbed material by stabilization.

Surface Course - One or more layers of a pavement structure designed to accommodate the traffic load, the top layer of which resists skidding, traffic abrasion, and the disintegrating effects of climate. The top layer is sometimes called "Wearing Course".

Pedestrian Crossing (Crosswalk) - An area clearly marked for the passage of pedestrians at street junctions or other locations where drivers must yield the right-of-way by stopping to enable pedestrians to cross safely.

Profile - A longitudinal section of a roadway, drainage course, etc.

Recreation Vehicle (RV) - A vehicle specifically designed for recreational use, usually considerably larger than a passenger car and frequently containing kitchen, sleeping and toilet facilities.

Resurfacing - The placing of one or more new courses on an existing road surface.

Reverse Curve - A curve consisting of two arcs of the same or different radii curving in opposite directions and having a common tangent or transition curve at their point of junction.

Road (Highway) - A general term denoting a public way for purposes of vehicular travel, including the entire area within the right-ofway.

Roadside - A general term denoting the area adjoining the outer edge of the roadway. Extensive areas between the roadways of a divided road may also be considered roadside.

Roadway - The portion of a highway, including shoulders, for vehicular use. A divided highway has two or more roadways.

Running Speed - cf. "Average Running Speed".

Service Volume - The maximum number of vehicles that can pass over a given section of a lane or roadway in one direction on a multilane road or in both directions on a two-lane road during a specified time period, which is stated as an hourly volume and which varies according to the level of service.

Shoulder - The portion of the roadway contiguous with the traveled way for accommodation of stopped vehicles, for emergency use, and for lateral support of base and surface courses.

Sight Distance - The length of roadway ahead visible to a driver.

Skid Resistance - The frictional force between a locked tire and a pavement, which force resists motion.

Slope - The face of an embankment or cut section; any ground the surface of which makes an angle with the plane of the horizon.

Speed - The rate of movement of a vehicle, generally expressed in miles per hour (mph).

Spiral Curve - cf. "Transition Curve".

Standard - Criteria having recognized and usually permanent values which are established formally as a model or requirement.

Stopping Sight Distance - The distance required by a driver of a vehicle, traveling at a given speed, to bring his vehicle to a stop after an object on the roadway becomes visible, including the distance traveled during the perception and reaction times, as well as the vehicle braking distance.

Superelevation - The elevating of the outside edge of a curve to partially offset the centrifugal force generated when a vehicle rounds the curve.

Superelevation Runoff - The transition distance between normal crown and fully superelevated roadway.

Sustained Grade - A continuous road grade of appreciable length and consistent, or nearly consistent, gradient.

Traffic - All types of vehicles, together with their loads, either singly or as a whole, including pedestrians, while using a roadway for the purpose of transportation.

Traffic Control Device - A sign, signal, marking or other device placed on or adjacent to a street or highway by authority of a public body or official having jurisdiction to regulate, warn, or guide traffic.

Traffic Control Signal - Any device--whether manually, electrically, or mechanically operated--by which traffic is alternately directed to stop and permitted to proceed.

Traffic Markings - All lines, patterns, words, colors, or other devices--except signs--set into the surface of, applied upon, or attached to the pavement or curbing or to objects within or adjacent to the roadway, officially placed for the purpose of regulating, warning, or guiding traffic.

Traffic Sign - A device mounted on a fixed or portable support whereby a specific message is conveyed by means of words or symbols, officially erected for the purpose of regulating, warning, or guiding traffic.

Traffic Signal - A power-operated traffic control device by which traffic is regulated, warned, or alternately directed to take specific actions.

Traffic Volume - The number of vehicles passing a given point during a specified period of time.

Transition - A section of variable pavement width required when changing from one width of traveled way to a greater or lesser width.

Transition Curve (Spiral) - A curve of variable radius intended to effect a smooth transition from tangent to curved alignment.

Traveled Way - The portion of the roadway for the movement of vehicles, exclusive of shoulders and auxiliary lanes.

Turn Angle - cf. "Angle of Turn".

Turning Path - The path of a designated point on a vehicle making a specified turn. (cf. also "Minimum Turning Path").

Turning Track Width - The radial distance between the turning paths of the outside of the outer front tire and the outside of the rear tire which is nearest the center of the turn.

Vertical Alignment (Profile Grade) - The trace of a vertical plane intersecting the top surface of the proposed wearing surface, usually along the longitudinal centerline of the roadbed, being either elevation or gradient of such trace according to the context.

Vertical Curve - A curve on the longitudinal profile of a road providing a change of gradient.

Wearing Course (Surface Course) - The top layer of a pavement.