DETERMINATION OF OPTIMUM SETTING DIMENSIONS AND ROAD STANDARDS FOR UNIFORM TERRAIN

by

Yun Huat Yeap

A PAPER

submitted to

College of Forestry
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Title: Determination of Optimum Setting Dimensions and Road Standards for Uniform Terrain

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The calculation of optimum setting dimensions and road standards simultaneously on a timber sale is a common problem in uniform terrain. Analysis usually begins by evaluating certain road standards under various road spacings and profile geometries. Linear costs, single period entry and simplified skidding patterns are often assumed to permit simpler calculations and closed form solutions. Various skidding patterns, nonlinear costs, multiple periods, and variable road standards are not considered. In this paper, the simultaneous solution of spur road spacing, collector road spacing, and choice of collector road standards for linear and nonlinear skidding functions are considered. For the linear skidding function, a multiple period formulation is made. The road and landing spacing problem is solved by (1) complete enumeration, (2) a combination of complete enumeration and the Hooke and Jeeves pattern search method, and (3) by the Hooke and Jeeves pattern search method. The Hooke and Jeeves pattern search

method provided the fastest solution times with solutions almost as good as the complete enumeration. The improvements in road spacings, and cost evaluation using the more complex assumptions are compared with simpler analyses.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

DETERMINATION OF OPTIMUM SETTING DIMENSIONS AND ROAD STANDARDS FOR UNIFORM TERRAIN

1. INTRODUCTION

The simultaneous calculation of optimum setting dimensions and road standards on a timber sale is a common problem not well defined in the literature. Analysis usually begins by evaluating certain road standards under various road spacings and profile geometries. The planner must decide:

a) What standard should be built along each section of a collector?

b) What skidding patterns will be set up along a collector and spur roads?

c) Are the roads built for a single entry or multiple entries?

Usually planners do not consider varying the road standards along a low volume road. Once a road standard has been determined, often the same road standard will be built from the existing road to near the end of the unit.

In order to economically get the logs out from the woods, reducing road building cost by appropriately varying the road standard along the road would be a wise decision. Also, combining various skidding patterns in a setting could optimize skidding cost. We want to find the point at which the sum of road building, hauling, and skidding cost is a minimum.

Volume entering a low standard road depends on the type of landings used. Some volume could be coming into the road along continuous landings or discontinuously at discrete landing locations. Some calculation methods may be more appropriate than others depending upon how the volume comes to the road.

Very often a low standard road would be used more than one period. This depends on the silviculture and harvesting schedule of the area. The choice of optimal road standards could be affected by the schedule of entries.

The road system density as well as cost may be affected by road standards and skidding patterns. In this paper we will consider on an infinite area with a system of existing mainline roads evenly spaced over it. Now more roads are needed in order to access the timber. The future road system will consist of evenly spaced collectors along both sides of the existing mainline roads. Again, perpendicular to these collectors will be evenly spaced spur roads (Figure 1). Each collector can be further divided into high and low standard collectors. Also, along the collector are triangular skidding pattern settings (Figure 2). Here, each spur road is surrounded with triangular, radial, and right-angle skidding pattern settings.

2. OBJECTIVES

The objectives of this paper are:

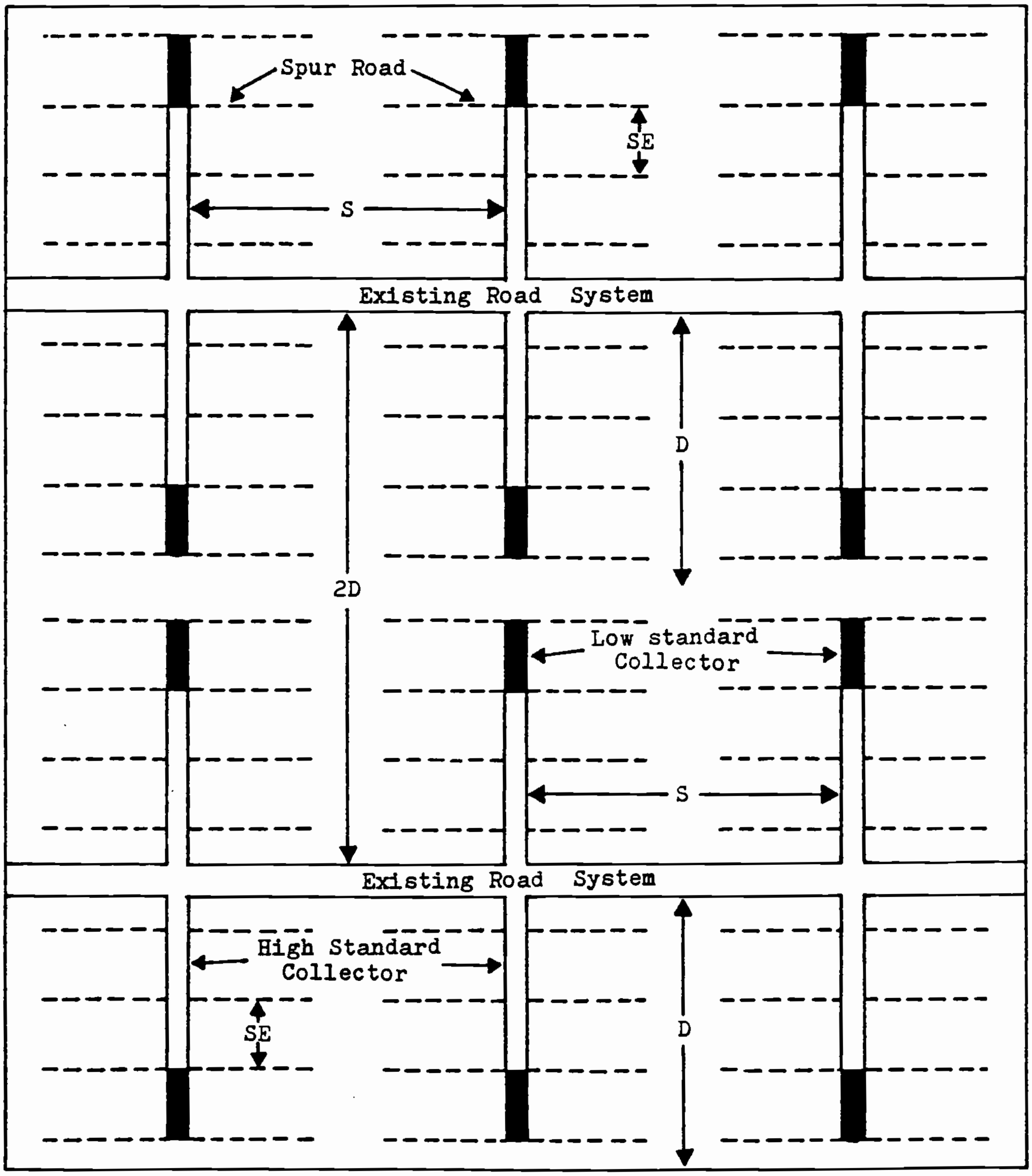


Figure 1. Spacings for the Existing Road System, Collectors and Spur Roads.

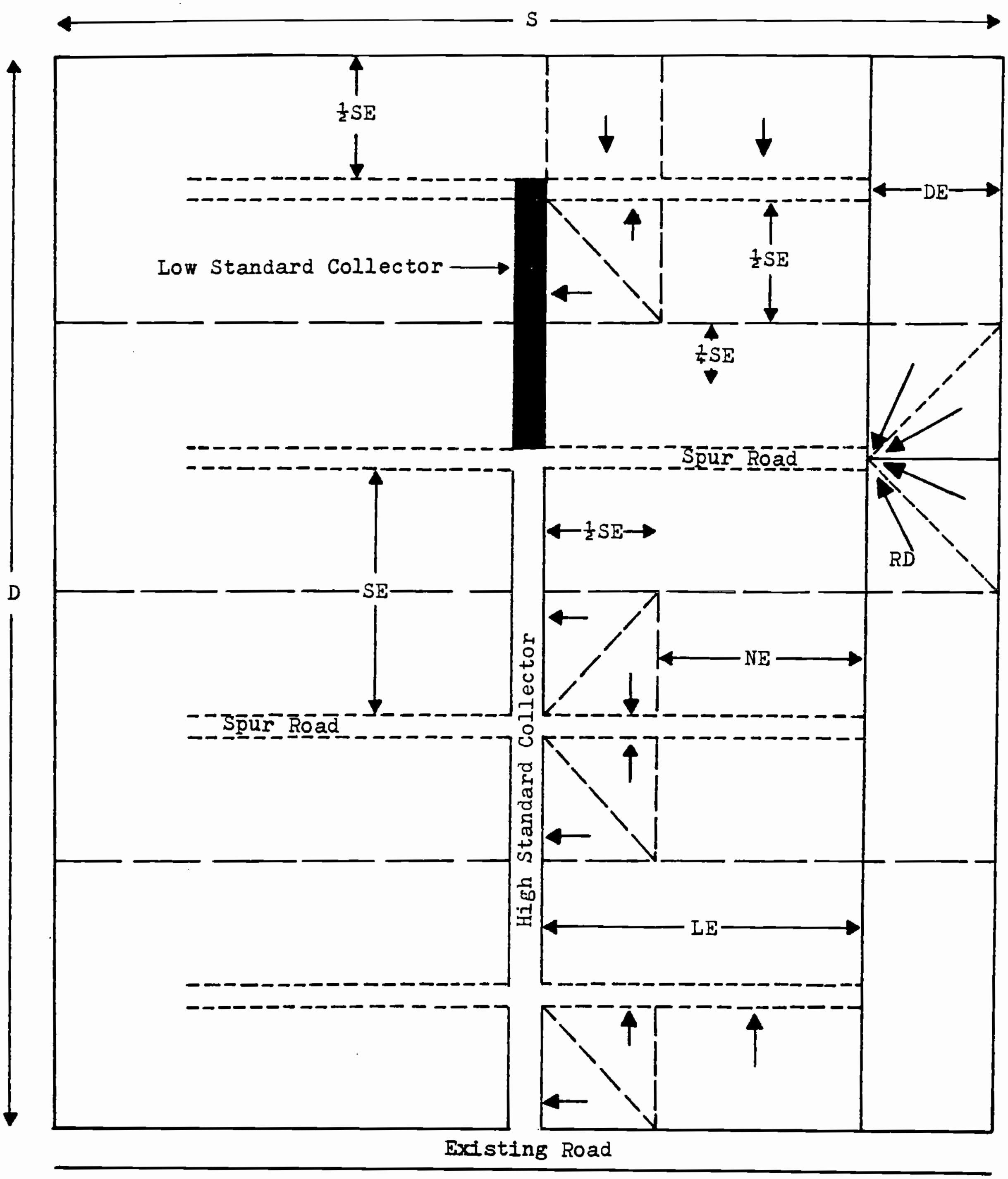


Figure 2. Basic Geometry.

1) Prepare mathematical formulations for single entry with:

   a) linear skidding costs

   b) non-linear skidding costs

   in various skidding pattern settings associated with high and low standard collectors.

2) Prepare mathematical formulation for multiple entries with linear skidding costs in various skidding pattern settings associated with high and low standard collectors.

3) Set up solution procedures using Complete Enumeration Method, combining Complete Enumeration Method and Hooke and Jeeves Pattern Search Method, and Hooke and Jeeves Pattern Search Method to find optimum dimensions for:

   a) the spacing between collectors.

   b) the spacing between spur roads.

   c) the distance that the high standard collector must extend from the existing road into the unit.

   d) various skidding patterns settings.

4) Examine assumptions that must be made in the mathematical formulations of the problems.

5) Write computer programs to perform the optimization calculations.

6) Use Bowman and Hessler's inputs to run through examples and compare the outcomes.

3. LITERATURE REVIEW

Matthews' (1942) solves for the optimal road and landing spacing by breakeven analysis. His classic formula for the unit cost of skidding and road construction for two-way skidding and continuous landings when the spacing of roads has not been predetermined is

$$X = \frac{CS}{4} + \frac{R}{VS}$$

where C is the cost of skidding per unit volume per unit distance, R is the cost of road construction per unit distance, S is road spacing in distance units, and V is volume per unit area. This method is simple and most commonly used where there is only one unknown variable. The skidding cost must be linear with respect to distance. Matthews did extensive work evaluating road standards for an interior mainline road when branch roads are used. Unfortunately his work involved only right-angle skidding pattern to the branch roads.

Nickerson (1978) combined several skidding patterns adjacent to each another along swing roads to determine the optimum dimensions for: 1) truck road spacing, 2) landing spacing, and 3) length of tractor swing road. However he considers only one road standard in the discussion. Moreover, truck hauling cost is omitted. He solved for the optimal dimensions using the Newton Multivariate Gradient Iteration Method.

Peters (1978) developed a dimensionless solution for optimum spacing of roads and landings for rectangular havest units in table and graph forms. Peters used a landing and road spacing ratio concept to solve for optimum road spacing and optimum landing spacing as a direct method. Using this method, a necessary condition to minimize cost is that variable yarding costs equal road cost plus twice the landing cost. Subsequent work extended the method to rectangular havest units, for one-way and two-way yarding in an L-pattern to a landing.

Not many authors consider nonlinear skidding costs. Nonlinear skidding costs can occur in highlead logging where lift becomes progressively less at greater distances and in animal skidding where animals tire at longer distances. Olsen (1981) showed that substantial errors can result from using average skidding distance to estimate average skidding costs when the relationship between skidding cost and skidding distance is nonlinear. Sessions and Li (1987) demonstrate techniques using microcomputers to determine optimum road and landing spacing with linear and nonlinear costs in various skidding patterns. These techniques are simple and easy, but are only demonstrated for one particular skidding pattern at a time. That is either a radial or a right-angle skidding pattern.

Bowman and Hessler (1983) compared the existing road densities in Chequamegon National Forest in Northern Wisconsin with the theoretical optimum road densities. Their objective was to evaluate the optimum road spacings for spur roads and collector roads for unroaded areas with existing access roads. Their original problem identification motivated this project paper. To simplify their analysis Bowman and Hessler assumed linear skidding costs, skidding to spur roads only, and a single time period. They constructed a total cost equation and differentiated it with respect to the spur road and collector road spacing. The solution of the resulting equations provided a closed form solution for spur road and collector road spacing.

Baldwin, Hanson, and Thompson (1987) looked at the Bowman and Hessler problem in more detail. Using a method similar to Bowman and Hessler, optimum road spacing is calculated. Their model differs from Bowman and Hessler in that they considered the simultaneous spacing of the mainline access roads as well as the spacing of the spur and collector roads. For the skidding and haul cost assumptions in their formulation, they found that the spacing decision of the mainline roads could be taken independently from the spur and collector road spacing.

4. PROBLEM FORMULATION

Based on different practical conditions, three mathematical formulations were developed for determining the relationship between road standards and setting dimensions. These three formulations will be referred to as the "single entry with linear skidding costs" method, the "multiple entries with linear skidding costs" method, and the "single entry with non-linear skidding costs" method.

4.1 Assumptions

Some assumptions have to be made in order to clarify and simplify the problem. The following are some of the most significant assumptions in these formulations:

1) The timber is evenly distributed over the area.
2) Uniform terrain which is regular enough to be fitted with a pattern of logging settings.
3) The existing mainline standard road system is at least the same standard as for the collector. Without the existing mainline road system, the problem would become more complicated. In addition to the collector and spur roads, it would be necessary to include another higher level of road system with different road standards in the formulation.
4) The landing cost is insignificant. If landing costs were to be included, the landing cost would be added to the road cost to increase the unit cost of roads.

5) Skidding cost is directly proportional to skidding distance for single entry and multiple entries with linear skidding costs.

6) For non-linear skidding costs, the skidding cost ($/CCF) for very short distance is a constant like $1/CCF and increases nonlinearly with distance, d(FT), the skidding cost is of the form:

$$1+.005(d)^{1.2}$$

4.2 Variables

The unit of volume used in this project is in CCF per square feet. CCF is units of one hundred cubic feet of timber.

The following four variables are used in all the formulations:

DE = The depth (parallel to spurs) of radial skidding pattern setting. Unit is in feet. (Figure 2)

NE = The length of spur road between triangular and radial skidding pattern setting. This is the length of right-angle skidding pattern setting along spur road. Unit is in feet.

J = The number of spur roads (must be at least one) on one side of the collector for the depth of the unit. This is also equal to the number of collector road segments. See Figure 2A.

K = The number of road segments (can be zero and up to J) of low standard collector.

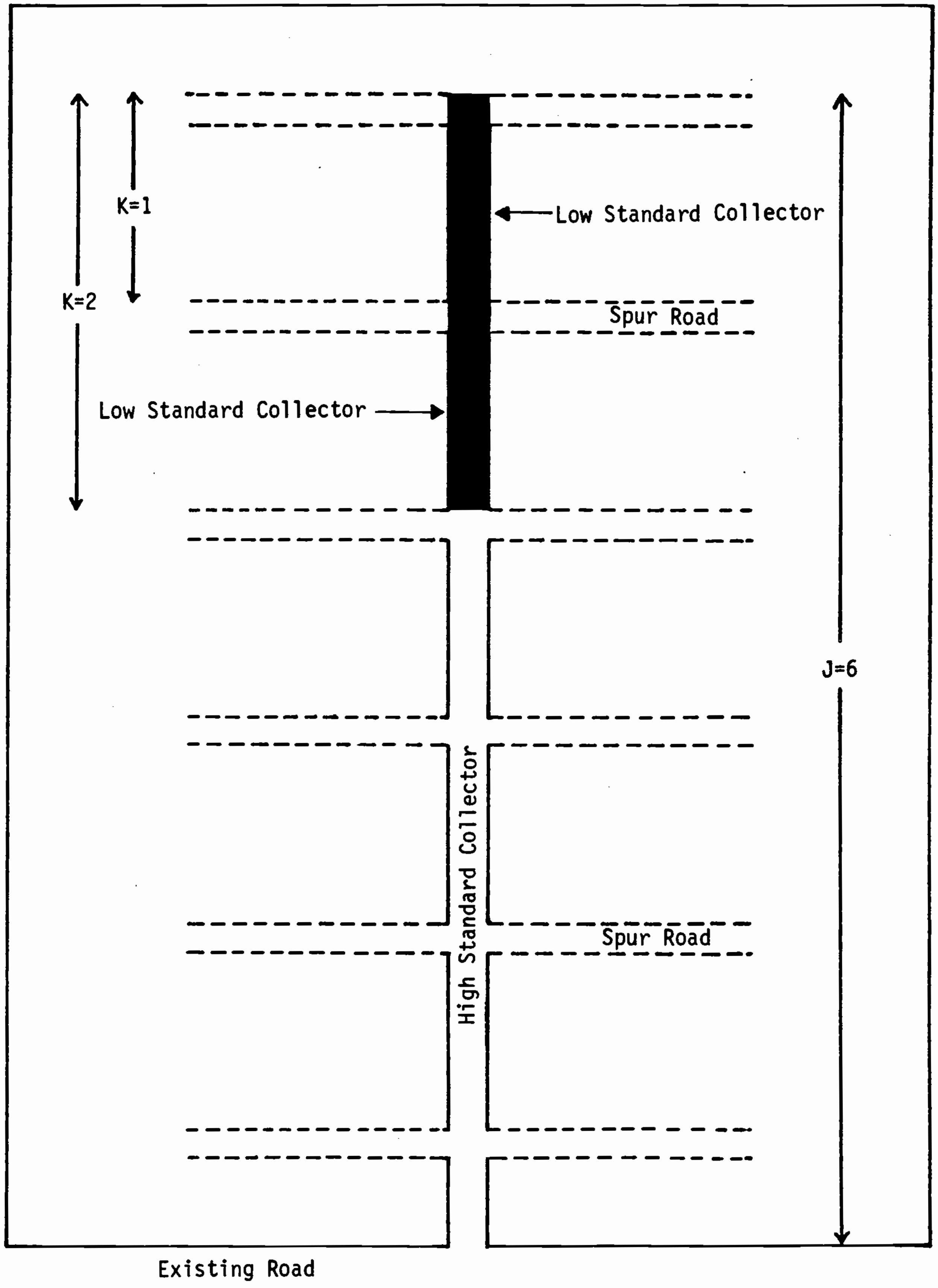


Figure 2A. Example Showing Directions and Number of Road Segments for J and K.

J and K must be integers.

4.2.1 Single Entry with Linear Skidding Costs

Variables	Units
V = Volume removed	CCF/FT^2
D = Depth of the unit	FT
RH = High standard collector cost	$/FT
RL = Low standard collector cost	$/FT
RS = Spur road cost	$/FT
SC = Skid cost to collector	$/CCF/FT
SS = Skid cost to spur roads	$/CCF/FT
HH = Haul cost on high standard collector	$/CCF/FT
HL = Haul cost on low standard collector	$/CCF/FT
HS = Haul cost on spur roads	$/CCF/FT

4.2.2 Single Entry with Non-Linear Skidding Costs

All variables used in the formulations are the same as in the Single Entry with Linear Skidding Costs except the skidding costs. The non-linear skid cost function used is similar to the non-linear skid cost function in Sessions and Li (1987). The non-linear skid cost function in this paper is set to $1+.005(d)^{1.2}$, $/CCF.

Where d = Skid distance in feet.

The non-linear skid cost function is used to determine skid distance cost ($/CCF) in various skidding pattern settings:

TD = Skid distance costs for triangular skidding pattern settings (skid to collector and spur roads).

UD = Skid distance costs for right-angle skidding pattern settings at end of collector.

LD = Skid distance costs for right-angle skidding pattern settings along the spur roads.

DD = Skid distance costs for radial skidding pattern settings at end of spur roads.

4.2.3 Multiple Entries with Linear Skidding Costs

Assume that collectors and spur roads will be built in year zero. The following year is the first entry. Each entry from then on would be some i years from now. Except for the first entry, all the roads have to be reconstructed in each entry. Reconstruction and entry to the stand occur in the same year. Four entries is the maximum in this formulation.

Variables		Units
i	= Index for the number of years starting at year 0	
Y_i	= Enter the stand in year i	
I	= Interest rate	%/100
RHC0	= High standard collector cost in year 0	$/FT
RLC0	= Low standard collector cost in year 0	$/FT
RS0	= Spur road cost in year 0	$/FT
RHCi	= High standard collector reconstruction cost in year i	$/FT
RLCi	= Low standard collector reconstruction	$/FT

cost in year i

RSi	=	Spur road reconstruction cost in year i	\$/FT
VFi	=	Volume removed in year i	CCF/FT^2
SCi	=	Skid cost to collector in year i	\$/CCF/FT
SSi	=	Skid cost to spur roads in year i	\$/CCF/FT
HHCi	=	Haul cost on high standard collector in year i	\$/CCF/FT
HLCi	=	Haul cost on low standard collector in year i	\$/CCF/FT
HSCi	=	Haul cost on spur roads in year i	\$/CCF/FT

4.3 Basic Geometry

All dimensions are in feet. For an infinite area, the spacing of the existing road system is 2 x D (Figure 1). The pattern of settings is repeated infinitely over the area (Figure 2). Collectors will be built from each side of the existing mainline. Therefore, the depth of each unit is D. Let the spacing of the collectors be S. Perpendicular to each collector are evenly spaced spur roads on both sides of the collector. J is the number of spur roads (on one side of the collector) or the number of collector road segments for the depth of the unit. The spur road spacing, SE, is inversely proportional to the number of spur roads. Therefore,

$$SE = D/J$$

Along each collector, there are triangular skidding pattern settings with continuous landings on both sides (Figure 2). Surrounding each spur road are triangular, right-angle and radial skidding pattern settings. There are no triangular skidding pattern settings for the other side of the last spur road which is near to the boundary and also beyond the end of collector (Figure 2). On this side, only right-angle and radial skidding pattern settings are present. All the triangular skidding pattern settings are right-angle triangle in shape. Therefore, the altitude and the base is equal to SE/2. The distance from the first spur road to the existing road and the last spur road to the boundary is also assumed equal to SE/2. So, the length of collector, B, is shorter than the depth of the unit by SE/2.

$$B = D - SE/2$$

The length of high standard collector would be

$$L = D - SE/2 - K(SE)$$

Where K = Number of road segments of low standard collector.

At the end of each spur road, a landing is built for radial skidding pattern setting. The distance out (parallel to spur road) from the landing to the boundary is DE. NE is the length between the triangular and radial skidding pattern setting. This NE is the length for right-angle skidding pattern setting along spur road. Given the base of triangular skidding pattern, the length of spur road, LE, can be determined:

$$LE = SE/2 + NE$$

Parallel to the spur roads, the distance between the collector and the boundary is

$$LE+DE$$

The collector spacing is twice this distance,

$$S = 2(LE+DE).$$

4.4 Single Entry with Linear Skidding Costs Formulation

Given the values for all the variables, the total costs can be determined.

4.4.1 Total Spur Roads Cost

The road cost for each spur road is equal to RS x LE. For the whole unit, the total spur roads costs would be

$$S1 = 2 \times J \times RS \times LE$$

4.4.2 Total Skid Cost to Spur Roads

Skid cost (one side of collector) for volume(s) from

i) Right-angle skidding pattern settings (both sides) along spur roads with continuous landings along spur roads

$$= J \times SS \times \frac{SE}{4} \times \left(LE - \frac{SE}{2}\right) \times SE \times V$$

where $\frac{SE}{4}$ is the average skidding distance

ii) Radial skidding pattern settings at end of spur roads with landings at end of spur roads

$$= J \times SS \times RD \times DE \times SE \times V$$

Matthews' average skidding distance formula is applied in these settings. In which,

$$RD = \frac{1}{6}\sqrt{SE^2 + DE^2} + \frac{1}{3}\sqrt{\frac{SE^2}{16} + DE^2}$$

iii) Triangular skidding pattern settings with continuous landings along spur roads (skid to spur roads)

$$= (2J - 1) \times SS \times \frac{1}{3} \times \frac{SE}{2} \times \frac{1}{2} \times \left(\frac{SE}{2}\right)^2 \times V$$

Here, the average skidding distance $= \frac{1}{3} \times \frac{SE}{2}$

(2J-1) = # of triangular skidding settings along spur roads (skid to spur roads). See Appendix A and Figure 2. Simplifying the equation

$$= \frac{(2J-1)\times SS\times SE^3\times V}{48}$$

iv) Right-angle skidding pattern setting at end of collector with continuous landings along the last spur road

$$= SS\times\frac{SE}{4}\times\left(\frac{SE}{2}\right)^2\times V$$

where $\frac{SE}{4}$ is the average skidding distance

Simplifying,

$$= \frac{SS\times SE^3\times V}{16}$$

Summing up all four skid costs and simplifying, the total skid cost to spur roads becomes

$$S2 = 2\times SS\times SE\times V\left\{J\,[\frac{SE}{4}\times\left(LE-\frac{SE}{2}\right)+RD\times DE\,]+[\frac{(2J-1)}{48}+\frac{1}{16}]\times SE^2\right\}.$$

4.4.3 Total Haul Cost on Spur Roads

Haul cost (one side of collector) for volume(s) from

i) Right-angle skidding pattern settings (both sides) along spur roads with continuous landings along spur roads

$$= J\times HS\times[\frac{SE}{2}+\left(\frac{LE-\frac{SE}{2}}{2}\right)]\times\left(LE-\frac{SE}{2}\right)\times SE\times V$$

where $[\frac{SE}{2}+\left(\frac{LE-\frac{SE}{2}}{2}\right)]$ is the average haul distance

Simplifying,

$$= \frac{1}{2}\times J\times HS\times SE\times[LE^2-\frac{SE^2}{4}]\times V$$

ii) Radial skidding pattern settings at end of spur roads with landings at end of spur roads

$$= J \times HS \times LE \times DE \times SE \times V$$

The hauling distance for volume from landing at the end of spur road to the collector is equal to the length of the spur road, LE.

iii) Triangular skidding pattern settings with continuous landings along spur roads (skid to spur roads)

$$= (2J-1) \times HS \times \frac{2}{3} \times \frac{SE}{2} \times \frac{1}{2} \times \left(\frac{SE}{2}\right)^2 \times V$$

Average hauling distance to the collector $= \frac{2}{3} \times \frac{SE}{2}$

and

(2J-1) = # of triangular skidding pattern settings along spur roads (skid to spur roads). See Appendix B and Figure 2.

Simplifying,

$$= \frac{(2J-1) \times HS \times SE^3 \times V}{24}$$

iv) Right-angle skidding pattern setting at end of collector with continuous landings along the last spur road

$$= \frac{1}{2} \times HS \times \frac{SE}{2} \times \left(\frac{SE}{2}\right)^2 \times V$$

Average hauling distance $= \frac{1}{2} \times \frac{SE}{2}$

Simplifying,

$$= \frac{HS \times SE^3 \times V}{16}$$

Summing up all the haul costs and simplifying, the total haul cost on spur roads is

$$S3 = 2 \times HS \times SE \times V \left\{ J \left[\frac{1}{2} \left(LE^2 - \frac{SE^2}{4} \right) + LE \times DE \right] + \left[\frac{(2J-1)}{24} + \frac{1}{16} \right] \times SE^2 \right\}.$$

4.4.4 Total Collector Cost

The collector could be made up of both high and low standard sections, only high standard or only low standard.

When $K = 1,2,3,4,---$ and $L = \frac{SE}{2}, \frac{3SE}{2}, \frac{5SE}{2}, ---,$

the collector has both high and low standard sections (Figure 2). The collector cost is

$$S4 = \left(D - \frac{SE}{2} - K \times SE\right) \times RH + K \times SE \times RL$$

where

$$\text{High standard collector cost} = \left(D - \frac{SE}{2} - K \times SE\right) \times RH$$

$$\text{Low standard collector cost} = K \times SE \times RL$$

When $K = 0$ and $L = \frac{SE}{2}, \frac{3SE}{2}, \frac{5SE}{2}, ---,$

the whole collector is a high standard collector. The collector cost is

$$S4 = \left(D - \frac{SE}{2}\right) \times RH$$

When $L = 0, K = J$ and $K = 1,2,3,---$ i.e. $B = \frac{SE}{2}, \frac{3SE}{2}, \frac{5SE}{2}, ---,$

the whole collector is a low standard collector. The collector cost will be

$$S4 = \left(D - \frac{SE}{2}\right) \times RL.$$

4.4.5 Total Skid Cost to Collector

Assuming that continuous landings are allowed along both sides of the collector. Timber from the settings is skidded directly to the collector. Total skid cost to collector will be

$$S5 = 2 \times (2 \times J - 1) \times SC \times \frac{1}{3} \times \frac{SE}{2} \times \frac{1}{2} \times \left(\frac{SE}{2}\right)^2 \times V$$

where $2 \times (2 \times J - 1)$ = Total number of triangular skidding pattern settings along both sides of the collector

$\frac{1}{3} \times \frac{SE}{2}$ = Average skidding distance

Simplifying,

$$S5 = \frac{(2 \times J - 1) \times SC \times SE^3 \times V}{24}.$$

4.4.6 Haul Cost on Collector

Since the collector could be in different road standards, the haul cost must consider the different combinations.

When $K = 0$ and $L = \frac{SE}{2}, \frac{3SE}{2}, \frac{5SE}{2}, ---,$

the whole collector is a high standard collector. The haul cost on the collector is

$$S6 = HH \times LL \times S \times D \times V$$

where

LL = Average haul distance on high standard collector only. See Appendix C.

When $L = 0, K = J$ and $K = 1,2,3,4,---$ i.e. $B = \frac{SE}{2}, \frac{3SE}{2}, \frac{5SE}{2}, ---,$

the entire collector is a low standard collector. The haul cost on it is

$$S6 = HL \times BB \times S \times D \times V$$

where

BB = Average haul distance on low standard collector only. See Appendix C.

When $K = 1,2,3,4,---$ and $L = \frac{SE}{2}, \frac{3SE}{2}, \frac{5SE}{2}, ---,$

the collector is made up of both high and low standard collector. The total haul cost will be

$$S6 = [S \times SE \times K + \left(\frac{SE}{2}\right)^2] \times [(HL \times BL) + (HH \times L)] \times V + \left\{S \times D - [S \times SE \times K + \left(\frac{SE}{2}\right)^2]\right\} \times HH \times LB \times V$$

where

BL = Average haul distance on low standard collector. See Appendix C.

LB = Average haul distance on high standard collector. See Appendix C.

Haul cost on low standard collector for volumes to low standard collector

$$= [S \times SE \times K + \left(\frac{SE}{2}\right)^2] \times HL \times BL \times V$$

Haul cost on high standard collector for volumes to low standard collector

$$= [S \times SE \times K + \left(\frac{SE}{2}\right)^2] \times HH \times L \times V$$

Haul cost on high standard collector for volumes to high standard collector

$$= [S \times D - (S \times SE \times K + \left(\frac{SE}{2}\right)^2] \times HH \times LB \times V$$

4.4.7 Average Cost

Total cost

$$\mathrm{COST} = S1 + S2 + S3 + S4 + S5 + S6.$$

The total volume for the unit is

$$\mathrm{VOL} = S \times D \times V.$$

Average cost per unit volume

$$\mathrm{TC} = \frac{COST}{VOL}.$$

4.5 Multiple Entries with Linear Skidding Costs Formulation

All the costs are discounted to net present cost. The interest rate, I, is assumed to be constant for the rotation. The average cost calculated as net present cost per acre.

4.5.1 Total Spur Roads Cost

Summing up the construction or reconstruction costs for spur roads in each entry, the discounted spur roads cost is:

$$S1 = \Sigma \text{Construct or reconstruct spur roads cost in year } i \times \frac{1}{(1+I)^{Yi}}$$

$$S1 = 2 \times J \times LE \left\{ RS0 \times \frac{1}{(1+I)^{Y0}} + RS10 \times \frac{1}{(1+I)^{Y10}} + RS20 \times \frac{1}{(1+I)^{Y20}} + RS30 \times \frac{1}{(1+I)^{Y30}} \right\}$$

4.5.2 Total Skid Cost to Spur Roads

The method and formulation used is similar to those in Single Entry. However, the skid cost to spur roads has to be discounted for each entry,

$$S2 = \Sigma \text{Total skid cost to spur roads in year i} \times \frac{1}{(1+I)^{Yi}}.$$

Skid cost (one side of collector) in year i for volume(s) from

i) Right-angle skidding pattern settings (both sides) along spur roads with continuous landings along spur roads

$$= J \times \frac{SE}{4} \times \left(LE - \frac{SE}{2} \right) \times SE \times SSi \times VFi \times \frac{1}{(1+I)^{Yi}}.$$

ii) Radial skidding pattern settings at end of spur roads with landings at end of spur roads

$$= J \times RD \times DE \times SE \times SSi \times VFi \times \frac{1}{(1+I)^{Yi}}.$$

iii) Triangular skidding pattern settings with continuous landings along spur roads (skid to spur roads)

$$= (2J-1) \times \frac{1}{3} \times \frac{SE}{2} \times \frac{1}{2} \times \left(\frac{SE}{2} \right)^2 \times SSi \times VFi \times \frac{1}{(1+I)^{Yi}}$$

$$=\frac{(2J-1)\times SE^3}{48}\times SSi\times VFi\times\frac{1}{(1+I)^{Yi}}.$$

iv) Right-angle skidding pattern setting at end of collector with continuous landings along the last spur road

$$=\frac{SE}{4}\times\left(\frac{SE}{4}\right)^2\times SSi\times VFi\times\frac{1}{(1+I)^{Yi}}$$
$$=\frac{SE^3}{16}\times SSi\times VFi\times\frac{1}{(1+I)^{Yi}}.$$

Summing up and simplifying the total skid cost to spur roads

$$S2=2\times SE\left\{J\,[\frac{SE}{4}\times\left(LE-\frac{SE}{2}\right)+RD\times DE\,]+[\frac{2J-1}{48}+\frac{1}{16}]\times SE^2\right\}\times$$
$$[VF1\times\frac{SS1}{(1+I)^{Y1}}+VF10\times\frac{SS10}{(1+I)^{Y10}}+VF20\times\frac{SS20}{(1+I)^{Y20}}+VF30\times\frac{SS30}{(1+I)^{Y30}}]$$

4.5.3 Total Haul Cost on Spur Roads

Discounting the haul cost on spur roads in each entry and summing up to get the total haul cost on spur roads,

$$S3=\Sigma\text{Total haul cost on spur roads in year i}\times\frac{1}{(1+I)^{Yi}}.$$

The haul cost (one side of collector) in year i for volume(s) from:

i) Right-angle skidding pattern settings (both sides) along spur roads with continuous landings along spur roads

$$=J\times\left\{\frac{SE}{2}+\frac{(LE-\frac{SE}{2})}{2}\right\}\times\left(LE-\frac{SE}{2}\right)\times SE\times HSi\times VFi\times\frac{1}{(1+I)^{Yi}}$$
$$=\frac{1}{2}\times J\times\left(LE^2-\frac{SE^2}{4}\right)\times SE\times HSi\times VFi\times\frac{1}{(1+I)^{Yi}},$$

ii) Radial skidding pattern settings at end of spur roads with landings at end of spur roads

$$= J \times LE \times DE \times SE \times HSi \times VFi \times \frac{1}{(1+I)^{Yi}},$$

iii) Triangular skidding pattern settings with continuous landings along spur roads (skid to spur roads)

$$= (2J-1) \times \frac{2}{3} \times \frac{SE}{2} \times \frac{1}{2}\left(\frac{SE}{2}\right)^2 \times HSi \times VFi \times \frac{1}{(1+I)^{Yi}}$$
$$= \frac{(2J-1) \times SE^3 \times HSi \times VFi}{24} \times \frac{1}{(1+I)^{Yi}},$$

iv) Right-angle skidding pattern setting at end of collector with continuous landings along the last spur road

$$= \frac{1}{2} \times \frac{SE}{2} \times \left(\frac{SE}{2}\right)^2 \times HSi \times VFi \times \frac{1}{(1+I)^{Yi}}$$
$$= \frac{SE^3}{16} \times HSi \times VFi \times \frac{1}{(1+I)^{Yi}}.$$

Summing up and simplifying, the total haul cost on spur roads is

$$S3 = 2 \times SE\left\{J\left[\frac{1}{2}\left(LE^2 - \frac{SE^2}{4}\right) + LE \times DE\right] + \left[\frac{2J-1}{24} + \frac{1}{16}\right] \times SE^2\right\}$$
$$\times\left\{VF1 \times \frac{HS1}{(1+I)^{Y1}} + VF10 \times \frac{HS10}{(1+I)^{Y10}} + VF20 \times \frac{HS20}{(1+I)^{Y20}} + VF30 \times \frac{HS30}{(1+I)^{Y30}}\right\}$$

4.5.4 Total Collector Cost

When $K = 1,2,3,4,---$, and $L = \frac{SE}{2}, \frac{3SE}{2}, \frac{5SE}{2}, ---$,

the collector is made up of both high and low standard collector. Discounting the collector cost in each entry and summing up to obtain the total collector cost.

$$S4 = \Sigma \text{High standard collector cost in year } i \times \frac{1}{(1+I)^{Yi}}$$
$$+ \Sigma \text{Low standard collector cost in year } i \times \frac{1}{(1+I)^{Yi}}$$

$$= \Sigma\left(D - \frac{SE}{2} - K \times SE\right) \times RHCi \times \frac{1}{(1+I)^{Yi}} + \Sigma K \times SE \times RLCi \times \frac{1}{(1+I)^{Yi}}$$

The total collector cost becomes:

$$S41 = \left(D - \frac{SE}{2} - K \times SE\right) \times [RHC0 \times \frac{1}{(1+I)^{Y0}} + RHC10 \times \frac{1}{(1+I)^{Y10}} + RHC20 \times \frac{1}{(1+I)^{Y20}} + RHC30 \times \frac{1}{(1+I)^{Y30}}]$$

$$S42 = K \times SE \times [RLCO \times \frac{1}{(1+I)^{Y0}} + RLC10 \times \frac{1}{(1+I)^{Y10}} + RLC20 \times \frac{1}{(1+I)^{Y20}} + RLC30 \times \frac{1}{(1+I)^{Y30}}]$$

$$S4 = S41 + S42$$

When $K = 0$ and $L = \frac{SE}{2}, \frac{3SE}{2}, \frac{5SE}{2}, ---,$

the whole collector is a high standard collector. Discounting and summing up the collector cost in each entry, the total collector cost is

$$S4 = \left(D - \frac{SE}{2}\right) \times \left\{ \frac{RHC0}{(1+I)^{Y0}} + \frac{RHC10}{(1+I)^{Y10}} + \frac{RHC20}{(1+I)^{Y20}} + \frac{RHC30}{(1+I)^{Y30}} \right\}$$

When $L = 0, K = J$ and $K = 1,2,3, ---$ i.e. $B = \frac{SE}{2}, \frac{3SE}{2}, \frac{5SE}{2}, ---,$

the entire collector is a low standard collector. Summing up the discounted collector cost in each entry, the total collector cost will be

$$S4 = \left(D - \frac{SE}{2}\right) \times \{ \frac{RLC0}{(1+I)^{Y0}} + \frac{RLC10}{(1+I)^{Y10}} + \frac{RLC20}{(1+I)^{Y20}} + \frac{RLC30}{(1+I)^{Y30}}].$$

4.5.5 Total Skid Cost to Collector

Timber from the triangular skidding pattern settings along both sides of the collector is skidded to the collector during each entry. Discounting the skid cost to collector in each entry and summing up to get the total.

$$S5 = \Sigma 2(2J-1) \times \frac{1}{3} \times \frac{SE}{2} \times \frac{1}{2} \times \left(\frac{SE}{2}\right)^2 \times SCi \times VFi \times \frac{1}{(1+I)^{Yi}}.$$

Here, the total skid cost to collector becomes:

$$S5 = \frac{(2J-1) \times SE^3}{24} \times \left\{ VF1 \times \frac{SC1}{(1+I)^{Y1}} + VF10 \times \frac{SC10}{(1+I)^{Y10}} + VF20 \times \frac{SC20}{(1+I)^{Y20}} + VF30 \times \frac{SC30}{(1+I)^{Y30}} \right\}.$$

4.5.6 Total Haul Cost on Collector

The method of formulation is similar to those in Single entry with linear skidding costs. The only difference is the necessity to discount and sum up the haul cost to collector in each entry.

