A COMPUTER PROGRAMME FOR THE EVALUATION OF ALTERNATIVE METHODS

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The shortest path method of analysing network diagrams in which alternative methods of performing farm tasks was described by Preston (6 & 7). This paper describes the application of computers to the shortest path network technique (SPNA) for the evaluation of alternative irrigation systems, using data prepared by Mussivand and Preston (1). A typical network, illustrating the main alternative methods of irrigation, is contained in Figure 1. This example ignores, for reason of space, the evaluation of some of the more complex effects, such as the reduction in labour by increasing pipe lengths or the effects of certain types of crops. These could have been included by using more sophisticated computer sub-routines. These cannot be included in break-even charts such as are given in Figure 5, whose limitations are described later.

The computer programme which is described in this paper is a new and mechanised technique for speedily and cheaply solving problems previously only resolvable by break-even charts or linear programme analyses.

The Programme

The programme has been written so that any number of alternatives can be optimized by using basic networks to which many alternative "T" formulae and "V" variables can subsequently be applied. This paper is intended to allow any IBM 7040 Fortran user to solve problems which have the general formula.

Minimize \( \sum C_i X_{ij} \)

where \( C \) is the total route length through the network
\( X \) is any individual connection
\( i \) is an origin node
\( j \) is a terminal node.

This may be paraphrased as finding the cheapest cost method from an array of alternatives displayed as a network.

The programme, which is written in four parts, is illustrated in block diagram form in Figure 2.

Part I is the basic critical path routine which is the algorithm described below.

Part II is a sub-routine which contains "T" formulae from which arrow lengths are calculated. "T" formulae are static data relating to arrow lengths.

Part III contains the variables such as wages, acreage to be irrigated, interest rate, and so on, which are given as \( V(1) \) \( V(2) \ldots \) \( V(N) \). These are included separately from the "T" formulae to allow flexibility in analysis of the basic network.

Part IV is the tabulation of the matrix of the network diagram. This is given in Figure 1, part of whose matrix is given in Table 1.

The Solution

The full tabulation of the costs of each component arrow is preceded by a short extract of the shortest path, which is found by the following formula:

\[ \text{LS}(J) = \text{D}(IJ) + \text{ES}(I) = 0 \]  

where
\( \text{LS} \) = latest start date \( \text{D} \) = duration of the operation or activity.
\( \text{ES} \) = earliest start date \( \text{I} \) = origin node \( \text{J} \) = terminal node

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Figure 1. Network Diagram


CANADIAN AGRICULTURAL ENGINEERING VOL. 9, 1967 109
Algorithm

The algorithm used by the computer is similar to L. R. Ford and D. R. Fulkerson's (12) and is based on assigning a sequence of node numbers so that no activity has a start node number which is less than that of any preceding node. Having numbered the nodes, the computer dates each, on a forward and then on a backward path, from the start to the finish and vice versa. Date is equivalent to the total cost up to that node.

In the forward pass each node is dated in ascending node-number order with the earliest date or the shortest duration from the start at which it can be reached. The forward pass commences with the first node and proceeds in numerical sequence of nodes until the last node is reached.

The backward pass is then commenced. This differs substantially from the normal critical-longest-path procedures such as IBM's, PERT, RAMPS, or PECOS. By descending node numbers each node is ascribed the shortest of all possible alternative routes backwards from the network's terminal node. This retreat ends with the first node to which time zero must be given. These node dates are then allotted to the activities that join them and the calculation is made of the difference by formula (2) above. Those activities and operations having zero difference lie on the critical shortest path.

Method of Use

The way in which the computer will operate is governed by a "parameter" card. This parameter card contains eight items of information essential to the computer; they are listed to provide the reader with an indication of the size of problem which can be resolved by computer.

Copies of the full programme are available on request from the author.

PARAMETER CARD

<table>
<thead>
<tr>
<th>Columns</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - 2</td>
<td>number identifying the run</td>
</tr>
<tr>
<td>6 - 12</td>
<td>N1: the number of activities—the programme has a limit of 1,000.</td>
</tr>
<tr>
<td>13 - 15</td>
<td>N2: the number of nodes—the programme has a limit of 600.</td>
</tr>
<tr>
<td>16 - 20</td>
<td>N3: if random or non-random node numbering is to be used, an indication is provided. The programme has provision for either.</td>
</tr>
</tbody>
</table>

If the "V" variables are to be used, and the use of V's is the main strength of the technique, "T" formulae must be used. Each can be of up to 10 lines of 70 characters each. N4 allows for scalar values to be used instead of simple "T" formulae.

V(17), which is labour cost per hour, is used frequently in for example T(38), whose value is 1.5 hours at the prevailing wage rate times the average number of sets per year at the expected times per acre. This type of "T" sub-routine

![Figure 2. Outline Block Diagram of Computer Programme.](image-url)
formula is appropriate where there is! a

direct linear relationship. Such rela-
tionships do not apply in the case of
machines which may accommodate up

to say 150 acres per year and a second
unit would be required for 151 to 300
acres. The charges on capital costs of
such equipment should therefore be
graduated in steps of 150 acres; this
feature can be accommodated by IF
statements in the "T" formulae.

