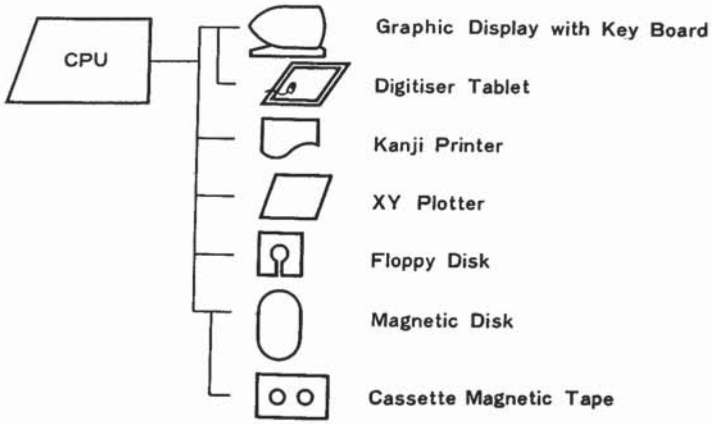

Figure 3. Workstation Configuration

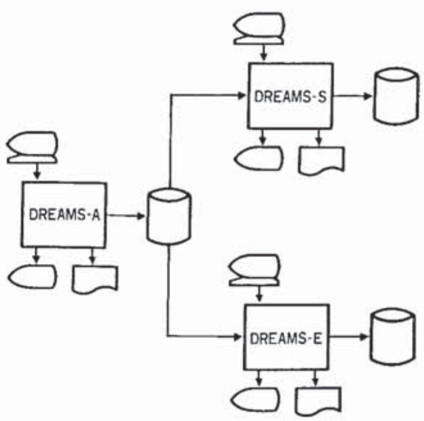

Figure 4. Software Configuration

Earthwork Analysis on Personal Computers

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KEYWORDS

Earthwork, microcomputers, simulation, linear programming, heavy construction.

ABSTRACT

The analysis of heavy earthwork operations at the project site level requires many considerations. Some factors involved are: 1) technology used; 2) uncertainty in the duration of construction activities; 3) resource configuration; 4) interaction between resources; 5) characteristics of each project. A description is presented of a system designed to analyze heavy construction operations on microcomputers. The structure of the system is presented. The system described was developed on a project sponsored by the National Science Foundation. The system addresses the following areas: 1) estimates of earthwork quantities; 2) resource definition; 3) productivity and unit cost estimates; 4) earthwork allocation. It is based on operation research techniques such as simulation, and linear programming. No knowledge of these techniques is required to run the programs. A user needs only to enter the required data in an interactive environment. It provides construction decision-makers with a quantitative tool for the analysis of earthwork operations.

Analyse de travaux de terrassement sur microordinateurs

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Mots-clés

Travaux de terrassement, microordinateurs, simulation, programmation linéaire, gros ouvrages

Sommaire

De nombreux facteurs entrent en jeu dans l'analyse de travaux de terrassement à grande envergure au niveau de l'emplacement du projet: 1) le choix de la technologie utilisée; 2) l'incertitude de la durée de travaux; 3) la configuration des ressources; 4) l'interaction des resources; 5) les caractéristiques de chaque projet. La présente communication a pour objet d'introduire un système conçu pour analyser sur ordinateur des opérations de gros ouvrages et d'indiquer la structure de ce système. Une subvention de la National Science Foundation a rendu possible le développement de ce système. Le système est applicable aux domaines suivants: 1) calcul de la quantité de travaux de terrassement à effectuer; 2) désignation des ressources; 3) productivité et prévisions budgétaires; 4) répartition des travaux de terrassement. Le système est basé sur des techniques de recherches opérationnelles telles que la simulation et la programmation linéaire et son utilisation ne requiert aucune connaissance préalable de ces techniques. L'usager n'a qu'a entrer les données nécessaires dans un milieu interactif. Le système offre au personnel décisionnaire chargé des travaux un outil quantitatif permettant l'analyse des opérations de terrassement.