When $K = 0$ and $L = \frac{SE}{2}, \frac{3SE}{2}, \frac{5SE}{2}, ---,$

the total discounted haul cost on the entire high standard collector is

$$S6 = \Sigma S \times D \times HHCi \times LLi \times VFi \times \frac{1}{(1+I)^{Yi}}$$

where

LLi = Average haul distance on high standard collector only in year i

See Appendix C.

Total haul cost on collector is

$$S6 = S \times D \left\{ LL1 \times VF1 \times \frac{HHC1}{(1+I)^{Y1}} + LL10 \times VF10 \times \frac{HHC10}{(1+I)^{Y10}} + LL20 \times VF20 \times \frac{HHC20}{(1+I)^{Y20}} + LL30 \times VF30 \times \frac{HHC30}{(1+I)^{Y30}} \right\}.$$

When $L = 0, K = J$ and $K = 1,2,3, ---$ i.e. $B = \frac{SE}{2}, \frac{3SE}{2}, \frac{5SE}{2}, ---,$

the total discounted haul cost on the entire low standard collector is

$$S6 = \Sigma S \times D \times HLCi \times BBi \times VFi \times \frac{1}{(1+I)^{Yi}}$$

where

BBi = Average haul distance on low standard collector only in year i

See Appendix C.

Total haul cost on collector is

$$S6 = S \times D \times \left\{ BB1 \times VF1 \times \frac{HLC1}{(1+I)^{Y1}} + BB10 \times VF10 \times \frac{HLC10}{(1+I)^{Y10}} + BB20 \times VF20 \times \frac{HLC20}{(1+I)^{Y20}} + BB30 \times VF30 \times \frac{HLC30}{(1+I)^{Y30}} \right\}.$$

When $K = 1,2,3,4,---$ and $L = \frac{SE}{2}, \frac{3SE}{2}, \frac{5SE}{2}, ---,$

the total discount haul cost on the high and low standard collector is as follows:

$$S6 = \Sigma \left\{ S \times SE \times K + \left(\frac{SE}{2}\right)^2 \right\} \times \{(HLCi \times BLi) + (HHCi \times L)\} \times VFi \times \frac{1}{(1+I)^{Yi}}$$

$$+ \Sigma \left\{ S \times D - \left(S \times SE \times K + \left(\frac{SE}{2}\right)^2 \right) \right\} \times \{HHCi \times LBi \times VFi\} \times \frac{1}{(1+I)^{Yi}}$$

where

BLi = Average haul distance on low standard collector in year i

LBi = Average haul distance on high standard collector in year i

See Appendix C

The discounted haul cost on high and low standard collector is:

S61 = Σ Haul cost on low standard collector for volumes to low standard collector in year i

$$= \Sigma \left\{ S \times SE \times K + \left(\frac{SE}{2}\right)^2 \right\} \times BLi \times VFi \times \frac{HLCi}{(1+I)^{Yi}}$$

S62 = Σ Haul cost on high standard collector for volumes to low standard collector in year i

$$= \Sigma \left\{ S \times SE \times K + \left(\frac{SE}{2}\right)^2 \right\} \times L \times VFi \times \frac{HHCi}{(1+I)^{Yi}}$$

S63 = Σ Haul cost on high standard collector for volumes to high standard collector in year i

$$= \Sigma \left\{ S \times D - \left(S \times SE \times K + \left(\frac{SE}{2} \right)^2 \right) \right\} \times LBi \times VFi \times \frac{HHCi}{(1+I)^{Yi}}.$$

Expanding, the total haul cost on collector, S6 is

$$S61 = [S \times SE \times K + \left(\frac{SE}{2} \right)^2] \times [BL1 \times VF1 \times \frac{HLC1}{(1+I)^{Y1}} + BL10 \times VF10 \times \frac{HLC10}{(1+I)^{Y10}} + BL20 \times VF20 \times \frac{HLC20}{(1+I)^{Y20}} + BL30 \times VF30 \times \frac{HLC30}{(1+I)^{Y30}}]$$

$$S62 = [S \times SE \times K + \left(\frac{SE}{2} \right)^2] \times [L \times VF1 \times \frac{HHC1}{(1+I)^{Y1}} + L \times VF10 \times \frac{HHC10}{(1+I)^{Y10}} + L \times VF20 \times \frac{HHC20}{(1+I)^{Y20}} + L \times VF30 \times \frac{HHC30}{(1+I)^{Y30}}]$$

$$S63 = [S \times D - \left(S \times SE \times K \times \left(\frac{SE}{2} \right)^2 \right)] \times [LB1 \times VF1 \times \frac{HHC1}{(1+I)^{Y1}} + LB10 \times VF10 \times \frac{HHC10}{(1+I)^{Y10}} + LB20 \times VF20 \times \frac{HHC20}{(1+I)^{Y20}} + LB30 \times VF30 \times \frac{HHC30}{(1+I)^{Y30}}]$$

$$S6 = S61 + S62 + S63.$$

4.5.7 Average Cost

Total Cost

$$\text{COST} = S1 + S2 + S3 + S4 + S5 + S6.$$

The total area in acres is

$$\text{AREA} = \frac{S \times D}{43560}.$$

The average cost per acre is

$$\text{TC} = \frac{\text{COST}}{\text{AREA}}.$$

4.6 Single Entry with Non-linear Skidding Costs Formulation

Assume that the dimensions of all the skidding pattern settings are either parallel or perpendicular to the collector are in fifty-foot increments. Let I equal the number of increments perpendicular to the spur roads and X(I) denoted the total length of I increments. The distance perpendicular from the spur roads for the triangular, radial and both right-angle (at end of collector and along spur roads) skidding pattern settings is the same (Figure 2). This means this distance is equal to one half of the spur road spacing. The skid cost function is $1+.005x(d)^{1.2}$ where d is the skid distance.

4.6.1 Skid Cost for Triangular Skidding Pattern Settings

These triangular skidding pattern settings are right-angle triangle in shape. Triangular skidding pattern settings are set up with continuous landings along collector and spur roads. The right-angle triangle is made up of I increments. So, for the whole right-angle triangle, there will be I sections (Figure 3). Except for the very last section, each section is trapezoidal in shape. For simplicity, each of these sections is treated as a rectangle. For the very last section, it is a right-angle triangle (Figure 4). The total skid cost for the whole triangular skidding pattern setting is determined by summing

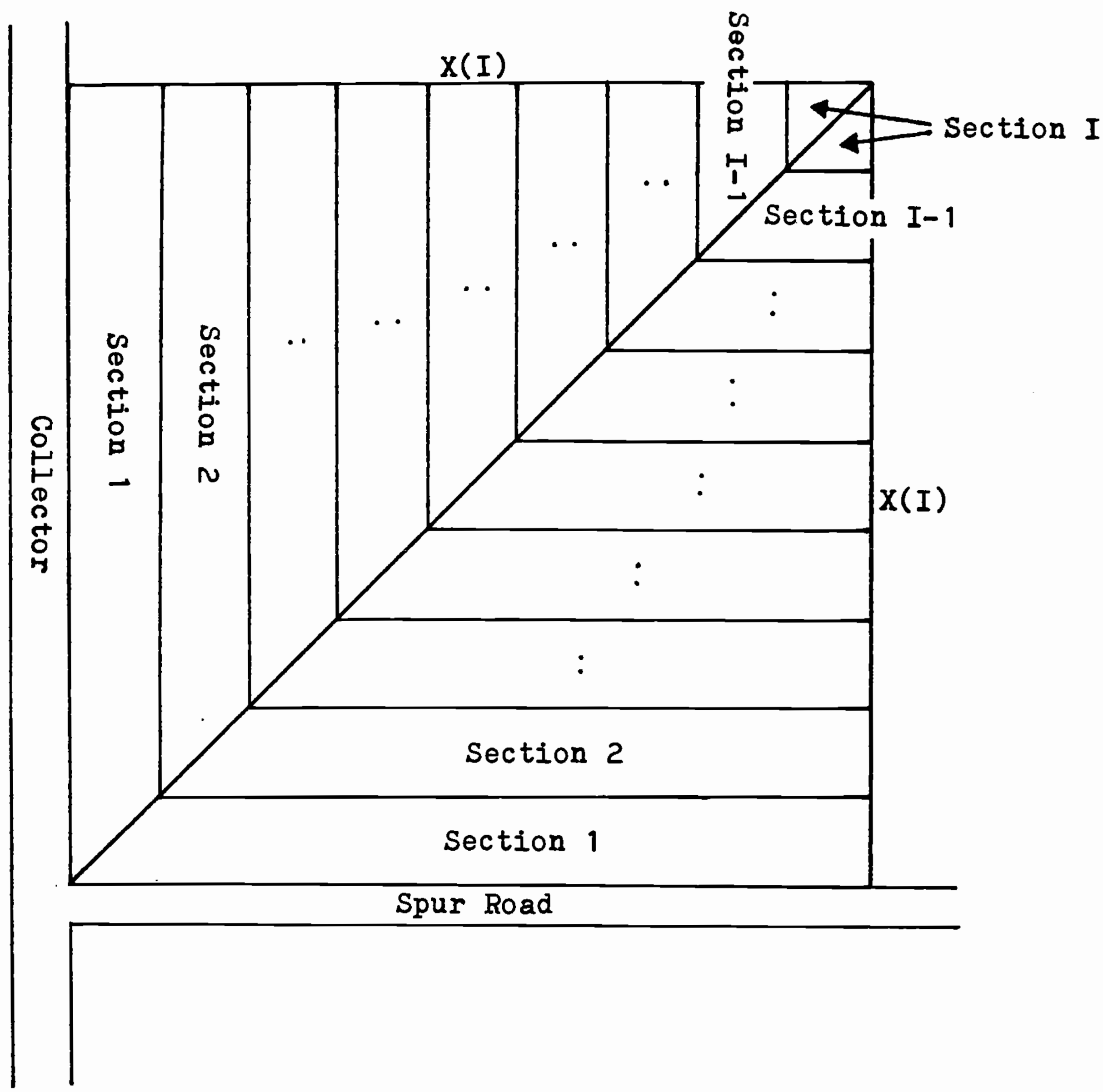
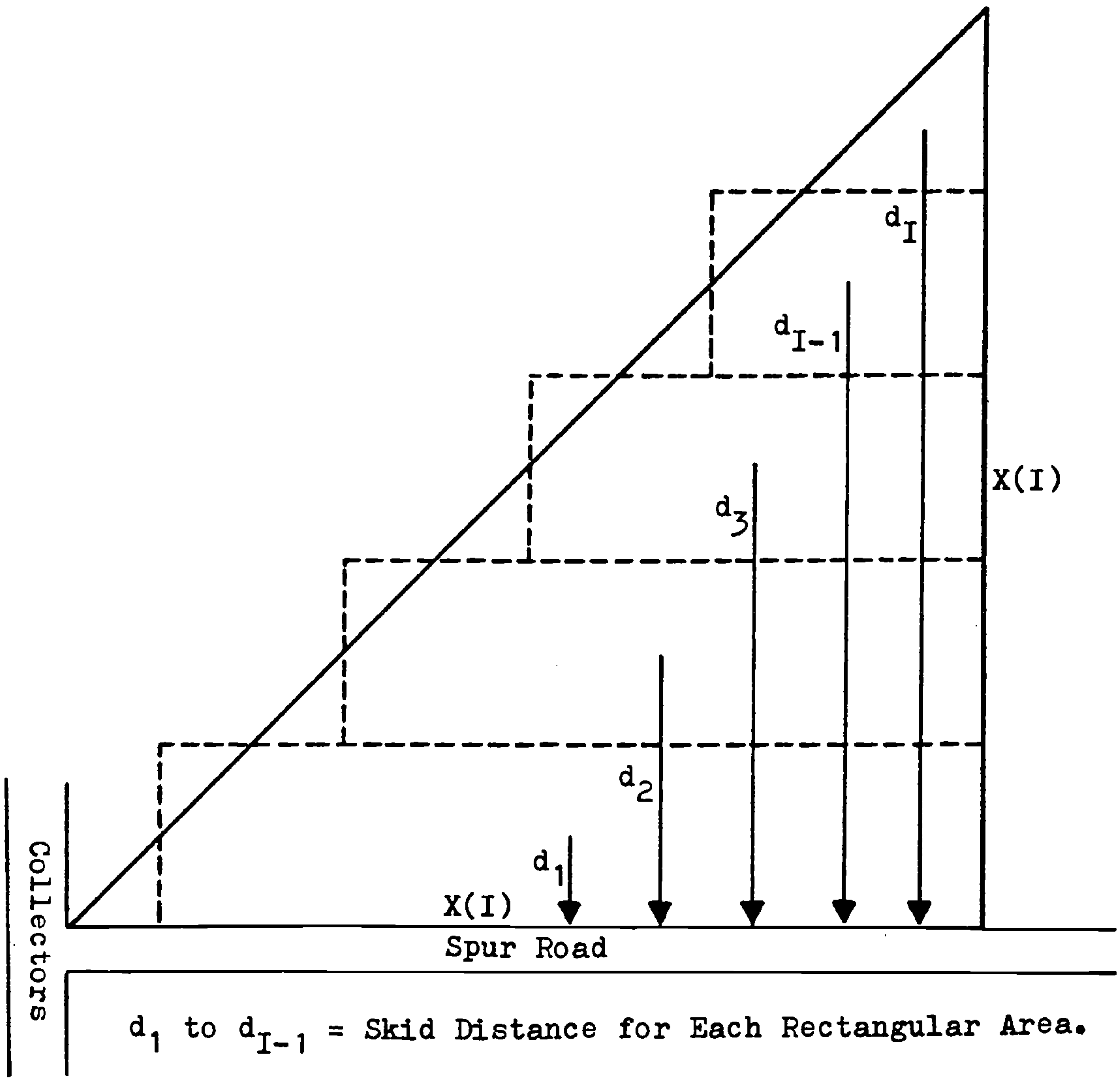


Figure 3. Triangular Skidding Pattern Settings along the Collector and Spur Roads.



d_1 to d_{I-1} = Skid Distance for Each Rectangular Area.

d_I = Skid Distance for the Last Sectional Area (Triangular).

Figure 4. Skid Distances and Sectional Areas for Triangular Skidding Pattern Settings.

up the skid costs for the rectangular (trapezoidal) and the triangular areas.

When T = 1,2,3,4,......,I-1, the skid distance cost for the respective section is

$$TD = 1+.005x(50xT-25)^{1.2}$$

and the skid cost

$$TSC = [X(I)-(50xT-25)]x50xVxTD$$

When T = I, this is the last section (triangle), the skid distance cost for this section is

$$TD = 1+.005x[50x(T-1)+50/3]^{1.2}$$

The skid cost

$$TSC = .5x50^{2}xVxTD$$

The total skid cost for the whole triangular skidding pattern setting with I sections out

$$TC(I) = \Sigma \text{ TSC from 1 to I-1 + TSC (triangle)}$$

The total volume for the whole triangular skidding pattern setting with I sections

$$TV(I) = .5x[(X(I)]^{2}xV$$

The same procedure is repeated with different dimensions to obtain different total skid costs and volumes.

4.6.1.1 Total Skid Cost and Weighted Average Total Skid Cost

The base and altitude of these triangular skidding pattern settings is equal to one half of the spur road spacing, SE/2. SE varies inversely proportional to J. Different incremental lengths have been used to generate the total skid cost for each right-angle triangle dimension. Among these right-angle triangle dimensions, very often the computer generated dimension is not exactly equal to SE/2. If so, the weighted average total skid cost has to be determined.

Case 1

Half of the spur road spacing is equal to the total length of I increments, that is SE/2 = X(I). The total skid cost will be equal to the generated total skid cost for the specified dimension.

$$ASCT = TC(I)$$

The total volume is equal to TV(I).

Case 2

Half of the spur road spacing is greater than the total length of I-1 increments but less than the total length of I increments, that is SE/2 > X(I-1) and SE/2 < X(I). The weighted average total skid cost for the triangular skidding pattern setting with dimension of SE/2 will be

$$ASCT = TC(I-1)+[TC(I)-TC(I-1)]x \frac{.5x(SE/2)^2 xV-TV(I-1)}{TV(I) -TV(I-1)}$$

The total volume = $.5x(SE/2)^2xV$.

4.6.2 Skid Cost for Right-angle Skidding Pattern Settings at end of Collector

The right-angle skidding pattern settings is square in shape. Timber is skidded perpendicularly to the last spur road with continuous landings along it. The sides of the square are made up of I increments and there will be I sections (Figure 5). Each section is rectangular in shape. The total skid cost for the square area is computed by accumulating the skid cost for each section (rectangle). T = 1,2,3,4,......, I. The skid distance cost for the respective section (rectangle)

$$UD = 1+.005 \times (50xT-25)^{1.2}$$

The skid cost for the respective section (rectangle)

$$USC = X(I) \times 50 \times V \times UD$$

Total skid cost for the right-angle skidding pattern setting (square) with length of sides of X(I) is

$$UC(I) = \Sigma \text{ USC from 1 to T}$$

Total volume for the setting

$$UV(I) = [X(I)]^2 \times V$$

The same procedure is repeated to get different total skid costs and total volumes for different dimensions.

4.6.2.1 Total Skid Cost and Weighted Average Total Skid Cost

Half of the spur road spacing is SE/2. The square with sides of SE/2 might not exactly equal the dimensions that

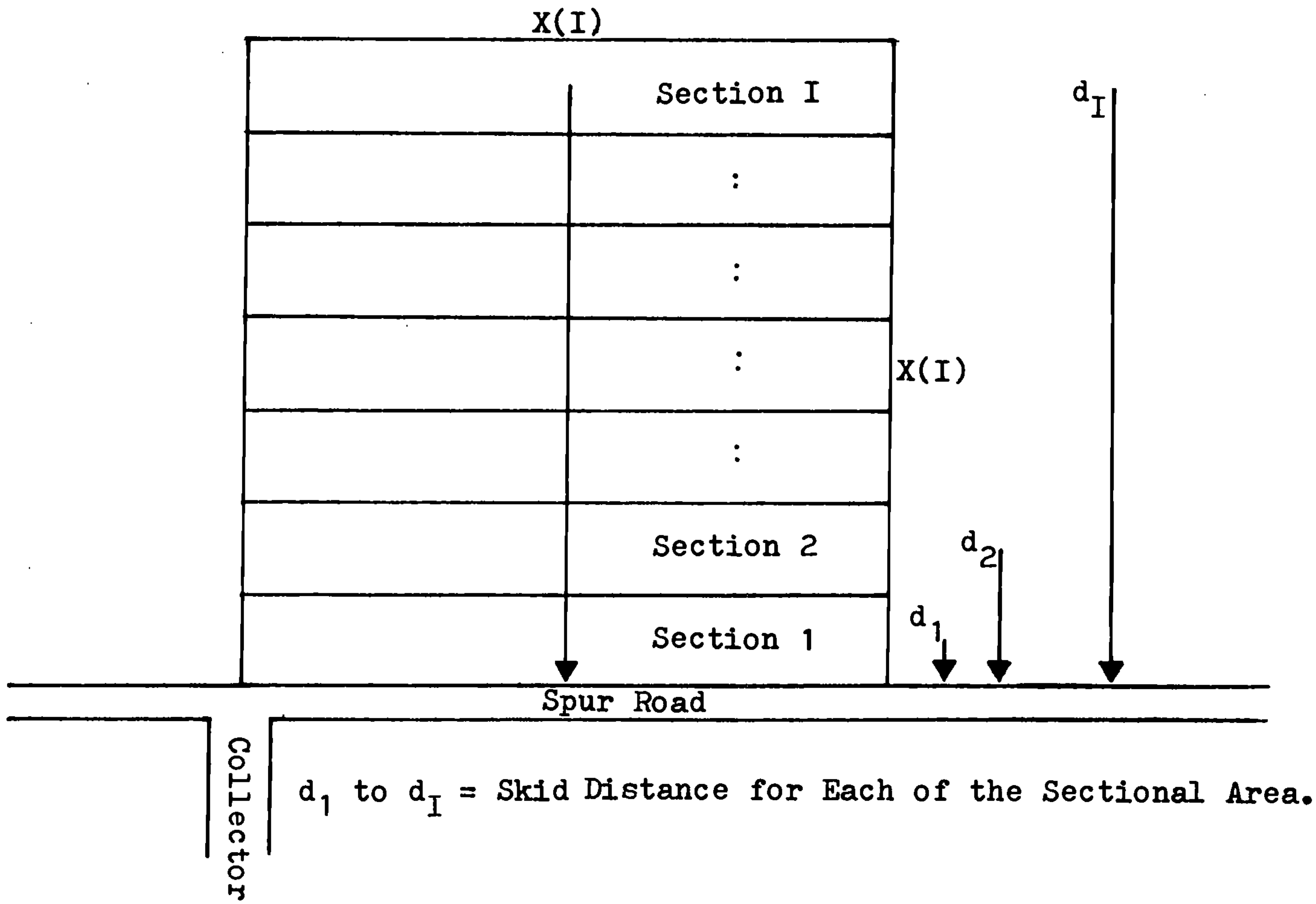


Figure 5. Skid Distances and Sectional Areas for the Right-Angle Skidding Pattern Setting at the End of the Collector.

have been used to generate the total skid costs. Therefore, a weighted average total skid cost for the square area with sides of SE/2 has to be determined.

Case 1

When SE/2 = X(I), the total skid cost for the given dimension will be equal to one of the generated total skid costs for that dimension.

$$ASCU = UC(I)$$

The total volume is equal to UV(I).

Case 2

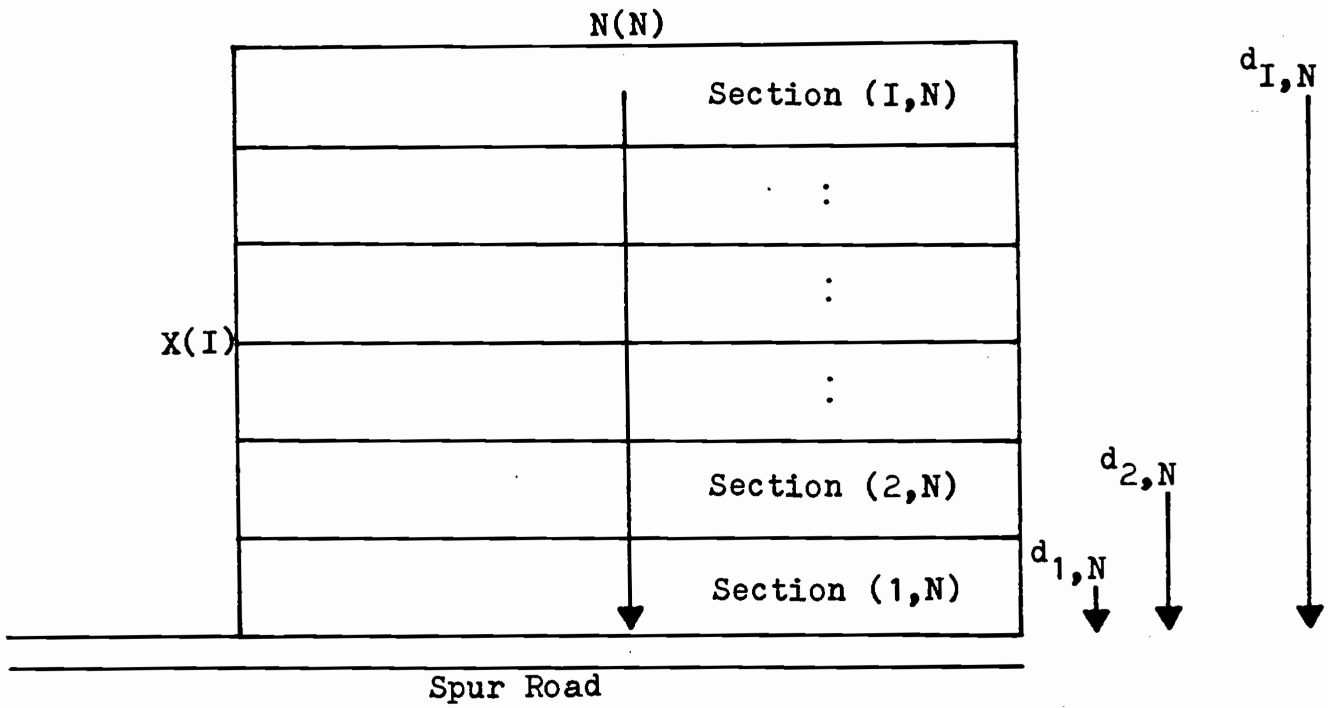
When SE/2 > X(I-1) and SE/2 < X(I), the weighted average total skid cost is:

$$ASCU = UC(I-1)+[UC(I)-UC(I-1)]x \frac{(SE/2)^2 xV-UV(I-1)}{UV(I)-UV(I-1)}$$

$$\text{Total volume} = (SE/2)^2 xV \ .$$

4.6.3 Skid Cost for Right-angle Skidding Pattern Settings along Spur Roads

The shape of these settings is a rectangle and the skidding direction is perpendicular to the spur roads (Figure 6). The length of the rectangle is parallel to the spur roads and consists of N increments. Let N(N) denotes the total length of N increments. The width of the rectangle is made up of I increments. In this way, there will be I sections for the whole rectangle (Figure 6). Similar to the total skid cost computation method as in the right-angle



$d_{1,N}$ to $d_{I,N}$ = Skid Distance for Each of the Sectional Areas.

Figure 6. Skid Distances and Sectional Areas for the Right-Angle Skidding Pattern Setting along the Spur Roads.

skidding pattern setting (at end of collector), the total skid cost for a particular dimensions is computed by accumulating skid costs for each section. The complete enumeration method is used in generating various widths and lengths for the rectangular settings. The same procedure is used to determine the total skid costs.

For Complete Enumeration method, I is the inner loop and N is in the outer loop. Here, the width is changing but the length is a "temporary" constant. The skid distance cost for the corresponding section is

$$LD = 1+.005 \times (50xI-25)^{1.2}$$

The skid cost for the corresponding section is

$$LSC = N(N) \times 50 \times V \times LD$$

The total skid cost for right-angle skidding pattern setting with sides X(I) and N(N) is

$LC(I,N) = \Sigma$ LSC (from 1 up to the corresponding I increments with that particular length, N(N))

and the total volume

$$LV(I,N) = X(I) \times N(N) \times V$$

The same procedure is repeated for different N values.

4.6.3.1 Total Skid Cost and Weighted Average Total Skid Cost

Given a rectangular area with the dimensions SE/2 and NE and a right-angle skidding pattern, the total skid cost is calculated for the following cases using numerical integration. If the actual dimensions do not match with the generated dimensions, one way to determine the total skid cost is by the weighted average method.

Case 1

When SE/2 = X(I) and NE = N(N), the total skid cost for the given dimensions will be equal to one of the generated.

$$ASCL = LC(I,N)$$

and the total volume = LV(I,N)

Case 2

For SE/2 = X(I) and N(N) > NE > N(N-1), the weighted average total skid cost, ASCL, is:

$$ASCL = LC(I,N-1)+[LC(I,N)-LC(I,N-1)] \times \frac{SE/2 \times NE \times V-LV(I,N-1)}{LV(I,N)-LV(I,N-1)}$$

Case 3

When NE = N(N) and X(I) > SE/2 > X(I-1), the weighted average total skid cost is

$$ASCL = LC(I-1,N)+[LC(I,N)-LC(I-1,N)] \times \frac{SE/2 \times NE \times V-LV(I-1,N)}{LV(I,N)-LV(I-1,N)}$$

Case 4

When X(I) > SE/2 > X(I-1) and N(N) > NE > N(N-1), the weighted average total skid cost, ASCL, is:

$$ASCL=LC(I-1,N-1)+[LC(I,N)-LC(I-1,N-1)] \times \frac{SE/2 \times NE \times V-LV(I-1,N-1)}{LV(I,N)-LV(I-1,N-1)}$$

The total volume for Case 2, 3 and 4 = SE/2 x NE x V.

4.6.4 Skid Cost for Radial Skidding Pattern Settings

The shape of these skidding pattern settings is a rectangle. Timber is skidded to the landings at end of the spur roads. With the spur road (extended) as the axis, the radial skidding pattern setting is divided into two rectangles. For now, only consider one of them. Again, assuming that the width of the rectangle is made up of I increments. The length of the setting which is parallel to spur roads consists of M increments out from the landing. Let D(M) denotes the total length of M increments. The methodology used in the cost computation is similar to Sessions and Li (1987). The area to be skidded is divided in subareas or cells (Figure 7). In this way, the rectangle is made up of I rows by M columns of cells. The total skid cost is found by summing the skid cost for each cell. The complete enumeration method is used in generating rectangles with various widths and lengths. Meanwhile, total skid costs are being determined.

The skid distance from a cell in I^{th} row and M^{th} column to the landing is

$$DIST = SQRT[(50xI-25)^2+(50xM-25)^2]$$

and the skid distance cost

$$DD = 1+.005x(DIST)^{1.2}$$

The skid cost = 50 x 50 x V x DD.

The total skid cost for all the cells in the M^{th} column

$$DSC = DSC + (50x50xVxDD)$$

and

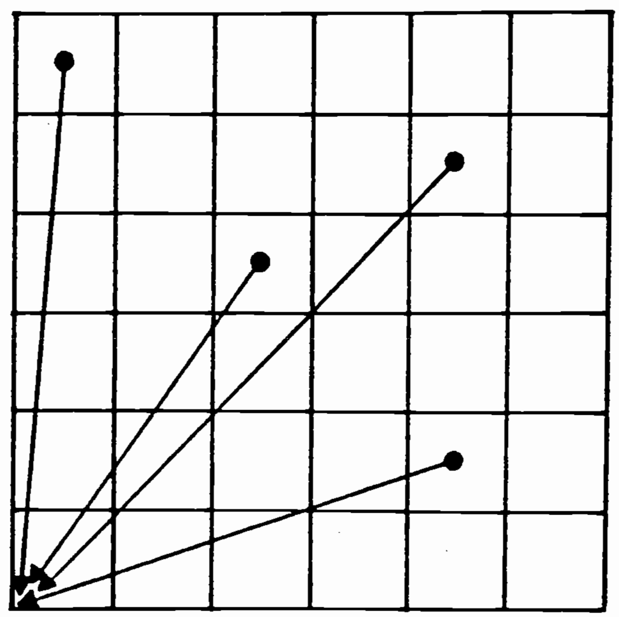


Figure 7. Radial Skidding Pattern Divided Into Subareas. Arrows Indicate Skidding Directions (Sessions and Li 1987).

DSC on the right-hand side

= Accumulated skid cost for cell (1,M),(2,M),....,(I-1,M)

Skid cost for the current (I,M) cell = (50 x 50 x V x DD)

DSC on the left-hand side

= Accumulated skid cost for all the cells in the M^{th} column

See Figure 8.

Total skid cost for rectangular section with I rows and M columns is

$$DC(I,M) = DSC + DC(I,M-1)$$

and,

DC(I,M-1) = Accumulated skid cost for all the cells in I rows by (M-1) columns

DSC = Accumulated skid cost for all the cells in the M^{th} column

The total volume for rectangular dimensions with I rows and M columns is

$$DV(I,M) = 50 \times I \times 50 \times M \times V$$

The same procedure is repeated for various rows and columns to determine the total skid costs.

4.6.4.1 Average Skid Cost and Weighted Average Total Skid Cost

If we have a radial skidding pattern with one side equal to half of the spur road spacing, SE/2, and the depth of the radial skidding pattern setting equal to DE, we can determine the total skid cost for the following cases. As

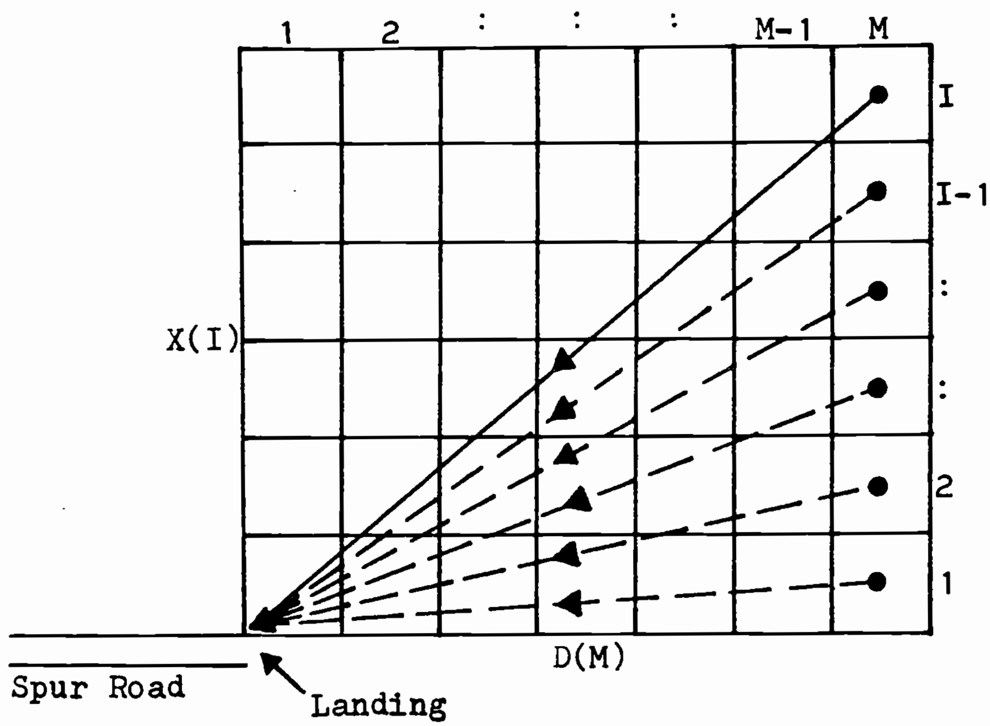


Figure 8. Accumulating Skid Cost for all the Cells in a Column.

before, if the actual dimensions do not match with those generated dimensions, one way to determine the total skid cost is by the weighted average method.

Case 1

When SE/2 = X(I) and DE = D(M), the total skid cost for the given dimensions will be equal to one of the generated.

$$ASCD = DC(I,M)$$

Total volume = DV(I,M).

Case 2

When SE/2 = X(I) and D(M) > DE > D(M-1), the weighted average total skid cost

$$ASCD = DC(I,M-1)+[DC(I,M)-DC(I,M-1)]x \frac{SE/2xDExV-DV(I,M-1)}{DV(I,M)-DV(I,M-1)} .$$

Case 3

When DE = D(M) and X(I) > SE/2 > X(I-1), the weighted average total skid cost

$$ASCD = DC(I-1,M)+[DC(I,M)-DC(I-1,M)]x \frac{SE/2xDExV-DV(I-1,M)}{DV(I,M)-DV(I-1,M)} .$$

Case 4

When X(I) > SE/2 > X(I-1) and D(M) > DE > D(M-1), the weighted average total skid cost, ASCD, is determined as follows:

$$ASCD=DC(I-1,M-1)+[DC(I,M)-DC(I-1,M-1)]x\frac{SE/2xDExV-DV(I-1,M-1)}{DV(I,M)-DV(I-1,M-1)}$$

The total volume for Case 2, 3, and 4 = SE/2 x DE x V.

4.6.5 Average Cost

The total skid cost to spur roads, S2, is determined as follows:

$$S2 = 2 \times [2 \times J \times (ASCL+ASCD) + (2 \times J-1) \times ASCT+ASCU]$$

where (2 x J-1) = number of triangular skidding pattern settings along the spur roads.

The total skid cost to collector will be

$$S5 = 2 \times (2 \times J-1) \times ASCT$$

The other total costs S1, S3, S4 and S6 are the same as in the Single entry with the linear skidding costs formulation.

Total cost for the whole unit

$$COST = S1 + S2 + S3 + S4 + S5 + S6$$

The total volume for the whole unit is

$$VOL = S \times D \times V$$

Average cost per unit volume

$$TC = \frac{COST}{VOL}$$

5. SOLUTION PROCEDURE

5.1 Complete Enumeration Method

All the values for the variables are given (inputs) except J, K, NE and DE (See Figure 2 and 2A). The question is what values of these variables should be in order to obtain the minimum cost per unit volume or per unit area? For all the formulations derived, the value for J must be at least one. K can be any value from zero and up to J. The minimum value for both NE and DE is zero. When NE and DE equal to zero, only triangular skidding pattern settings can exist.

Programs were written for linear and non-linear skidding costs for single entry and for linear skidding costs for multiple entries.

5.1.1 Linear Skidding Costs

The following discussion applies to the single entry and multiple entries with linear skidding costs.

Each of the four variables is assigned to a loop. Within the nested loops, the minimum average cost per unit volume or per unit area is determined by means of logical operators. If the lowest average cost had occurred at one or more of the upper limits for the variables being considered, the value(s) of the variable(s) should be increased. For variables NE and DE, start with a larger step size (100 ft) and larger upper value considered (based on professional experience, probably 2000 ft). One or two would be the reasonable step size value for variables J and K. In doing so, in a shorter time period the program can isolate roughly what values of the variables are somewhere near optimum. Based on the outcomes, reconsider the lower and upper values for the variables. Also reduce the step size value before subsequent run(s).

5.1.2 Non-linear Costs

The same procedure is used in the single entry with non-linear costs. In addition, one-dimensional arrays and two-dimensional arrays are used to generate and store the total skid costs and total volumes for different skidding pattern settings with various dimensions. If the lowest average cost had occurred at the upper limits of the variable(s) being considered, the value(s) of the variable(s) should be increased or the solution is being artificially constrained. J is inversely proportional to SE. The maximum value of X(I) should be greater than the maximum SE/2 being considered to make sure that all possible cases are evaluated.

Three programs were written using the Complete Enumeration method:

Program 1 -- Single Entry with Linear Skidding Costs

Program 3 -- Multiple Entries with Linear Skidding Costs

Program 5 -- Single Entry with Non-linear Skidding Costs

5.2 Complete Enumeration and Hooke and Jeeves Pattern Search Combined Method

Programs were written using both the single entry and multiple entries with linear skidding costs. The Hooke and Jeeves pattern search method (Shoup and Mistree, 1987) can be used to find the minimum of a multivariable function. Rather than use the pattern search procedure for all four variables K, J, NE, and DE, a combination of complete enumeration and pattern search was done. The rationale for combining the search method was that J and K are usually small (within units or tens) and must be integers. Within this range, it is not too inefficient to assign them to nested loops and evaluate them with a step size of one. Whereas the values of NE and DE can range from hundred to thousands. Therefore, these variables are assigned as the variables in the pattern search method.

With the combined enumeration and pattern search the direct solution can be obtained in one run unless the lowest average cost had occurred at the maximum value of J or K. Each of the variables, J and K, is assigned to a loop. NE and DE are assigned as the variables in the pattern search method. The penalty function for the pattern search is the average cost per unit volume or per unit area for the total area considering skidding, road and haul costs. In each run of the pattern search method, this is only the minimum average for the particular J and K values (Figure 8A). Whenever the minimum is found, it will go back to the loops

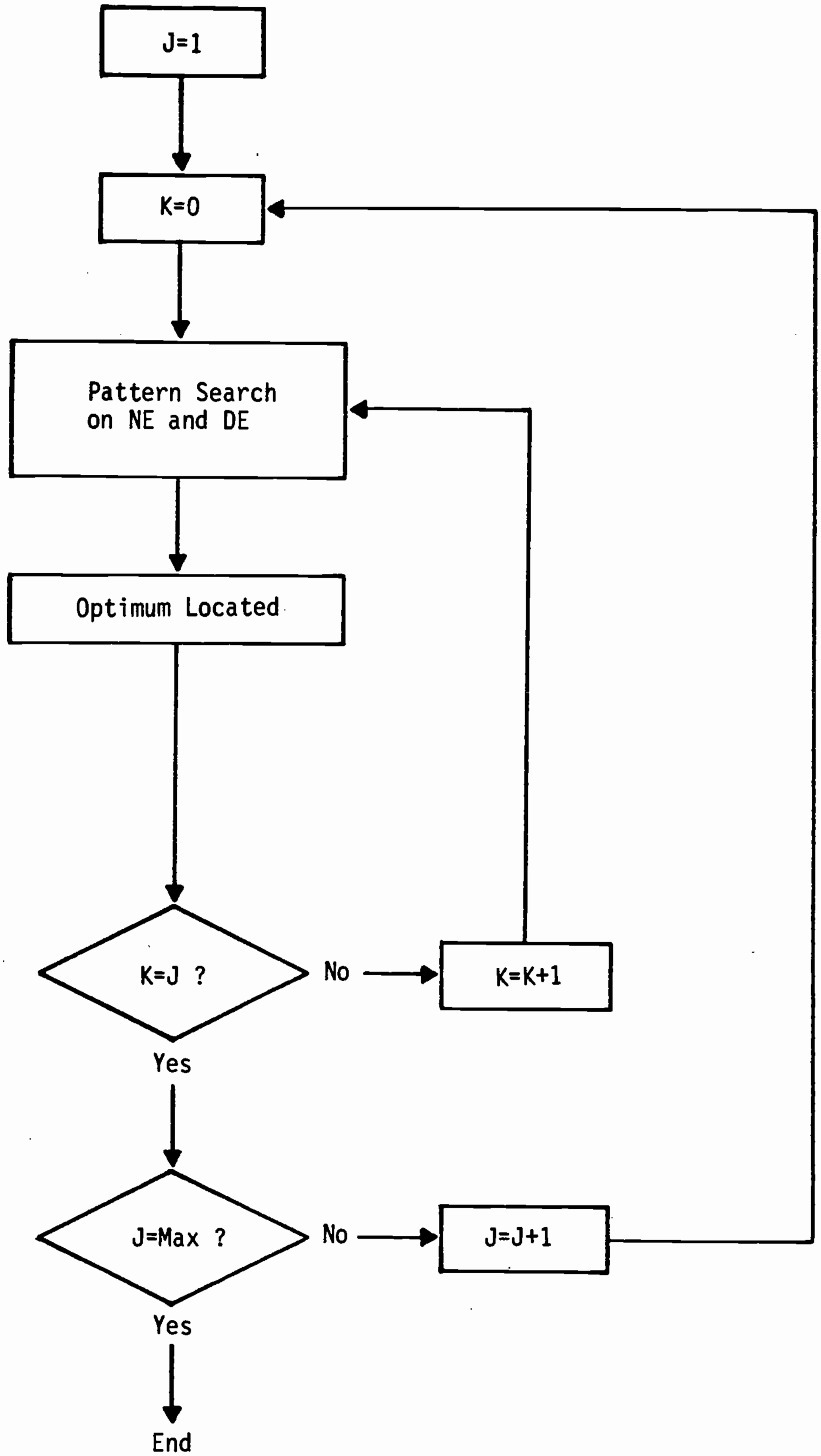


Figure 8A. Flow Chart for Complete Enumeration and Hooke and Jeeves Pattern Search Combined Method.

and generate different J and K values until the enumeration is complete. Meanwhile the final minimum average cost is determined by the logical operators.