The IF statement for T(12) would
read . . .

IF the irrigated acreage V(33)
is less than 150 then T,(12) would
equal the current cost of the
equipment times the prevailing
interest rate, V(34).

In FORTRAN IV this is:—
IF V(##)LT 150.00 T(12) = 1500* V(34)

Another use of the IF statements in
the "T" formulae is to accommodate a
form of by-pass switch on an activity
such as T(94) which allows for the use
of fertilizer if the value of the fertilizer
is equal to or less than the added value
of the crop likely to be gained from it.

The limitations to the considerations
which can be included in the "T" for-
muale are thus only the limitations of
the available data in respect of any
machine alternative facing a farmer.

Break-Even Charts

An alternative method of making such
comparisons might be the break-even
charts such as given in Figures 3a, 3b
and 3c which are based on the data
given in Table 1. The limitations of
break-even charts is that a very great
number of them would need to be pre-
pared for all alternative combinations
of circumstances. These would take a
great deal of time to prepare. Further
inaccuracies are introduced when the
assumptions of linear relationships and
the economies of scale are made. As
has been shown above, these can be
readily accommodated in a computer
sub-routine in IF statements. This
greatly favours the use of a digital
computer and network diagram as a
universal statement of farming proced-
uire. The break-even chart can, how-
ever, only be replaced in this way
when the network diagrams for all
agricultural engineering operations have
been prepared.

It can be seen from Figures 3a, 3b
and 3c that as the number of irriga-
tions per year changes so the optimum
equipment choice also changes. There
is a simultaneous migration of best
alternative as the wage rate and other
items such as interest on investment
are changed. The Table shows the
assumptions on which the break-even
charts are based. These are taken from
Rapp (2), Miller (3), McAndrews (4),
Strong (9), and the Oliver Chemical
Company (10).

Advantages of SPNA Over Break-Even

The great strength of the SPNA tech-
nique lies in the fact that once the
formulae and networks have been con-
structed and committed to punch cards
they can be readily copied and re-used
for any circumstances. This is done by
selecting "V" values which are ap-
propriate to a particular farming en-
vironment. The best or cheapest method
can then be determined cheaply and
repeatedly without any danger of arith-
metic error.

FIG. 3a ONE IRRIGATION PER YEAR

FIG. 3b THREE IRRIGATIONS PER YEAR

CANADIAN AGRICULTURAL ENGINEERING VOL. 9, 1967 111
When new methods of irrigation, such as booms, are developed, these can easily be added to the network. Their effects can be calculated in theory even before they have been developed by using hypothetical labour and other cost characteristics. Machinery manufacturers can study their sales prices. To the farmer the advantages of any new method over existing machines can easily be assessed. The major problem is to accumulate such data in a form which can be compiled into a single programme.

OECD (8) have compiled sufficient data for European farms. This required the cooperation of many workers in different fields. The problem in North America is now merely one of administrative organization and funds for personnel. Three man months were needed to collect the detail for the irrigation alternatives shown in Figure 1 and summarized in Figure 3, and to produce a network and "T" formulae.

REFERENCES


6. Preston, T. A., Systems and Industrial Engineering Techniques. Section 1.2. Ibid.


![Comparison of Break Even Points](image)

**FIG. 3c FIVE IRRIGATIONS PER YEAR**

**TABLE 1**

<table>
<thead>
<tr>
<th>Method and Abbreviation used on graph</th>
<th>Initial Outlay $</th>
<th>Annual Replacements $</th>
<th>Dep't &amp; Interest on Equipment at 1.50 per acre/irrig./150 acres</th>
<th>Total Annual Costs</th>
<th>Total Annual Irrigation irg. per yr.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flood Irrig. (FI)</td>
<td>400</td>
<td>150</td>
<td>10% = 4.00</td>
<td>3.25 = 730.00</td>
<td>884</td>
</tr>
<tr>
<td>Gated Pipe (GP)</td>
<td>1000</td>
<td>150</td>
<td>10% = 10.00</td>
<td>2.25 = 507.00</td>
<td>667</td>
</tr>
<tr>
<td>Border Dike (BD)</td>
<td>3500</td>
<td>100</td>
<td>7.5% = 278.00</td>
<td>-</td>
<td>820</td>
</tr>
<tr>
<td>Corrugations (C)</td>
<td>3400</td>
<td>100</td>
<td></td>
<td>-</td>
<td>900</td>
</tr>
<tr>
<td>Hand Move (HM)</td>
<td>1500</td>
<td>150</td>
<td>15% = 225.00</td>
<td>0.31 = 205.00</td>
<td>580</td>
</tr>
<tr>
<td>Wheel Move (WM)</td>
<td>1500</td>
<td>200</td>
<td>15% = 375.00</td>
<td>0.31 = 70.00</td>
<td>645</td>
</tr>
<tr>
<td>Valley System (VS)</td>
<td>4000</td>
<td>300</td>
<td>15% = 500.00</td>
<td>0.17 = 38.00</td>
<td>938</td>
</tr>
</tbody>
</table>

112 CANADIAN AGRICULTURAL ENGINEERING VOL. 9, 1967