Before running this program, the user must set values for certain components in the pattern search method. These components are:

a) A = acceleration factor

b) R = the starting step size for exploration

c) F = penalty surface

d) RF = the end step size for exploration

e) X(i) = feasible starting point for variables (this is not the same as X(I) used in section 4.6)

Two programs were written by using the Complete Enumeration and Hooke and Jeeves Pattern Search Combined Method. The following section 5.3 explains how the search is done.

Program 2 -- Single Entry with Linear Skidding Costs

Program 4 -- Multiple Entries with Linear Skidding Costs

5.3 Hooke and Jeeves Pattern Search Method

With a few changes in Program 2 and 4, these programs will solve for optimum dimensions by the Hooke and Jeeves Pattern Search Method. We need to eliminate the loops and logical operator, add J and K as the third and fourth variables in the pattern search, and set feasible starting points for them. Because the variables J and K must be integers certain rules need to be followed in the choice of the initial step size, final exploration step size, and the acceleration factor. One set of rules that can be used to provide integer values for J and K are (1) to start the initial step size as an even number, (2) to have a final exploration step size as 1.0, and (3) to choose an acceleration factor that is an integer. The rationale for these rules are that the pattern search algorithm used divides the step size by two in stepping down to the final exploration step size. The algorithm terminates when all variables have been reduced to a step size less than the final exploration step size. This implies that if the final step size for all variables will be one, that the starting point must be a multiple of two and the choice of acceleration factor must keep the step size as an even number until the final exploration step size of 1.0 is reached. For the road spacing problem investigated here, an acceleration factor of 1.0 or 2.0 seems reasonable.

The programs for single entry and multiple entries with linear skidding costs (enumeration and pattern search combined method) are converted to the Hooke and Jeeves pattern search method in Programs 2A and 4A where:

Program 2A -- Single Entry with Linear Skidding Cost
Program 4A -- Multiple Entries with Linear Skidding Costs

6. EXAMPLES

6.1 Results

Each program was run through an example. There are three different programs for solving both the single entry and multiple entries with linear skidding costs. Therefore, with the same inputs for the three different programs, the same outcomes are expected. Bowman and Hesslers' inputs (Table 1) were used to run the programs for single entry with linear skidding cost. For the non-linear skidding costs program, the same inputs were used except for the skidding cost function. Bowman and Hesslers' inputs were also used to run the multiple entries with linear skidding costs programs (Table 2). It was assumed that the future reconstruction cost will be 10% of the initial road building costs. Skidding costs and haul costs were assumed to not change in future entries. The results are shown in Table 3.

TABLE 1. Inputs for Example Problems (Single Entry with Linear and Non-linear Skidding Costs).

(units are defined on page 12)

	linear skidding costs	non-linear skidding costs
V	10/43560	10/43560
D	8000	8000
RH	11000/5280	11000/5280
RL	5700/5280	5700/5280
RS	5700/5280	5700/5280
SC	1.74/100	$1+.005(d)^{1.2}$
SS	1.74/100	$1+.005(d)^{1.2}$
HH	2/5280	2/5280
HL	5.15/5280	5.15/5280
HS	5.15/5280	5.15/5280

TABLE 2. Inputs for Example Problems (Multiple Entries with Linear Skidding Costs).

Year	0	1	10	20	30
		(units are defined on page 13 to 14)			
I	.04	.04	.04	.04	.04
VF		5/43560	5/43560	8/43560	15/43560
RHC	11000/5280		1100/5280	1100/5280	1100/5280
RLC	5700/5280		570/5280	570/5280	570/5280
RSC	5700/5280		570/5280	570/5280	570/5280
SS		1.74/100	1.74/100	1.74/100	1.74/100
SC		1.74/100	1.74/100	1.74/100	1.74/100
HHC		2/5280	2/5280	2/5280	2/5280
HLC		5.15/5280	5.15/5280	5.15/5280	5.15/5280
HS		5.15/5280	5.15/5280	5.15/5280	5.15/5280

TABLE 3. Results for Example Problems.
(Program 1,3 and 5 -- Complete Enumeration Method
Program 2 and 4 -- Enumeration and Pattern Search Combined
Program 2A and 4A -- Hooke and Jeeves Pattern Search Method
Program 5 -- Single Entry with Non-linear Skidding Costs)

	Single Entry			Multiple Entries			
Program	1	2	2A	3	4	4A	5
S	3898	3899	3600	3309	3309	3305	4000
SE	1000	1000	1000	889	889	889	1000
J	8	8	8	9	9	9	8
K	1	1	1	1	1	0	1
$/CCF	12.54	12.54	12.55				13.20
$/acre				176.64	176.64	177.35	

6.2 Comparison with Results of Bowman and Hessler

Bowman and Hessler's (1983) results for single entry with only right-angle skidding pattern settings along spur roads are shown in Table 4.

TABLE 4. Results from Bowman and Hessler (1983).

Volume	5 CCF/acre	10 CCF/acre	15 CCF/acre
Collector spacing (ft)	8570	6060	4950
Spur road spacing (ft)	1460	1030	842

For either Program 1 or 2, triangular and radial skidding patterns setting can be eliminated by setting LE equal to NE and DE equal to zero. If we also limit the collector standard to high standard collectors only, we can run the Bowman and Hessler problem (Table 5).

TABLE 5. Road Spacings and Average Costs for Single Entry with Linear Skidding Costs and Right-angle Skidding Pattern Settings.

Volume	5 CCF/acre	10 CCF/acre	15 CCF/acre
Collector spacing (ft)	8190	5904	4840
Spur road spacing (ft)	1600	1000	889
Average cost ($/acre)	91.725	134.48	169.035

Table 5 results compare very closely with the values calculated by Bowman and Hessler. Relaxing the assumptions of Bowman and Hessler, Table 6 shows the results for linear skidding costs and a single entry. These values are derived by considering various skidding pattern settings and multiple collector standards.

TABLE 6. Road Spacings, Road Segments and Average Costs for Single Entry with Linear Skidding Costs.

Volume	5 CCF/acre	10 CCF/acre	15 CCF/acre
Collector Spacing (ft)	5042	3899	3239
Spur Road Spacing (ft)	1600	1000	889
Collector Segments, J	5	8	9
Low Standard Collector Segments, K	1	1	1
Average Cost ($/acre)	85.02	125.44	158.19

Comparing the average costs in Table 5 and 6, the difference of the corresponding values shows the saving from harvesting with various skidding patterns settings layout and multiple road standards for the collector. Here, the low standard collector road is permitted to extend along the collector. The road standard for the low standard collector is the same as for spur road. In other words, they have the same construction and haul cost. In Tables 6, the J and K values indicate the number of collector segments and the number of low standard collector segments respectively. When K is equal to or greater than one there is a change in collector road standard.

The differences in cost for the 5, 10, 15 CCF volume removals are approximately 7.3 %, 6.3 %, and 7.4 % lower than the skidding patterns and road standards permitted by Bowman and Hessler.

6.3 Effects of High Standard Collector Costs

To test the sensitivity of road spacing, road standards and total unit cost, I varied the high standard collector costs for the single entry, linear cost problem (Table 7 and Figure 9). As the cost of the higher road standard increased, the average cost of skidding plus roads increased, the proportion of the road constructed to the lower standard increased, and collector road spacing increased. At the point that high standard construction costs became so high that the roads became entire low standard, the collector road spacing became independent of the high standard collector cost. The spur road spacing remained almost independent of collector road spacing.

TABLE 7. Effect of High Standard Collector Cost on Road Spacings, Average Cost and Low Standard Collector for Single Entry with Linear Skidding Costs.

High Standard Collector Cost $/FT	Average Cost $/CCF	Spacings (FT) S	SE	Road Segments J	K
1.14	11.25	2000	1000	8	0
1.33	11.63	2200	1000	8	0
1.52	11.93	2600	1000	8	1
1.70	12.16	3200	1000	8	1
1.89	12.36	3600	1000	8	1
2.08	12.55	4000	1000	8	1
2.27	12.70	4000	1000	8	2
2.46	12.84	4200	1000	8	2
2.65	12.97	4400	1000	8	2
2.84	13.09	4800	1000	8	2
3.03	13.21	4600	1000	8	3
3.22	13.31	4800	1000	8	3
3.41	13.41	5000	1000	8	3
3.60	13.50	5000	1000	8	3
3.79	13.52	2000	1000	8	8
3.98	13.52	2000	1000	8	8
4.17	13.52	2000	1000	8	8
4.36	13.52	2000	1000	8	8

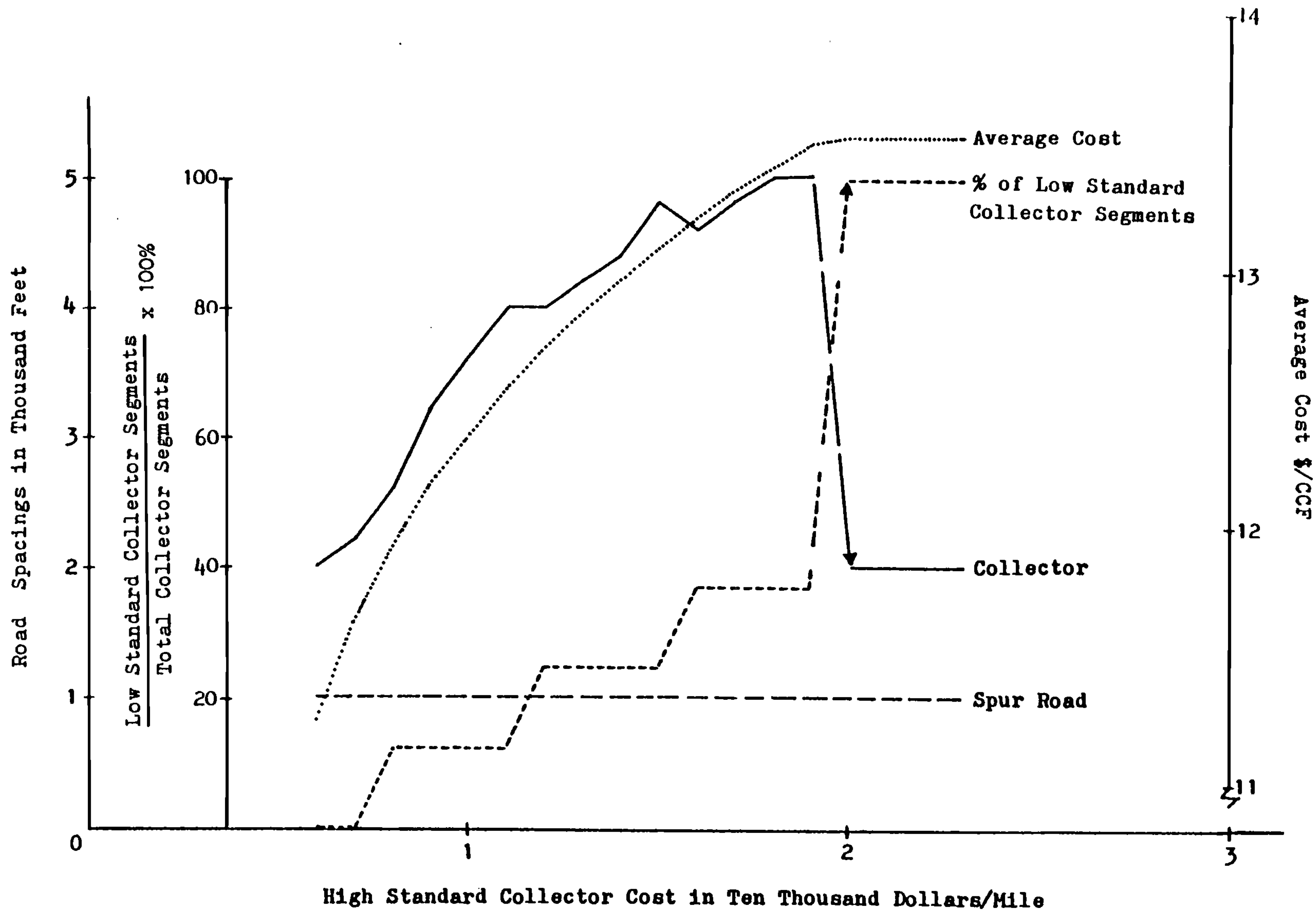


Figure 9. Effects of High Standard Collector Cost on Road Spacings, Average Cost and Low Standard Collactor Segments for the Single Entry with Linear Skidding Costs.

6.4 Effects of Multiple Entries

The effects of single entry and multiple entries to a stand for a given volume is shown in Table 8. For the multiple entries, part of the given volume will be taken out in each entry. The entry interval is 10 years. As the volume is spread over time, instead of being concentrated in the first entry, the optimal spur road and collector road spacing increases. For example, instead of taking 20 CCF/acre in the first year, the harvest is spread over 4 entries of 5 CCF/acre, the optimal collector spacing increases from 2927 to 3800 ft and the optimal spur road spacing increases from 727 ft to 1000 ft. Conversely, for a given harvest schedule, if future entries were not considered in the initial road spacing decision, the road spacing might be overestimated because future volumes were not considered.

TABLE 8. Effects of Multiple Entries on Road Spacings and Road Segments. Entry interval is 10 years.

# of Entries	Vol Removal CCF/Acre	Road Spacings (ft) S	SE	Road Segments J	K
1	20	2927	727	11	1
2	10,10	3200	800	10	1
3	5,5,10	3600	1000	8	1
4	5,5,5,5	3800	1000	8	1

6.5 Skid Cost Functions

Two additional skid cost functions were used in Program 5 and the road spacings recalculated (Table 9). As the exponent on the non-linear skidding cost was increased, skidding costs became more sensitive to distance. The optimal spur road spacing decreased rapidly. The collector road spacing and collector road standard were relatively insensitive to the changes in the skidding cost.

TABLE 9. Skid Cost Functions with Different Volumes for Single Entry with Non-linear Skidding Costs. NE and DE evaluated with step size of 100 ft.

Cost Function	Spacing (Feet)	Road Segments	5CCF /acre	10CCF /acre	15CCF /acre
$1+.005(d)^{1.1}$	S		4800	3733	3143
	SE		2000	1333	1143
		J	4	6	7
		K	1	1	1
$1+.005(d)^{1.15}$	S		5200	3943	3200
	SE		1600	1143	1000
		J	5	7	8
		K	1	1	1
$1+.005(d)^{1.2}$	S		4933	4000	3400
	SE		1333	1000	800
		J	6	8	10
		K	2	1	1

6.6 Run-time Comparison

All programs were run in TURBO BASIC on a 4.77-mz IBM XT computer with an 8087 math coprocessor. A step size of one was used for both the variables J and K in Programs 1, 2, 3 and 4. NE and DE evaluated with step size of 100 ft for both of the complete enumeration methods (Program 1 and 3). The step sizes for NE and DE in the enumeration and pattern search combined method (Program 2 and 4) and Hooke and Jeeves pattern search method (Program 2A and 4A) depends on the inputs of the initial and final exploration step sizes, R and RF. In addition the user must supply a penalty surface, a starting vector for each of the variables and an acceleration factor. The maximum and minimum values for all the variables considered in the enumeration and pattern search combined method and the pattern search method (Program 2,4,2A and 4A) are 3000 and 0 respectively. Other necessary inputs for the example are listed in Table 10. A comparision of run times for the three methods is shown in Table 11.

The relatively small savings using the combined enumeration and pattern search in Table 11 must recognize the narrower search range in the complete enumeration runs. If the complete enumeration had been run over the same range as the combined enumeration and pattern search the ratio of run times would have been on the order of 3:1 to 4:1. Runs were also done using the Hooke and Jeeves pattern search for

TABLE 10. Inputs (Maximum and Minimum Values Considered, Feasible Starting Points and Components Set) for the Three Methods.
(Program 1 and 3 -- Complete enumeration method.
Program 2 and 4 -- Enumeration and pattern search combined
Program 2A and 4A -- Hooke and Jeeves pattern search)

	Single Entry			Multiple Entry		
Program	1	2	2A	3	4	4A
Max	1000	-	-	1000	-	-
DE or X(1)	-	400	600	-	300	300
Min	0	-	-	0	-	-
Max	2000	-	-	2000	-	-
NE or X(2)	-	800	1200	-	600	1000
Min	0	-	-	0	-	-
Max	10	10	-	10	10	-
J or X(3)	-	-	14	-	-	12
Min	1	1	-	0	0	-
Max	10	10	-	10	10	-
K or X(4)	-	-	4	-	-	4
Min	0	0	-	0	0	-
A	-	2	1	-	2	2
RF	-	.01	2	-	.01	2
R		10	2		10	2
F		20	25		20	250

TABLE 11. Comparison of Run Times for the Three Methods.
(Program 1 and 3 -- Complete enumeration method
Program 2 and 4 -- Enumeration and pattern search combined
Program 2A and 4A -- Hooke and Jeeves pattern search)

	Single Entry			Multiple Entries		
Program	1	2	2A	3	4	4A
S	4000	3899	3600	3289	3309	3305
SE	1000	1000	1000	889	889	889
J	8	8	8	9	9	9
K	1	1	1	1	1	0
Average Cost ($/CCF)	12.545	12.544	12.550	-	-	-
($/acre)	-	-	-	176.637	176.635	177.347
Combinations Executed	15015	12780	342	15015	9696	420
Actual Runtime (seconds)	195	191	9	589	403	22
Comparative Run Time	600	191	9	1800	403	22

all variables (DE, NE, J, and K). The requirement for integer values of J and K can be done by controlling the initial and final exploration step sizes and the feasible starting points. These solution times were very fast. Approximately 9 seconds was required for the single entry problem as compared to 191 seconds for the combined enumeration and patttern search. Approximately 22 seconds was required for the multiple entries problem as compared to 403 seconds for the combined enumeration and pattern search. For the multiple entries, Program 4A, the pattern search without enumeration, failed to included one segment of low standard collector. This resulted in a slightly higher cost. However, when comparing the average cost with the other two methods (results of Program 3 and 4), the difference is very small.

7.CONCLUSIONS

A set of computer programs have been developed to simultaneously optimize spur road spacing, collector road spacing, and collector road standard on gentle terrain. Linear and non-linear skidding costs can be used. Single and multiple entries can be evaluated with up to a maximum of three future entries. A comparison of run times for complete enumeration, combined enumeration and pattern search, and pattern search have been shown. The road spacing methodology presented by Bowman and Hessler appears to give good results for the single entry, linear skidding cost problem. Skidding costs are overestimated by Bowman and Hessler due to the restrictive skidding patterns permitted increasing overall costs 6 % to 7 % in this case. Joint optimization of the collector road standard with the road spacing decision was accomplished in this model, but it only had a small impact on results. In planning, it appears that spur road and collector road spacing optimization might be done first and optimization of the collector road standard done afterwards.

A unique aspect in this model is the ability to consider non-linear skidding costs in a broader context than Sessions and Li (1987). Although mechanized ground skidding vehicles such as rubber tired skidders, tractors, and forwarders are usually assumed to have linear skidding costs; highlead cable skidding and animal skidding have non-linear skidding costs. The ability to consider the non-linear skidding costs may therefore be important on swampy wet ground or in developing countries where animal skidding is used in plantation harvesting.

The superiority of a search method over complete enumeration was demonstrated. Although search methods are a little more complicated than complete enumeration, if a program will be repeatedly used, particularly involving a multivariable search, the time investment in a search technique seem justified. The very fast solution times for the pattern search over the combined enumeration and pattern search suggest the straight pattern search is the superior method with respect to computational time. There is some risk, however, that the pattern search will not find the global minimum. See Shoup and Mistree (1987) for examples where the pattern search can converge to a nonoptimum point. In the examples in this paper the solutions identified by the pattern search were very close to those identified in complete enumeration.

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APPENDICES

APPENDIX A

Total Skid Cost to Spur Roads

J	Distance	Volume
1	$\frac{SE}{4}$	$\frac{SE}{2}\times\frac{SE}{2}\times V$
	$\frac{SE}{4}$	$\left(LE-\frac{SE}{2}\right)\times SE\times V$
	RD	$DE\times SE\times V$
	$\frac{1}{3}\left(\frac{SE}{2}\right)$	$\frac{1}{2}\times\frac{SE}{2}\times\frac{SE}{2}\times V$
2	$\frac{SE}{4}$	$\frac{SE}{2}\times\frac{SE}{2}\times V$
	$\frac{SE}{4}$	$2\left(LE-\frac{SE}{2}\right)\times SE\times V$
	RD	$2\times DE\times SE\times V$
	$\frac{1}{3}\left(\frac{SE}{2}\right)$	$3\times\frac{1}{2}\times\frac{SE}{2}\times\frac{SE}{2}\times V$
3	$\frac{SE}{4}$	$\frac{SE}{2}\times\frac{SE}{2}\times V$
	$\frac{SE}{4}$	$3\left(LE-\frac{SE}{2}\right)\times SE\times V$

	RD	$3 \times DE \times SE \times V$
	$\frac{1}{3}\left(\frac{SE}{2}\right)$	$5 \times \frac{1}{2} \times \frac{SE}{2} \times \frac{SE}{2} \times V$
4	$\frac{SE}{4}$	$\frac{SE}{2} \times \frac{SE}{2} \times V$
	$\frac{SE}{4}$	$4\left(LE - \frac{SE}{2}\right) \times SE \times V$
	RD	$4 \times DE \times SE \times V$
	$\frac{1}{3}\left(\frac{SE}{2}\right)$	$7 \times \frac{1}{2} \times \frac{SE}{2} \times \frac{SE}{2} \times V$

General formula for total skid cost to spur roads

$$S2 = 2\{SS \times \frac{SE}{4} \times J \times \left(LE - \frac{SE}{2}\right) \times SE \times V + SS \times RD \times J \times DE \times SE \times V$$

$$+SS \times \frac{1}{3} \times \frac{SE}{2}(2 \times J - 1)\frac{1}{2} \times \frac{SE}{2} \times \frac{SE}{2} \times V + SS \times \frac{SE}{4} \times \frac{SE}{2} \times \frac{SE}{2} \times V\}$$

Simplifying,

$$S2 = 2 \times SS \times SE \times V\left\{J \times [\frac{SE}{4} \times \left(LE - \frac{SE}{2}\right) + RD \times DE] + [\frac{(2J-1)}{48} + \frac{1}{16}] \times SE^2\right\}.$$

APPENDIX B

Total Haul Cost on Spur Roads

J	Distance	Volume
1	$\frac{SE}{2}+\frac{LE-\frac{SE}{2}}{2}$	$\left(LE-\frac{SE}{2}\right)\times SE\times V$
	LE	$DE\times SE\times V$
	$\frac{2}{3}\left(\frac{SE}{2}\right)$	$\frac{1}{2}\times\frac{SE}{2}\times\frac{SE}{2}\times V$
	$\frac{1}{2}\left(\frac{SE}{2}\right)$	$\frac{SE}{2}\times\frac{SE}{2}\times V$
2	$\frac{SE}{2}+\left(\frac{LE}{2}-\frac{SE}{4}\right)$	$2\left(LE-\frac{SE}{2}\right)\times SE\times V$
	LE	$2\times DE\times SE\times V$
	$\frac{2}{3}\left(\frac{SE}{2}\right)$	$3\times\frac{1}{2}\times\frac{SE}{2}\times\frac{SE}{2}\times V$
	$\frac{1}{2}\left(\frac{SE}{2}\right)$	$\frac{SE}{2}\times\frac{SE}{2}\times V$
3	$\frac{SE}{2}+\left(\frac{LE}{2}-\frac{SE}{4}\right)$	$3\left(LE-\frac{SE}{2}\right)\times SE\times V$
	LE	$3\times DE\times SE\times V$

	$\frac{2}{3}\left(\frac{SE}{2}\right)$	$5\times\frac{1}{2}\times\frac{SE}{2}\times\frac{SE}{2}\times V$
	$\frac{1}{2}\left(\frac{SE}{2}\right)$	$\frac{SE}{2}\times\frac{SE}{2}\times V$
4	$\frac{SE}{2}+\left(\frac{LE}{2}-\frac{SE}{4}\right)$	$4\left(LE-\frac{SE}{2}\right)\times SE\times V$
	LE	$4\times DE\times SE\times V$
	$\frac{2}{3}\left(\frac{SE}{2}\right)$	$7\times\frac{1}{2}\times\frac{SE}{2}\times\frac{SE}{2}\times V$
	$\frac{1}{2}\left(\frac{SE}{2}\right)$	$\frac{SE}{2}\times\frac{SE}{2}\times V$

General formula for total haul cost on spur roads

$$S3=2\times\{HS\times J\times[\frac{SE}{2}+\left(\frac{LE}{2}-\frac{SE}{4}\right)]\times\left(LE-\frac{SE}{2}\right)\times SE\times V+HS\times J\times LE\times DE\times SE\times V$$
$$+HS\times(2\times J-1)\times\frac{2}{3}\times\frac{SE}{2}\times\frac{1}{2}\times\frac{SE}{2}\times\frac{SE}{2}\times V+HS\times\frac{1}{2}\times\frac{SE}{2}\times\frac{SE}{2}\times\frac{SE}{2}\times V\}$$

Simplifying,

$$S3=2\times HS\times\left\{J\times\left([\frac{SE}{2}+\left(\frac{LE}{2}-\frac{SE}{4}\right)]\times\left(LE-\frac{SE}{2}\right)+LE\times DE\right)+[\frac{(2J-1)}{24}+\frac{1}{16}]\times SE^2\right\}\times SE\times V$$

$$S3=2\times HS\times SE\times V\times\left\{J\times[\frac{1}{2}\left(LE^2-\frac{SE^2}{4}\right)+LE\times DE]+[\frac{(2J-1)}{24}+\frac{1}{16}]\times SE^2\right\}\times SE\times V$$

APPENDIX C

Average Haul Distance on Collector

Average haul distance on high standard collector only

When $K = 0$ and $L = \frac{SE}{2}, \frac{3SE}{2}, \frac{5SE}{2}, ---,$

$$LL = \frac{L \times VS + \left\{ \frac{1}{2}(\frac{L}{SE} - \frac{1}{2})^2 \times VL + [(\frac{L}{SE})^2 - \frac{1}{12}] \times VC \right\} \times SE}{VS + (\frac{L}{SE} - \frac{1}{2}) \times VL + 2\frac{L}{SE} \times VC}$$

where

$$VS = (LE + DE) \times SE \times V - \frac{1}{2}\left(\frac{SE}{2}\right)^2 \times V$$

VS = Volumes enter the last spur road (from right-angle skidding pattern setting at the end of the collector, triangular and right-angle skidding pattern settings along the last spur road, and radial skidding pattern setting at the end of the last spur road) except volume from the triangular skidding pattern setting, adjacent to the collector. See Figure 2.

$$VL = (LE + DE) \times SE \times V - \left(\frac{SE}{2}\right)^2 \times V$$

VL = Volumes enter each spur road (from triangular and right-angle skidding pattern settings along spur road and radial skidding pattern setting at end of spur road) except volumes from two of the triangular skidding pattern settings, adjacent to the collector.

$$VC = \frac{1}{2}\left(\frac{SE}{2}\right)^2 \times V$$

VC = Volume enter the collector from any one of the triangular skidding pattern settings adjacent to the collector.

See Appendix D and Figure 2. It is assumed that the whole collector on Figure 2 is a high standard collector.

Average haul distance on low standard collector only

$$\text{When } L=0, K=J \text{ and } K=1,2,3,4,--- \text{ i.e. } B=\frac{SE}{2},\frac{3SE}{2},\frac{5SE}{2},---,$$

$$BB=\frac{B\times VS+\left\{\frac{1}{2}(\frac{B}{SE}-\frac{1}{2})^2\times VL+[(\frac{B}{SE})^2-\frac{1}{12}]\times VC\right\}\times SE}{VS+(\frac{B}{SE}-\frac{1}{2})\times VL+2\frac{B}{SE}\times VC}$$

See Appendix E and Figure 2. It is assumed that the whole collector on Figure 2 is a low standard collector.

Average haul distance on high and low standard collector

$$\text{When } K=1,2,3,4,--- \text{ and } L=\frac{SE}{2},\frac{3SE}{2},\frac{5SE}{2},---,$$

Average haul distance on low standard collector

$$BL=\frac{K\{VS+(\frac{K-1}{2})\times VL+K\times VC\}\times SE}{VS+(K-1)\times VL+2K\times VC}$$

See Appendix F and Figure 2.

Average haul distance on high standard collector

$$LB=\frac{\left\{\left(\frac{\frac{L}{SE}+\frac{1}{2}}{2}\right)^2\times VL+[(\frac{L}{SE})^2-\frac{1}{12}]\times VC\right\}\times SE}{(\frac{L}{SE}+\frac{1}{2})\times VL+2\frac{L}{SE}\times VC}$$

See Appendix G and Figure 2.

APPENDIX D

Average Haul Distance on High Standard Collector only

When $K = 0$ and $L = \frac{SE}{2}, \frac{3SE}{2}, \frac{5SE}{2}, \frac{7SE}{2}, ---,$

L	Distance	Volume
$\frac{SE}{2}$	$\frac{SE}{2}$	VS
$\frac{3SE}{2}$	$\frac{3SE}{2}$	VS
	$\frac{SE}{2}$	VL
	$SE + \frac{1}{3}\left(\frac{SE}{2}\right)$	VC
	$\left(\frac{SE}{2}\right) + \frac{2}{3}\left(\frac{SE}{2}\right)$	VC
	$\frac{1}{3}\left(\frac{SE}{2}\right)$	VC
$\frac{5SE}{2}$	$\frac{5SE}{2}$	VS
	$\frac{3SE}{2}$	VL
	$\frac{SE}{2}$	VL
	$2SE + \frac{1}{3}\left(\frac{SE}{2}\right)$	VC
	$3\left(\frac{SE}{2}\right) + \frac{2}{3}\left(\frac{SE}{2}\right)$	VC
	$SE + \frac{1}{3}\left(\frac{SE}{2}\right)$	VC

	$\left(\frac{SE}{2}\right)+\frac{2}{3}\left(\frac{SE}{2}\right)$	VC
	$\frac{1}{3}\left(\frac{SE}{2}\right)$	VC
$\frac{7SE}{2}$	$\frac{7SE}{2}$	VS
	$\frac{5SE}{2}$	VL
	$\frac{3SE}{2}$	VL
	$\frac{SE}{2}$	VL
	$3SE+\frac{1}{3}\left(\frac{SE}{2}\right)$	VC
	$5\left(\frac{SE}{2}\right)+\frac{2}{3}\left(\frac{SE}{2}\right)$	VC
	$2SE+\frac{1}{3}\left(\frac{SE}{2}\right)$	VC
	$3\left(\frac{SE}{2}\right)+\frac{2}{3}\left(\frac{SE}{2}\right)$	VC
	$SE+\frac{1}{3}\left(\frac{SE}{2}\right)$	VC
	$\left(\frac{SE}{2}\right)+\frac{2}{3}\left(\frac{SE}{2}\right)$	VC
	$\frac{1}{3}\left(\frac{SE}{2}\right)$	VC

Average haul distance for

i) $VS=L$

ii) $$VL = \frac{(L - \frac{SE}{2})^2}{2SE}$$

iii) $$VC = [\frac{(\frac{L}{SE} + \frac{1}{2})^2 - (\frac{L}{SE} + \frac{1}{2})}{2} + \frac{1}{2}\left(\frac{L}{SE} - \frac{1}{2}\right)^2 + \left(\frac{L}{2SE} - \frac{1}{12}\right)] \times SE$$

where

$$\frac{(\frac{L}{SE} + \frac{1}{2})^2 - (\frac{L}{SE} + \frac{1}{2})}{2} \times SE = \text{sum of distance in (SE) term}$$

$$\frac{1}{2}\left(\frac{L}{SE} - \frac{1}{2}\right)^2 \times SE = \text{sum of distance in } \left(\frac{SE}{2}\right) \text{ term}$$

$$\left(\frac{L}{2SE} - \frac{1}{12}\right) \times SE = \text{sum of distance in } [\frac{1}{3}\left(\frac{SE}{2}\right)] \text{ term and } [\frac{2}{3}\left(\frac{SE}{2}\right)] \text{ term}$$

Volume for

i) $VS = 1$

ii) $VL = \frac{L}{SE} - \frac{1}{2}$

iii) $VC = 2\frac{L}{SE}$

General formula for average haul distance on high standard collector only:

$$LL = \frac{L \times VS + \frac{\left(\frac{L-SE}{2}\right)^2}{2SE} \times VL + \left\{\frac{\left(\frac{L}{SE}+\frac{1}{2}\right)^2 - \left(\frac{L}{SE}+\frac{1}{2}\right)}{2} + \frac{1}{2}(\frac{L}{SE} - \frac{1}{2})^2 + (\frac{L}{2SE} - \frac{1}{12})\right\} \times SE \times VC}{VS + (\frac{L}{SE} - \frac{1}{2}) \times VL + 2\frac{L}{SE} \times VC}$$

Simplifying,

$$LL = \frac{L \times VS + \left\{ \frac{1}{2}\left(\frac{L}{SE} - \frac{1}{2}\right)^2 \times VL + \left[\left(\frac{L}{SE}\right)^2 - \frac{1}{12}\right] \times VC \right\} \times SE}{VS + \left(\frac{L}{SE} - \frac{1}{2}\right) \times VL + 2\frac{L}{SE} \times VC}.$$

APPENDIX E

Average Haul Distance on Low Standard Collector only

When $L = 0, K = J$ and $K \geq 1$ i.e. $B = \frac{SE}{2}, \frac{3SE}{2}, \frac{5SE}{2}, \frac{7SE}{2}, ---,$

K	Distance	Volume
1	$\frac{SE}{2}$	VS
	$\frac{1}{3}\left(\frac{SE}{2}\right)$	VC
2	$\frac{3SE}{2}$	VS
	$\frac{SE}{2}$	VL
	$SE + \frac{1}{3}\left(\frac{SE}{2}\right)$	VC
	$\left(\frac{SE}{2}\right) + \frac{2}{3}\left(\frac{SE}{2}\right)$	VC
	$\frac{1}{3}\left(\frac{SE}{2}\right)$	VC
3	$\frac{5SE}{2}$	VS
	$\frac{3SE}{2}$	VL
	$\frac{SE}{2}$	VL
	$2SE + \frac{1}{3}\left(\frac{SE}{2}\right)$	VC
	$3\left(\frac{SE}{2}\right) + \frac{2}{3}\left(\frac{SE}{2}\right)$	VC

	$SE+\frac{1}{3}\left(\frac{SE}{2}\right)$	VC
	$\left(\frac{SE}{2}\right)+\frac{2}{3}\left(\frac{SE}{2}\right)$	VC
	$\frac{1}{3}\left(\frac{SE}{2}\right)$	VC
4	$\frac{7SE}{2}$	VS
	$\frac{5SE}{2}$	VL
	$\frac{3SE}{2}$	VL
	$\frac{SE}{2}$	VL
	$3SE+\frac{1}{3}\left(\frac{SE}{2}\right)$	VC
	$5\left(\frac{SE}{2}\right)+\frac{2}{3}\left(\frac{SE}{2}\right)$	VC
	$2SE+\frac{1}{3}\left(\frac{SE}{2}\right)$	VC
	$3\left(\frac{SE}{2}\right)+\frac{2}{3}\left(\frac{SE}{2}\right)$	VC
	$SE+\frac{1}{3}\left(\frac{SE}{2}\right)$	VC
	$\left(\frac{SE}{2}\right)+\frac{2}{3}\left(\frac{SE}{2}\right)$	VC
	$\frac{1}{3}\left(\frac{SE}{2}\right)$	VC

Average haul distance for

i) VS = B

ii) VL = $\dfrac{(B-\frac{SE}{2})^2}{2SE}$

iii) VC = $[\dfrac{(\frac{B}{SE}+\frac{1}{2})^2-(\frac{B}{SE}+\frac{1}{2})}{2}+\frac{1}{2}\left(\frac{B}{SE}-\frac{1}{2}\right)^2+\left(\frac{B}{2SE}-\frac{1}{12}\right)]\times SE$

Where

$$\frac{(\frac{B}{SE}+\frac{1}{2})^2-(\frac{B}{SE}+\frac{1}{2})}{2}\times SE = \text{sum of distance in}(SE)\text{ term}$$

$$\frac{1}{2}\left(\frac{B}{SE}-\frac{1}{2}\right)^2\times SE = \text{sum of distance in}\left(\frac{SE}{2}\right)\text{term}$$

$$\left(\frac{B}{2SE}-\frac{1}{12}\right)\times SE = \text{sum of distance in }[\frac{1}{3}\left(\frac{SE}{2}\right)]\text{ term and }[\frac{2}{3}\left(\frac{SE}{2}\right)]\text{ term}$$

Volume for

i) VS = 1

ii) VL = $\dfrac{B}{SE}-\dfrac{1}{2}$

iii) VC = $2\dfrac{B}{SE}$

General formula for average haul distance on low standard collector only:

$$BB = \frac{B \times VS + \frac{\left(B - \frac{SE}{2}\right)^2}{2SE} \times VL + [\frac{\left(\frac{B}{SE} + \frac{1}{2}\right)^2 - \left(\frac{B}{SE} + \frac{1}{2}\right)}{2} + \frac{1}{2}(\frac{B}{SE} - \frac{1}{2})^2 + (\frac{B}{2SE} - \frac{1}{12})] \times SE \times VC}{VS + (\frac{B}{SE} - \frac{1}{2}) \times VL + 2\frac{B}{SE} \times VC}$$

Simplifying,

$$BB = \frac{B \times VS + \left\{\frac{1}{2}(\frac{B}{SE} - \frac{1}{2})^2 \times VL + [(\frac{B}{SE})^2 - \frac{1}{12}] \times VC\right\} \times SE}{VS + (\frac{B}{SE} - \frac{1}{2}) \times VL + 2\frac{B}{SE} \times VC}.$$

APPENDIX F

Average Haul Distance on Low Standard Collector

When $K = 1,2,3,---$ and $L = \frac{SE}{2}, \frac{3SE}{2}, \frac{5SE}{2}, ---,$

K	Distance	Volume
1	SE	VS
	$\left(\frac{SE}{2}\right)+\frac{1}{3}\left(\frac{SE}{2}\right)$	VC
	$\frac{2}{3}\left(\frac{SE}{2}\right)$	VC
2	2SE	VS
	SE	VL
	$3\left(\frac{SE}{2}\right)+\frac{1}{3}\left(\frac{SE}{2}\right)$	VC
	$SE+\frac{2}{3}\left(\frac{SE}{2}\right)$	VC
	$\left(\frac{SE}{2}\right)+\frac{1}{3}\left(\frac{SE}{2}\right)$	VC
	$\frac{2}{3}\left(\frac{SE}{2}\right)$	VC
3	3SE	VS
	2SE	VL
	SE	VL
	$5\left(\frac{SE}{2}\right)+\frac{1}{3}\left(\frac{SE}{2}\right)$	VC
	$2SE+\frac{2}{3}\left(\frac{SE}{2}\right)$	VC
	$3\left(\frac{SE}{2}\right)+\frac{1}{3}\left(\frac{SE}{2}\right)$	VC

$$SE + \frac{2}{3}\left(\frac{SE}{2}\right) \qquad \text{VC}$$

$$\left(\frac{SE}{2}\right) + \frac{1}{3}\left(\frac{SE}{2}\right) \qquad \text{VC}$$

$$\frac{2}{3}\left(\frac{SE}{2}\right) \qquad \text{VC}$$

Average haul distance for

i) VS = K x SE

ii) VL = $K(K-1)\times\frac{SE}{2}$

iii) VC = $[\frac{K^2-K}{2}+\frac{K^2}{2}+\left(\frac{K}{3}+\frac{K}{6}\right)]\times SE$

Where

$$\frac{K^2-K}{2}\times SE = \text{sum of distance in}(SE)\text{ term}$$

$$\frac{K^2}{2}\times SE = \text{sum of distance in}\left(\frac{SE}{2}\right)\text{term}$$

$$\left(\frac{K}{3}+\frac{K}{6}\right)\times SE = \text{sum of distance in }[\frac{2}{3}\left(\frac{SE}{2}\right)]\text{ term and }[\frac{1}{3}\left(\frac{SE}{2}\right)]\text{ term}$$

Volume for

i) VS = 1

ii) VL = K - 1

iii) VC = 2K

General formula for average haul distance on low standard collector:

$$BL = \frac{\left\{K\times VS + \frac{K^2-K}{2}\times VL + [\frac{K^2-K}{2}+\frac{K^2}{2}+(\frac{K}{3}+\frac{K}{6})]\times VC\right\}\times SE}{VS+(K-1)\times VL + 2K\times VC}$$

Simplifying,

$$BL = \frac{K\,[VS + \frac{(K-1)}{2} \times VL + K \times VC\,] \times SE}{VS + (K-1) \times VL + 2K \times VC}.$$

APPENDIX G

Average Haul Distance on High Standard Collector

When $K = 1,2,3,---$ and $L = \frac{SE}{2}, \frac{3SE}{2}, \frac{5SE}{2}, ---$,

L	Distance	Volume
$\frac{SE}{2}$	$\frac{SE}{2}$	VL
	$\frac{1}{3}\left(\frac{SE}{2}\right)$	VC
$\frac{3SE}{2}$	$\frac{3SE}{2}$	VL
	$\frac{SE}{2}$	VL
	$SE + \frac{1}{3}\left(\frac{SE}{2}\right)$	VC
	$\left(\frac{SE}{2}\right) + \frac{2}{3}\left(\frac{SE}{2}\right)$	VC
	$\frac{1}{3}\left(\frac{SE}{2}\right)$	VC
$\frac{5SE}{2}$	$\frac{5SE}{2}$	VL
	$\frac{3SE}{2}$	VL
	$\frac{SE}{2}$	VL
	$2SE + \frac{1}{3}\left(\frac{SE}{2}\right)$	VC
	$3\left(\frac{SE}{2}\right) + \frac{2}{3}\left(\frac{SE}{2}\right)$	VC

$$SE+\frac{1}{3}\left(\frac{SE}{2}\right)$$ VC

$$\left(\frac{SE}{2}\right)+\frac{2}{3}\left(\frac{SE}{2}\right)$$ VC

$$\frac{1}{3}\left(\frac{SE}{2}\right)$$ VC

Average haul distance for

i) VL = $$\frac{(\frac{L}{SE}+\frac{1}{2})^2}{2}\times SE$$

ii) VC = $$\frac{[\frac{(\frac{L}{SE}+\frac{1}{2})^2-(\frac{L}{SE}+\frac{1}{2})}{2}+\frac{(\frac{L}{SE}-\frac{1}{2})^2}{2}+\frac{1}{6}(\frac{L}{SE}+\frac{1}{2})+\frac{1}{3}(\frac{L}{SE}-\frac{1}{2})]\times SE}{(\frac{L}{SE}+\frac{1}{2})\times VL+2\frac{L}{SE}\times VC}$$

Where

$$\frac{(\frac{L}{SE}+\frac{1}{2})^2-(\frac{L}{SE}+\frac{1}{2})}{2}\times SE=\text{sum of volume in}(SE)\text{ term}$$

$$\frac{(\frac{L}{SE}-\frac{1}{2})}{2}\times SE=\text{sum of volume in}\left(\frac{SE}{2}\right)\text{term}$$

$$\frac{1}{6}\left(\frac{L}{SE}+\frac{1}{2}\right)\times SE=\text{sum of volume in }[\frac{1}{3}\left(\frac{SE}{2}\right)]\text{ term}$$

$$\frac{1}{3}\left(\frac{L}{SE}-\frac{1}{2}\right)\times SE=\text{sum of volume in }[\frac{2}{3}\left(\frac{SE}{2}\right)]\text{ term}$$

Volume for

i) VL = $$\frac{L}{SE}+\frac{1}{2}$$

ii) VC = $$2\frac{L}{SE}$$

General formula for average hauling distance on high standard collector:

$$LB = \frac{\left\{ \frac{\left(\frac{L}{SE}+\frac{1}{2}\right)^2}{2} \times VL + \left[\frac{\left(\frac{L}{SE}+\frac{1}{2}\right)^2 - \left(\frac{L}{SE}+\frac{1}{2}\right)}{2} + \frac{\left(\frac{L}{SE}-\frac{1}{2}\right)^2}{2} + \frac{1}{6}\left(\frac{L}{SE}+\frac{1}{2}\right) + \frac{1}{3}\left(\frac{L}{SE}-\frac{1}{2}\right) \right] \times VC \right\} \times SE}{\left(\frac{L}{SE}+\frac{1}{2}\right) \times VL + 2\frac{L}{SE} \times VC}$$

Simplifying,

$$LB = \frac{\left\{ \frac{\left(\frac{L}{SE}+\frac{1}{2}\right)^2}{2} \times VL + \left[\left(\frac{L}{SE}\right)^2 - \frac{1}{12} \right] \times VC \right\} \times SE}{\left(\frac{L}{SE}+\frac{1}{2}\right) \times VL + 2\frac{L}{SE} \times VC}.$$

APPENDIX H

Program 1. Single Entry with Linear Skidding Costs

Program Listing

```
10  REM      ************************************************************
20  REM      *                                                          *
30  REM      *         SINGLE ENTRY WITH LINEAR SKIDDING COSTS          *
40  REM      *                                                          *
50  REM      *               COMPLETE ENUMERATION METHOD                *
60  REM      *                                                          *
70  REM      ************************************************************
80  REM
90  REM
100 REM     **************************************************************
110 REM     *                                                            *
120 REM     *     PROGRAM TO DETERMINE OPTIMUM SETTINGS DIMENSIONS FOR   *
130 REM     *                                                            *
140 REM     *     TRIANGULAR, RIGHT-ANGLE AND RADIAL SKIDDING PATTERNS   *
150 REM     *                                                            *
160 REM     *     ASSOCIATED WITH HIGH AND LOW STANDARD COLLECTOR        *
170 REM     *                                                            *
180 REM     **************************************************************
190 REM
200 REM
210 REM  PURPOSE: TO FIND THE MINIMUM SUM OF ROADING, SKIDDING AND HAULING
220 REM           COST.
230 REM
240 REM           TO FIND THE OPTIMUM SPACINGS FOR COLLECTORS AND SPUR ROADS.
250 REM
260 REM           TO FIND THE OPTIMUM LENGTHS FOR HIGH AND LOW STANDARD
270 REM           COLLECTOR.
280 REM
290 REM           TO DETERMINE THE OPTIMUM SETTINGS DIMENSIONS FOR VARIOUS
300 REM           SKIDDING PATTERNS ADJACENT TO ONE AND ANOTHER.
310 REM
320 REM
330 REM  **** ASSIGNED CONDITIONS ****
340 REM
350 REM  NUMBER OF ENTRIES = 1
360 REM  SKIDDING COST = LINEAR (AVERAGE SKIDDING DISTANCE)
370 REM
380 REM
390 REM  **** SKIDDING PATTERNS ****
400 REM
410 REM  DESIGN TRIANGULAR SKIDDING PATTERN SETTINGS WHICH ARE RIGHT-ANGLE
420 REM  TRIANGLE IN SHAPE ALONG COLLECTOR AND SPURS. CONTINUOUS LANDINGS ARE
430 REM  ALLOWED ALONG COLLECTOR AND SPURS. SKIDDING DIRECTION IS PERPENDICULAR
440 REM  TO COLLECTOR OR SPURS.
450 REM
460 REM  DESIGN RIGHT-ANGLE SKIDDING PATTERN SETTINGS WHICH ARE SQUARE IN SHAPE
```

```
470 REM  ALONG THE LAST SPUR AND END OF COLLECTOR. CONTINUOUS LANDINGS ARE
480 REM  ALLOWED ALONG THE LAST SPUR. SKIDDING DIRECTION IS PERPENDICULAR TO
490 REM  SPURS.
500 REM
510 REM  DESIGN RIGHT-ANGLE SKIDDING PATTERN SETTINGS IN RECTANGULAR SHAPE
520 REM  ALONG SPURS. CONTINUOUS LANDINGS ARE ALLOWED ALONG SPURS. SKIDDING
530 REM  DIRECTION IS PERPENDICULAR TO SPURS.
540 REM
550 REM  DESIGN RADIAL SKIDDING PATTERN SETTINGS IN RECTANGULAR SHAPE AT THE END
560 REM  OF SPURS. LANDINGS AT END OF SPURS.
570 REM
580 REM
590 REM  *************** SINGLE ENTRY WITH LINEAR SKIDDING COSTS **************
600 REM
610 REM
620 REM  **** VARIABLES ( SUBJECT TO CHANGE i.e. INPUTS ) ****
630 REM
640 REM -------------------------------------------------------------------------
650 REM
660 REM        VOLUME PER ACRE OR PER SQUARE FEET, CCF/ACRE OR CCF/FT^2
670 REM        DEPTH OF UNIT, FT
680 REM        ROAD CONSTRUCTION COSTS, $/FT                  ' FT = FEET
690 REM        SKIDDING COSTS, $/CCF/FT
700 REM        HAULING COSTS, $/CCF/FT
710 REM
720 REM
730 REM  CCF = UNITS OF 100 CUBIC FEET OF TIMBER
740 REM  VOLUME = 10 CCF PER ACRE OR 10/43560 CCF PER SQUARE FEET
750 REM
760 V=10/43560!                                             ' VOLUME, CCF/FT^2
770 D=8000                                                  ' DEPTH OF UNIT, FT
780 TCMIN=10^10                                ' SERVE TO MINIMIZE AVERAGE COST
790 REM
800 REM   COLL = COLLECTOR : STD = STANDARD : AVE = AVERAGE : DIS = DISTANCE
810 REM
820 REM
830 REM  **** ROAD CONSTRUCTION COSTS ****
840 REM
850 REM  ROAD COSTS FOR COLLECTOR AND SPURS
860 REM
870 RH=11000/5280                                        ' HIGH STD COLL, $/FT
880 RL=5700/5280                                         ' LOW STD COLL, $/FT
890 RS=5700/5280                                         ' SPUR ROAD, $/FT
900 REM
910 REM  **** SKIDDING COSTS ****
920 REM
930 SC=1.74/100                                       ' SKID TO COLL, $/CCF/FT
940 SS=1.74/100                                       ' SKID TO SPUR, $/CCF/FT
950 REM
960 REM  **** HAULING COSTS ****
970 REM
980 HH=2/5280                               ' HAUL ON HIGH STD COLL, $/CCF/FT
990 HL=5.15/5280                            ' HAUL ON LOW STD COLL, $/CCF/FT
1000 HS=5.15/5280                           ' HAUL ON SPUR, $/CCF/FT
```

```
1010 REM ------------------------------------------------------------------
1020 REM
1030 REM
1040 REM  **** ASSIGN VARIABLES ****
1050 REM
1060 REM  DE = DEPTH (PARALLEL TO SPUR) OF RADIAL SKIDDING PATTERN SETTING, FT.
1070 REM  NE = LENGTH OF SPUR BETWEEN TRIANGULAR AND RADIAL SKIDDING PATTERN
1080 REM       SETTING WHICH IS THE LENGTH OF RIGHT-ANGLE SKIDDING PATTERN
1090 REM       SETTING ALONG SPUR, FT.
1100 REM  J  = # OF SPURS (MUST BE AT LEAST ONE) PERPENDICULAR TO ONE SIDE OF
1110 REM       THE COLLECTOR FOR THE DEPTH OF THE UNIT.
1120 REM  K  = # OF ROAD SEGMENTS (ZERO AND UP TO J) TO LOW STANDARD COLLECTOR.
1130 REM
1140 REM
1150 REM  ******** LOOPS FOR ASSIGN VARIABLES ********
1160 REM
1170 FOR DE=100 TO 2000 STEP 100
1180 FOR NE=100 TO 2000 STEP 100
1190 FOR J=1 TO 15
1200 FOR K=0 TO J
1210 REM
1220 REM
1230 REM  **** ROAD LENGTHS AND SPACINGS ****
1240 REM
1250 SE=D/J                                           ' SPUR ROAD  SPACING, FT
1260 B=D-SE/2                                         ' LENGTH OF COLLECTOR, FT
1270 LE=SE/2+NE                                       ' LENGTH OF SPUR ROAD, FT
1280 S=2*(LE+DE)                                      ' COLLECTOR  SPACING, FT
1290 RD=1/6*SQR(SE^2+DE^2)+1/3*SQR(SE^2/16+DE^2)      ' AVE SKID DIS (RADIAL), FT
1300 REM
1310 IF J>K THEN L=D-.5*SE-K*SE ELSE L=0            ' LENGTH OF HIGH STD COLL, FT
1320 REM
1330 REM  AS LONG AS J>K THEN PART OR ALL OF THE COLLECTOR WILL BE IN HIGH
1340 REM  STANDARD.
1350 REM  IF K=0 THEN THE WHOLE COLLECTOR WILL BE IN HIGH STANDARD.
1360 REM  IF J=K THEN THERE WILL BE NO HIGH STANDARD COLLECTOR, L=0.
1370 REM
1380 REM
1390 REM  **** VOLUMES FROM VARIOUS SKIDDING PATTERNS SETTINGS ****
1400 REM
1410 VS=((LE+DE)*SE-.5*(SE/2)^2)*V                                      ' CCF
1420 REM
1430 REM  VS = VOLUMES ENTER THE LAST SPUR (FROM RIGHT-ANGLE SKIDDING PATTERN
1440 REM       SETTING AT END OF COLLECTOR, TRIANGULAR AND RIGHT-ANGLE SKIDDING
1450 REM       PATTERN SETTINGS ALONG THE LAST SPUR, AND RADIAL SKIDDING
1460 REM       PATTERN SETTING AT END OF THE LAST SPUR) EXCEPT VOLUME FROM THE
1470 REM       TRIANGULAR SKIDDING PATTERN SETTING ADJACENT TO THE COLLECTOR.
1480 REM
1490 VL=((LE+DE)*SE-(SE/2)^2)*V                                         ' CCF
1500 REM
1510 REM  VL = VOLUMES ENTER EACH SPUR (FROM TRIANGULAR AND RIGHT-ANGLE
1520 REM       SKIDDING PATTERN SETTINGS ALONG SPUR AND RADIAL SKIDDING PATTERN
1530 REM       AT END OF SPUR) EXCEPT VOLUMES FROM TWO OF THE TRIANGULAR
1540 REM       SKIDDING PATTERN SETTINGS ADJACENT TO THE COLLECTOR.
```

```
1550 REM
1560 VC=.5*(SE/2)^2*V                                                ' CCF
1570 REM
1580 REM  VC = VOLUME ENTER THE COLLECTOR FROM ANY ONE OF THE TRIANGULAR
1590 REM       SKIDDING PATTERN SETTINGS ADJACENT TO THE COLLECTOR.
1600 REM
1610 REM
1620 REM  **** AVERAGE HAUL DISTANCE ON COLLECTOR ****
1630 REM
1640 IF L>0 AND K>0 THEN 2220                                 ' CONDITION #1
1650 REM
1660 REM  CONDITION #1 THAT BOTH HIGH AND LOW STANDARD COLLECTORS EXIST, THEN
1670 REM  GO TO EQUATIONS THAT COMPUTE AVERAGE HAUL DISTANCE ON HIGH AND LOW
1680 REM  STANDARD COLLECTORS.
1690 REM
1700 IF K>0 OR L=0 THEN 1950                                  ' CONDITION #2
1710 REM
1720 REM  CONDITION #2 THAT LOW STANDARD COLLECTOR OR NO HIGH STANDARD
1730 REM  COLLECTOR EXISTS, THEN GO TO EQUATION THAT COMPUTES AVERAGE HAUL
1740 REM  DISTANCE ON LOW STANDARD COLLECTOR ONLY.
1750 REM
1760 REM
1770 REM  IF CONDITION #1 AND #2 ARE NOT TRUE THEN HIGH STANDARD COLLECTOR
1780 REM  ONLY EXISTS.
1790 REM
1800 REM
1810 REM  **** EQUATION THAT COMPUTES AVERAGE HAUL DISTANCE ON HIGH ****
1820 REM                      STANDARD COLLECTOR ONLY
1830 REM
1840 REM ------------------------------------------------------------------
1850 LL1=L*VS+.5*(L/SE-.5)^2*SE*VL+((L/SE)^2-1/12)*VC*SE
1860 LL=LL1/(VS+(L/SE-.5)*VL+2*L*VC/SE)                              ' FT
1870 REM
1880 REM  HAULING DISTANCE FOR
1890 REM    VS = L                                                   ' FT
1900 REM    VL = .5*(L/SE-.5)^2*SE                                   ' FT
1910 REM    VC = ((L/SE)^2-1/12)*SE                                  ' FT
1920 REM  SUM OF VOLUME FOR THE ABOVE AREAS = VS+(L/SE-.5)*VL+2*L*VC/SE   ' CCF
1930 REM ------------------------------------------------------------------
1940 REM
1950 IF L>0 OR K=0 THEN 2160
1960 REM
1970 REM  CONDITION THAT HIGH STANDARD COLLECTOR OR NO LOW STANDARD COLLECTOR
1980 REM  EXISTS, THEN GO TO COST COMPUTATIONS. IF THE ABOVE CONDITION IS NOT
1990 REM  TRUE THEN LOW STANDARD COLLECTOR ONLY EXISTS.
2000 REM
2010 REM
2020 REM  **** EQUATION THAT COMPUTES AVERAGE HAUL DISTANCE ON LOW ****
2030 REM                     STANDARD COLLECTOR ONLY
2040 REM
2050 REM ------------------------------------------------------------------
2060 BB1=B*VS+.5*(B/SE-.5)^2*SE*VL+((B/SE)^2-1/12)*VC*SE
2070 BB=BB1/(VS+(B/SE-.5)*VL+2*B*VC/SE)                              ' FT
2080 REM
```

```
2090 REM  HAULING DISTANCE FOR
2100 REM    VS = B                                                         ' FT
2110 REM    VL = .5*(B/SE-.5)^2*SE                                         ' FT
2120 REM    VC = ((B/SE)^2-1/12)*SE                                        ' FT
2130 REM  SUM OF VOLUME FOR THE ABOVE AREAS = (VS+(B/SE-.5)*VL+2*B*VC/SE)  ' CCF
2140 REM ------------------------------------------------------------------------
2150 REM
2160 IF K=0 OR L=0 THEN 2510
2170 REM
2180 REM  CONDITION THAT NO LOW STANDARD COLLECTOR OR NO HIGH STANDARD
2190 REM  COLLECTOR EXISTS, THEN GO TO COST COMPUTATIONS.
2200 REM
2210 REM
2220 REM  **** EQUATION THAT COMPUTES AVERAGE HAUL DISTANCE ON ****
2230 REM                    LOW STANDARD COLLECTOR
2240 REM
2250 REM ------------------------------------------------------------------------
2260 BL1=(K*SE*VS+K*(K-1)*SE*VL/2+K^2*SE*VC)
2270 BL=BL1/(VS+(K-1)*VL+2*K*VC)                                           ' FT
2280 REM
2290 REM  HAULING DISTANCE FOR
2300 REM    VS = K*SE                                                      ' FT
2310 REM    VL = K*(K-1)*SE/2                                              ' FT
2320 REM    VC = K^2*SE                                                    ' FT
2330 REM  SUM OF VOLUME FOR THE ABOVE AREAS = (VS+(K-1)*VL+2*K*VC)         ' CCF
2340 REM ------------------------------------------------------------------------
2350 REM
2360 REM
2370 REM  **** EQUATION THAT COMPUTES AVERAGE HAUL DISTANCE ON ****
2380 REM                    HIGH STANDARD COLLECTOR
2390 REM
2400 REM ------------------------------------------------------------------------
2410 LB1=((L/SE+.5)^2*SE*VL/2+((L/SE)^2-1/12)*SE*VC)
2420 LB=LB1/((L/SE+.5)*VL+2*L*VC/SE)                                       ' FT
2430 REM
2440 REM  HAULING DISTANCE FOR
2450 REM    VL = (L/SE+.5)^2*SE/2                                          ' FT
2460 REM    VC = ((L/SE)^2-1/12)*SE                                        ' FT
2470 REM  SUM OF VOLUME FOR THE ABOVE AREAS = (L/SE+.5)*VL+2*L*VC/SE       ' CCF
2480 REM ------------------------------------------------------------------------
2490 REM
2500 REM
2510 REM  ************************* COST COMPUTAIONS *************************
2520 REM
2530 REM
2540 REM  **** TOTAL SPUR ROADS COST, $ ****
2550 REM
2560 S1=2*J*RS*LE                                                           ' $
2570 REM
2580 REM
2590 REM  **** TOTAL SKID COST TO SPUR ROADS, $ ****
2600 REM
2610 REM ------------------------------------------------------------------------
2620 S2=2*SS*SE*V*(J*((SE/4)*(LE-SE/2)+RD*DE)+((2*J-1)/48+1/16)*SE^2)      ' $
```

```
2630 REM
2640 REM  SKID COST (ONE SIDE OF COLLECTOR) FOR VOLUME(S) FROM
2650 REM    RIGHT-ANGLE SKIDDING PATTERN SETTINGS (BOTH SIDES) ALONG SPURS
2660 REM    WITH CONTINUOUS LANDINGS ALONG SPURS
2670 REM    = SS*SE*V*J*(SE/4)*(LE-SE/2)                                  ' $
2680 REM    RADIAL SKIDDING PATTERN SETTINGS AT END OF SPURS WITH
2690 REM    LANDINGS AT END OF SPURS = SS*SE*V*J*RD*DE                    ' $
2700 REM    TRIANGULAR SKIDDING PATTERN SETTINGS WITH CONTINUOUS LANDINGS
2710 REM    ALONG SPURS (SKID TO SPURS) = SS*SE^3*V*(2*J-1)/48            ' $
2720 REM    RIGHT-ANGLE SKIDDING PATTERN SETTING AT END OF COLLECTOR WITH
2730 REM    CONTINUOUS LANDINGS ALONG THE LAST SPUR = SS*SE^3*V/16        ' $
2740 REM ----------------------------------------------------------------------
2750 REM
2760 REM
2770 REM  **** TOTAL HAUL COST ON SPUR ROADS, $ ****
2780 REM
2790 REM ----------------------------------------------------------------------
2800 S3=2*HS*SE*V*(J*(.5*(LE^2-SE^2/4)+LE*DE)+((2*J-1)/24+1/16)*SE^2)      ' $
2810 REM
2820 REM  HAUL COST (ONE SIDE OF COLLECTOR) FOR VOLUME(S) FROM
2830 REM    RIGHT-ANGLE SKIDDING PATTERN SETTINGS (BOTH SIDES) ALONG
2840 REM    SPURS WITH CONTINUOUS LANDINGS ALONG SPURS
2850 REM    = .5*HS*SE*V*J*(LE^2-SE^2/4)                                  ' $
2860 REM    RADIAL SKIDDING PATTERN SETTINGS AT END OF SPURS WITH
2870 REM    LANDINGS AT END OF SPURS = HS*SE*V*J*LE*DE                    ' $
2880 REM    TRIANGULAR SKIDDING PATTERN SETTINGS WITH CONTINUOUS LANDINGS
2890 REM    ALONG SPURS (SKID TO SPURS) = HS*SE^3*V*(2*J-1)/24            ' $
2900 REM    RIGHT-ANGLE SKIDDING PATTERN SETTING AT END OF COLLECTOR WITH
2910 REM    CONTINUOUS LANDING ALONG THE LAST SPUR = HS*SE^3*V/16         ' $
2920 REM ----------------------------------------------------------------------
2930 REM
2940 IF K=J THEN GOTO 3070
2950 REM
2960 REM
2970 REM  **** TOTAL HIGH AND LOW STANDARD COLLECTOR COSTS, $ ****
2980 REM
2990 REM ----------------------------------------------------------------------
3000 S4=((D-SE/2-K*SE)*RH+K*SE*RL) : GOTO 3120                            ' $
3010 REM
3020 REM   HIGH STANDARD COLLECTOR COST = (D-SE/2-K*SE)*RH                ' $
3030 REM   LOW STANDARD COLLECTOR COST = K*SE*RL                          ' $
3040 REM ----------------------------------------------------------------------
3050 REM
3060 REM
3070 REM  **** TOTAL LOW STANDARD COLLECTOR COST ONLY, $ ****
3080 REM
3090 S4=(D-SE/2)*RL                                                       ' $
3100 REM
3110 REM
3120 REM  **** TOTAL SKID COST TO COLLECTOR, $ ****
3130 REM
3140 S5=((2*J-1)/24)*SC*SE^3*V                                            ' $
3150 REM
3160 REM
```

```
3170 IF K=0 AND L=>SE/2 THEN 3200
3180 IF K=J THEN GOTO 3250 ELSE 3300
3190 REM
3200 REM  **** TOTAL HAUL COST ON HIGH STANDARD COLLECTOR ONLY, $ ****
3210 REM
3220 S6=HH*LL*S*D*V : GOTO 3440                                           ' $
3230 REM
3240 REM
3250 REM  **** TOTAL HAUL COST ON LOW STANDARD COLLECTOR ONLY, $ ****
3260 REM
3270 S6=HL*BB*S*D*V : GOTO 3440                                           ' $
3280 REM
3290 REM
3300 REM  **** TOTAL HAUL COST ON HIGH AND LOW STANDARD COLLECTOR, $ ****
3310 REM
3320 REM ---------------------------------------------------------------------
3330 S61=(S*SE*K+(SE/2)^2)*HL*BL*V
3340 S62=(S*SE*K+(SE/2)^2)*HH*L*V
3350 S63=(S*D-(S*SE*K+(SE/2)^2))*HH*LB*V
3360 S6=(S61+S62+S63)                                                     ' $
3370 REM
3380 REM   S61 = HAUL COST ON LOW STD COLL FOR VOL TO LOW STD COLL        ' $
3390 REM   S62 = HAUL COST ON HIGH STD COLL FOR VOL TO LOW STD COLL       ' $
3400 REM   S63 = HAUL COST ON HIGH STD COLL FOR VOL TO HIGH STD COLL      ' $
3410 REM ---------------------------------------------------------------------
3420 REM
3430 REM
3440 REM  **** TOTAL AREA, TOTAL VOLUME, TOTAL COST AND AVERAGE COST ****
3450 REM
3460 AREA=D*S/43560!                                    ' TOTAL AREA, ACRES
3470 VOL=S*D*V                                          ' TOTAL VOLUME, CCF
3480 COST=S1+S2+S3+S4+S5+S6                             ' TOTAL COST, $
3490 TC=COST/VOL                                        ' AVE COST, $/CCF
3500 REM
3510 REM  IF AVERAGE COST IN $/ACRE IS DESIRED, CHANGE TC=COST/VOL ($/CCF)
3520 REM  TO TC=COST/AREA ($/ACRE). BOTH MINIMUM VALUES WILL GIVE THE SAME
3530 REM  RESULTS.
3540 REM
3550 IF TC>TCMIN THEN 3590                      ' FIND MINIMUM AVERAGE COST
3560 REM
3570 TCMIN=TC : SEMIN=SE : LEMIN=LE : DEMIN=DE : KMIN=K : JMIN=J : BMIN=B
3580 LMIN=L : SMIN=S
3590 NEXT K
3600 NEXT J
3610 NEXT NE
3620 NEXT DE
3630 REM
3640 REM  ******** END OF LOOPS ********
3650 REM
3660 PRINT "
3670 PRINT USING " MINIMUM AVERAGE COST = $###.###/CCF ";TCMIN
3680 PRINT "
3690 PRINT USING " LENGTH OF COLLECTOR = #### FEET ";BMIN
3700 PRINT "
```

```
3710 PRINT USING " COLLECTOR  SPACING = #### FEET ";SMIN
3720 PRINT "
3730 PRINT USING " LENGTH OF HIGH STANDARD COLLECTOR = #### FEET ";LMIN
3740 PRINT "
3750 PRINT USING " LENGTH OF LOW STANDARD COLLECTOR = #### FEET ";BMIN-LMIN
3760 PRINT "
3770 PRINT USING " LENGTH OF SPUR ROAD = #### FEET ";LEMIN
3780 PRINT "
3790 PRINT USING " SPUR ROAD  SPACING = #### FEET ";SEMIN
3800 PRINT "
3810 PRINT USING " DEPTH OF RADIAL SKIDDING PATTERN = ### FEET ";DEMIN
3820 PRINT "
3830 PRINT USING " NUMBER OF SPUR ROADS PERPENDICULAR TO ONE SIDE OF THE
COLLECTOR = ##" ;JMIN
3840 PRINT "
3850 PRINT USING " NUMBER OF ROAD SEGMENTS TO LOW STANDARD COLLECTOR = # ";KMIN
3860 PRINT "
3870 END
```

APPENDIX I

Program 2. Single Entry with Linear Skidding Costs

Program Listing

```
10  REM      *************************************************************
20  REM      *                                                           *
30  REM      *           SINGLE ENTRY WITH LINEAR SKIDDING COSTS         *
40  REM      *                                                           *
50  REM      *               COMPLETE ENUMERATION METHOD AND             *
60  REM      *                                                           *
70  REM      *           HOOKE AND JEEVES PATTERN SEARCH METHOD          *
80  REM      *                                                           *
90  REM      *************************************************************
100 REM
110 REM
120 REM     ***************************************************************
130 REM     *                                                             *
140 REM     *     PROGRAM TO DETERMINE OPTIMUM SETTINGS DIMENSIONS FOR    *
150 REM     *                                                             *
160 REM     *     TRIANGULAR, RIGHT-ANGLE AND RADIAL SKIDDING PATTERNS    *
170 REM     *                                                             *
180 REM     *     ASSOCIATED WITH HIGH AND LOW STANDARD COLLECTOR         *
190 REM     *                                                             *
200 REM     ***************************************************************
210 REM
220 REM
230 REM  PURPOSE: TO FIND THE MINIMUM SUM OF ROADING, SKIDDING AND HAULING
240 REM           COST.
250 REM
260 REM           TO FIND THE OPTIMUM SPACINGS FOR COLLECTORS AND SPUR ROADS.
270 REM
280 REM           TO FIND THE OPTIMUM LENGTHS FOR HIGH AND LOW STANDARD
290 REM           COLLECTOR.
300 REM
310 REM           TO DETERMINE THE OPTIMUM SETTINGS DIMENSIONS FOR VARIOUS
320 REM           SKIDDING PATTERNS ADJACENT TO ONE AND ANOTHER.
330 REM
340 REM
350 REM  **** ASSIGNED CONDITIONS ****
360 REM
370 REM  NUMBER OF ENTRIES = 1
380 REM  SKIDDING COST = LINEAR (AVERAGE SKIDDING DISTANCE)
390 REM
400 REM
410 REM  **** SKIDDING PATTERNS ****
420 REM
430 REM  DESIGN TRIANGULAR SKIDDING PATTERN SETTINGS WHICH ARE RIGHT-ANGLE
440 REM  TRIANGLE IN SHAPE ALONG COLLECTOR AND SPURS. CONTINUOUS LANDINGS ARE
450 REM  ALLOWED ALONG COLLECTOR AND SPURS. SKIDDING DIRECTION IS PERPENDICULAR
460 REM  TO COLLECTOR OR SPURS.
```

```
470 REM
480 REM  DESIGN RIGHT-ANGLE SKIDDING PATTERN SETTINGS WHICH ARE SQUARE IN SHAPE
490 REM  ALONG THE LAST SPUR AND END OF COLLECTOR. CONTINUOUS LANDINGS ARE
500 REM  ALLOWED ALONG THE LAST SPUR. SKIDDING DIRECTION IS PERPENDICULAR TO
510 REM  SPURS.
520 REM
530 REM  DESIGN RIGHT-ANGLE SKIDDING PATTERN SETTINGS IN RECTANGULAR SHAPE
540 REM  ALONG SPURS. CONTINUOUS LANDINGS ARE ALLOWED ALONG SPURS. SKIDDING
550 REM  DIRECTION IS PERPENDICULAR TO SPURS.
560 REM
570 REM  DESIGN RADIAL SKIDDING PATTERN SETTINGS IN RECTANGULAR SHAPE AT THE END
580 REM  OF SPURS. LANDINGS AT END OF SPURS.
590 REM
600 REM
610 REM  ************** SINGLE ENTRY WITH LINEAR SKIDDING COSTS *************
620 REM
630 REM
640 REM  **** VARIABLES ( SUBJECT TO CHANGE i.e. INPUTS ) ****
650 REM
660 REM -----------------------------------------------------------------------
670 REM
680 REM        VOLUME PER ACRE OR PER SQUARE FEET, CCF/ACRE OR CCF/FT^2
690 REM        DEPTH OF UNIT, FT
700 REM        ROAD CONSTRUCTION COSTS, $/FT                    ' FT =FEET
710 REM        SKIDDING COSTS, $/CCF/FT
720 REM        HAULING COSTS, $/CCF/FT
730 REM
740 REM
750 REM  CCF = UNITS OF 100 CUBIC FEET OF TIMBER
760 REM  VOLUME = 10 CCF PER ACRE OR 10/43560 PER SQUARE FEET
770 REM
780 V=10/43560!                                          ' VOLUME, CCF/FT^2
790 D=8000                                               ' DEPTH OF UNIT, FT
800 FMIN= 10^10                              ' SERVE TO MINIMIZE AVERAGE COST
810 REM
820 REM   COLL = COLLECTOR : STD = STANDARD : AVE = AVERAGE : DIS = DISTANCE
830 REM
840 REM
850 REM  **** ROAD CONSTRUCTION COSTS ****
860 REM
870 REM  ROAD COSTS FOR COLLECTOR AND SPURS
880 REM
890 RH=11000/5280                                      ' HIGH STD COLL, $/FT
900 RL=5700/5280                                       ' LOW STD COLL, $/FT
910 RS=5700/5280                                       ' SPUR ROAD, $/FT
920 REM
930 REM  **** SKIDDING COSTS ****
940 REM
950 SC=1.74/100                                    ' SKID TO COLL, $/CCF/FT
960 SS=1.74/100                                    ' SKID TO SPUR, $/CCF/FT
970 REM
980 REM  **** HAULING COSTS ****
990 REM
1000 HH=2/5280                             ' HAUL ON HIGH STD COLL, $/CCF/FT
```

```
1010 HL=5.15/5280                              ' HAUL ON LOW STD COLL , $/CCF/FT
1020 HS=5.15/5280                              ' HAUL ON SPUR, $/CCF/FT
1030 REM ---------------------------------------------------------------------
1040 REM
1050 REM
1060 REM  **** ASSIGN VARIABLES ****
1070 REM
1080 REM  DE = DEPTH (PARALLEL TO SPUR) OF RADIAL SKIDDING PATTERN SETTING, FT.
1090 REM  NE = LENGTH OF SPUR BETWEEN TRIANGULAR AND RADIAL SKIDDING PATTERN
1100 REM       SETTING WHICH IS THE LENGTH OF RIGHT-ANGLE SKIDDING PATTERN
1110 REM       SETTING ALONG SPUR, FT.
1120 REM  J  = # OF SPURS (MUST BE AT LEAST ONE) PERPENDICULAR TO ONE SIDE OF
1130 REM       THE COLLECTOR FOR THE DEPTH OF THE UNIT.
1140 REM  K  = # OF ROAD SEGMENTS (ZERO AND UP TO J) TO LOW STANDARD COLLECTOR.
1150 REM
1160 REM
1170 REM  ******** LOOPS FOR ASSIGN VARIABLES ********
1180 REM
1190 REM
1200 FOR J=1 TO 15
1210 FOR K=0 TO J
1220 :
1230 REM
1240 REM           ****************************************************
1250 REM           *                                                  *
1260 REM           *       HOOKE AND JEEVES PATTERN SEARCH METHOD     *
1270 REM           *                                                  *
1280 REM           ****************************************************
1290 REM
1300 :
1310 GOTO 19000
1320 :
1500 DE=X(1) : NE=X(2)
1510 REM
1520 REM  *************************
1530 REM  * EQUATIONS FOR SINGLE  *
1540 REM  * ENTRY WITH LINEAR     *
1550 REM  * SKIDDING COST         *
1560 REM  *************************
1570 REM
1580 REM
1590 REM  **** ROAD LENGTHS AND SPACINGS ****
1600 REM
1610 REM
1620 SE=D/J                                          ' SPUR ROAD  SPACING, FT
1630 B=D-SE/2                                        ' LENGTH OF COLLECTOR, FT
1640 LE=SE/2+NE                                      ' LENGTH OF SPUR ROAD, FT
1650 S=2*(LE+DE)                                     ' COLLECTOR  SPACING, FT
1660 RD=1/6*SQR(SE^2+DE^2)+1/3*SQR(SE^2/16+DE^2)     ' AVE SKID DIS (RADIAL), FT
1670 REM
1680 IF J>K THEN L=D-.5*SE-K*SE ELSE L=0            ' LENGTH OF HIGH STD COLL,FT
1690 REM
1700 REM  AS LONG AS J>K THEN PART OR ALL OF THE COLLECTOR WILL BE IN HIGH
1710 REM  STANDARD.
```

```
1720 REM  IF K=0 THEN THE WHOLE COLLECTOR WILL BE IN HIGH STANDARD.
1730 REM  IF J=K THEN THERE WILL BE NO HIGH STANDARD COLLECTOR, L=0.
1740 REM
1750 REM
1760 REM  **** VOLUMES FROM VARIOUS SKIDDING PATTERNS SETTINGS ****
1770 REM
1780 VS=((LE+DE)*SE-.5*(SE/2)^2)*V                                    ' CCF
1790 REM
1800 REM  VS = VOLUMES ENTER THE LAST SPUR (FROM RIGHT-ANGLE SKIDDING PATTERN
1810 REM       SETTING AT END OF COLLECTOR, TRIANGULAR AND RIGHT-ANGLE SKIDDING
1820 REM       PATTERN SETTINGS ALONG THE LAST SPUR, AND RADIAL SKIDDING
1830 REM       PATTERN SETTING AT END OF THE LAST SPUR) EXCEPT VOLUME FROM THE
1840 REM       TRIANGULAR SKIDDING PATTERN SETTING ADJACENT TO THE COLLECTOR.
1850 REM
1860 VL=((LE+DE)*SE-(SE/2)^2)*V                                        ' CCF
1870 REM
1880 REM  VL = VOLUMES ENTER EACH SPUR (FROM TRIANGULAR AND RIGHT-ANGLE
1890 REM       SKIDDING PATTERN SETTINGS ALONG SPUR AND RADIAL SKIDDING PATTERN
1900 REM       AT END OF SPUR) EXCEPT VOLUMES FROM TWO OF THE TRIANGULAR
1910 REM       SKIDDING PATTERN SETTINGS ADJACENT TO THE COLLECTOR.
1920 REM
1930 VC=.5*(SE/2)^2*V                                                  ' CCF
1940 REM
1950 REM  VC = VOLUME ENTER THE COLLECTOR FROM ANY ONE OF THE TRIANGULAR
1960 REM       SKIDDING PATTERN SETTINGS ADJACENT TO THE COLLECTOR.
1970 REM
1980 REM
1990 REM  **** AVERAGE HAUL DISTANCE ON COLLECTOR ****
2000 REM
2010 REM
2020 IF L>0 AND K>0 THEN 2600                                 ' CONDITION #1
2030 REM
2040 REM  CONDITION #1 THAT BOTH HIGH AND LOW STANDARD COLLECTORS EXIST, THEN
2050 REM  GO TO EQUATIONS THAT COMPUTE AVERAGE HAUL DISTANCE ON HIGH AND LOW
2060 REM  STANDARD COLLECTORS.
2070 REM
2080 IF K>0 OR L=0 THEN 2330                                  ' CONDITION #2
2090 REM
2100 REM  CONDITION #2 THAT LOW STANDARD COLLECTOR OR NO HIGH STANDARD
2110 REM  COLLECTOR EXISTS, THEN GO TO EQUATION THAT COMPUTES AVERAGE HAUL
2120 REM  DISTANCE ON LOW STANDARD COLLECTOR ONLY.
2130 REM
2140 REM
2150 REM  IF CONDITION #1 AND #2 ARE NOT TRUE THEN HIGH STANDARD COLLECTOR
2160 REM  ONLY EXISTS.
2170 REM
2180 REM
2190 REM  **** EQUATION THAT COMPUTES AVERAGE HAUL DISTANCE ON HIGH ****
2200 REM                    STANDARD COLLECTOR ONLY
2210 REM
2220 REM ------------------------------------------------------------------
2230 LL1=L*VS+(.5*(L/SE-.5)^2*VL+((L/SE)^2-1/12)*VC)*SE
2240 LL=LL1/(VS+(L/SE-.5)*VL+2*L*VC/SE)                                ' FT
2250 REM
```

```
2260 REM  HAULING DISTANCE FOR
2270 REM    VS = L                                                        ' FT
2280 REM    VL = .5*(L/SE-.5)^2*SE                                        ' FT
2290 REM    VC = ((L/SE)^2-1/12)*SE                                       ' FT
2300 REM  SUM OF VOLUME FOR THE ABOVE AREAS = VS+(L/SE-.5)*VL+2*L*VC/SE   ' CCF
2310 REM -----------------------------------------------------------------------
2320 REM
2330 IF L>0 OR K=0 THEN 2540
2340 REM
2350 REM  CONDITION THAT HIGH STANDARD COLLECTOR OR NO LOW STANDARD COLLECTOR
2360 REM  EXISTS, THEN GO TO COST COMPUTATIONS. IF THE ABOVE CONDITION IS NOT
2370 REM  TRUE THEN LOW STANDARD COLLECTOR ONLY EXISTS.
2380 REM
2390 REM
2400 REM  **** EQUATION THAT COMPUTES AVERAGE HAUL DISTANCE ON LOW ****
2410 REM                    STANDARD COLLECTOR ONLY
2420 REM
2430 REM -----------------------------------------------------------------------
2440 BB1=B*VS+(.5*(B/SE-.5)^2*VL+((B/SE)^2-1/12)*VC)*SE
2450 BB=BB1/(VS+(B/SE-.5)*VL+2*B*VC/SE)                                   ' FT
2460 REM
2470 REM  HAULING DISTANCE FOR
2480 REM    VS = B                                                        ' FT
2490 REM    VL = .5*(B/SE-.5)^2*SE                                        ' FT
2500 REM    VC = ((B/SE)^2-1/12)*SE                                       ' FT
2510 REM  SUM OF VOLUME FOR THE ABOVE AREAS = (VS+(B/SE-.5)*VL+2*B*VC/SE) ' CCF
2520 REM -----------------------------------------------------------------------
2530 REM
2540 IF K=0 OR L=0 THEN 2890
2550 REM
2560 REM  CONDITION THAT NO LOW STANDARD COLLECTOR OR NO HIGH STANDARD
2570 REM  COLLECTOR EXISTS, THEN GO TO COST COMPUTATIONS.
2580 REM
2590 REM
2600 REM  **** EQUATION THAT COMPUTES AVERAGE HAUL DISTANCE ON ****
2610 REM                  LOW STANDARD COLLECTOR
2620 REM
2630 REM -----------------------------------------------------------------------
2640 BL1=(K*SE*VS+K*(K-1)*SE*VL/2+K^2*SE*VC)
2650 BL=BL1/(VS+(K-1)*VL+2*K*VC)                                          ' FT
2660 REM
2670 REM  HAULING DISTANCE FOR
2680 REM    VS = K*SE                                                     ' FT
2690 REM    VL = K*(K-1)*SE/2                                             ' FT
2700 REM    VC = K^2*SE                                                   ' FT
2710 REM  SUM OF VOLUME FOR THE ABOVE AREAS = (VS+(K-1)*VL+2*K*VC)        ' CCF
2720 REM -----------------------------------------------------------------------
2730 REM
2740 REM
2750 REM  **** EQUATION THAT COMPUTES AVERAGE HAUL DISTANCE ON ****
2760 REM                  HIGH STANDARD COLLECTOR
2770 REM
2780 REM -----------------------------------------------------------------------
2790 LB1=((L/SE+.5)^2*SE*VL/2+((L/SE)^2-1/12)*SE*VC)
```

```
2800 LB=LB1/((L/SE+.5)*VL+2*L*VC/SE)                              ' FT
2810 REM
2820 REM  HAULING DISTANCE FOR
2830 REM    VL = (L/SE+.5)^2*SE/2                                  ' FT
2840 REM    VC = ((L/SE)^2-1/12)*SE                                ' FT
2850 REM  SUM OF VOLUME FOR THE ABOVE AREAS = (L/SE+.5)*VL+2*L*VC/SE     ' CCF
2860 REM ------------------------------------------------------------------
2870 REM
2880 REM
2890 REM  ************************ COST COMPUTAIONS ************************
2900 REM
2910 REM
2920 REM  **** TOTAL SPUR ROADS COST, $ ****
2930 REM
2940 S1=2*J*RS*LE                                                   ' $
2950 REM
2960 REM
2970 REM  **** TOTAL SKID COST TO SPUR ROADS, $ ****
2980 REM
2990 REM ------------------------------------------------------------------
3000 S2=2*SS*SE*V*(J*((SE/4)*(LE-SE/2)+RD*DE)+((2*J-1)/48+1/16)*SE^2)     ' $
3010 REM
3020 REM  SKID COST (ONE SIDE OF COLLECTOR) FOR VOLUME(S) FROM
3030 REM    RIGHT-ANGLE SKIDDING PATTERN SETTINGS (BOTH SIDES) ALONG SPURS
3040 REM    WITH CONTINUOUS LANDINGS ALONG SPURS
3050 REM    = SS*SE*V*J*(SE/4)*(LE-SE/2)                            ' $
3060 REM    RADIAL SKIDDING PATTERN SETTINGS AT END OF SPURS WITH
3070 REM    LANDINGS AT END OF SPURS = SS*SE*V*J*RD*DE              ' $
3080 REM    TRIANGULAR SKIDDING PATTERN SETTINGS WITH CONTINUOUS LANDINGS
3090 REM    ALONG SPURS (SKID TO SPURS) = SS*SE^3*V*(2*J-1)/48      ' $
3100 REM    RIGHT-ANGLE SKIDDING PATTERN SETTING AT END OF COLLECTOR WITH
3110 REM    CONTINUOUS LANDINGS ALONG THE LAST SPUR = SS*SE^3*V/16  ' $
3120 REM ------------------------------------------------------------------
3130 REM
3140 REM
3150 REM  **** TOTAL HAUL COST ON SPUR ROADS, $ ****
3160 REM
3170 REM ------------------------------------------------------------------
3180 S3=2*HS*SE*V*(J*(.5*(LE^2-SE^2/4)+LE*DE)+((2*J-1)/24+1/16)*SE^2)     ' $
3190 REM
3200 REM  HAUL COST (ONE SIDE OF COLLECTOR) FOR VOLUME(S) FROM
3210 REM    RIGHT-ANGLE SKIDDING PATTERN SETTINGS (BOTH SIDES) ALONG
3220 REM    SPURS WITH CONTINUOUS LANDINGS ALONG SPURS
3230 REM    = .5*HS*SE*V*J*(LE^2-SE^2/4)                            ' $
3240 REM    RADIAL SKIDDING PATTERN SETTINGS AT END OF SPURS WITH
3250 REM    LANDINGS AT END OF SPURS = HS*SE*V*J*LE*DE              ' $
3260 REM    TRIANGULAR SKIDDING PATTERN SETTINGS WITH CONTINUOUS LANDINGS
3270 REM    ALONG SPURS (SKID TO SPURS) = HS*SE^3*V*(2*J-1)/24      ' $
3280 REM    RIGHT-ANGLE SKIDDING PATTERN SETTING AT END OF COLLECTOR WITH
3290 REM    CONTINUOUS LANDING ALONG THE LAST SPUR = HS*SE^3*V/16   ' $
3300 REM ------------------------------------------------------------------
3310 REM
3320 IF K=J THEN GOTO 3450
3330 REM
```

```
3340 REM
3350 REM  **** TOTAL HIGH AND LOW STANDARD COLLECTOR COSTS, $ ****
3360 REM
3370 REM -----------------------------------------------------------------------
3380 S4=((D-SE/2-K*SE)*RH+K*SE*RL) : GOTO 3500                              ' $
3390 REM
3400 REM   HIGH STANDARD COLLECTOR COST = (D-SE/2-K*SE)*RH                  ' $
3410 REM   LOW STANDARD COLLECTOR COST = K*SE*RL                            ' $
3420 REM -----------------------------------------------------------------------
3430 REM
3440 REM
3450 REM  **** TOTAL LOW STANDARD COLLECTOR COST ONLY, $ ****
3460 REM
3470 S4=(D-SE/2)*RL                                                         ' $
3480 REM
3490 REM
3500 REM  **** TOTAL SKID COST TO COLLECTOR, $ ****
3510 REM
3520 S5=((2*J-1)/24)*SC*SE^3*V                                              ' $
3530 REM
3540 REM
3550 IF K=0 AND L=>SE/2 THEN 3580
3560 IF K=J THEN GOTO 3630 ELSE 3680
3570 REM
3580 REM  **** TOTAL HAUL COST ON HIGH STANDARD COLLECTOR ONLY, $ ****
3590 REM
3600 S6=HH*LL*S*D*V : GOTO 3820                                             ' $
3610 REM
3620 REM
3630 REM  **** TOTAL HAUL COST ON LOW STANDARD COLLECTOR ONLY, $ ****
3640 REM
3650 S6=HL*BB*S*D*V : GOTO 3820                                             ' $
3660 REM
3670 REM
3680 REM  **** TOTAL HAUL COST ON HIGH AND LOW STANDARD COLLECTOR, $ ****
3690 REM
3700 REM -----------------------------------------------------------------------
3710 S61=(S*SE*K+(SE/2)^2)*HL*BL*V
3720 S62=(S*SE*K+(SE/2)^2)*HH*L*V
3730 S63=(S*D-(S*SE*K+(SE/2)^2))*HH*LB*V
3740 S6=(S61+S62+S63)                                                       ' $
3750 REM
3760 REM   S61 = HAUL COST ON LOW STD COLL FOR VOL TO LOW STD COLL          ' $
3770 REM   S62 = HAUL COST ON HIGH STD COLL FOR VOL TO LOW STD COLL         ' $
3780 REM   S63 = HAUL COST ON HIGH STD COLL FOR VOL TO HIGH STD COLL        ' $
3790 REM -----------------------------------------------------------------------
3800 REM
3810 REM
3820 REM  **** TOTAL AREA, TOTAL VOLUME, TOTAL COST AND AVERAGE COST ****
3830 REM
3840 AREA=S*D/43560!                                         ' TOTAL AREA, ACRE
3850 VOL=S*D*V                                               ' TOTAL VOLUME, CCF
3860 COST=S1+S2+S3+S4+S5+S6                                  ' TOTAL COST, $
3870 F=COST/VOL                                              ' AVE COST , $/CCF
```

```
3880 REM
3890 REM  IF AVERAGE COST IN $/ACRE IS DESIRED, CHANGE F=COST/VOL ($/CCF)
3900 REM  TO F=COST/AREA ($/ACRE). BOTH MINIMUM VALUES WILL GIVE THE SAME
3910 REM  RESULTS.
3920 REM
3930 :
3940 REM CHECK CONSTRAINTS
3950 FOR IX=1 TO NV
3960 IF X(IX)>3000 OR X(IX)<=0 THEN GOTO 4010
3970 NEXT IX
3980 RETURN
3990 :
4000 REM PENALIZE
4010 F=25
4020 RETURN
4030 :
12000 REM **********************
12010 REM * THIS SUBROUTINE    *
12020 REM * APPLIES THE HOOKE  *
12030 REM * & JEEVES ALGORITHM *
12040 REM * OF EXPLORATION AND *
12050 REM * PATTERN MOVES TO   *
12060 REM * FIND THE UNCON-    *
12070 REM * STRAINED MINIMUM   *
12080 REM * OF A MERIT FUNC-   *
12090 REM * TION.  THE USER    *
12100 REM * MUST SUPPLY A      *
12110 REM * STARTING VECTOR    *
12120 REM * X(I).              *
12130 REM *                    *
12140 REM * PARAMETERS:        *
12150 REM *                    *
12160 REM *  NV   - THE NUMBER *
12170 REM *         OF DESIGN  *
12180 REM *         VARIABLES. *
12190 REM *                    *
12200 REM * R     - INITIAL    *
12210 REM *         EXPLORATION *
12220 REM *         STEP SIZE  *
12230 REM *                    *
12240 REM * A     - ACCELERA-  *
12250 REM *         TION FACTOR *
12260 REM *         SET >=1.0  *
12270 REM *                    *
12280 REM * RF    - FINAL      *
12290 REM *         EXPLORATION *
12300 REM *         STEP SIZE. *
12310 REM *                    *
12320 REM * 1500 - SUBROUTINE  *
12330 REM *         TO EVALUATE *
12340 REM *         THE MERIT  *
12350 REM *         VALUE "F"  *
12360 REM *         USING A    *
12370 REM *         DESIGN VEC- *
```

```
12380 REM *         TOR "X(I)"  *
12390 REM *                     *
12400 REM * FB    - ON RETURN   *
12410 REM *         THE BEST    *
12420 REM *         MERIT VALUE *
12430 REM *         FOUND.      *
12440 REM *                     *
12450 REM * XB(I)- THE DESIGN   *
12460 REM *         VECTOR COR- *
12470 REM *         RESPONDING  *
12480 REM *         TO FB.      *
12490 REM *                     *
12500 REM **********************
12510 :
12520 GOSUB 1500
12530 FB=F
12540 R=R
12550 FOR N=1 TO NV
12560 X(N)=XB(N)
12570 NEXT N
12580 :
12590 REM EXPLORE
12600 GOSUB 12960
12610 :
12620 REM IS IT BETTER?
12630 REM IF SO GO TO PATTERN
12640 IF FE<FB THEN GOTO 12720
12650 :
12660 REM IF NOT DECREASE
12670 REM STEP SIZE DOWN TO RF
12680 IF R<RF THEN RETURN
12690 R=R/2
12700 GOTO 12550
12710 :
12720 REM MAKE PATTERN MOVE
12730 FOR N=1 TO NV
12740 X(N)=XE(N)+A*(XE(N)-XB(N))
12750 NEXT N
12760 :
12770 REM REPLACE XB WITH XE
12780 FOR N=1 TO NV
12790 XB(N)=XE(N)
12800 NEXT N
12810 FB=FE
12820 :
12830 REM EXPLORE FROM HERE
12840 GOSUB 12960
12850 :
12860 REM IF ITS BETTER
12870 REM REPEAT PATTERN
12880 :
12890 IF FE<FB GOTO  12720
12900 :
12910 REM IF NOT SO BACK TO
```

```
12920 REM BEST BASE POINT
12930 REM AND EXPLORE
12940 GOTO 12540
12950 :
12960 REM *********************
12970 REM * THIS SUBROUTINE    *
12980 REM * PERFORMS THE       *
12990 REM * EXPLORATION STEP   *
13000 REM *********************
13010 :
13020 GOSUB 1500 :FF=F
13030 FE=F
13040 FOR N=1 TO NV
13050 XE(N)=X(N)
13060 X(N)=X(N)+R
13070 GOSUB 1500
13080 IF F<FF GOTO 13140
13090 X(N)=X(N)-2*R
13100 GOSUB 1500
13110 IF F<FF GOTO 13140
13120 X(N)=X(N)+R
13130 GOTO 13160
13140 FE=F : FF=FE
13150 XE(N)=X(N)
13160 NEXT N
13170 RETURN
13180 :
19000 REM *********************
19010 REM * DRIVER PROGRAM     *
19020 REM * PERFORMS AN UNCON- *
19030 REM * STRAINED OPTIMIZA- *
19040 REM * TION OF A MERIT    *
19050 REM * FUNCTION.          *
19060 REM *********************
19070 :
19080 RF=.01 : A=2
19090 NV=2 : R=10
19100 'DIM XB(2),X(2),XE(2)
19110 :
19120 REM FEASIBLE START POINT
19130 X(1)=400 : X(2)=800
19140 FOR IX=1 TO NV
19150 XB(IX)=X(IX)
19160 NEXT IX
19170 :
19180 REM CALL HOOKE & JEEVES
19190 GOSUB 12000
19200 :
19210 IF F>FMIN THEN 19250                          ' FIND MINIMUM AVERAGE COST
19220 REM
19230 FMIN=F : SEMIN=SE : LEMIN=LE : DEMIN=DE : KMIN=K : JMIN=J : BMIN=B
19240 LMIN=L : SMIN=S
19250 NEXT K
19260 NEXT J
```

```
19270 REM
19280 REM ******** END OF LOOPS ********
19290 REM
19300 PRINT "
19310 PRINT USING " MINIMUM AVERAGE COST = $###.###/CCF ";FMIN
19320 PRINT "
19330 PRINT USING " LENGTH OF COLLECTOR = #### FEET ";BMIN
19340 PRINT "
19350 PRINT USING " COLLECTOR  SPACING = #### FEET ";SMIN
19360 PRINT
19370 PRINT USING " LENGTH OF HIGH STANDARD COLLECTOR = #### FEET ";LMIN
19380 PRINT "
19390 PRINT USING " LENGTH OF LOW STANDARD COLLECTOR = #### FEET ";BMIN-LMIN
19400 PRINT "
19410 PRINT USING " LENGTH OF SPUR ROAD = #### FEET ";LEMIN
19420 PRINT "
19430 PRINT USING " SPUR ROAD  SPACING = #### FEET ";SEMIN
19440 PRINT "
19450 PRINT USING " DEPTH OF RADIAL SKIDDING PATTERN = ### FEET ";DEMIN
19460 PRINT "
19470 PRINT USING " NUMBER OF SPUR ROADS PERPENDICULAR TO ONE SIDE OF THE
COLLECTOR = ##" ;JMIN
19480 PRINT "
19490 PRINT USING " NUMBER OF ROAD SEGMENTS TO LOW STANDARD COLLECTOR = # ";KMIN
19500 PRINT "
19510 END
```

APPENDIX J

Program 3. Multiple Entries with Linear Skidding Costs

Program Listing

```
10  REM      ****************************************************************
20  REM      *                                                              *
30  REM      *         MULTIPLE ENTRIES WITH LINEAR SKIDDING COSTS          *
40  REM      *                                                              *
50  REM      *                 COMPLETE ENUMERATION METHOD                  *
60  REM      *                                                              *
70  REM      ****************************************************************
80  REM
90  REM
100 REM     *****************************************************************
110 REM     *                                                               *
120 REM     *     PROGRAM TO DETERMINE OPTIMUM SETTINGS DIMENSIONS FOR      *
130 REM     *                                                               *
140 REM     *     TRIANGULAR, RIGHT-ANGLE AND RADIAL SKIDDING PATTERNS      *
150 REM     *                                                               *
160 REM     *     ASSOCIATED WITH HIGH AND LOW STANDARD COLLECTOR           *
170 REM     *                                                               *
180 REM     *****************************************************************
190 REM
200 REM
210 REM  PURPOSE: TO FIND THE MINIMUM SUM OF ROADING, SKIDDING AND HAULING
220 REM           COST.
230 REM
240 REM           TO FIND THE OPTIMUM SPACINGS FOR COLLECTORS AND SPUR ROADS.
250 REM
260 REM           TO FIND THE OPTIMUM LENGTHS FOR HIGH AND LOW STANDARD
270 REM           COLLECTOR.
280 REM
290 REM           TO DETERMINE THE OPTIMUM SETTINGS DIMENSIONS FOR VARIOUS
300 REM           SKIDDING PATTERNS ADJACENT TO ONE AND ANOTHER.
310 REM
320 REM
330 REM  **** ASSIGNED CONDITIONS ****
340 REM
350 REM  NUMBER OF ENTRIES = 4
360 REM    YEAR 0 = BUILD COLLECTOR AND SPUR ROADS
370 REM    1ST ENTRY = 1 YEAR FROM NOW
380 REM    2ND ENTRY = 10 YEARS FROM NOW
390 REM    3RD ENTRY = 20 YEARS FROM NOW
400 REM    4TH ENTRY = 30 YEARS FROM NOW
410 REM
420 REM  SKIDDING COST = LINEAR (AVERAGE SKIDDING DISTANCE)
430 REM
440 REM
450 REM **** SKIDDING PATTERNS ****
460 REM
```

```
470 REM  DESIGN TRIANGULAR SKIDDING PATTERN SETTINGS WHICH ARE RIGHT-ANGLE
480 REM  TRIANGLE IN SHAPE ALONG COLLECTOR AND SPURS. CONTINUOUS LANDINGS ARE
490 REM  ALLOWED ALONG COLLECTOR AND SPURS. SKIDDING DIRECTION IS PERPENDICULAR
500 REM  TO COLLECTOR OR SPURS.
510 REM
520 REM  DESIGN RIGHT-ANGLE SKIDDING PATTERN SETTINGS WHICH ARE SQUARE IN SHAPE
530 REM  ALONG THE LAST SPUR AND END OF COLLECTOR. CONTINUOUS LANDINGS ARE
540 REM  ALLOWED ALONG THE LAST SPUR. SKIDDING DIRECTION IS PERPENDICULAR TO
550 REM  SPURS.
560 REM
570 REM  DESIGN RIGHT-ANGLE SKIDDING PATTERN SETTINGS IN RECTANGULAR SHAPE
580 REM  ALONG SPURS. CONTINUOUS LANDINGS ARE ALLOWED ALONG SPURS. SKIDDING
590 REM  DIRECTION IS PERPENDICULAR TO SPURS.
600 REM
610 REM  DESIGN RADIAL SKIDDING PATTERN SETTINGS IN RECTANGULAR SHAPE AT THE END
620 REM  OF SPURS. LANDINGS AT END OF SPURS.
630 REM
640 REM
650 REM  ************ MULTIPLE ENTRIES WITH LINEAR SKIDDING COSTS ************
660 REM
670 REM
680 REM  **** VARIABLES ( SUBJECT TO CHANGE i.e. INPUTS ) ****
690 REM
700 REM
710 REM  VOLUME PER ACRE OR PER SQUARE FEET TO BE REMOVED, CCF/ACRE OR CCF/FT^2
720 REM  DEPTH OF UNIT, FT
730 REM  NUMBER OF YEARS FROM NOW TO ENTER THE STAND                  ' FT = FEET
740 REM  DISCOUNTED RATE, %/100
750 REM  ROAD CONSTRUCTION COSTS, $/FT
760 REM  ROAD RECONSTRUCTION COSTS, $/FT
770 REM  SKIDDING COSTS, $/CCF/FT
780 REM  HAULING COSTS, $/CCF/FT
790 REM
800 REM  CCF = UNITS OF 100 CUBIC FEET OF TIMBER
810 REM  Yi  = # OF YEARS FROM NOW
820 REM  Vi  = CCF/ACRE REMOVED IN Yi
830 REM  VFi = CCF/FT^2 REMOVED IN Yi
840 REM   I  = DISCOUNTED RATE %/100
850 REM
860 V1=5 : V10=5 : V20=8 : V30=15                                       ' CCF/ACRE
870 VF1=5/43560! : VF10=5/43560!                                        ' CCF/FT^2
880 VF20=8/43560! : VF30=15/43560!                                      ' CCF/FT^2
890 Y0=0 : Y1=1 : Y10=10 : Y20=20 : Y30=30                         ' YEARS FROM NOW
900 I=.04                                                         ' DISCOUNTED RATE
910 D=8000                                                      ' DEPTH OF UNIT, FT
920 TCMIN=10^10                                 ' SERVE TO MINIMIZE AVERAGE COST
930 REM
940 REM    COLL = COLLECTOR : STD = STANDARD : AVE = AVERAGE : DIS = DISTANCE
950 REM    VOL = VOLUME
960 REM
970 REM
980 REM  **** ROAD CONSTRUCTION AND RECONSTRUCTION COSTS, $/FT ****
990 REM
1000 REM   ROAD AND RECONSTRUCTION COSTS FOR COLLECTOR
```

```
1010 REM
1020 REM ------------------------------------------------------------------
1030 REM     HIGH STANDARD COLLECTOR
1040 REM
1050 RHC0=11000/5280              ' CONSTRUCT HIGH STD COLL IN Y0, $/FT
1060 RHC10=1100/5280              ' RECONSTRUCT HIGH STD COLL IN Y10, $/FT
1070 RHC20=1100/5280              ' RECONSTRUCT HIGH STD COLL IN Y20, $/FT
1080 RHC30=1100/5280              ' RECONSTRUCT HIGH STD COLL IN Y30, $/FT
1090 REM
1100 REM     LOW STANDARD COLLECTOR
1110 REM
1120 RLC0=5700/5280                ' CONSTRUCT LOW STD COLL IN Y0, $/FT
1130 RLC10=570/5280                ' RECONSTRUCT LOW STD COLL IN Y10, $/FT
1140 RLC20=570/5280                ' RECONSTRUCT LOW STD COLL IN Y20, $/FT
1150 RLC30=570/5280                ' RECONSTRUCT LOW STD COLL IN Y30, $/FT
1160 REM
1170 REM  RECONSTRUCTION COST IS ASSUMED TO BE 10% OF THE ROAD CONSTRUCTION COST
1180 REM -------------------------------------------------------------------
1190 REM
1200 REM   ROAD AND RECONSTRUCTION COSTS FOR SPURS
1210 REM
1220 RS0=5700/5280                   ' CONSTRUCT SPUR ROADS IN Y0, $/FT
1230 RS10=570/5280                   ' RECONSTRUCT SPUR ROADS IN Y10, $/FT
1240 RS20=570/5280                   ' RECONSTRUCT SPUR ROADS IN Y20, $/FT
1250 RS30=570/5280                   ' RECONSTRUCT SPUR ROADS IN Y30, $/FT
1260 REM
1270 REM  RECONSTRUCTION COST IS ASSUMED TO BE 10% OF THE ROAD CONSTRUCTION COST
1280 REM
1290 REM
1300 REM  **** SKIDDING COSTS, $/CCF/FT ****
1310 REM
1320 REM ------------------------------------------------------------------
1330 REM   SKID COST TOWARD SPUR
1340 REM
1350 SS1=1.74/100                            ' SKID TO SPUR IN Y1, $/CCF/FT
1360 SS10=1.74/100                           ' SKID TO SPUR IN Y10, $/CCF/FT
1370 SS20=1.74/100                           ' SKID TO SPUR IN Y20, $/CCF/FT
1380 SS30=1.74/100                           ' SKID TO SPUR IN Y30, $/CCF/FT
1390 REM
1400 REM  SKID COST TOWARD COLLECTOR
1410 REM
1420 SC1=1.74/100                            ' SKID TO COLL IN Y1, $/CCF/FT
1430 SC10=1.74/100                           ' SKID TO COLL IN Y10, $/CCF/FT
1440 SC20=1.74/100                           ' SKID TO COLL IN Y20, $/CCF/FT
1450 SC30=1.74/100                           ' SKID TO COLL IN Y30, $/CCF/FT
1460 REM ------------------------------------------------------------------
1470 REM
1480 REM
1490 REM  **** HAULING COSTS ON COLLECTOR AND SPURS, $/CCF/FT ****
1500 REM
1510 REM ------------------------------------------------------------------
1520 REM   HAUL COST ON HIGH STANDARD COLLECTOR
1530 REM
1540 HHC1=2/5280                 ' HAUL COST ON HIGH STD COLL IN Y1, $/CCF/FT
```

```
1550 HHC10=2/5280                     ' HAUL COST ON HIGH STD COLL IN Y10, $/CCF/FT
1560 HHC20=2/5280                     ' HAUL COST ON HIGH STD COLL IN Y20, $/CCF/FT
1570 HHC30=2/5280                     ' HAUL COST ON HIGH STD COLL IN Y30, $/CCF/FT
1580 REM
1590 REM   HAUL COST ON LOW STANDARD COLLECTOR
1600 REM
1610 HLC1=5.15/5280                    ' HAUL COST ON LOW STD COLL IN Y1, $/CCF/FT
1620 HLC10=5.15/5280                   ' HAUL COST ON LOW STD COLL IN Y10, $/CCF/FT
1630 HLC20=5.15/5280                   ' HAUL COST ON LOW STD COLL IN Y20, $/CCF/FT
1640 HLC30=5.15/5280                   ' HAUL COST ON LOW STD COLL IN Y30, $/CCF/FT
1650 REM ---------------------------------------------------------------------------
1660 REM
1670 REM   HAUL COST ON SPUR
1680 REM
1690 HS1=5.15/5280                             ' HAUL COST ON SPUR IN Y1, $/CCF/FT
1700 HS10=5.15/5280                            ' HAUL COST ON SPUR IN Y10, $/CCF/FT
1710 HS20=5.15/5280                            ' HAUL COST ON SPUR IN Y20, $/CCF/FT
1720 HS30=5.15/5280                            ' HAUL COST ON SPUR IN Y30, $/CCF/FT
1730 REM
1740 REM
1750 REM  **** ASSIGN VARIABLES ****
1760 REM
1770 REM  DE = DEPTH (PARALLEL TO SPUR) OF RADIAL SKIDDING PATTERN SETTING, FT.
1780 REM  NE = LENGTH OF SPUR BETWEEN TRIANGULAR AND RADIAL SKIDDING PATTERN
1790 REM       SETTING WHICH IS THE LENGTH OF RIGHT-ANGLE SKIDDING PATTERN
1800 REM       SETTING ALONG SPURS, FT.
1810 REM   J = # OF SPURS (MUST BE AT LEAST ONE) PERPENDICULAR TO ONE SIDE OF
1820 REM       THE COLLECTOR FOR THE DEPTH OF THE UNIT.
1830 REM   K = # OF ROAD SEGMENTS (ZERO AND UP TO J) TO LOW STANDARD COLLECTOR.
1840 REM
1850 FOR DE=100 TO 2000 STEP 100
1860 FOR NE=100 TO 2000 STEP 100
1870 FOR J=1 TO 12
1880 FOR K=0 TO J
1890 REM
1900 REM
1910 REM  **** ROAD LENGTHS AND SPACINGS ****
1920 REM
1930 SE=D/J                                             ' SPUR ROAD  SPACING, FT
1940 B=D-SE/2                                           ' LENGTH OF COLLECTOR, FT
1950 LE=SE/2+NE                                         ' LENGTH OF SPUR ROAD, FT
1960 S=2*(LE+DE)                                        ' COLLECTOR  SPACING, FT
1970 RD=1/6*SQR(SE^2+DE^2)+1/3*SQR(SE^2/16+DE^2)        ' AVE SKID DIS (RADIAL), FT
1980 REM
1990 IF J>K THEN L=D-.5*SE-K*SE ELSE L=0           ' LENGTH OF HIGH STD COLL, FT
2000 REM
2010 REM  AS LONG AS J>K THEN PART OR ALL OF THE COLLECTOR WILL BE IN HIGH
2020 REM  STANDARD.
2030 REM  IF K=0 THEN THE WHOLE COLLECTOR WILL BE IN HIGH STANDARD.
2040 REM  IF J=K THEN THERE WILL BE NO HIGH STANDARD COLLECTOR, L=0.
2050 REM
2060 REM
2070 REM  **** VOLUMES FROM VARIOUS SKIDDING PATTERNS SETTINGS IN Yi, CCF ****
2080 REM
```

```
2090 VS1=((LE+DE)-.5*SE/4)*SE*VF1                                    ' CCF IN Y1
2100 VS10=((LE+DE)-.5*SE/4)*SE*VF10                                  ' CCF IN Y10
2110 VS20=((LE+DE)-.5*SE/4)*SE*VF20                                  ' CCF IN Y20
2120 VS30=((LE+DE)-.5*SE/4)*SE*VF30                                  ' CCF IN Y30
2130 REM
2140 REM  VSi = VOLUMES ENTER THE LAST SPUR (FROM RIGHT-ANGLE SKIDDING PATTERN
2150 REM        SETTING AT END OF COLLECTOR, TRIANGULAR AND RIGHT-ANGLE
2160 REM        SKIDDING PATTERN SETTINGS ALONG THE LAST SPUR AND RADIAL
2170 REM        SKIDDING PATTERN SETTING AT END OF THE LAST SPUR) EXCEPT VOLUME
2180 REM        FROM THE TRIANGULAR SKIDDING PATTERN SETTING ADJACENT TO THE
2190 REM        COLLECTOR IN YEAR i.
2200 REM
2210 VL1=((LE+DE)-SE/4)*SE*VF1                                       ' CCF IN Y1
2220 VL10=((LE+DE)-SE/4)*SE*VF10                                     ' CCF IN Y10
2230 VL20=((LE+DE)-SE/4)*SE*VF20                                     ' CCF IN Y20
2240 VL30=((LE+DE)-SE/4)*SE*VF30                                     ' CCF IN Y30
2250 REM
2260 REM  VLi = VOLUMES ENTER EACH SPUR (FROM TRIANGULAR AND RIGHT-ANGLE
2270 REM        SKIDDING PATTERN SETTINGS ALONG SPUR AND RADIAL SKIDDING
2280 REM        PATTERN SETTING AT END OF SPUR) EXCEPT VOLUME FROM TWO OF THE
2290 REM        TRIANGULAR SKIDDING PATTERN SETTINGS ADJACENT TO THE COLLECTOR
2300 REM        IN YEAR i.
2310 REM
2320 VC1=.5*(SE/2)^2*VF1                                             ' CCF IN Y1
2330 VC10=.5*(SE/2)^2*VF10                                           ' CCF IN Y10
2340 VC20=.5*(SE/2)^2*VF20                                           ' CCF IN Y20
2350 VC30=.5*(SE/2)^2*VF30                                           ' CCF IN Y30
2360 REM
2370 REM  VCi = VOLUME ENTER THE COLLECTOR FROM ANY ONE OF THE TRIANGULAR
2380 REM        SKIDDING PATTERN SETTINGS ADJACENT TO THE COLLECTOR IN YEAR i.
2390 REM
2400 REM
2410 REM  **** AVERAGE HAUL DISTANCE ON COLLECTOR, FT ****
2420 REM
2430 IF L>0 AND K>0 THEN 3170                                     ' CONDITION #1
2440 REM
2450 REM  CONDITION #1 THAT BOTH HIGH AND LOW STANDARD COLLECTORS EXIST, THEN
2460 REM  GO TO EQUATIONS THAT COMPUTE AVERAGE HAUL DISTANCE ON HIGH AND LOW
2470 REM  STANDARD COLLECTORS.
2480 REM
2490 IF K>0 OR L=0 THEN 2820                                      ' CONDITION #2
2500 REM
2510 REM  CONDITION #2 THAT LOW STANDARD COLLECTOR OR NO HIGH STANDARD
2520 REM  COLLECTOR EXISTS, THEN GO TO EQUATIONS THAT COMPUTE AVERAGE HAUL
2530 REM  DISTANCE ON LOW STANDARD COLLECTOR ONLY.
2540 REM
2550 REM
2560 REM  IF CONDITION #1 AND #2 ARE NOT TRUE THEN HIGH STANDARD COLLECTOR
2570 REM  ONLY EXISTS.
2580 REM
2590 REM
2600 REM  **** EQUATIONS THAT COMPUTE AVERAGE HAUL DISTANCE ON HIGH ****
2610 REM                      STANDARD COLLECTOR ONLY
2620 REM
```

```
2630 REM -----------------------------------------------------------------------
2640 LL11=L*VS1+.5*(L/SE-.5)^2*SE*VL1+((L/SE)^2-1/12)*VC1*SE
2650 LL12=L*VS10+.5*(L/SE-.5)^2*SE*VL10+((L/SE)^2-1/12)*VC10*SE
2660 LL13=L*VS20+.5*(L/SE-.5)^2*SE*VL20+((L/SE)^2-1/12)*VC20*SE
2670 LL14=L*VS30+.5*(L/SE-.5)^2*SE*VL30+((L/SE)^2-1/12)*VC30*SE
2680 :
2690 LL1=LL11/(VS1+(L/SE-.5)*VL1+2*L*VC1/SE)                    ' FT IN Y1
2700 LL10=LL12/(VS10+(L/SE-.5)*VL10+2*L*VC10/SE)                ' FT IN Y10
2710 LL20=LL13/(VS20+(L/SE-.5)*VL20+2*L*VC20/SE)                ' FT IN Y20
2720 LL30=LL14/(VS30+(L/SE-.5)*VL30+2*L*VC30/SE)                ' FT IN Y30
2730 REM
2740 REM  HAULING DISTANCE FOR
2750 REM    VSi = L                                                   ' FT
2760 REM    VLi = .5*(L/SE-.5)^2*SE                                   ' FT
2770 REM    VCi = ((L/SE)^2-1/12)*SE                                  ' FT
2780 REM  SUM OF VOLUME FOR THE ABOVE AREAS IN Yi
2790 REM  = VSi+(L/SE-.5)*VLi+2*L*VCi/SE                              ' CCF
2800 REM ----------------------------------------------------------------------
2810 REM
2820 IF L>0 OR K=0 THEN 3110
2830 REM
2840 REM  CONDITION THAT HIGH STANDARD COLLECTOR OR NO LOW STANDARD COLLECTOR
2850 REM  EXISTS, THEN GO TO COST COMPUTATIONS. IF THE ABOVE CONDITION IS NOT
2860 REM  TRUE THEN LOW STANDARD COLLECTOR ONLY EXISTS.
2870 REM
2880 REM
2890 REM  **** EQUATIONS THAT COMPUTE AVERAGE HAUL DISTANCE ON LOW ****
2900 REM                   STANDARD COLLECTOR ONLY
2910 REM
2920 REM ----------------------------------------------------------------------
2930 BB11=B*VS1+.5*(B/SE-.5)^2*SE*VL1+((B/SE)^2-1/12)*VC1*SE
2940 BB12=B*VS10+.5*(B/SE-.5)^2*SE*VL10+((B/SE)^2-1/12)*VC10*SE
2950 BB13=B*VS20+.5*(B/SE-.5)^2*SE*VL20+((B/SE)^2-1/12)*VC20*SE
2960 BB14=B*VS30+.5*(B/SE-.5)^2*SE*VL30+((B/SE)^2-1/12)*VC30*SE
2970 :
2980 BB1=BB11/(VS1+(B/SE-.5)*VL1+2*B*VC1/SE)                   ' FT IN Y1
2990 BB10=BB12/(VS10+(B/SE-.5)*VL10+2*B*VC10/SE)               ' FT IN Y10
3000 BB20=BB13/(VS20+(B/SE-.5)*VL20+2*B*VC20/SE)               ' FT IN Y20
3010 BB30=BB14/(VS30+(B/SE-.5)*VL30+2*B*VC30/SE)               ' FT IN Y30
3020 REM
3030 REM  HAULING DISTANCE FOR
3040 REM    VSi = B                                                  ' FT
3050 REM    VLi = .5*(B/SE-.5)^2*SE                                  ' FT
3060 REM    VCi = ((B/SE)^2-1/12)*SE                                 ' FT
3070 REM  SUM OF VOLUME FOR THE ABOVE AREAS IN Yi
3080 REM  = VSi+(B/SE-.5)*VLi+2*B*VCi/SE                             ' CCF
3090 REM ----------------------------------------------------------------------
3100 REM
3110 IF K=0 OR L=0 THEN 3670
3120 REM
3130 REM  CONDITION THAT NO LOW STANDARD COLLECTOR OR NO HIGH STANDARD
3140 REM  COLLECTOR EXISTS, THEN GO TO COST COMPUTATIONS.
3150 REM
3160 REM
```

```
3170 REM  **** EQUATIONS THAT COMPUTE AVERAGE HAUL DISTANCE ON LOW ****
3180 REM                       STANDARD COLLECTOR
3190 REM
3200 REM -----------------------------------------------------------------
3210 BL11=K*SE*VS1+K*(K-1)*SE*VL1/2+K^2*SE*VC1
3220 BL12=K*SE*VS10+K*(K-1)*SE*VL10/2+K^2*SE*VC10
3230 BL13=K*SE*VS20+K*(K-1)*SE*VL20/2+K^2*SE*VC20
3240 BL14=K*SE*VS30+K*(K-1)*SE*VL30/2+K^2*SE*VC30
3250 :
3260 BL1=BL11/(VS1+(K-1)*VL1+2*K*VC1)                          ' FT IN Y1
3270 BL10=BL12/(VS10+(K-1)*VL10+2*K*VC10)                      ' FT IN Y10
3280 BL20=BL13/(VS20+(K-1)*VL20+2*K*VC20)                      ' FT IN Y20
3290 BL30=BL14/(VS30+(K-1)*VL30+2*K*VC30)                      ' FT IN Y30
3300 REM
3310 REM  HAULING DISTANCE FOR
3320 REM    VSi = K*SE                                             ' FT
3330 REM    VLi = K*(K-1)*SE/2                                     ' FT
3340 REM    VCi = K^2*SE                                           ' FT
3350 REM  SUM OF VOLUME FOR THE ABOVE AREAS IN Yi
3360 REM  = VSi+(K-1)*VLi+2*K*VCi                                  ' CCF
3370 REM -----------------------------------------------------------------
3380 REM
3390 REM
3400 REM  **** EQUATIONS THAT COMPUTE AVERAGE HAUL DISTANCE ON HIGH ****
3410 REM                       STANDARD COLLECTOR
3420 REM
3430 REM -----------------------------------------------------------------
3440 LB11=(L/SE+.5)^2*SE*VL1/2+((L/SE)^2-1/12)*VC1*SE
3450 LB12=(L/SE+.5)^2*SE*VL10/2+((L/SE)^2-1/12)*VC10*SE
3460 LB13=(L/SE+.5)^2*SE*VL20/2+((L/SE)^2-1/12)*VC20*SE
3470 LB14=(L/SE+.5)^2*SE*VL30/2+((L/SE)^2-1/12)*VC30*SE
3480 :
3490 LB1=LB11/((L/SE+.5)*VL1+2*L*VC1/SE)                       ' FT IN Y1
3500 LB10=LB12/((L/SE+.5)*VL10+2*L*VC10/SE)                    ' FT IN Y10
3510 LB20=LB13/((L/SE+.5)*VL20+2*L*VC20/SE)                    ' FT IN Y20
3520 LB30=LB14/((L/SE+.5)*VL30+2*L*VC30/SE)                    ' FT IN Y30
3530 REM
3540 REM  HAULING DISTANCE FOR
3550 REM    VLi = (L/SE+.5)^2*SE/2                                 ' FT
3560 REM    VCi = ((L/SE)^2-1/12)*SE                               ' FT
3570 REM  SUM OF VOLUME FOR THE ABOVE AREAS IN Yi
3580 REM  = (L/SE+.5)*VLi+2*L*VCi/SE                               ' CCF
3590 REM -----------------------------------------------------------------
3600 REM
3610 REM
3620 REM  *************** COST COMPUTATIONS ( NET PRESENT VALUE ) *************
3630 REM
3640 REM
3650 REM  N.P.V. = NET PRESENT VALUE
3660 REM
3670 REM  **** TOTAL SPUR ROADS COST (N.P.V.), $ ****
3680 REM
3690 S1=2*J*LE*(RS0/(1+I)^Y0+ RS10/(1+I)^Y10+RS20/(1+I)^Y20+RS30/(1+I)^Y30) ' $
3700 REM
```

```
3710 REM
3720 REM  **** TOTAL SKID COST TO SPUR ROADS (N.P.V.), $ ****
3730 REM
3740 REM ----------------------------------------------------------------------
3750 S21=2*(J*((SE/4)*(LE-SE/2)+RD*DE)+((2*J-1)/48+1/16)*SE^2)*SE
3760 S22=SS1*VF1/(1+I)^Y1+SS10*VF10/(1+I)^Y10
3770 S23=SS20*VF20/(1+I)^Y20+SS30*VF30/(1+I)^Y30
3780 S2=S21*(S22+S23)                                                    ' $
3790 REM
3800 REM  SKID COST (ONE SIDE OF COLLECTOR) IN Yi FOR VOLUME(S) FROM
3810 REM    RIGHT-ANGLE SKIDDING PATTERN SETTINGS (BOTH SIDES) ALONG SPURS
3820 REM    WITH CONTINUOUS LANDINGS ALONG SPURS
3830 REM    = J*SE*(SE/4)*(LE-SE/2)*(SSi*VFi/(1+I)^Yi)                   ' $
3840 REM    RADIAL SKIDDING PATTERN SETTINGS AT END OF SPURS WITH LANDINGS
3850 REM    AT END OF SPURS = J*SE*RD*DE*(SSi*VFi/(1+I)^Yi)              ' $
3860 REM    TRIANGULAR SKIDDING PATTERN SETTINGS WITH CONTINUOUS
3870 REM    LANDINGS ALONG SPURS (SKID TO SPURS)
3880 REM    = SE^3*(2*J-1)/48*(SSi*VFi/(1+I)^Yi)                         ' $
3890 REM    RIGHT-ANGLE SKIDDING PATTERN SETTING AT END OF COLLECTOR WITH
3900 REM    CONTINUOUS LANDINGS ALONG THE LAST SPUR
3910 REM    = SE^3*(SSi*VFi/(1+I)^Yi)/16                                 ' $
3920 REM ----------------------------------------------------------------------
3930 REM
3940 REM
3950 REM  **** TOTAL HAUL COST ON SPUR ROADS (N.P.V.), $ ****
3960 REM
3970 REM ----------------------------------------------------------------------
3980 S31=2*SE*(J*(.5*(LE^2-SE^2/4)+LE*DE)+((2*J-1)/24+1/16)*SE^2)
3990 S32=HS1*VF1/(1+I)^Y1+HS10*VF10/(1+I)^Y10
4000 S33=HS20*VF20/(1+I)^Y20+HS30*VF30/(1+I)^Y30
4010 S3=S31*(S32+S33)                                                    ' $
4020 REM
4030 REM  HAUL COST (ONE SIDE OF COLLECTOR) IN Yi FOR VOLUME(S) FROM
4040 REM    RIGHT-ANGLE SKIDDING PATTERN SETTINGS (BOTH SIDES) ALONG
4050 REM    SPURS WITH CONTINUOUS LANDINGS ALONG SPURS
4060 REM    = .5*SE*J*(LE^2-SE^2/4)*(HSi*VFi/(1+I)^Yi)                   ' $
4070 REM    RADIAL SKIDDING PATTERN SETTINGS AT END OF SPURS WITH LANDINGS
4080 REM    AT END OF SPURS = SE*J*LE*DE*(HSi*VFi/(1+I)^Yi)              ' $
4090 REM    TRIANGULAR SKIDDING PATTERN SETTINGS WITH CONTINUOUS LANDINGS
4100 REM    ALONG SPURS (SKID TO SPURS)
4110 REM    = SE^3*(2*J-1)*(HSi*VFi/(1+I)^Yi)/24                         ' $
4120 REM    RIGHT-ANGLE SKIDDING PATTERN SETTING AT END OF COLLECTOR WITH
4130 REM    CONTINUOUS LANDINGS ALONG THE LAST SPUR
4140 REM    = SE^3*(HSi*VFi/(1+I)^Yi)/16                                 ' $
4150 REM ---------------------------------------------------------------------
4160 REM
4170 IF K=J THEN GOTO 4330
4180 REM
4190 REM
4200 REM  **** TOTAL HIGH AND LOW STANDARD COLLECTOR COSTS ****
4210 REM                   IN Yi (N.P.V.), $
4220 REM
4230 REM ----------------------------------------------------------------------
4240 S41=RHC0/(1+I)^Y0+RHC10/(1+I)^Y10+RHC20/(1+I)^Y20+RHC30/(1+I)^Y30
```

```
4250 S42=RLC0/(1+I)^Y0+RLC10/(1+I)^Y10+RLC20/(1+I)^Y20+RLC30/(1+I)^Y30
4260 S4=(D-SE/2-K*SE)*S41+K*SE*S42 : GOTO 4390                            ' $
4270 REM
4280 REM  HIGH STANDARD COLLECTOR COST = (D-SE/2-K*SE)*S41                ' $
4290 REM  LOW STANDARD COLLECTOR COST = K*SE*S42                          ' $
4300 REM ------------------------------------------------------------------------
4310 REM
4320 REM
4330 REM  **** TOTAL LOW STANDARD COLLECTOR COST ONLY IN Yi (N.P.V.), $ ****
4340 REM
4350 S44=RLC0/(1+I)^Y0+RLC10/(1+I)^Y10+RLC20/(1+I)^Y20+RLC30/(1+I)^Y30
4360 S4=(D-SE/2)*S44                                                      ' $
4370 REM
4380 REM
4390 REM **** TOTAL SKID COST TO COLLECTOR IN Yi (N.P.V.), $ ****
4400 REM
4410 S51=SC1*VF1/(1+I)^Y1+SC10*VF10/(1+I)^Y10
4420 S52=SC20*VF20/(1+I)^Y20+SC30*VF30/(1+I)^Y30
4430 S5=(2*J-1)/24*SE^3*(S51+S52)                                         ' $
4440 REM
4450 REM
4460 IF K=0 AND L=>SE/2 THEN 4490
4470 IF K=J THEN GOTO 4570 ELSE 4650
4480 REM
4490 REM  **** TOTAL HAUL COST ON HIGH STANDARD COLLECTOR ONLY ***
4500 REM                        IN Yi (N.P.V.), $
4510 REM
4520 S61=HHC1*LL1*VF1/(1+I)^Y1+HHC10*LL10*VF10/(1+I)^Y10
4530 S62=HHC20*LL20*VF20/(1+I)^Y20+HHC30*LL30*VF30/(1+I)^Y30
4540 S6=S*D*(S61+S62) : GOTO 4950                                         ' $
4550 REM
4560 REM
4570 REM  **** TOTAL HAUL COST ON LOW STANDARD COLLECTOR ONLY ****
4580 REM                       IN Yi (N.P.V.), $
4590 REM
4600 S61=HLC1*BB1*VF1/(1+I)^Y1+HLC10*BB10*VF10/(1+I)^Y10
4610 S62=HLC20*BB20*VF20/(1+I)^Y20+HLC30*BB30*VF30/(1+I)^Y30
4620 S6=S*D*(S61+S62) : GOTO 4950                                         ' $
4630 REM
4640 REM
4650 REM  **** TOTAL HAUL COST ON HIGH AND LOW STANDARD COLLECTOR ****
4660 REM                         IN Yi (N.P.V.), $
4670 REM
4680 REM ------------------------------------------------------------------------
4690 S611=HLC1*BL1*VF1/(1+I)^Y1
4700 S612=HLC10*BL10*VF10/(1+I)^Y10
4710 S613=HLC20*BL20*VF20/(1+I)^Y20
4720 S614=HLC30*BL30*VF30/(1+I)^Y30
4730 S61=(S*SE*K+(SE/2)^2)*(S611+S612+S613+S614)
4740 :
4750 S621=HHC1*L*VF1/(1+I)^Y1
4760 S622=HHC10*L*VF10/(1+I)^Y10
4770 S623=HHC20*L*VF20/(1+I)^Y20
4780 S624=HHC30*L*VF30/(1+I)^Y30
```

```
4790 S62=(S*SE*K+(SE/2)^2)*(S621+S622+S623+S624)
4800 :
4810 S631=HHC1*LB1*VF1/(1+I)^Y1
4820 S632=HHC10*LB10*VF10/(1+I)^Y10
4830 S633=HHC20*LB20*VF20/(1+I)^Y20
4840 S634=HHC30*LB30*VF30/(1+I)^Y30
4850 S63=(S*D-(S*SE*K+(SE/2)^2))*(S631+S632+S633+S634)
4860 :
4870 S6=S61+S62+S63                                                        ' $
4880 REM
4890 REM   S61 = HAUL COST ON LOW STD COLL FOR VOL TO LOW STD COLL IN Yi    ' $
4900 REM   S62 = HAUL COST ON HIGH STD COLL FOR VOL TO LOW STD COLL IN Yi   ' $
4910 REM   S63 = HAUL COST ON HIGH STD COLL FOR VOL TO HIGH STD COLL IN Yi  ' $
4920 REM -------------------------------------------------------------------------
4930 REM
4940 REM
4950 REM  **** TOTAL AREA, TOTAL VOLUME, TOTAL COST (N.P.V.) ****
4960 REM                 AND AVERAGE COST (N.P.V.)
4970 REM
4980 AREA=D*S/43560!                                         ' TOTAL AREA, ACRES
4990 VOL=(V1+V10+V20+V30)*AREA                               ' TOTAL VOLUME, CCF
5000 COST=S1+S2+S3+S4+S5+S6                                  ' TOTAL COST, $
5010 TC=COST/AREA                                            ' AVE COST, $/ACRE
5020 REM
5030 REM  IF AVERAGE COST IN $/CCF IS DESIRED, CHANGE TC=COST/AREA ($/ACRE)
5040 REM  TO TC=COST/VOL ($/CCF). BOTH MINIMUM VALUES WILL GIVE THE SAME
5050 REM  RESULTS.
5060 REM
5070 IF TC>TCMIN THEN 5110                           ' FIND MINIMUM AVERAGE COST
5080 REM
5090 TCMIN=TC : SEMIN=SE : LEMIN=LE : DEMIN=DE : KMIN=K : JMIN=J : BMIN=B
5100 LMIN=L : SMIN=S
5110 NEXT K
5120 NEXT J
5130 NEXT NE
5140 NEXT DE
5150 REM
5160 REM ******** END OF LOOPS ********
5170 REM
5180 PRINT "
5190 PRINT USING " MINIMUM AVERAGE COST = $####.###/ACRE ";TCMIN
5200 PRINT "
5210 PRINT USING " LENGTH OF COLLECTOR = #### FEET ";BMIN
5220 PRINT "
5230 PRINT USING " COLLECTOR  SPACING = #### FEET ";SMIN
5240 PRINT "
5250 PRINT USING " LENGTH OF HIGH STANDARD COLLECTOR = #### FEET ";LMIN
5260 PRINT "
5270 PRINT USING " LENGTH OF LOW STANDARD COLLECTOR = #### FEET ";BMIN-LMIN
5280 PRINT "
5290 PRINT USING " LENGTH OF SPUR ROAD = #### FEET ";LEMIN
5300 PRINT "
5310 PRINT USING " SPUR ROAD  SPACING = #### FEET ";SEMIN
5320 PRINT "
```

```
5330 PRINT USING " DEPTH OF RADIAL SKIDDING PATTERN = ### FEET ";DEMIN
5340 PRINT "
5350 PRINT USING " NUMBER OF SPUR ROADS PERPENDICULAR TO ONE SIDE OF THE
COLLECTOR = ##" ;JMIN
5360 PRINT "
5370 PRINT USING " NUMBER OF ROAD SEGMENTS TO LOW STANDARD COLLECTOR = # ";KMIN
5380 PRINT "
5390 END
```

APPENDIX K

Program 4. Multiple Entries with Linear Skidding Costs

Program Listing

```
10  REM      ************************************************************
20  REM      *                                                          *
30  REM      *        MULTIPLE ENTRIES WITH LINEAR SKIDDING COSTS       *
40  REM      *                                                          *
50  REM      *              COMPLETE ENUMERATION METHOD AND             *
60  REM      *                                                          *
70  REM      *           HOOKE AND JEEVES PATTERN SEARCH METHOD         *
80  REM      *                                                          *
90  REM      ************************************************************
100 REM
110 REM
120 REM     **************************************************************
130 REM     *                                                            *
140 REM     *     PROGRAM TO DETERMINE OPTIMUM SETTINGS DIMENSIONS FOR   *
150 REM     *                                                            *
160 REM     *     TRIANGULAR, RIGHT-ANGLE AND RADIAL SKIDDING PATTERNS   *
170 REM     *                                                            *
180 REM     *     ASSOCIATED WITH HIGH AND LOW STANDARD COLLECTOR        *
190 REM     *                                                            *
200 REM     **************************************************************
210 REM
220 REM
230 REM  PURPOSE: TO FIND THE MINIMUM SUM OF ROADING, SKIDDING AND HAULING
240 REM           COST.
250 REM
260 REM           TO FIND THE OPTIMUM SPACINGS FOR COLLECTORS AND SPUR ROADS.
270 REM
280 REM           TO FIND THE OPTIMUM LENGTHS FOR HIGH AND LOW STANDARD
290 REM           COLLECTOR.
300 REM
310 REM           TO DETERMINE THE OPTIMUM SETTINGS DIMENSIONS FOR VARIOUS
320 REM           SKIDDING PATTERNS ADJACENT TO ONE AND ANOTHER.
330 REM
340 REM
350 REM  **** ASSIGNED CONDITIONS ****
360 REM
370 REM  NUMBER OF ENTRIES = 4
380 REM    YEAR 0 = BUILD COLLECTOR AND SPUR ROADS
390 REM    1ST ENTRY = 1 YEAR FROM NOW
400 REM    2ND ENTRY = 10 YEARS FROM NOW
410 REM    3RD ENTRY = 20 YEARS FROM NOW
420 REM    4TH ENTRY = 30 YEARS FROM NOW
430 REM
440 REM  SKIDDING COST = LINEAR (AVERAGE SKIDDING DISTANCE)
450 REM
460 REM
```

```
470 REM  **** SKIDDING PATTERNS ****
480 REM
490 REM  DESIGN TRIANGULAR SKIDDING PATTERN SETTINGS WHICH ARE RIGHT-ANGLE
500 REM  TRIANGLE IN SHAPE ALONG COLLECTOR AND SPURS. CONTINUOUS LANDINGS ARE
510 REM  ALLOWED ALONG COLLECTOR AND SPURS. SKIDDING DIRECTION IS PERPENDICULAR
520 REM  TO COLLECTOR OR SPURS.
530 REM
540 REM  DESIGN RIGHT-ANGLE SKIDDING PATTERN SETTINGS WHICH ARE SQUARE IN SHAPE
550 REM  ALONG THE LAST SPUR AND END OF COLLECTOR. CONTINUOUS LANDINGS ARE
560 REM  ALLOWED ALONG THE LAST SPUR. SKIDDING DIRECTION IS PERPENDICULAR TO
570 REM  SPURS.
580 REM
590 REM  DESIGN RIGHT-ANGLE SKIDDING PATTERN SETTINGS IN RECTANGULAR SHAPE
600 REM  ALONG SPURS. CONTINUOUS LANDINGS ARE ALLOWED ALONG SPURS. SKIDDING
610 REM  DIRECTION IS PERPENDICULAR TO SPURS.
620 REM
630 REM  DESIGN RADIAL SKIDDING PATTERN SETTINGS IN RECTANGULAR SHAPE AT THE END
640 REM  OF SPURS. LANDINGS AT END OF SPURS.
650 REM
660 REM
670 REM  ************ MULTIPLE ENTRIES WITH LINEAR SKIDDING COSTS ************
680 REM
690 REM
700 REM  **** VARIABLES ( SUBJECT TO CHANGE i.e. INPUTS ) ****
710 REM
720 REM  VOLUME PER ACRE OR PER SQUARE FEET TO BE REMOVED, CCF/ACRE OR CCF/FT^2
730 REM  DEPTH OF UNIT, FT                              ' FT = FEET
740 REM  NUMBER OF YEARS FROM NOW TO ENTER THE STAND
750 REM  DISCOUNTED RATE, %/100
760 REM  ROAD CONSTRUCTION COSTS, $/FT
770 REM  ROAD RECONSTRUCTION COSTS, $/FT
780 REM  SKIDDING COSTS, $/CCF/FT
790 REM  HAULING COSTS, $/CCF/FT
800 REM
810 REM  CCF = UNITS OF 100 CUBIC FEET OF TIMBER
820 REM  Yi  = # OF YEARS FROM NOW
830 REM  Vi  = CCF/ACRE REMOVED IN Yi
840 REM  VFi = CCF/FT^2 REMOVED IN Yi
850 REM   I  = DISCOUNTED RATE %/100
860 REM
870 V1=5 : V10=5 : V20=8 : V30=15                                ' CCF/ACRE
880 VF1=5/43560! : VF10=5/43560!                                 ' CCF/FT^2
890 VF20=8/43560! : VF30=15/43560!                               ' CCF/FT^2
900 Y0=0 : Y1=1 : Y10=10 : Y20=20 : Y30=30                  ' YEARS FROM NOW
910 I=.04                                                   ' DISCOUNTED RATE
920 D=8000                                               ' DEPTH OF UNIT, FT
930 FMIN=10^10                               ' SERVE TO MINIMIZE AVERAGE COST
940 REM
950 REM    COLL = COLLECTOR : AVE = AVERAGE : STD = STANDARD : DIS = DISTANCE
960 REM    VOL = VOLUME
970 REM
980 REM
990 REM  **** ROAD CONSTRUCTION AND RECONSTRUCTION COSTS, $/FT ****
1000 REM
```

```
1010 REM   ROAD AND RECONSTRUCTION COSTS FOR COLLECTOR
1020 REM
1030 REM --------------------------------------------------------------------
1040 REM      HIGH STANDARD COLLECTOR
1050 REM
1060 RHC0=11000/5280                  ' CONSTRUCT HIGH STD COLL IN Y0, $/FT
1070 RHC10=1100/5280                  ' RECONSTRUCT HIGH STD COLL IN Y10, $/FT
1080 RHC20=1100/5280                  ' RECONSTRUCT HIGH STD COLL IN Y20, $/FT
1090 RHC30=1100/5280                  ' RECONSTRUCT HIGH STD COLL IN Y30, $/FT
1100 REM
1110 REM      LOW STANDARD COLLECTOR
1120 REM
1130 RLC0=5700/5280                    ' CONSTRUCT LOW STD COLL IN Y0, $/FT
1140 RLC10=570/5280                    ' RECONSTRUCT LOW STD COLL IN Y10, $/FT
1150 RLC20=570/5280                    ' RECONSTRUCT LOW STD COLL IN Y20, $/FT
1160 RLC30=570/5280                    ' RECONSTRUCT LOW STD COLL IN Y30, $/FT
1170 REM
1180 REM  RECONSTRUCTION COST IS ASSUMED TO BE 10% OF THE ROAD CONSTRUCTION COST
1190 REM --------------------------------------------------------------------
1200 REM
1210 REM   ROAD AND RECONSTRUCTION COSTS FOR SPURS
1220 REM
1230 RS0=5700/5280                      ' CONSTRUCT SPUR ROADS IN Y0, $/FT
1240 RS10=570/5280                      ' RECONSTRUCT SPUR ROADS IN Y10, $/FT
1250 RS20=570/5280                      ' RECONSTRUCT SPUR ROADS IN Y20, $/FT
1260 RS30=570/5280                      ' RECONSTRUCT SPUR ROADS IN Y30, $/FT
1270 REM
1280 REM  RECONSTRUCTION COST IS ASSUMED TO BE 10% OF THE ROAD CONSTRUCTION COST
1290 REM
1300 REM
1310 REM  **** SKIDDING COSTS, $/CCF/FT ****
1320 REM
1330 REM --------------------------------------------------------------------
1340 REM   SKID COST TOWARD SPUR
1350 REM
1360 SS1=1.74/100                             ' SKID TO SPUR IN Y1, $/CCF/FT
1370 SS10=1.74/100                            ' SKID TO SPUR IN Y10, $/CCF/FT
1380 SS20=1.74/100                            ' SKID TO SPUR IN Y20, $/CCF/FT
1390 SS30=1.74/100                            ' SKID TO SPUR IN Y30, $/CCF/FT
1400 REM
1410 REM  SKID COST TOWARD COLLECTOR
1420 REM
1430 SC1=1.74/100                             ' SKID TO COLL IN Y1, $/CCF/FT
1440 SC10=1.74/100                            ' SKID TO COLL IN Y10, $/CCF/FT
1450 SC20=1.74/100                            ' SKID TO COLL IN Y20, $/CCF/FT
1460 SC30=1.74/100                            ' SKID TO COLL IN Y30, $/CCF/FT
1470 REM --------------------------------------------------------------------
1480 REM
1490 REM
1500 REM  **** HAULING COSTS ON COLLECTOR AND SPURS, $/CCF/FT ****
1510 REM
1520 REM --------------------------------------------------------------------
1530 REM   HAUL COST ON HIGH STANDARD COLLECTOR
1540 REM
```

```
1550 HHC1=2/5280                    ' HAUL COST ON HIGH STD COLL IN Y1, $/CCF/FT
1560 HHC10=2/5280                   ' HAUL COST ON HIGH STD COLL IN Y10, $/CCF/FT
1570 HHC20=2/5280                   ' HAUL COST ON HIGH STD COLL IN Y20, $/CCF/FT
1580 HHC30=2/5280                   ' HAUL COST ON HIGH STD COLL IN Y30, $/CCF/FT
1590 REM
1600 REM   HAUL COST ON LOW STANDARD COLLECTOR
1610 REM
1620 HLC1=5.15/5280                  ' HAUL COST ON LOW STD COLL IN Y1, $/CCF/FT
1630 HLC10=5.15/5280                 ' HAUL COST ON LOW STD COLL IN Y10, $/CCF/FT
1640 HLC20=5.15/5280                 ' HAUL COST ON LOW STD COLL IN Y20, $/CCF/FT
1650 HLC30=5.15/5280                 ' HAUL COST ON LOW STD COLL IN Y30, $/CCF/FT
1660 REM -------------------------------------------------------------------
1670 REM
1680 REM   HAUL COST ON SPUR
1690 REM
1700 HS1=5.15/5280                          ' HAUL COST ON SPUR IN Y1, $/CCF/FT
1710 HS10=5.15/5280                         ' HAUL COST ON SPUR IN Y10, $/CCF/FT
1720 HS20=5.15/5280                         ' HAUL COST ON SPUR IN Y20, $/CCF/FT
1730 HS30=5.15/5280                         ' HAUL COST ON SPUR IN Y30, $/CCF/FT
1740 REM
1750 REM
1760 REM  **** ASSIGN VARIABLES ****
1770 REM
1780 REM  DE = DEPTH (PARALLEL TO SPUR) OF RADIAL SKIDDING PATTERN SETTING, FT.
1790 REM  NE = LENGTH OF SPUR BETWEEN TRIANGULAR AND RADIAL SKIDDING PATTERN
1800 REM       SETTING WHICH IS THE LENGTH OF RIGHT-ANGLE SKIDDING PATTERN
1810 REM       SETTING ALONG SPURS, FT.
1820 REM   J = # OF SPURS (MUST BE AT LEAST ONE) PERPENDICULAR TO ONE SIDE OF
1830 REM       THE COLLECTOR FOR THE DEPTH OF THE UNIT.
1840 REM   K = # OF ROAD SEGMENTS (ZERO AND UP TO J) TO LOW STANDARD COLLECTOR.
1850 REM
1860 REM
1870 REM  ******** LOOPS FOR ASSIGN VARIABLES ********
1880 REM
1890 REM
1900 FOR J=1 TO 15
1910 FOR K=0 TO J
1920 :
1930 REM
1940 REM         ********************************************************
1950 REM         *                                                      *
1960 REM         *       HOOKE AND JEEVES PATTERN SEARCH METHOD         *
1970 REM         *                                                      *
1980 REM         ********************************************************
1990 REM
2000 REM
2010 REM ****************************
2020 REM *  EQUATIONS FOR MULTIPLE   *
2030 REM *  ENTRIES WITH LINEAR      *
2040 REM *  SKIDDING COST            *
2050 REM ****************************
2060 :
2070 GOTO 19000
2080 :
```

```
2500 DE=X(1) : NE=X(2)
2510 REM
2520 REM
2530 REM  **** ROAD LENGHTS AND SPACINGS ****
2540 REM
2550 REM
2560 SE=D/J                                          ' SPUR  ROAD SPACING, FT
2570 B=D-SE/2                                        ' LENGTH OF COLLECTOR, FT
2580 LE=SE/2+NE                                      ' LENGTH OF SPUR ROAD, FT
2590 S=2*(LE+DE)                                     ' COLLECTOR  SPACING, FT
2600 RD=1/6*SQR(SE^2+DE^2)+1/3*SQR(SE^2/16+DE^2)     ' AVE SKID DIS (RADIAL), FT
2610 REM
2620 IF J>K THEN L=D-.5*SE-K*SE ELSE L=0           ' LENGTH OF HIGH STD COLL, FT
2630 REM
2640 REM  AS LONG AS J>K THEN PART OR ALL OF THE COLLECTOR WILL BE IN HIGH
2650 REM  STANDARD.
2660 REM  IF K=0 THEN THE WHOLE COLLECTOR WILL BE IN HIGH STANDARD.
2670 REM  IF J=K THEN THERE WILL BE NO HIGH STANDARD COLLECOTR, L=0.
2680 REM
2690 REM
2700 REM  **** VOLUMES FROM VARIOUS SKIDDING PATTERNS SETTINGS IN Yi, CCF ****
2710 REM
2720 VS1=((LE+DE)-.5*SE/4)*SE*VF1                                  ' CCF IN Y1
2730 VS10=((LE+DE)-.5*SE/4)*SE*VF10                                ' CCF IN Y10
2740 VS20=((LE+DE)-.5*SE/4)*SE*VF20                                ' CCF IN Y20
2750 VS30=((LE+DE)-.5*SE/4)*SE*VF30                                ' CCF IN Y30
2760 REM
2770 REM  VSi = VOLUMES ENTER THE LAST SPUR (FROM RIGHT-ANGLE SKIDDING PATTERN
2780 REM        SETTING AT END OF COLLECTOR, TRIANGULAR AND RIGHT-ANGLE
2790 REM        SKIDDING PATTERN SETTINGS ALONG THE LAST SPUR AND RADIAL
2800 REM        SKIDDING PATTERN SETTING AT END OF THE LAST SPUR) EXCEPT VOLUME
2810 REM        FROM THE TRIANGULAR SKIDDING PATTERN SETTING ADJACENT TO THE
2820 REM        COLLECTOR IN YEAR i.
2830 REM
2840 VL1=((LE+DE)-SE/4)*SE*VF1                                     ' CCF IN Y1
2850 VL10=((LE+DE)-SE/4)*SE*VF10                                   ' CCF IN Y10
2860 VL20=((LE+DE)-SE/4)*SE*VF20                                   ' CCF IN Y20
2870 VL30=((LE+DE)-SE/4)*SE*VF30                                   ' CCF IN Y30
2880 REM
2890 REM  VLi = VOLUMES ENTER EACH SPUR (FROM TRIANGULAR AND RIGHT-ANGLE
2900 REM        SKIDDING PATTERN SETTINGS ALONG SPUR AND RADIAL SKIDDING
2910 REM        PATTERN SETTING AT END OF SPUR) EXCEPT VOLUME FROM TWO OF THE
2920 REM        TRIANGULAR SKIDDING PATTERN SETTINGS ADJACENT TO THE COLLECTOR
2930 REM        IN YEAR i.
2940 REM
2950 VC1=.5*(SE/2)^2*VF1                                           ' CCF IN Y1
2960 VC10=.5*(SE/2)^2*VF10                                         ' CCF IN Y10
2970 VC20=.5*(SE/2)^2*VF20                                         ' CCF IN Y20
2980 VC30=.5*(SE/2)^2*VF30                                         ' CCF IN Y30
2990 REM
3000 REM  VCi = VOLUME ENTER THE COLLECTOR FROM ANY ONE OF THE TRIANGULAR
3010 REM        SKIDDING PATTERN SETTINGS ADJACENT TO THE COLLECTOR IN YEAR i.
3020 REM
3030 REM
```

```
3040 REM  **** AVERAGE HAUL DISTANCE ON COLLECTOR, FT ****
3050 REM
3060 IF L>0 AND K>0 THEN 3800                                  ' CONDITION #1
3070 REM
3080 REM  CONDITION #1 THAT BOTH HIGH AND LOW STANDARD COLLECTORS EXIST, THEN
3090 REM  GO TO EQUATIONS THAT COMPUTE AVERAGE HAUL DISTANCE ON HIGH AND LOW
3100 REM  STANDARD COLLECTORS.
3110 REM
3120 IF K>0 OR L=0 THEN 3450                                   ' CONDITION #2
3130 REM
3140 REM  CONDITION #2 THAT LOW STANDARD COLLECTOR OR NO HIGH STANDARD
3150 REM  COLLECTOR EXISTS, THEN GO TO EQUATIONS THAT COMPUTE AVERAGE HAUL
3160 REM  DISTANCE ON LOW STANDARD COLLECTOR ONLY.
3170 REM
3180 REM
3190 REM  IF CONDITION #1 AND #2 ARE NOT TRUE THEN HIGH STANDARD COLLECTOR
3200 REM  ONLY EXISTS.
3210 REM
3220 REM
3230 REM  **** EQUATIONS THAT COMPUTE AVERAGE HAUL DISTANCE ON HIGH ****
3240 REM                      STANDARD COLLECTOR ONLY
3250 REM
3260 REM -----------------------------------------------------------------
3270 LL11=L*VS1+.5*(L/SE-.5)^2*SE*VL1+((L/SE)^2-1/12)*VC1*SE
3280 LL12=L*VS10+.5*(L/SE-.5)^2*SE*VL10+((L/SE)^2-1/12)*VC10*SE
3290 LL13=L*VS20+.5*(L/SE-.5)^2*SE*VL20+((L/SE)^2-1/12)*VC20*SE
3300 LL14=L*VS30+.5*(L/SE-.5)^2*SE*VL30+((L/SE)^2-1/12)*VC30*SE
3310 :
3320 LL1=LL11/(VS1+(L/SE-.5)*VL1+2*L*VC1/SE)                     ' FT IN Y1
3330 LL10=LL12/(VS10+(L/SE-.5)*VL10+2*L*VC10/SE)                 ' FT IN Y10
3340 LL20=LL13/(VS20+(L/SE-.5)*VL20+2*L*VC20/SE)                 ' FT IN Y20
3350 LL30=LL14/(VS30+(L/SE-.5)*VL30+2*L*VC30/SE)                 ' FT IN Y30
3360 REM
3370 REM  HAULING DISTANCE FOR
3380 REM    VSi = L                                                    ' FT
3390 REM    VLi = .5*(L/SE-.5)^2*SE                                    ' FT
3400 REM    VCi = ((L/SE)^2-1/12)*SE                                   ' FT
3410 REM  SUM OF VOLUME FOR THE ABOVE AREAS IN Yi
3420 REM  = VSi+(L/SE-.5)*VLi+2*L*VCi/SE                               ' CCF
3430 REM ----------------------------------------------------------------
3440 REM
3450 IF L>0 OR K=0 THEN 3740
3460 REM
3470 REM  CONDITION THAT HIGH STANDARD COLLECTOR OR NO LOW STANDARD COLLECTOR
3480 REM  EXISTS, THEN GO TO COST COMPUTATIONS. IF THE ABOVE CONDITION IS NOT
3490 REM  TRUE THEN LOW STANDARD COLLECTOR ONLY EXISTS.
3500 REM
3510 REM
3520 REM  **** EQUATIONS THAT COMPUTE AVERAGE HAUL DISTANCE ON LOW ****
3530 REM                    STANDARD COLLECTOR ONLY
3540 REM
3550 REM -----------------------------------------------------------------
3560 BB11=B*VS1+.5*(B/SE-.5)^2*SE*VL1+((B/SE)^2-1/12)*VC1*SE
3570 BB12=B*VS10+.5*(B/SE-.5)^2*SE*VL10+((B/SE)^2-1/12)*VC10*SE
```

```
3580 BB13=B*VS20+.5*(B/SE-.5)^2*SE*VL20+((B/SE)^2-1/12)*VC20*SE
3590 BB14=B*VS30+.5*(B/SE-.5)^2*SE*VL30+((B/SE)^2-1/12)*VC30*SE
3600 :
3610 BB1=BB11/(VS1+(B/SE-.5)*VL1+2*B*VC1/SE)                  ' FT IN Y1
3620 BB10=BB12/(VS10+(B/SE-.5)*VL10+2*B*VC10/SE)              ' FT IN Y10
3630 BB20=BB13/(VS20+(B/SE-.5)*VL20+2*B*VC20/SE)              ' FT IN Y20
3640 BB30=BB14/(VS30+(B/SE-.5)*VL30+2*B*VC30/SE)              ' FT IN Y30
3650 REM
3660 REM  HAULING DISTANCE FOR
3670 REM    VSi = B                                                 ' FT
3680 REM    VLi = .5*(B/SE-.5)^2*SE                                 ' FT
3690 REM    VCi = ((B/SE)^2-1/12)*SE                                ' FT
3700 REM  SUM OF VOLUME FOR THE ABOVE AREAS IN Yi
3710 REM  = VSi+(B/SE-.5)*VLi+2*B*VCi/SE                            ' CCF
3720 REM ------------------------------------------------------------------
3730 REM
3740 IF K=0 OR L=0 THEN 4250
3750 REM
3760 REM  CONDITION THAT NO LOW STANDARD COLLECTOR OR NO HIGH STANDARD
3770 REM  COLLECTOR EXISTS, THEN GO TO COST COMPUTATIONS.
3780 REM
3790 REM
3800 REM  **** EQUATIONS THAT COMPUTE AVERAGE HAUL DISTANCE ON LOW ****
3810 REM                      STANDARD COLLECTOR
3820 REM
3830 REM ------------------------------------------------------------------
3840 BL11=K*SE*VS1+K*(K-1)*SE*VL1/2+K^2*SE*VC1
3850 BL12=K*SE*VS10+K*(K-1)*SE*VL10/2+K^2*SE*VC10
3860 BL13=K*SE*VS20+K*(K-1)*SE*VL20/2+K^2*SE*VC20
3870 BL14=K*SE*VS30+K*(K-1)*SE*VL30/2+K^2*SE*VC30
3880 :
3890 BL1=BL11/(VS1+(K-1)*VL1+2*K*VC1)                         ' FT IN Y1
3900 BL10=BL12/(VS10+(K-1)*VL10+2*K*VC10)                     ' FT IN Y10
3910 BL20=BL13/(VS20+(K-1)*VL20+2*K*VC20)                     ' FT IN Y20
3920 BL30=BL14/(VS30+(K-1)*VL30+2*K*VC30)                     ' FT IN Y30
3930 REM
3940 REM  HAULING DISTANCE FOR
3950 REM    VSi = K*SE                                              ' FT
3960 REM    VLi = K*(K-1)*SE/2                                      ' FT
3970 REM    VCi = K^2*SE                                            ' FT
3980 REM  SUM OF VOLUME FOR THE ABOVE AREAS IN Yi
3990 REM  = VSi+(K-1)*VLi+2*K*VCi                                   ' CCF
4000 REM ------------------------------------------------------------------
4010 REM
4020 REM
4030 REM  **** EQUATIONS THAT COMPUTE AVERAGE HAUL DISTANCE ON HIGH ****
4040 REM                      STANDARD COLLECTOR
4050 REM
4060 REM ------------------------------------------------------------------
4070 LB11=(L/SE+.5)^2*SE*VL1/2+((L/SE)^2-1/12)*VC1*SE
4080 LB12=(L/SE+.5)^2*SE*VL10/2+((L/SE)^2-1/12)*VC10*SE
4090 LB13=(L/SE+.5)^2*SE*VL20/2+((L/SE)^2-1/12)*VC20*SE
4100 LB14=(L/SE+.5)^2*SE*VL30/2+((L/SE)^2-1/12)*VC30*SE
4110 :
```

```
4120 LB1=LB11/((L/SE+.5)*VL1+2*L*VC1/SE)                              ' FT IN Y1
4130 LB10=LB12/((L/SE+.5)*VL10+2*L*VC10/SE)                           ' FT IN Y10
4140 LB20=LB13/((L/SE+.5)*VL20+2*L*VC20/SE)                           ' FT IN Y20
4150 LB30=LB14/((L/SE+.5)*VL30+2*L*VC30/SE)                           ' FT IN Y30
4160 REM
4170 REM  HAULING DISTANCE FOR
4180 REM    VLi = (L/SE+.5)^2*SE/2                                        ' FT
4190 REM    VCi = ((L/SE)^2-1/12)*SE                                      ' FT
4200 REM  SUM OF VOLUME FOR THE ABOVE AREAS IN Yi
4210 REM  = (L/SE+.5)*VLi+2*L*VCi/SE                                      ' CCF
4220 REM ----------------------------------------------------------------------
4230 REM
4240 REM
4250 REM  *************** COST COMPUTATIONS ( NET PRESENT VALUE ) *************
4260 REM
4270 REM
4280 REM  N.P.V. = NET PRESENT VALUE
4290 REM
4300 REM  **** TOTAL SPUR ROADS COST (N.P.V.), $ ****
4310 REM
4320 S1=2*J*LE*(RS0/(1+I)^Y0+ RS10/(1+I)^Y10+RS20/(1+I)^Y20+RS30/(1+I)^Y30) ' $
4330 REM
4340 REM
4350 REM **** TOTAL SKID COST TO SPUR ROADS (N.P.V.), $ ****
4360 REM
4370 REM ----------------------------------------------------------------------
4380 S21=(2*(J*((SE/4)*(LE-SE/2)+RD*DE)+((2*J-1)/48+1/16)*SE^2)*SE)
4390 S22=SS1*VF1/(1+I)^Y1+SS10*VF10/(1+I)^Y10
4400 S23=SS20*VF20/(1+I)^Y20+SS30*VF30/(1+I)^Y30
4410 S2=S21*(S22+S23)                                                      ' $
4420 REM
4430 REM  SKID COST (ONE SIDE OF COLLECTOR) IN Yi FOR VOLUME(S) FROM
4440 REM    RIGHT-ANGLE SKIDDING PATTERN SETTINGS (BOTH SIDES) ALONG SPURS
4450 REM    WITH CONTINUOUS LANDINGS ALONG SPURS
4460 REM    = J*SE*(SE/4)*(LE-SE/2)*(SSi*VFi/(1+I)^Yi)                     ' $
4470 REM    RADIAL SKIDDING PATTERN SETTINGS AT END OF SPURS WITH LANDINGS
4480 REM    AT END OF SPURS = J*SE*RD*DE*(SSi*VFi/(1+I)^Yi)                ' $
4490 REM    TRIANGULAR SKIDDING PATTERN SETTINGS WITH CONTINUOUS
4500 REM    LANDINGS ALONG SPURS (SKID TO SPURS)
4510 REM    = SE^3*(2*J-1)/48*(SSi*VFi/(1+I)^Yi)                           ' $
4520 REM    RIGHT-ANGLE SKIDDING PATTERN SETTING AT END OF COLLECTOR WITH
4530 REM    CONTINUOUS LANDINGS ALONG THE LAST SPUR
4540 REM    = SE^3*(SSi*VFi/(1+I)^Yi)/16                                   ' $
4550 REM ----------------------------------------------------------------------
4560 REM
4570 REM
4580 REM  **** TOTAL HAUL COST ON SPUR ROADS (N.P.V.), $ ****
4590 REM
4600 REM ----------------------------------------------------------------------
4610 S31=2*SE*(J*(.5*(LE^2-SE^2/4)+LE*DE)+((2*J-1)/24+1/16)*SE^2)
4620 S32=HS1*VF1/(1+I)^Y1+HS10*VF10/(1+I)^Y10
4630 S33=HS20*VF20/(1+I)^Y20+HS30*VF30/(1+I)^Y30
4640 S3=S31*(S32+S33)                                                      ' $
4650 REM
```

```
4660 REM  HAUL COST (ONE SIDE OF COLLECTOR) IN Yi FOR VOLUME(S) FROM
4670 REM    RIGHT-ANGLE SKIDDING PATTERN SETTINGS (BOTH SIDES) ALONG
4680 REM    SPURS WITH CONTINUOUS LANDINGS ALONG SPURS
4690 REM    = .5*SE*J*(LE^2-SE^2/4)*(HSi*VFi/(1+I)^Yi)                  ' $
4700 REM    RADIAL SKIDDING PATTERN SETTINGS AT END OF SPURS WITH LANDINGS
4710 REM    AT END OF SPURS = SE*J*LE*DE*(HSi*VFi/(1+I)^Yi)             ' $
4720 REM    TRIANGULAR SKIDDING PATTERN SETTINGS WITH CONTINUOUS LANDINGS
4730 REM    ALONG SPURS (SKID TO SPURS)
4740 REM    = SE^3*(2*J-1)*(HSi*VFi/(1+I)^Yi)/24                        ' $
4750 REM    RIGHT-ANGLE SKIDDING PATTERN SETTING AT END OF COLLECTOR WITH
4760 REM    CONTINUOUS LANDINGS ALONG THE LAST SPUR
4770 REM    = SE^3*(HSi*VFi/(1+I)^Yi)/16                                ' $
4780 REM ----------------------------------------------------------------------
4790 REM
4800 REM
4810 IF K=J THEN GOTO 4960
4820 REM
4830 REM  **** TOTAL HIGH AND LOW STANDARD COLLECTOR COSTS ****
4840 REM                  IN Yi (N.P.V.), $
4850 REM
4860 REM ----------------------------------------------------------------------
4870 S41=RHC0/(1+I)^Y0+RHC10/(1+I)^Y10+RHC20/(1+I)^Y20+RHC30/(1+I)^Y30
4880 S42=RLC0/(1+I)^Y0+RLC10/(1+I)^Y10+RLC20/(1+I)^Y20+RLC30/(1+I)^Y30
4890 S4=(D-SE/2-K*SE)*S41+K*SE*S42 : GOTO 5020                          ' $
4900 REM
4910 REM  HIGH STANDARD COLLECTOR COST = (D-SE/2-K*SE)*S41              ' $
4920 REM  LOW STANDARD COLLECTOR COST = K*SE*S42                        ' $
4930 REM ----------------------------------------------------------------------
4940 REM
4950 REM
4960 REM  **** TOTAL LOW STANDARD COLLECTOR COST ONLY IN Yi (N.P.V.), $ ****
4970 REM
4980 S44=RLC0/(1+I)^Y0+RLC10/(1+I)^Y10+RLC20/(1+I)^Y20+RLC3O/(1+I)^Y30
4990 S4=(D-SE/2)*S44                                                    ' $
5000 REM
5010 REM
5020 REM  **** TOTAL SKID COST TO COLLECTOR IN Yi (N.P.V.), $ ****
5030 REM
5040 S51=SC1*VF1/(1+I)^Y1+SC10*VF10/(1+I)^Y10
5050 S52=SC20*VF20/(1+I)^Y20+SC30*VF30/(1+I)^Y30
5060 S5=(2*J-1)/24*SE^3*(S51+S52)                                       ' $
5070 REM
5080 REM
5090 IF K=0 AND L=>SE/2 THEN 5120
5100 IF K=J THEN GOTO 5190 ELSE 5270
5110 REM
5120 REM  **** TOTAL HAUL COST ON HIGH STANDARD COLLECTOR ONLY ****
5130 REM                     IN Yi (N.P.V.), $
5140 REM
5150 S61=HHC1*LL1*VF1/(1+I)^Y1+HHC10*LL10*VF10/(1+I)^Y10
5160 S62=HHC20*LL20*VF20/(1+I)^Y20+HHC30*LL30*VF30/(1+I)^Y30
5170 S6=S*D*(S61+S62) : GOTO 5570                                      ' $
5180 REM
5190 REM  **** TOTAL HAUL COST ON LOW STANDARD COLLECTOR ONLY ****
```

```
5200 REM                        IN Yi (N.P.V.), $
5210 REM
5220 S61=HLC1*BB1*VF1/(1+I)^Y1+HLC10*BB10*VF10/(1+I)^Y10
5230 S62=HLC20*BB20*VF20/(1+I)^Y20+HLC30*BB30*VF30/(1+I)^Y30
5240 S6=S*D*(S61+S62) : GOTO 5570                                          ' $
5250 REM
5260 REM
5270 REM  **** TOTAL HAUL COST ON HIGH AND LOW STANDARD COLLECTOR ****
5280 REM                          IN Yi (N.P.V.), $
5290 REM
5300 REM ---------------------------------------------------------------------
5310 S611=HLC1*BL1*VF1/(1+I)^Y1
5320 S612=HLC10*BL10*VF10/(1+I)^Y10
5330 S613=HLC20*BL20*VF20/(1+I)^Y20
5340 S614=HLC30*BL30*VF30/(1+I)^Y30
5350 S61=(S*SE*K+(SE/2)^2)*(S611+S612+S613+S614)
5360 :
5370 S621=HHC1*L*VF1/(1+I)^Y1
5380 S622=HHC10*L*VF10/(1+I)^Y10
5390 S623=HHC20*L*VF20/(1+I)^Y20
5400 S624=HHC30*L*VF30/(1+I)^Y30
5410 S62=(S*SE*K+(SE/2)^2)*(S621+S622+S623+S624)
5420 :
5430 S631=HHC1*LB1*VF1/(1+I)^Y1
5440 S632=HHC10*LB10*VF10/(1+I)^Y10
5450 S633=HHC20*LB20*VF20/(1+I)^Y20
5460 S634=HHC30*LB30*VF30/(1+I)^Y30
5470 S63=(S*D-(S*SE*K+(SE/2)^2))*(S631+S632+S633+S634)
5480 :
5490 S6=S61+S62+S63                                                        ' $
5500 REM
5510 REM   S61 = HAUL COST ON LOW STD COLL FOR VOL TO LOW STD COLL IN Yi    ' $
5520 REM   S62 = HAUL COST ON HIGH STD COLL FOR VOL TO LOW STD COLL IN Yi   ' $
5530 REM   S63 = HAUL COST ON HIGH STD COLL FOR VOL TO HIGH STD COLL IN Yi  ' $
5540 REM ---------------------------------------------------------------------
5550 REM
5560 REM
5570 REM  **** TOTAL AREA, TOTAL VOLUME, TOTAL COST (N.P.V.) ****
5580 REM                  AND AVERAGE COST (N.P.V.)
5590 REM
5600 AREA=D*S/43560!                                    ' TOTAL AREA   ,ACRES
5610 VOLUME=(V1+V10+V20+V30)*AREA                       ' TOTAL VOLUME   ,CCF
5620 COST=S1+S2+S3+S4+S5+S6                             ' TOTAL COST       ,$
5630 F=COST/AREA                                        ' AVE COST    ,$/ACRE
5640 REM
5650 REM  IF AVERAGE COST IN $/CCF IS DESIRED, CHANGE F=COST/AREA ($/ACRE)
5660 REM  TO F=COST/VOLUME ($/CCF). BOTH MINIMUM VALUES WILL GIVE THE SAME
5670 REM  RESULTS.
5680 REM
5690 :
5700 REM CHECK CONSTRAINTS
5710 FOR IX=1 TO NV
5720 IF X(IX)>3000 OR X(IX)<=0 THEN GOTO 5770
5730 NEXT IX
```

```
5740 RETURN
5750 :
5760 REM PENALIZE
5770 F=200
5780 RETURN
5790 :
12000 REM *********************
12010 REM * THIS SUBROUTINE    *
12020 REM * APPLIES THE HOOKE  *
12030 REM * & JEEVES ALGORITHM *
12040 REM * OF EXPLORATION AND *
12050 REM * PATTERN MOVES TO   *
12060 REM * FIND THE UNCON-    *
12070 REM * STRAINED MINIMUM   *
12080 REM * OF A MERIT FUNC-   *
12090 REM * TION.  THE USER    *
12100 REM * MUST SUPPLY A      *
12110 REM * STARTING VECTOR    *
12120 REM * X(I).              *
12130 REM *                    *
12140 REM *                    *
12150 REM *                    *
12160 REM * NV    - THE NUMBER *
12170 REM *         OF DESIGN  *
12180 REM *         VARIABLES. *
12190 REM *                    *
12200 REM * R     - INITIAL    *
12210 REM *         EXPLORATION *
12220 REM *         STEP SIZE  *
12230 REM *                    *
12240 REM * A     - ACCELERA-  *
12250 REM *         TION FACTOR *
12260 REM *         SET >=1.0  *
12270 REM *                    *
12280 REM * RF    - FINAL      *
12290 REM *         EXPLORATION *
12300 REM *         STEP SIZE  *
12310 REM *                    *
12320 REM * 2500 - SUBROUTINE  *
12330 REM *         TO EVALUATE *
12340 REM *         THE MERIT  *
12350 REM *         VALUE "F"  *
12360 REM *         USING A    *
12370 REM *         DESIGN VEC- *
12380 REM *         TOR "X(I)" *
12390 REM *                    *
12400 REM * FB    - ON RETURN  *
12410 REM *         THE BEST   *
12420 REM *         MERIT VALUE *
12430 REM *         FOUND.     *
12440 REM *                    *
12450 REM * XB(I)- THE DESIGN  *
12460 REM *         VECTOR COR- *
12470 REM *         RESPONDING *
```

```
12480 REM *         TO FB.       *
12490 REM *                      *
12500 REM **********************
12510 :
12520 GOSUB 2500
12530 FB=F
12540 R=R
12550 FOR N=1 TO NV
12560 X(N)=XB(N)
12570 NEXT N
12580 :
12590 REM EXPLORE
12600 GOSUB 12960
12610 :
12620 REM IS IT BETTER?
12630 REM IF SO GO TO PATTERN
12640 IF FE<FB THEN GOTO 12720
12650 :
12660 REM IF NOT DECREASE
12670 REM STEP SIZE DOWN TO RF
12680 IF R<RF THEN RETURN
12690 R=R/2
12700 GOTO 12550
12710 :
12720 REM MAKE PATTERN MOVE
12730 FOR N=1 TO NV
12740 X(N)=XE(N)+A*(XE(N)-XB(N))
12750 NEXT N
12760 :
12770 REM REPLACE XB WITH XE
12780 FOR N=1 TO NV
12790 XB(N)=XE(N)
12800 NEXT N
12810 FB=FE
12820 :
12830 REM EXPLORE FROM HERE
12840 GOSUB 12960
12850 :
12860 REM IF ITS BETTER
12870 REM REPEAT PATTERN
12880 :
12890 IF FE<FB GOTO  12720
12900 :
12910 REM IF NOT SO BACK TO
12920 REM BEST BASE POINT
12930 REM AND EXPLORE
12940 GOTO 12540
12950 :
12960 REM *********************
12970 REM * THIS SUBROUTINE    *
12980 REM * PERFORMS THE       *
12990 REM * EXPLORATION STEP   *
13000 REM *********************
13010 :
```

```
13020 GOSUB 2500 :FF=F
13030 FE=F
13040 FOR N=1 TO NV
13050 XE(N)=X(N)
13060 X(N)=X(N)+R
13070 GOSUB 2500
13080 IF F<FF GOTO 13140
13090 X(N)=X(N)-2*R
13100 GOSUB 2500
13110 IF F<FF GOTO 13140
13120 X(N)=X(N)+R
13130 GOTO 13160
13140 FE=F : FF=FE
13150 XE(N)=X(N)
13160 NEXT N
13170 RETURN
13180 :
19000 REM *********************
19010 REM * DRIVER PROGRAM      *
19020 REM * PERFORMS AN UNCON-  *
19030 REM * STRAINED OPTIMIZA-  *
19040 REM * TION OF A MERIT     *
19050 REM * FUNCTION.           *
19060 REM *********************
19070 :
19080 RF=.01 : A=2
19090 NV=2 : R=10
19100 DIM XB(2),X(2),XE(2)
19110 :
19120 REM FEASIBLE START POINT
19130 X(1)=300 : X(2)=600
19140 FOR IX=1 TO NV
19150 XB(IX)=X(IX)
19160 NEXT IX
19170 :
19180 REM CALL HOOKE & JEEVES
19190 GOSUB 12000
19200 :
19210 IF F>FMIN THEN 19250                         ' FIND MINIMUM AVERAGE COST
19220 REM
19230 FMIN=F : SEMIN=SE : LEMIN=LE : DEMIN=DE : KMIN=K : JMIN=J : BMIN=B
19240 LMIN=L : SMIN=S
19250 NEXT K
19260 NEXT J
19270 REM
19280 REM  ******** END OF LOOPS ********
19290 REM
19300 PRINT "
19310 PRINT USING " MINIMUM AVERAGE COST = $####.###/ACRE ";FMIN
19320 PRINT "
19330 PRINT USING " LENGTH OF COLLECTOR = #### FEET ";BMIN
19340 PRINT "
19350 PRINT USING " COLLECTOR  SPACING = #### FEET ";SMIN
19360 PRINT "
```

```
19370 PRINT USING " LENGTH OF HIGH STANDARD COLLECTOR = #### FEET ";LMIN
19380 PRINT "
19390 PRINT USING " LENGTH OF LOW STANDARD COLLECTOR = #### FEET ";BMIN-LMIN
19400 PRINT "
19410 PRINT USING " LENGTH OF SPUR ROAD = #### FEET ";LEMIN
19420 PRINT "
19430 PRINT USING " SPUR ROAD  SPACING = #### FEET ";SEMIN
19440 PRINT "
19450 PRINT USING " DEPTH OF RADIAL SKIDDING PATTERN = ### FEET ";DEMIN
19460 PRINT "
19470 PRINT USING " NUMBER OF SPUR ROADS PERPENDICULAR TO ONE SIDE OF THE
COLLECTOR = ##" ;JMIN
19480 PRINT "
19490 PRINT USING " NUMBER OF ROAD SEGMENTS TO LOW STANDARD COLLECTOR = # ";KMIN
19500 PRINT "
19510 END
```

APPENDIX L

Program 5. Single Entry with Non-linear Skidding Costs

Program Listing

```
10  REM      ************************************************************
20  REM      *                                                          *
30  REM      *       SINGLE ENTRY WITH NON-LINEAR SKIDDING COSTS        *
40  REM      *                                                          *
50  REM      *               COMPLETE ENUMERATION METHOD                *
60  REM      *                                                          *
70  REM      ************************************************************
80  REM
90  REM
100 REM     **************************************************************
110 REM     *                                                            *
120 REM     *     PROGRAM TO DETERMINE OPTIMUM SETTINGS DIMENSIONS FOR   *
130 REM     *                                                            *
140 REM     *     TRIANGULAR, RIGHT-ANGLE AND RADIAL SKIDDING PATTERNS   *
150 REM     *                                                            *
160 REM     *     ASSOCIATED WITH HIGH AND LOW STANDARD COLLECTOR        *
170 REM     *                                                            *
180 REM     **************************************************************
190 REM
200 REM
210 REM  PURPOSE: TO FIND THE MINIMUM SUM OF ROADING, SKIDDING AND HAULING
220 REM           COST.
230 REM
240 REM           TO FIND THE OPTIMUM SPACINGS FOR COLLECTORS AND SPUR ROADS.
250 REM
260 REM           TO FIND THE OPTIMUM LENGTHS FOR HIGH AND LOW STANDARD
270 REM           COLLECTOR.
280 REM
290 REM           TO DETERMINE THE OPTIMUM SETTINGS DIMENSIONS FOR VARIOUS
300 REM           SKIDDING PATTERNS ADJACENT TO ONE AND ANOTHER.
310 REM
320 REM
330 REM  **** ASSIGNED CONDITIONS ****
340 REM
350 REM  NUMBER OF ENTRIES = 1
360 REM  SKID COST FUNCTION = 1+.005(d)^1.2
370 REM  d = SKID DISTANCE
380 REM
390 REM
400 REM  **** SKIDDING PATTERNS ****
410 REM
420 REM  DESIGN TRIANGULAR SKIDDING PATTERN SETTINGS WHICH ARE RIGHT-ANGLE
430 REM  TRIANGLE IN SHAPE ALONG COLLECTOR AND SPURS. CONTINUOUS LANDINGS ARE
440 REM  ALLOWED ALONG COLLECTOR AND SPURS. SKIDDING DIRECTION IS PERPENDICULAR
450 REM  TO COLLECTOR OR SPURS.
460 REM
```

```
470 REM  DESIGN RIGHT-ANGLE SKIDDING PATTERN SETTINGS WHICH ARE SQUARE IN SHAPE
480 REM  ALONG THE LAST SPUR AND END OF COLLECTOR. CONTINUOUS LANDINGS ARE
490 REM  ALLOWED ALONG THE LAST SPUR. SKIDDING DIRECTION IS PERPENDICULAR TO
500 REM  SPURS.
510 REM
520 REM  DESIGN RIGHT-ANGLE SKIDDING PATTERN SETTINGS IN RECTANGULAR SHAPE
530 REM  ALONG SPURS. CONTINUOUS LANDINGS ARE ALLOWED ALONG SPURS. SKIDDING
540 REM  DIRECTION IS PERPENDICULAR TO SPURS.
550 REM
560 REM  DESIGN RADIAL SKIDDING PATTERN SETTINGS IN RECTANGULAR SHAPE AT THE END
570 REM  OF SPURS. LANDINGS AT END OF SPURS.
580 REM
590 REM
600 REM ************* SINGLE ENTRY WITH NON-LINEAR SKIDDING COSTS *************
610 REM
620 REM
630 REM  **** VARIABLES ( SUBJECT TO CHANGE i.e. INPUTS ) ****
640 REM
650 REM ---------------------------------------------------------------------
660 REM
670 REM      VOLUME PER ACRE OR PER SQUARE FEET, CCF/ACRE OR CCF/FT^2
680 REM      DEPTH OF UNIT, FT                          FT = FEET
690 REM      ROAD CONSTRUCTION COSTS, $/FT
700 REM      SKID DISTANCE COSTS, $/CCF
710 REM      HAULING COSTS, $/CCF/FT
720 REM
730 REM
740 REM  CCF = UNITS OF 100 CUBIC FEET OF TIMBER
750 REM  VOLUME = 10 CCF PER ACRE OR 10/43560 CCF PER SQUARE FEET
760 REM
770 V=10/43560!                                          ' VOLUME, CCF/FT^2
780 D=8000                                               ' DEPTH OF UNIT, FT
790 TCMIN=10^10                               ' SERVE TO MINIMIZE AVERAGE COST
800 REM
810 REM   COLL = COLLECTOR : STD = STANDARD : AVE = AVERAGE : VOL = VOLUME
820 REM
830 REM
840 REM  **** ROAD CONSTRUCTION COSTS ****
850 REM
860 REM  ROAD COSTS FOR COLLECTOR AND SPURS
870 REM
880 RH=11000/5280                                     ' HIGH STD COLL, $/FT
890 RL=5700/5280                                      ' LOW STD COLL, $/FT
900 RS=5700/5280                                      ' SPUR ROAD, $/FT
910 REM
920 REM  **** SKID DISTANCE COSTS ****
930 REM
940 REM  INSERT SKID COST FUNCTION IN LINE 1950, 2090, 2230, 2580 AND 2880
950 REM
960 REM  **** HAULING COSTS ****
970 REM
980 HH=2/5280                          ' HAUL ON HIGH STD COLL, $/CCF/FT
990 HL=5.15/5280                       ' HAUL ON LOW STD COLL, $/CCF/FT
1000 HS=5.15/5280                       ' HAUL ON SPUR, $/CCF/FT
```

```
1010 REM -----------------------------------------------------------------------
1020 REM
1030 REM
1040 REM  **** ARRAYS ****
1050 REM
1060 REM -----------------------------------------------------------------------
1070 REM
1080 DIM X(50) , N(50) , D(50)
1090 REM
1100 REM  X(I) = TOTAL LENGTH OF I SECTIONS, FT.
1110 REM  N(N) = LENGTH OF RECTANGLE WHICH CONSISTS OF N SECTIONS FOR RIGHT-
1120 REM         ANGLE SKIDDING PATTERN ALONG SPURS, FT.
1130 REM  D(M) = LENGTH OF RECTANGLE WHICH CONSISTS OF M SECTIONS FOR RADIAL
1140 REM         SKIDDING PATTERN AT END OF SPURS, FT.
1150 REM
1160 DIM TC(50) , UC(50) , LC(50,50) , DC(50,50)
1170 REM
1180 REM  TC(I)    = SKID COST FOR TRIANGULAR SKIDDING PATTERN WITH VARIOUS
1190 REM             DIMENSIONS, $.
1200 REM  UC(I)    = SKID COST FOR RIGHT-ANGLE SKIDDING PATTERN AT END OF
1210 REM             COLLECTOR WITH VARIOUS DIMENSIONS, $.
1220 REM  LC(I,N) = SKID COST FOR RIGHT-ANGLE SKIDDING PATTERN ALONG SPUR WITH
1230 REM             VARIOUS DIMENSIONS, $.
1240 REM  DC(I,M) = SKID COST FOR RADIAL SKIDDING PATTERN WITH VARIOUS
1250 REM             DIMENSIONS, $.
1260 REM
1270 DIM TV(50),UV(50),LV(50,50),DV(50,50)
1280 REM
1290 REM   TV(I)    = VOLUME FOR TRIANGULAR SKIDDING PATTERN WITH VARIOUS
1300 REM              DIMENSIONS, CCF.
1310 REM   UV(I)    = VOLUME FOR RIGHT-ANGLE SKIDDING PATTERN AT END OF
1320 REM              COLLECTOR WITH VARIOUS DIMENSIONS,CCF.
1330 REM   LV(I,N) = VOLUME FOR RIGHT-ANGLE SKIDDING PATTERN ALONG SPUR WITH
1340 REM              VARIOUS DIMENSIONS, CCF.
1350 REM   DV(I,M) = VOLUME FOR RADIAL SKIDDING PATTERN AT END OF SPUR WITH
1360 REM              VARIOUS DIMENSIONS, CCF.
1370 REM
1380 REM
1390 REM   TRI = TRIANGULAR OR TRIANGLE : TSP = TRIANGULAR SKIDDING PATTERN
1400 REM   RASP = RIGHT-ANGLE SKIDDING PATTERN
1410 REM
1420 TC(0)=0 : TV(0)=0                       ' WHEN SE=0 ,TRI SKID COST=0 : VOL=0
1430 UC(0)=0 : UV(0)=0                       ' WHEN SE=0 ,RASP SKID COST=0 : VOL=0
1440 LC(0,0)=0 : LC(1,0)=0 : LC(0,1)=0      ' WHEN SE OR LE=0 ,RASP SKID COST=0
1450 LV(0,0)=0 : LV(1,0)=0 : LV(0,1)=0      '   VOLUME=0
1460 DC(0,0)=0 : DC(1,0)=0 : DC(0,1)=0      ' WHEN SE OR DE=0 ,RADIAL SKID COST=0
1470 DV(0,0)=0 : DV(1,0)=0 : DV(0,1)=0      '   VOLUME=0
1480 REM -----------------------------------------------------------------------
1490 REM
1500 REM
1510 REM  **** GENERATE SKID COSTS AND VOLUMES FOR VARIOUS ****
1520 REM                      SKIDDING PATTERNS
1530 REM
1540 X(0)=0
```

```
1550 REM
1560 FOR I=1 TO 50
1570 REM
1580 REM  I = # OF SECTIONS PERPENDICULARLY OUT FROM EVERY SPUR ROAD, EACH
1590 REM      SECTION IS 50 FEET.
1600 REM
1610 X(I)=X(I-1)+50                                ' 1/2 SPUR ROADS SPACING, FT
1620 X=X(I)/50
1630 REM
1640 REM   X IS EQUAL TO I, X IS THE # OF SECTIONS OUT FROM (PERPENDICULAR TO)
1650 REM   SPUR IN THE TRIANGULAR SKIDDING PATTERN AND RIGHT-ANGLE SKIDDING
1660 REM   PATTERN AT END OF COLLECTOR, FT.
1670 REM
1680 REM
1690 REM  **** TRIANGULAR SKIDDING PATTERN ****
1700 REM
1710 REM  TRIANGLES ARE RIGHT-ANGLE TRIANGLE IN SHAPE.
1720 REM  SKIDDING DIRECTION IS PERPENDICULAR TO SPUR OR COLLECTOR.
1730 REM  EACH SECTIONAL AREA OUT FROM THE COLLECTOR OR SPUR IS TRAPAZOID IN
1740 REM    SHAPE. EACH TRAPAZOID IS TREATED AS A RECTANGLE IN SKID DISTANCE
1750 REM    AND COST COMPUTATIONS. THE SHAPE OF THE LAST SECTIONAL AREA IS A
1760 REM    TRIANGLE AND IT IS TREATED AS SO IN SKID DISTANCE AND COST
1770 REM    COMPUTATIONS.
1780 REM
1790 TCV=0 : UCV=0
1800 FOR T=1 TO X
1810 REM
1820 REM     T = # OF SECTIONS OUT FROM SPUR, 50 FEET EACH. T IS LESS THAN OR
1830 REM         EQUAL TO X.
1840 REM
1850 IF T=X THEN GOTO 2060
1860 REM
1870 REM  IF THE ABOVE CONDITION IS TRUE THEN IT IS THE LAST SECTION, THE SHAPE
1880 REM  OF THE AREA IS A TRIANGLE. IF NOT THE SHAPE OF THE AREA TO BE SKIDDED
1890 REM  IS A TRAPAZOID.
1900 REM
1910 REM
1920 REM  **** SKID FROM TRAPAZOID AREA (TREAT IT AS A RECTANGLE) ****
1930 REM
1940 REM ---------------------------------------------------------------------
1950 TD=1+.005*(50*T-25)^1.2
1960 TSC=(X(I)-(50*T-25))*50*V*TD
1970 REM
1980 REM  50*T-25 = SKIDDING DISTANCE, FT
1990 REM  TD = SKID DISTANCE COST, $/CCF
2000 REM  TSC = SKID COST, $
2010 REM ---------------------------------------------------------------------
2020 REM
2030 GOTO 2110
2040 REM
2050 REM
2060 REM  **** SKID FROM THE LAST SECTIONAL AREA (RIGHT-ANGLE TRIANGLE)  ****
2070 REM
2080 REM ---------------------------------------------------------------------
```

```
2090 TD=1+.005*(50*(T-1)+50/3)^1.2
2100 TSC=.5*50^2*V*TD
2110 TCV=TCV+TSC
2120 REM
2130 REM  50*(T-1)+50/3 = SKIDDING DISTANCE, FT
2140 REM  TD = SKID DISTANCE COST, $/CCF
2150 REM  TCV = ACCUMULATE SKID COST FOR BOTH TRIANGULAR AND TRAPAZOID AREAS, $
2160 REM -----------------------------------------------------------------------
2170 REM
2180 REM
2190 REM  **** RIGHT-ANGLE SKIDDING PATTERN (AT THE END OF COLLECTOR) ****
2200 REM                 THE SHAPE OF THE AREA IS A SQUARE
2210 REM
2220 REM ----------------------------------------------------------------------
2230 UD=1+.005*(50*T-25)^1.2
2240 USC=X(I)*50*V*UD
2250 UCV=UCV+USC
2260 REM
2270 REM  50*T-25 = SKIDDING DISTANCE, FT
2280 REM  UD = SKID DISTANCE COST, $/CCF
2290 REM  USC = SKID COST, $
2300 REM  UCV = ACCUMULATE SKID COST, $
2310 REM ----------------------------------------------------------------------
2320 REM
2330 NEXT T
2340 REM
2350 REM  DIM = DIMENSION : ACCUM = ACCUMULATE : VOL = VOLUME : DIS = DISTANCE
2360 REM
2370 TC(I)=TCV                          ' STORE SKID COST (EACH TRI DIM), $
2380 TV(I)=.5*(X(I))^2*V                ' STORE ACCUM VOL (EACH TRI DIM), CCF
2390 UC(I)=UCV                       ' STORE SKID COST (EACH SQUARE DIM), $
2400 UV(I)=(X(I))^2*V                ' STORE ACCUM VOL (EACH SQUARE DIM), CCF
2410 REM
2420 REM
2430 REM  **** RIGHT-ANGLE SKIDDING PATTERN ALONG SPUR ****
2440 REM         THE SHAPE OF THE AREA IS A RECTANGLE
2450 REM
2460 REM ---------------------------------------------------------------------
2470 N(0)=0
2480 FOR N=1 TO 50
2490 REM
2500 REM  N = # OF SECTIONS FOR RIGHT-ANGLE SKIDDING PATTERN ALONG SPUR, EACH
2510 REM      SECTION IS 50 FEET.
2520 REM
2530 N(N)=N(N-1)+50     ' LENGTH OF RIGHT-ANGLE SKIDDING PATTERN ALONG SPUR, FT
2540 REM
2550 LCV=0
2560 FOR T=1 TO X
2570 REM
2580 LD=1+.005*(50*T-25)^1.2
2590 LSC=N(N)*50*V*LD
2600 LCV=LCV+LSC
2610 REM
2620 REM  50*T-25 = SKIDDING DISTANCE, FT
```

```
2630 REM  LD = SKID DISTANCE COST, $/CCF
2640 REM  LSC = SKID COST, $
2650 REM  LCV = ACCUMULATE SKID COST, $
2660 REM
2670 NEXT T
2680 REM
2690 LC(I,N)=LCV                     ' STORE SKID COST (EACH RECTANGULAR DIM), $
2700 LV(I,N)=X(I)*N(N)*V             ' STORE ACCUM VOL (EACH RECTANGULAR DIM), CCF
2710 NEXT N
2720 NEXT I
2730 REM -------------------------------------------------------------------
2740 REM
2750 REM
2760 REM  **** RADIAL SKIDDING PATTERN (SKID TO LANDING AT END OF SPUR) ****
2770 REM
2780 REM -------------------------------------------------------------------
2790 FOR M=1 TO 50
2800 REM
2810 REM  M = # OF SECTIONS OUT FROM END OF SPUR AND PARALLEL TO SPUR IN RADIAL
2820 REM      SKIDDING PATTERN, EACH 50 FEET
2830 REM
2840 D(M)=D(M-1)+50        ' DISTANCE OUT FROM END OF SPUR (PARALLEL TO SPUR), FT
2850 DSC=0
2860 FOR I=1 TO 50
2870 DIST=SQR((50*I-25)^2+(50*M-25)^2)
2880 DD=1+.005*(DIST)^1.2
2890 DSC=DSC+50*50*V*DD
2900 DC(I,M)=DSC+DC(I,M-1)
2910 DV(I,M)=50*M*50*I*V
2920 REM
2930 REM  DIST = SKIDDING DISTANCE FROM 50 FT X 50 FT CELL, FT
2940 REM  DD = SKID DISTANCE COST FOR CELL, $/CCF
2950 REM  DSC = SKID COST, $
2960 REM  DC(I,M) = STORE SKID COST (EACH RECTANGULAR DIM), $
2970 REM  DV(I,M) = STORE ACCUMULATE VOLUME (EACH RECTANGULAR DIM), CCF
2980 REM
2990 NEXT I
3000 NEXT M
3010 REM -------------------------------------------------------------------
3020 REM
3030 REM
3040 REM  **** ASSIGN VARIABLES ****
3050 REM
3060 REM  DE = DEPTH (PARALLEL TO SPUR) OF RADIAL SKIDDING PATTERN SETTING, FT.
3070 REM  NE = LENGTH OF SPUR BETWEEN TRIANGULAR AND RADIAL SKIDDING PATTERN
3080 REM       SETTING WHICH IS THE LENGTH OF RIGHT-ANGLE SKIDDING PATTERN
3090 REM       SETTING ALONG SPUR, FT.
3100 REM  J  = # OF SPURS (MUST BE AT LEAST ONE) PERPENDICULAR TO ONE SIDE OF
3110 REM       THE COLLECTOR FOR THE DEPTH OF THE UNIT.
3120 REM  K  = # OF ROAD SEGMENTS (ZERO AND UP TO J) TO LOW STANDARD COLLECTOR.
3130 REM
3140 REM
3150 REM  ******** LOOPS FOR ASSIGN VARIABLES ********
3160 REM
```

```
3170 FOR DE=100 TO 2000 STEP 100
3180 FOR NE=100 TO 2000 STEP 100
3190 FOR J=1 TO 10
3200 FOR K=0 TO J
3210 REM
3220 REM
3230 REM  **** ROAD LENGTHS AND SPACINGS ****
3240 REM
3250 SE=D/J                                         ' SPUR ROAD  SPACING, FT
3260 B=D-SE/2                                       ' LENGTH OF COLLECTOR, FT
3270 LE=SE/2+NE                                     ' LENGTH OF SPUR ROAD, FT
3280 S=2*(LE+DE)                                    ' COLLECTOR  SPACING, FT
3290 REM
3300 IF J>K THEN L=D-.5*SE-K*SE ELSE L=0        ' LENGTH OF HIGH STD COLL, FT
3310 REM
3320 REM  AS LONG AS J>K THEN PART OR ALL OF THE COLLECTOR WILL BE IN HIGH
3330 REM  STANDARD.
3340 REM  IF K=0 THEN THE WHOLE COLLECTOR WILL BE IN HIGH STANDARD.
3350 REM  IF J=K THEN THERE WILL BE NO HIGH STANDARD COLLECTOR, L=0.
3360 REM
3370 REM
3380 REM  **** VOLUMES FROM VARIOUS SKIDDING PATTERNS SETTINGS ****
3390 REM
3400 VS=((LE+DE)*SE-.5*(SE/2)^2)*V                                      ' CCF
3410 REM
3420 REM  VS = VOLUMES ENTER THE LAST SPUR (FROM RIGHT-ANGLE SKIDDING PATTERN
3430 REM       SETTING AT END OF COLLECTOR, TRIANGULAR AND RIGHT-ANGLE SKIDDING
3440 REM       PATTERN SETTINGS ALONG THE LAST SPUR, AND RADIAL SKIDDING
3450 REM       PATTERN SETTING AT END OF THE LAST SPUR) EXCEPT VOLUME FROM THE
3460 REM       TRIANGULAR SKIDDING PATTERN SETTING ADJACENT TO THE COLLECTOR.
3470 REM
3480 VL=((LE+DE)*SE-(SE/2)^2)*V                                         ' CCF
3490 REM
3500 REM  VL = VOLUMES ENTER EACH SPUR (FROM TRIANGULAR AND RIGHT-ANGLE
3510 REM       SKIDDING PATTERN SETTINGS ALONG SPUR AND RADIAL SKIDDING PATTERN
3520 REM       AT END OF SPUR) EXCEPT VOLUMES FROM TWO OF THE TRIANGULAR
3530 REM       SKIDDING PATTERN SETTINGS ADJACENT TO THE COLLECTOR.
3540 REM
3550 VC=.5*(SE/2)^2*V                                                   ' CCF
3560 REM
3570 REM  VC = VOLUME ENTER THE COLLECTOR FROM ANY ONE OF THE TRIANGULAR
3580 REM       SKIDDING PATTERN SETTINGS ADJACENT TO THE COLLECTOR.
3590 REM
3600 REM
3610 REM  **** AVERAGE HAUL DISTANCE ON COLLECTOR ****
3620 REM
3630 IF L>0 AND K>0 THEN 4210                               ' CONDITION #1
3640 REM
3650 REM  CONDITION #1 THAT BOTH HIGH AND LOW STANDARD COLLECTORS EXIST, THEN
3660 REM  GO TO EQUATIONS THAT COMPUTE AVERAGE HAUL DISTANCE ON HIGH AND LOW
3670 REM  STANDARD COLLECTORS.
3680 REM
3690 IF K>0 OR L=0 THEN 3940                                ' CONDITION #2
3700 REM
```

```
3710 REM  CONDITION #2 THAT LOW STANDARD COLLECTOR OR NO HIGH STANDARD
3720 REM  COLLECTOR EXISTS, THEN GO TO EQUATION THAT COMPUTES AVERAGE HAUL
3730 REM  DISTANCE ON LOW STANDARD COLLECTOR ONLY.
3740 REM
3750 REM
3760 REM  IF CONDITION #1 AND #2 ARE NOT TRUE THEN HIGH STANDARD COLLECTOR
3770 REM  ONLY EXISTS.
3780 REM
3790 REM
3800 REM  **** EQUATION THAT COMPUTES AVERAGE HAUL DISTANCE ON HIGH ****
3810 REM                      STANDARD COLLECTOR ONLY
3820 REM
3830 REM -----------------------------------------------------------------
3840 LL1=L*VS+.5*(L/SE-.5)^2*SE*VL+((L/SE)^2-1/12)*VC*SE
3850 LL=LL1/(VS+(L/SE-.5)*VL+2*L*VC/SE)                                ' FT
3860 REM
3870 REM  HAULING DISTANCE FOR
3880 REM    VS = L                                                     ' FT
3890 REM    VL = .5*(L/SE-.5)^2*SE                                     ' FT
3900 REM    VC = ((L/SE)^2-1/12)*SE                                    ' FT
3910 REM  SUM OF VOLUME FOR THE ABOVE AREAS = VS+(L/SE-.5)*VL+2*L*VC/SE   ' CCF
3920 REM -----------------------------------------------------------------
3930 REM
3940 IF L>0 OR K=0 THEN 4150
3950 REM
3960 REM  CONDITION THAT HIGH STANDARD COLLECTOR OR NO LOW STANDARD COLLECTOR
3970 REM  EXISTS, THEN GO TO COST COMPUTATIONS. IF THE ABOVE CONDITION IS NOT
3980 REM  TRUE THEN LOW STANDARD COLLECTOR ONLY EXISTS.
3990 REM
4000 REM
4010 REM  **** EQUATION THAT COMPUTES AVERAGE HAUL DISTANCE ON LOW ****
4020 REM                      STANDARD COLLECTOR ONLY
4030 REM
4040 REM -----------------------------------------------------------------
4050 BB1=B*VS+.5*(B/SE-.5)^2*SE*VL+((B/SE)^2-1/12)*VC*SE
4060 BB=BB1/(VS+(B/SE-.5)*VL+2*B*VC/SE)                                ' FT
4070 REM
4080 REM  HAULING DISTANCE FOR
4090 REM    VS = B                                                     ' FT
4100 REM    VL = .5*(B/SE-.5)^2*SE                                     ' FT
4110 REM    VC = ((B/SE)^2-1/12)*SE                                    ' FT
4120 REM  SUM OF VOLUME FOR THE ABOVE AREAS = (VS+(B/SE-.5)*VL+2*B*VC/SE) ' CCF
4130 REM -----------------------------------------------------------------
4140 REM
4150 IF K=0 OR L=0 THEN 4480
4160 REM
4170 REM  CONDITION THAT NO LOW STANDARD COLLECTOR OR NO HIGH STANDARD
4180 REM  COLLECTOR EXISTS, THEN GO TO COST COMPUTATIONS.
4190 REM
4200 REM
4210 REM  **** EQUATION THAT COMPUTES AVERAGE HAUL DISTANCE ON ****
4220 REM                    LOW STANDARD COLLECTOR
4230 REM
4240 REM -----------------------------------------------------------------
```

```
4250 BL1=(K*SE*VS+K*(K-1)*SE*VL/2+K^2*SE*VC)
4260 BL=BL1/(VS+(K-1)*VL+2*K*VC)                                      ' FT
4270 REM  HAULING DISTANCE FOR
4280 REM    VS = K*SE                                                  ' FT
4290 REM    VL = K*(K-1)*SE/2                                          ' FT
4300 REM    VC = K^2*SE                                                ' FT
4310 REM  SUM OF VOLUME FOR THE ABOVE AREAS = (VS+(K-1)*VL+2*K*VC)     ' CCF
4320 REM --------------------------------------------------------------------
4330 REM
4340 REM  **** EQUATION THAT COMPUTES AVERAGE HAUL DISTANCE ON ****
4350 REM                  HIGH STANDARD COLLECTOR
4360 REM
4370 REM --------------------------------------------------------------------
4380 LB1=((L/SE+.5)^2*SE*VL/2+((L/SE)^2-1/12)*SE*VC)
4390 LB=LB1/((L/SE+.5)*VL+2*L*VC/SE)                                   ' FT
4400 REM
4410 REM  HAULING DISTANCE FOR
4420 REM    VL = (L/SE+.5)^2*SE/2                                      ' FT
4430 REM    VC = ((L/SE)^2-1/12)*SE                                    ' FT
4440 REM  SUM OF VOLUME FOR THE ABOVE AREAS = (L/SE+.5)*VL+2*L*VC/SE   ' CCF
4450 REM --------------------------------------------------------------------
4460 REM
4470 REM
4480 REM  ************************* COST COMPUTAIONS *************************
4490 REM
4500 REM
4510 REM  **** TOTAL SPUR ROADS COST, $ ****
4520 REM
4530 S1=2*J*RS*LE                                                       ' $
4540 REM
4550 REM
4560 REM  **** SKID COSTS FOR VARIOUS SKIDDING PATTERNS SETTINGS, $ ****
4570 REM
4580 REM
4590 REM  **** AVERAGE SKID COST FOR TRIANGULAR SKIDDING PATTERN ****
4600 REM       SETTINGS ALONG SPURS AND COLLECTOR AND RIGHT-ANGLE
4610 REM        SKIDDING PATTERN SETTINGS AT END OF COLLECTOR, $
4620 REM
4630 FOR I=1 TO 50
4640 IF SE/2=X(I) THEN GOTO 4780
4650 REM
4660 REM  WHEN HALF OF THE SPUR ROADS SPACING IS EQUAL TO THE TOTAL LENGTH OF I
4670 REM  SECTIONS OUT FROM SPUR, GO TO THE GENERATED SKID COST.
4680 REM
4690 IF SE/2>X(I-1) AND SE/2<X(I) THEN GOTO 4800 ELSE GOTO 4990
4700 REM
4710 REM  IF HALF OF THE SPUR ROADS SPACING IS LONGER THAN THE TOTAL LENGTH OF
4720 REM  I-1 SECTIONS BUT LESS THAN THE TOTAL LENGTH OF I SECTIONS, GO TO
4730 REM  WEIGHTED AVERAGE SKID COST EQUATION.
4740 REM
4750 REM   TRIANGULAR SKIDDING PATTERN SETTING
4760 REM
4770 REM --------------------------------------------------------------------
4780 ASCT=TC(I)                                     ' GENERATED SKID COST, $
```

```
4790 GOTO 4910
4800 ASCT1=(.5*(SE/2)^2*V-TV(I-1))/(TV(I)-TV(I-1))
4810 ASCT=TC(I-1)+(TC(I)-TC(I-1))*ASCT1                                    ' $
4820 REM
4830 REM  ASCT = WEIGHTED AVERAGE SKID COST WHEN  X(I-1) < SE/2 < X(I)
4840 REM -------------------------------------------------------------------
4850 REM
4860 GOTO 4930
4870 REM
4880 REM   RECTANGULAR SKIDDING PATTERN SETTING
4890 REM
4900 REM --------------------------------------------------------------------
4910 ASCU=UC(I)                                          ' GENERATED SKID COST, $
4920 GOTO 5020
4930 ASCU1=((SE/2)^2*V-UV(I-1))/(UV(I)-UV(I-1))
4940 ASCU=UC(I-1)+(UC(I)-UC(I-1))*ASCU1                                    ' $
4950 REM
4960 REM  ASCU = WEIGHTED AVERAGE SKID COST WHEN  X(I-1) < SE/2 < X(I)
4970 REM --------------------------------------------------------------------
4980 GOTO 5020
4990 NEXT I
5000 REM
5010 REM
5020 REM  **** AVERAGE SKID COST FOR RIGHT-ANGLE SKIDDING PATTERN ****
5030 REM                   SETTINGS ALONG SPURS, $
5040 REM
5050 FOR N=1 TO 50
5060 REM --------------------------------------------------------------------
5070 IF SE/2=X(I) AND NE=N(N) THEN ASCL=LC(I,N) : GOTO 5400
5080 REM   ASCL = GENERATED SKID COST                                      ' $
5090 REM --------------------------------------------------------------------
5100 IF SE/2=X(I) OR NE=N(N) THEN GOTO 5110 ELSE GOTO 5130
5110 IF NE>N(N-1) AND NE<N(N) THEN GOTO 5240
5120 IF SE/2>X(I-1) AND SE/2<X(I) THEN GOTO 5300
5130 IF SE/2>X(I-1) AND SE/2<X(I) THEN 5140
5140 IF NE>N(N-1) AND NE<N(N) THEN GOTO 5180
5150 GOTO 5370
5160 REM
5170 REM --------------------------------------------------------------------
5180 ASCL1=(LC(I,N)-LC(I-1,N-1))*(NE*SE/2*V-LV(I-1,N-1))/(LV(I,N)-LV(I-1,N-1))
5190 ASCL=LC(I-1,N-1)+ASCL1 : GOTO 5400                                    ' $
5200 REM
5210 REM  ASCL = WEIGHTED AVERAGE SKID COST WHEN   X(I-1) < SE/2 < X(I) &
5220 REM                                           N(N-1) < NE < N(N)
5230 REM --------------------------------------------------------------------
5240 ASCL2=(LC(I,N)-LC(I,N-1))*(NE*SE/2*V-LV(I,N-1))/(LV(I,N)-LV(I,N-1))
5250 ASCL=LC(I,N-1)+ASCL2 : GOTO 5400                                      ' $
5260 REM
5270 REM  ASCL = WEIGHTED AVERAGE SKID COST WHEN  SE/2 = X(I) &
5280 REM                                          N(N-1) < NE < N(N)
5290 REM --------------------------------------------------------------------
5300 ASCL3=(LC(I,N)-LC(I-1,N))*(NE*SE/2*V-LV(I-1,N))/(LV(I,N)-LV(I-1,N))
5310 ASCL=LC(I-1,N)+ASCL3 : GOTO 5400                                      ' $
5320 REM
```

```
5330 REM  ASCL = WEIGHTED AVERAGE SKID COST WHEN  X(I-1) < SE/2 < X(I) &
5340 REM                                          NE = N(N)
5350 REM -------------------------------------------------------------------
5360 REM
5370 NEXT N
5380 REM
5390 REM
5400 REM  **** AVERAGE SKID COST FOR RADIAL SKIDDING PATTERN SETTINGS, $ ****
5410 REM
5420 FOR M=1 TO 50
5430 REM -------------------------------------------------------------------
5440 IF SE/2=X(I) AND DE=D(M) THEN ASCD=DC(I,M) : GOTO 5770
5450 REM   ASCD = GENERATED SKID COST                                    ' $
5460 REM -------------------------------------------------------------------
5470 IF SE/2=X(I) OR DE=D(M) THEN GOTO 5480 ELSE GOTO 5500
5480 IF DE>D(M-1) AND DE<D(M) THEN GOTO 5610
5490 IF SE/2>X(I-1) AND SE/2<X(I) THEN GOTO 5670
5500 IF SE/2>X(I-1) AND SE/2<X(I) THEN GOTO 5510
5510 IF DE>D(M-1) AND DE<D(M) THEN GOTO 5550
5520 GOTO 5740
5530 REM
5540 REM -------------------------------------------------------------------
5550 ASCD1=(DC(I,M)-DC(I-1,M-1))*(DE*SE/2*V-DV(I-1,M-1))/(DV(I,M)-DV(I-1,M-1))
5560 ASCD=DC(I-1,M-1)+ASCD1 : GOTO 5770                                  ' $
5570 REM
5580 REM  ASCD = WEIGHTED AVERAGE SKID COST WHEN  X(I-1) < SE/2 < X(I) &
5590 REM                                          D(M-1) < DE < D(M)
5600 REM -------------------------------------------------------------------
5610 ASCD2=(DC(I,M)-DC(I,M-1))*(DE*SE/2*V-DV(I,M-1))/(DV(I,M)-DV(I,M-1))
5620 ASCD=DC(I,M-1)+ASCD2 : GOTO 5770                                    ' $
5630 REM
5640 REM  ASCD = WEIGHTED AVERAGE SKID COST WHEN  X(I) = SE/2 &
5650 REM                                          D(M-1) < DE < D(M)
5660 REM -------------------------------------------------------------------
5670 ASCD3=(DC(I,M)-DC(I-1,M))*(DE*SE/2*V-DV(I-1,M))/(DV(I,M)-DV(I-1,M))
5680 ASCD=DC(I-1,M)+ASCD3 : GOTO 5770                                    ' $
5690 REM
5700 REM  ASCD = WEIGHTED AVERAGE SKID COST WHEN  X(I-1) < SE/2 < X(I) &
5710 REM                                          DE = D(M)
5720 REM -------------------------------------------------------------------
5730 REM
5740 NEXT M
5750 REM
5760 REM
5770 REM  **** TOTAL SKID COST TO SPUR ROADS, $ ****
5780 REM
5790 REM -------------------------------------------------------------------
5800 S2=2*(J*2*(ASCL+ASCD)+(2*J-1)*ASCT+ASCU)
5810 REM
5820 REM  SKID COST (ONE SIDE OF COLLECTOR) FOR VOLUME(S) FROM
5830 REM    RIGHT-ANGLE SKIDDING PATTERN SETTINGS (BOTH SIDES) ALONG SPURS
5840 REM    WITH CONTINUOUS LANDINGS ALONG SPURS = 2*J*ASCL              ' $
5850 REM    RADIAL SKIDDING PATTERN SETTINGS AT END OF SPURS WITH LANDINGS
5860 REM    AT END OF SPURS = 2*J*ASCD                                   ' $
```

```
5870 REM    TRIANGULAR SKIDDING PATTERN SETTINGS WITH CONTINUOUS LANDINGS
5880 REM    ALONG SPURS (SKID TO SPURS) = (2*J-1)*ASCT                    ' $
5890 REM    RIGHT-ANGLE SKIDDING PATTERN SETTING AT END OF COLLECTOR WITH
5900 REM    CONTINUOUS LANDINGS ALONG THE LAST SPUR = ASCU                ' $
5910 REM ----------------------------------------------------------------------
5920 REM
5930 REM
5940 REM  **** TOTAL HAUL COST ON SPUR ROADS, $ ****
5950 REM
5960 REM ----------------------------------------------------------------------
5970 S3=2*HS*SE*V*(J*(.5*(LE^2-SE^2/4)+LE*DE)+((2*J-1)/24+1/16)*SE^2)     ' $
5980 REM
5990 REM  HAUL COST (ONE SIDE OF COLLECTOR) FOR VOLUME(S) FROM
6000 REM    RIGHT-ANGLE SKIDDING PATTERN SETTINGS (BOTH SIDES) ALONG
6010 REM    SPURS WITH CONTINUOUS LANDINGS ALONG SPURS
6020 REM    = .5*HS*SE*V*J*(LE^2-SE^2/4)                                  ' $
6030 REM    RADIAL SKIDDING PATTERN SETTINGS AT END OF SPURS WITH
6040 REM    LANDINGS AT END OF SPURS = HS*SE*V*J*LE*DE                    ' $
6050 REM    TRIANGULAR SKIDDING PATTERN SETTINGS WITH CONTINUOUS LANDINGS
6060 REM    ALONG SPURS (SKID TO SPURS) = HS*SE^3*V*(2*J-1)/24            ' $
6070 REM    RIGHT-ANGLE SKIDDING PATTERN SETTING AT END OF COLLECTOR WITH
6080 REM    CONTINUOUS LANDING ALONG THE LAST SPUR = HS*SE^3*V/16         ' $
6090 REM ----------------------------------------------------------------------
6100 REM
6110 IF K=J THEN GOTO 6240
6120 REM
6130 REM
6140 REM  **** TOTAL HIGH AND LOW STANDARD COLLECTOR COSTS, $ ****
6150 REM
6160 REM ----------------------------------------------------------------------
6170 S4=((D-SE/2-K*SE)*RH+K*SE*RL) : GOTO 6290                            ' $
6180 REM
6190 REM  HIGH STANDARD COLLECTOR COST = (D-SE/2-K*SE)*RH                 ' $
6200 REM  LOW STANDARD COLLECTOR COST = K*SE*RL                           ' $
6210 REM ----------------------------------------------------------------------
6220 REM
6230 REM
6240 REM  **** TOTAL LOW STANDARD COLLECTOR COST ONLY, $ ****
6250 REM
6260 S4=(D-SE/2)*RL                                                       ' $
6270 REM
6280 REM
6290 REM  **** TOTAL SKID COST TO COLLECTOR, $ ****
6300 REM
6310 S5=2*(2*J-1)*ASCT                                                    ' $
6320 REM
6330 REM
6340 IF K=0 AND L=>SE/2 THEN 6370
6350 IF K=J THEN GOTO 6420 ELSE 6470
6360 REM
6370 REM  **** TOTAL HAUL COST ON HIGH STANDARD COLLECTOR ONLY, $ ****
6380 REM
6390 S6=HH*LL*S*D*V : GOTO 6610                                           ' $
6400 REM
```

```
6410 REM
6420 REM  **** TOTAL HAUL COST ON LOW STANDARD COLLECTOR ONLY, $ ****
6430 REM
6440 S6=HL*BB*S*D*V : GOTO 6610                                          ' $
6450 REM
6460 REM
6470 REM  **** TOTAL HAUL COSTS ON HIGH AND LOW STANDARD COLLECTOR, $ ****
6480 REM
6490 REM ---------------------------------------------------------------------
6500 S61=(S*SE*K+(SE/2)^2)*HL*BL*V
6510 S62=(S*SE*K+(SE/2)^2)*HH*L*V
6520 S63=(S*D-(S*SE*K+(SE/2)^2))*HH*LB*V
6530 S6=(S61+S62+S63)                                                    ' $
6540 REM
6550 REM   S61 = HAUL COST ON LOW STD COLL FOR VOL TO LOW STD COLL           ' $
6560 REM   S62 = HAUL COST ON HIGH STD COLL FOR VOL TO LOW STD COLL          ' $
6570 REM   S63 = HAUL COST ON HIGH STD COLL FOR VOL TO HIGH STD COLL         ' $
6580 REM ---------------------------------------------------------------------
6590 REM
6600 REM
6610 REM  **** TOTAL AREA, TOTAL VOLUME, TOTAL COST AND AVERAGE COST ****
6620 REM
6630 AREA=D*S/43560!                                      ' TOTAL AREA, ACRE
6640 VOL=S*D*V                                            ' TOTAL VOL , CCF
6650 COST=S1+S2+S3+S4+S5+S6                               ' TOTAL COST  , $
6660 TC=COST/VOL                                          ' AVE COST , $/CCF
6670 REM
6680 REM  IF AVERAGE COST IN $/ACRE IS DESIRED, CHANGE TC=COST/VOL ($/CCF)
6690 REM  TO TC=COST/AREA ($/ACRE). BOTH MINIMUM VALUES WILL GIVE THE SAME
6700 REM  RESULTS.
6710 REM
6720 IF TC>TCMIN THEN 6760                            ' FIND MINIMUM AVE COST
6730 REM
6740 TCMIN=TC : SEMIN=SE : LEMIN=LE : DEMIN=DE : KMIN=K : JMIN=J : BMIN=B
6750 LMIN=L : SMIN=S
6760 NEXT K
6770 NEXT J
6780 NEXT NE
6790 NEXT DE
6800 REM
6810 REM  ******** END OF LOOPS ********
6820 REM
6830 PRINT USING " MINIMUM AVERAGE COST = $###.###/CCF ";TCMIN
6840 PRINT "
6850 PRINT USING " LENGTH OF COLLECTOR = #### FEET ";BMIN
6860 PRINT "
6870 PRINT USING " COLLECTOR  SPACING = #### FEET ";SMIN
6880 PRINT "
6890 PRINT USING " LENGTH OF HIGH STANDARD COLLECTOR = #### FEET ";LMIN
6900 PRINT "
6910 PRINT USING " LENGTH OF LOW STANDARD COLLECTOR = #### FEET ";BMIN-LMIN
6920 PRINT "
6930 PRINT USING " LENGTH OF SPUR ROAD = #### FEET ";LEMIN
6940 PRINT "
```

```
6950 PRINT USING " SPUR ROAD  SPACING = #### FEET ";SEMIN
6960 PRINT "
6970 PRINT USING " DEPTH OF RADIAL SKIDDING PATTERN = ### FEET ";DEMIN
6980 PRINT "
6990 PRINT USING " NUMBER OF SPUR ROADS PERPENDICULAR TO ONE SIDE OF THE
COLLECTOR = ##" ;JMIN
7000 PRINT "
7010 PRINT USING " NUMBER OF ROAD SEGMENTS TO LOW STANDARD COLLECTOR = # ";KMIN
7020 PRINT "
7030 END
```

APPENDIX M

Program 2A. Single Entry with Linear Skidding Costs

Program Listing

```
10 STARTIME=TIMER
20  REM     ***************************************************************
30  REM     *                                                             *
40  REM     *             SINGLE ENTRY WITH LINEAR SKIDDING COSTS         *
50  REM     *                                                             *
60  REM     *             HOOKE AND JEEVES PATTERN SEARCH METHOD          *
70  REM     *                                                             *
80  REM     ***************************************************************
90  REM
100 REM
110 REM    ****************************************************************
120 REM    *                                                              *
130 REM    *      PROGRAM TO DETERMINE OPTIMUM SETTINGS DIMENSIONS FOR    *
140 REM    *                                                              *
150 REM    *      TRIANGULAR, RIGHT-ANGLE AND RADIAL SKIDDING PATTERNS    *
160 REM    *                                                              *
170 REM    *      ASSOCIATED WITH HIGH AND LOW STANDARD COLLECTOR         *
180 REM    *                                                              *
190 REM    ****************************************************************
200 REM
210 REM
220 REM  PURPOSE: TO FIND THE MINIMUM SUM OF ROADING, SKIDDING AND HAULING
230 REM           COST.
240 REM
250 REM           TO FIND THE OPTIMUM SPACINGS FOR COLLECTORS AND SPUR ROADS.
260 REM
270 REM           TO FIND THE OPTIMUM LENGTHS FOR HIGH AND LOW STANDARD
280 REM           COLLECTOR.
290 REM
300 REM           TO DETERMINE THE OPTIMUM SETTINGS DIMENSIONS FOR VARIOUS
310 REM           SKIDDING PATTERNS ADJACENT TO ONE AND ANOTHER.
320 REM
330 REM
340 REM  **** ASSIGNED CONDITIONS ****
350 REM
360 REM  NUMBER OF ENTRIES = 1
370 REM  SKIDDING COST = LINEAR (AVERAGE SKIDDING DISTANCE)
380 REM
390 REM
400 REM  **** SKIDDING PATTERNS ****
410 REM
420 REM  DESIGN TRIANGULAR SKIDDING PATTERN SETTINGS WHICH ARE RIGHT-ANGLE
430 REM  TRIANGLE IN SHAPE ALONG COLLECTOR AND SPURS. CONTINUOUS LANDINGS ARE
440 REM  ALLOWED ALONG COLLECTOR AND SPURS. SKIDDING DIRECTION IS PERPENDICULAR
450 REM  TO COLLECTOR OR SPURS.
```

```
460 REM
470 REM  DESIGN RIGHT-ANGLE SKIDDING PATTERN SETTINGS WHICH ARE SQUARE IN SHAPE
480 REM  ALONG THE LAST SPUR AND END OF COLLECTOR. CONTINUOUS LANDINGS ARE
490 REM  ALLOWED ALONG THE LAST SPUR. SKIDDING DIRECTION IS PERPENDICULAR TO
500 REM  SPURS.
510 REM
520 REM  DESIGN RIGHT-ANGLE SKIDDING PATTERN SETTINGS IN RECTANGULAR SHAPE
530 REM  ALONG SPURS. CONTINUOUS LANDINGS ARE ALLOWED ALONG SPURS. SKIDDING
540 REM  DIRECTION IS PERPENDICULAR TO SPURS.
550 REM
560 REM  DESIGN RADIAL SKIDDING PATTERN SETTINGS IN RECTANGULAR SHAPE AT THE END
570 REM  OF SPURS. LANDINGS AT END OF SPURS.
580 REM
590 REM
600 REM  ************** SINGLE ENTRY WITH LINEAR SKIDDING COSTS *************
610 REM
620 REM
630 REM  **** VARIABLES ( SUBJECT TO CHANGE i.e. INPUTS ) ****
640 REM
650 REM --------------------------------------------------------------------
660 REM
670 REM        VOLUME PER ACRE OR PER SQUARE FEET, CCF/ACRE OR CCF/FT^2
680 REM        DEPTH OF UNIT, FT
690 REM        ROAD CONSTRUCTION COSTS, $/FT                    ' FT =FEET
700 REM        SKIDDING COSTS, $/CCF/FT
710 REM        HAULING COSTS, $/CCF/FT
720 REM
730 REM
740 REM  CCF = UNITS OF 100 CUBIC FEET OF TIMBER
750 REM  VOLUME = 10 CCF PER ACRE OR 10/43560 PER SQUARE FEET
760 REM
770 V=10/43560!                                                ' VOLUME, CCF/FT^2
780 D=8000                                                     ' DEPTH OF UNIT, FT
790 REM
800 REM   COLL = COLLECTOR : STD = STANDARD : AVE = AVERAGE : DIS = DISTANCE
810 REM
820 REM
830 REM  **** ROAD CONSTRUCTION COSTS ****
840 REM
850 REM  ROAD COSTS FOR COLLECTOR AND SPURS
860 REM
870 RH=11000/5280                                            ' HIGH STD COLL, $/FT
880 RL=5700/5280                                             ' LOW STD COLL, $/FT
890 RS=5700/5280                                             ' SPUR ROAD, $/FT
900 REM
910 REM  **** SKIDDING COSTS ****
920 REM
930 SC=1.74/100                                           ' SKID TO COLL, $/CCF/FT
940 SS=1.74/100                                           ' SKID TO SPUR, $/CCF/FT
950 REM
960 REM  **** HAULING COSTS ****
970 REM
980 HH=2/5280                                  ' HAUL ON HIGH STD COLL, $/CCF/FT
990 HL=5.15/5280                               ' HAUL ON LOW STD COLL , $/CCF/FT
```

```
1000 HS=5.15/5280                              ' HAUL ON SPUR, $/CCF/FT
1010 REM -----------------------------------------------------------------
1020 REM
1030 REM
1040 REM  **** ASSIGN VARIABLES ****
1050 REM
1060 REM  DE = DEPTH (PARALLEL TO SPUR) OF RADIAL SKIDDING PATTERN SETTING, FT.
1070 REM  NE = LENGTH OF SPUR BETWEEN TRIANGULAR AND RADIAL SKIDDING PATTERN
1080 REM       SETTING WHICH IS THE LENGTH OF RIGHT-ANGLE SKIDDING PATTERN
1090 REM       SETTING ALONG SPUR, FT.
1100 REM  J  = # OF SPURS (MUST BE AT LEAST ONE) PERPENDICULAR TO ONE SIDE OF
1110 REM       THE COLLECTOR FOR THE DEPTH OF THE UNIT.
1120 REM  K  = # OF ROAD SEGMENTS (ZERO AND UP TO J) TO LOW STANDARD COLLECTOR.
1130 REM
1140 Z=0
1150 REM
1160 REM          ***************************************************
1170 REM          *                                                 *
1180 REM          *       HOOKE AND JEEVES PATTERN SEARCH METHOD    *
1190 REM          *                                                 *
1200 REM          ***************************************************
1210 REM
1220 :
1230 GOTO 19000
1240 :
1500 DE=X(1) : NE=X(2) : J=X(3) : K=X(4)
1510 REM
1520 REM  *************************
1530 REM  * EQUATIONS FOR SINGLE  *
1540 REM  * ENTRY WITH LINEAR     *
1550 REM  * SKIDDING COST         *
1560 REM  *************************
1570 REM
1580 REM
1590 REM  **** ROAD LENGTHS AND SPACINGS ****
1600 REM
1610 REM
1620 SE=D/J                                       ' SPUR ROAD  SPACING, FT
1630 B=D-SE/2                                     ' LENGTH OF COLLECTOR, FT
1640 LE=SE/2+NE                                   ' LENGTH OF SPUR ROAD, FT
1650 S=2*(LE+DE)                                  ' COLLECTOR  SPACING, FT
1660 RD=1/6*SQR(SE^2+DE^2)+1/3*SQR(SE^2/16+DE^2)  ' AVE SKID DIS (RADIAL), FT
1670 REM
1680 IF J>K THEN L=D-.5*SE-K*SE ELSE L=0         ' LENGTH OF HIGH STD COLL,FT
1690 REM
1700 REM  AS LONG AS J>K THEN PART OR ALL OF THE COLLECTOR WILL BE IN HIGH
1710 REM  STANDARD.
1720 REM  IF K=0 THEN THE WHOLE COLLECTOR WILL BE IN HIGH STANDARD.
1730 REM  IF J=K THEN THERE WILL BE NO HIGH STANDARD COLLECTOR, L=0.
1740 REM
1750 REM
1760 REM  **** VOLUMES FROM VARIOUS SKIDDING PATTERNS SETTINGS ****
1770 REM
1780 VS=((LE+DE)*SE-.5*(SE/2)^2)*V                                  ' CCF
```

```
1790 REM
1800 REM  VS = VOLUMES ENTER THE LAST SPUR (FROM RIGHT-ANGLE SKIDDING PATTERN
1810 REM       SETTING AT END OF COLLECTOR, TRIANGULAR AND RIGHT-ANGLE SKIDDING
1820 REM       PATTERN SETTINGS ALONG THE LAST SPUR, AND RADIAL SKIDDING
1830 REM       PATTERN SETTING AT END OF THE LAST SPUR) EXCEPT VOLUME FROM THE
1840 REM       TRIANGULAR SKIDDING PATTERN SETTING ADJACENT TO THE COLLECTOR.
1850 REM
1860 VL=((LE+DE)*SE-(SE/2)^2)*V                                      ' CCF
1870 REM
1880 REM  VL = VOLUMES ENTER EACH SPUR (FROM TRIANGULAR AND RIGHT-ANGLE
1890 REM       SKIDDING PATTERN SETTINGS ALONG SPUR AND RADIAL SKIDDING PATTERN
1900 REM       AT END OF SPUR) EXCEPT VOLUMES FROM TWO OF THE TRIANGULAR
1910 REM       SKIDDING PATTERN SETTINGS ADJACENT TO THE COLLECTOR.
1920 REM
1930 VC=.5*(SE/2)^2*V                                                ' CCF
1940 REM
1950 REM  VC = VOLUME ENTER THE COLLECTOR FROM ANY ONE OF THE TRIANGULAR
1960 REM       SKIDDING PATTERN SETTINGS ADJACENT TO THE COLLECTOR.
1970 REM
1980 REM
1990 REM  **** AVERAGE HAUL DISTANCE ON COLLECTOR ****
2000 REM
2010 REM
2020 IF L>0 AND K>0 THEN 2600                                  ' CONDITION #1
2030 REM
2040 REM  CONDITION #1 THAT BOTH HIGH AND LOW STANDARD COLLECTORS EXIST, THEN
2050 REM  GO TO EQUATIONS THAT COMPUTE AVERAGE HAUL DISTANCE ON HIGH AND LOW
2060 REM  STANDARD COLLECTORS.
2070 REM
2080 IF K>0 OR L=0 THEN 2330                                   ' CONDITION #2
2090 REM
2100 REM  CONDITION #2 THAT LOW STANDARD COLLECTOR OR NO HIGH STANDARD
2110 REM  COLLECTOR EXISTS, THEN GO TO EQUATION THAT COMPUTES AVERAGE HAUL
2120 REM  DISTANCE ON LOW STANDARD COLLECTOR ONLY.
2130 REM
2140 REM
2150 REM  IF CONDITION #1 AND #2 ARE NOT TRUE THEN HIGH STANDARD COLLECTOR
2160 REM  ONLY EXISTS.
2170 REM
2180 REM
2190 REM  **** EQUATION THAT COMPUTES AVERAGE HAUL DISTANCE ON HIGH ****
2200 REM                      STANDARD COLLECTOR ONLY
2210 REM
2220 REM ------------------------------------------------------------------
2230 LL1=L*VS+(.5*(L/SE-.5)^2*VL+((L/SE)^2-1/12)*VC)*SE
2240 LL=LL1/(VS+(L/SE-.5)*VL+2*L*VC/SE)                               ' FT
2250 REM
2260 REM  HAULING DISTANCE FOR
2270 REM    VS = L                                                    ' FT
2280 REM    VL = .5*(L/SE-.5)^2*SE                                    ' FT
2290 REM    VC = ((L/SE)^2-1/12)*SE                                   ' FT
2300 REM  SUM OF VOLUME FOR THE ABOVE AREAS = VS+(L/SE-.5)*VL+2*L*VC/SE  ' CCF
2310 REM ------------------------------------------------------------------
2320 REM
```

```
2330 IF L>0 OR K=0 THEN 2540
2340 REM
2350 REM  CONDITION THAT HIGH STANDARD COLLECTOR OR NO LOW STANDARD COLLECTOR
2360 REM  EXISTS, THEN GO TO COST COMPUTATIONS. IF THE ABOVE CONDITION IS NOT
2370 REM  TRUE THEN LOW STANDARD COLLECTOR ONLY EXISTS.
2380 REM
2390 REM
2400 REM  **** EQUATION THAT COMPUTES AVERAGE HAUL DISTANCE ON LOW ****
2410 REM                    STANDARD COLLECTOR ONLY
2420 REM
2430 REM ---------------------------------------------------------------------
2440 BB1=B*VS+(.5*(B/SE-.5)^2*VL+((B/SE)^2-1/12)*VC)*SE
2450 BB=BB1/(VS+(B/SE-.5)*VL+2*B*VC/SE)                                ' FT
2460 REM
2470 REM  HAULING DISTANCE FOR
2480 REM    VS = B                                                     ' FT
2490 REM    VL = .5*(B/SE-.5)^2*SE                                     ' FT
2500 REM    VC = ((B/SE)^2-1/12)*SE                                    ' FT
2510 REM  SUM OF VOLUME FOR THE ABOVE AREAS = (VS+(B/SE-.5)*VL+2*B*VC/SE) ' CCF
2520 REM ---------------------------------------------------------------------
2530 REM
2540 IF K=0 OR L=0 THEN 2890
2550 REM
2560 REM  CONDITION THAT NO LOW STANDARD COLLECTOR OR NO HIGH STANDARD
2570 REM  COLLECTOR EXISTS, THEN GO TO COST COMPUTATIONS.
2580 REM
2590 REM
2600 REM  **** EQUATION THAT COMPUTES AVERAGE HAUL DISTANCE ON ****
2610 REM                  LOW STANDARD COLLECTOR
2620 REM
2630 REM ---------------------------------------------------------------------
2640 BL1=(K*SE*VS+K*(K-1)*SE*VL/2+K^2*SE*VC)
2650 BL=BL1/(VS+(K-1)*VL+2*K*VC)                                       ' FT
2660 REM
2670 REM  HAULING DISTANCE FOR
2680 REM    VS = K*SE                                                  ' FT
2690 REM    VL = K*(K-1)*SE/2                                          ' FT
2700 REM    VC = K^2*SE                                                ' FT
2710 REM  SUM OF VOLUME FOR THE ABOVE AREAS = (VS+(K-1)*VL+2*K*VC)        ' CCF
2720 REM ---------------------------------------------------------------------
2730 REM
2740 REM
2750 REM  **** EQUATION THAT COMPUTES AVERAGE HAUL DISTANCE ON ****
2760 REM                  HIGH STANDARD COLLECTOR
2770 REM
2780 REM ---------------------------------------------------------------------
2790 LB1=((L/SE+.5)^2*SE*VL/2+((L/SE)^2-1/12)*SE*VC)
2800 LB=LB1/((L/SE+.5)*VL+2*L*VC/SE)                                   ' FT
2810 REM
2820 REM  HAULING DISTANCE FOR
2830 REM    VL = (L/SE+.5)^2*SE/2                                      ' FT
2840 REM    VC = ((L/SE)^2-1/12)*SE                                    ' FT
2850 REM  SUM OF VOLUME FOR THE ABOVE AREAS = (L/SE+.5)*VL+2*L*VC/SE     ' CCF
2860 REM ---------------------------------------------------------------------
```

```
2870 REM
2880 REM
2890 REM  ************************* COST COMPUTAIONS *************************
2900 REM
2910 REM
2920 REM  **** TOTAL SPUR ROADS COST, $ ****
2930 REM
2940 S1=2*J*RS*LE                                                         ' $
2950 REM
2960 REM
2970 REM  **** TOTAL SKID COST TO SPUR ROADS, $ ****
2980 REM
2990 REM ------------------------------------------------------------------
3000 S2=2*SS*SE*V*(J*((SE/4)*(LE-SE/2)+RD*DE)+((2*J-1)/48+1/16)*SE^2)     ' $
3010 REM
3020 REM  SKID COST (ONE SIDE OF COLLECTOR) FOR VOLUME(S) FROM
3030 REM    RIGHT-ANGLE SKIDDING PATTERN SETTINGS (BOTH SIDES) ALONG SPURS
3040 REM    WITH CONTINUOUS LANDINGS ALONG SPURS
3050 REM    = SS*SE*V*J*(SE/4)*(LE-SE/2)                                  ' $
3060 REM    RADIAL SKIDDING PATTERN SETTINGS AT END OF SPURS WITH
3070 REM    LANDINGS AT END OF SPURS = SS*SE*V*J*RD*DE                    ' $
3080 REM    TRIANGULAR SKIDDING PATTERN SETTINGS WITH CONTINUOUS LANDINGS
3090 REM    ALONG SPURS (SKID TO SPURS) = SS*SE^3*V*(2*J-1)/48            ' $
3100 REM    RIGHT-ANGLE SKIDDING PATTERN SETTING AT END OF COLLECTOR WITH
3110 REM    CONTINUOUS LANDINGS ALONG THE LAST SPUR = SS*SE^3*V/16        ' $
3120 REM ------------------------------------------------------------------
3130 REM
3140 REM
3150 REM  **** TOTAL HAUL COST ON SPUR ROADS, $ ****
3160 REM
3170 REM ------------------------------------------------------------------
3180 S3=2*HS*SE*V*(J*(.5*(LE^2-SE^2/4)+LE*DE)+((2*J-1)/24+1/16)*SE^2)     ' $
3190 REM
3200 REM  HAUL COST (ONE SIDE OF COLLECTOR) FOR VOLUME(S) FROM
3210 REM    RIGHT-ANGLE SKIDDING PATTERN SETTINGS (BOTH SIDES) ALONG
3220 REM    SPURS WITH CONTINUOUS LANDINGS ALONG SPURS
3230 REM    = .5*HS*SE*V*J*(LE^2-SE^2/4)                                  ' $
3240 REM    RADIAL SKIDDING PATTERN SETTINGS AT END OF SPURS WITH
3250 REM    LANDINGS AT END OF SPURS = HS*SE*V*J*LE*DE                    ' $
3260 REM    TRIANGULAR SKIDDING PATTERN SETTINGS WITH CONTINUOUS LANDINGS
3270 REM    ALONG SPURS (SKID TO SPURS) = HS*SE^3*V*(2*J-1)/24            ' $
3280 REM    RIGHT-ANGLE SKIDDING PATTERN SETTING AT END OF COLLECTOR WITH
3290 REM    CONTINUOUS LANDING ALONG THE LAST SPUR = HS*SE^3*V/16         ' $
3300 REM ------------------------------------------------------------------
3310 REM
3320 IF K=J THEN GOTO 3450
3330 REM
3340 REM
3350 REM  **** TOTAL HIGH AND LOW STANDARD COLLECTOR COSTS, $ ****
3360 REM
3370 REM ------------------------------------------------------------------
3380 S4=((D-SE/2-K*SE)*RH+K*SE*RL) : GOTO 3500                           ' $
3390 REM
3400 REM   HIGH STANDARD COLLECTOR COST = (D-SE/2-K*SE)*RH                ' $
```

```
3410 REM   LOW STANDARD COLLECTOR COST = K*SE*RL                              ' $
3420 REM ---------------------------------------------------------------------
3430 REM
3440 REM
3450 REM  **** TOTAL LOW STANDARD COLLECTOR COST ONLY, $ ****
3460 REM
3470 S4=(D-SE/2)*RL                                                           ' $
3480 REM
3490 REM
3500 REM  **** TOTAL SKID COST TO COLLECTOR, $ ****
3510 REM
3520 S5=((2*J-1)/24)*SC*SE^3*V                                                ' $
3530 REM
3540 REM
3550 IF K=0 AND L=>SE/2 THEN 3580
3560 IF K=J THEN GOTO 3630 ELSE 3680
3570 REM
3580 REM  **** TOTAL HAUL COST ON HIGH STANDARD COLLECTOR ONLY, $ ****
3590 REM
3600 S6=HH*LL*S*D*V : GOTO 3820                                               ' $
3610 REM
3620 REM
3630 REM  **** TOTAL HAUL COST ON LOW STANDARD COLLECTOR ONLY, $ ****
3640 REM
3650 S6=HL*BB*S*D*V : GOTO 3820                                               ' $
3660 REM
3670 REM
3680 REM  **** TOTAL HAUL COST ON HIGH AND LOW STANDARD COLLECTOR, $ ****
3690 REM
3700 REM ---------------------------------------------------------------------
3710 S61=(S*SE*K+(SE/2)^2)*HL*BL*V
3720 S62=(S*SE*K+(SE/2)^2)*HH*L*V
3730 S63=(S*D-(S*SE*K+(SE/2)^2))*HH*LB*V
3740 S6=(S61+S62+S63)                                                         ' $
3750 REM
3760 REM   S61 = HAUL COST ON LOW STD COLL FOR VOL TO LOW STD COLL             ' $
3770 REM   S62 = HAUL COST ON HIGH STD COLL FOR VOL TO LOW STD COLL           ' $
3780 REM   S63 = HAUL COST ON HIGH STD COLL FOR VOL TO HIGH STD COLL          ' $
3790 REM ---------------------------------------------------------------------
3800 REM
3810 REM
3820 REM  **** TOTAL AREA, TOTAL VOLUME, TOTAL COST AND AVERAGE COST ****
3830 REM
3840 AREA=S*D/43560!                                     ' TOTAL AREA, ACRE
3850 VOL=S*D*V                                           ' TOTAL VOLUME, CCF
3860 COST=S1+S2+S3+S4+S5+S6                              ' TOTAL COST, $
3870 F=COST/VOL                                          ' AVE COST , $/CCF
3880 Z=Z+1
3890 REM
3900 REM  IF AVERAGE COST IN $/ACRE IS DESIRED, CHANGE F=COST/VOL ($/CCF)
3910 REM  TO F=COST/AREA ($/ACRE). BOTH MINIMUM VALUES WILL GIVE THE SAME
3920 REM  RESULTS.
3930 REM
3940 :
```

```
3950 REM CHECK CONSTRAINTS
3960 FOR IX=1 TO NV
3970 IF X(IX)>3000 OR X(IX)<0 THEN GOTO 4020
3980 NEXT IX
3990 RETURN
4000 :
4010 REM PENALIZE
4020 F=25
4030 RETURN
4040 :
12000 REM **********************
12010 REM * THIS SUBROUTINE    *
12020 REM * APPLIES THE HOOKE  *
12030 REM * & JEEVES ALGORITHM *
12040 REM * OF EXPLORATION AND *
12050 REM * PATTERN MOVES TO   *
12060 REM * FIND THE UNCON-    *
12070 REM * STRAINED MINIMUM   *
12080 REM * OF A MERIT FUNC-   *
12090 REM * TION.  THE USER    *
12100 REM * MUST SUPPLY A      *
12110 REM * STARTING VECTOR    *
12120 REM * X(I).              *
12130 REM *                    *
12140 REM * PARAMETERS:        *
12150 REM *                    *
12160 REM *  NV  - THE NUMBER  *
12170 REM *        OF DESIGN   *
12180 REM *        VARIABLES.  *
12190 REM *                    *
12200 REM * R    - INITIAL     *
12210 REM *        EXPLORATION *
12220 REM *        STEP SIZE   *
12230 REM *                    *
12240 REM * A    - ACCELERA-   *
12250 REM *        TION FACTOR *
12260 REM *        SET >=1.0   *
12270 REM *                    *
12280 REM * RF   - FINAL       *
12290 REM *        EXPLORATION *
12300 REM *        STEP SIZE.  *
12310 REM *                    *
12320 REM * 1500 - SUBROUTINE  *
12330 REM *        TO EVALUATE *
12340 REM *        THE MERIT   *
12350 REM *        VALUE "F"   *
12360 REM *        USING A     *
12370 REM *        DESIGN VEC- *
12380 REM *        TOR "X(I)"  *
12390 REM *                    *
12400 REM * FB   - ON RETURN   *
12410 REM *        THE BEST    *
12420 REM *        MERIT VALUE *
12430 REM *        FOUND.      *
```

```
12440 REM *                    *
12450 REM * XB(I)- THE DESIGN  *
12460 REM *        VECTOR COR- *
12470 REM *        RESPONDING  *
12480 REM *        TO FB.      *
12490 REM *                    *
12500 REM **********************
12510 :
12520 GOSUB 1500
12530 FB=F
12540 R=R
12550 FOR N=1 TO NV
12560 X(N)=XB(N)
12570 NEXT N
12580 :
12590 REM EXPLORE
12600 GOSUB 12960
12610 :
12620 REM IS IT BETTER?
12630 REM IF SO GO TO PATTERN
12640 IF FE<FB THEN GOTO 12720
12650 :
12660 REM IF NOT DECREASE
12670 REM STEP SIZE DOWN TO RF
12680 IF R<RF THEN RETURN
12690 R=R/2
12700 GOTO 12550
12710 :
12720 REM MAKE PATTERN MOVE
12730 FOR N=1 TO NV
12740 X(N)=XE(N)+A*(XE(N)-XB(N))
12750 NEXT N
12760 :
12770 REM REPLACE XB WITH XE
12780 FOR N=1 TO NV
12790 XB(N)=XE(N)
12800 NEXT N
12810 FB=FE
12820 :
12830 REM EXPLORE FROM HERE
12840 GOSUB 12960
12850 :
12860 REM IF ITS BETTER
12870 REM REPEAT PATTERN
12880 :
12890 IF FE<FB GOTO  12720
12900 :
12910 REM IF NOT SO BACK TO
12920 REM BEST BASE POINT
12930 REM AND EXPLORE
12940 GOTO 12540
12950 :
12960 REM **********************
12970 REM * THIS SUBROUTINE    *
```

```
12980 REM * PERFORMS THE        *
12990 REM * EXPLORATION STEP    *
13000 REM **********************
13010 :
13020 GOSUB 1500 :FF=F
13030 FE=F
13040 FOR N=1 TO NV
13050 XE(N)=X(N)
13060 X(N)=X(N)+R
13070 GOSUB 1500
13080 IF F<FF GOTO 13140
13090 X(N)=X(N)-2*R
13100 GOSUB 1500
13110 IF F<FF GOTO 13140
13120 X(N)=X(N)+R
13130 GOTO 13160
13140 FE=F : FF=FE
13150 XE(N)=X(N)
13160 NEXT N
13170 RETURN
13180 :
19000 REM **********************
19010 REM * DRIVER PROGRAM      *
19020 REM * PERFORMS AN UNCON- *
19030 REM * STRAINED OPTIMIZA- *
19040 REM * TION OF A MERIT     *
19050 REM * FUNCTION.           *
19060 REM **********************
19070 :
19080 RF=2 : A=1
19090 NV=4 : R=2
19100 DIM XB(50),X(50),XE(50)
19110 :
19120 REM FEASIBLE START POINT
19130 X(1)=600 : X(2)=1200 : X(3)=14 : X(4)=4
19140 FOR IX=1 TO NV
19150 XB(IX)=X(IX)
19160 NEXT IX
19170 :
19180 REM CALL HOOKE & JEEVES
19190 GOSUB 12000
19200 :
19210 REM
19220 REM
19230 REM ******** END OF LOOPS ********
19240 REM
19250 PRINT "
19260 PRINT USING " MINIMUM AVERAGE COST = $###.###/CCF ";F
19270 PRINT "
19280 PRINT USING " LENGTH OF COLLECTOR = #### FEET ";B
19290 PRINT "
19300 PRINT USING " COLLECTOR  SPACING = #### FEET ";S
19310 PRINT
19320 PRINT USING " LENGTH OF HIGH STANDARD COLLECTOR = #### FEET ";L
```

```
19330 PRINT "
19340 PRINT USING " LENGTH OF LOW STANDARD COLLECTOR = #### FEET ";B-L
19350 PRINT "
19360 PRINT USING " LENGTH OF SPUR ROAD = #### FEET ";LE
19370 PRINT "
19380 PRINT USING " SPUR ROAD  SPACING = #### FEET ";SE
19390 PRINT "
19400 PRINT USING " DEPTH OF RADIAL SKIDDING PATTERN = ### FEET ";DE
19410 PRINT "
19420 PRINT USING " NUMBER OF SPUR ROADS PERPENDICULAR TO ONE SIDE OF THE
COLLECTOR = ##" ;J
19430 PRINT "
19440 PRINT USING " NUMBER OF ROAD SEGMENTS TO LOW STANDARD COLLECTOR = # ";K
19450 PRINT "
19460 ENDTIME=TIMER : N=ENDTIME-STARTIME :PRINT
19470 PRINT "PROGRAM EXECUTION FOR "Z" COMBINATIONS WAS "N" SECONDS"
19480 END
```