EARTHWORK ANALYSIS ON PERSONAL COMPUTERS

by José F. Lluch

Introduction

One of the main management tasks faced by construction managers in highway projects is to estimate earthmovement cost and to decide how much earth to move and from where to where. This paper describes the Resource Analysis of Construction Operations (RACO) System, that demonstrates the capacity of the personal computer to provide an interactive environment for carrying out these tasks. The system was developed under a grant from the National Science Foundation (Grant No. CEE 8302298).

The RACO System

The RACO system was developed for an IBM/PC (or compatible) with 128K. Bytes, 2 disk drives, and graphic monitor. It addresses the following:

1. Quantity Estimates. Earthwork quantities are estimated by dividing the project into stations. Actual and final profile data are specified for each station. The system supports the concept of a standard final cross section for the specification of the final profile data. Final elevation points are calculated from a standard cross section, and the elevation of a reference point. Earth volume between stations is calculated using either the average end area or the prismoidal formula.

2. Resource Definition. Resources are defined by specifying the resource categories (e.g. scrapers, loaders, etc.), the number of units of each category, direct cost per hour, and other parameters.

3. Productivity analysis. Productivity estimates are made by means of CYCLONE simulation (1-15). CYCLONE is a simulation language specially designed for the analysis of construction operations.

A number of typical "standard" earthmoving processes have been defined using the CYCLONE methodology. There is no need to re-define these processes in order to estimate their productivity and unit cost or to conduct a detailed process analysis. Only parameters which are specific to the operation analyzed need to be specified (e.g. activity durations, capacity of equipment units, etc.). A sample model of a pusher and scraper process defined in terms of a CYCLONE network is shown in Figure 1. It is a precedence network which models the states of the resources. The rectangles represent active states or activities. Nodes forming a "Q" represent idle states. A complete description of the CYCLONE building blocks is found in references 6, 9 and 13.

The CYCLONE processor is a discrete event simulator based on the next event algorithm (9). An interactive routine is implemented which allows the selection of the cost optimal resource configuration of the construction process. This routine carries out simulations of different

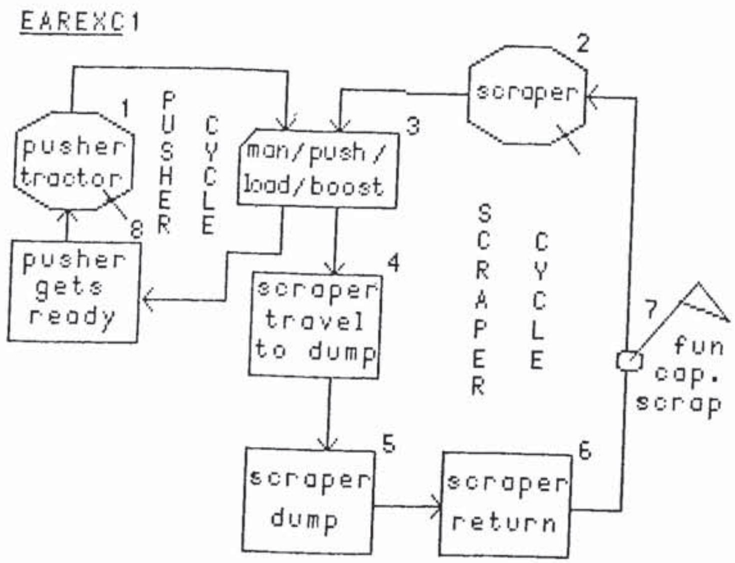

Figure 1. CYCLONE Network: Pusher-Scraper Process

resource configurations of the process allowing the user to select the one that provides the required productivity at the least unit cost.

4. Earthwork Allocation. How much earth to move and where to move it, is determined by minimizing total earthmoving cost using linear programming techniques (2,3). This method selects the earthwork allocation alternative with the least cost based on the assumption of linear relationships. Reference 16 contains a detailed description of this technique.

The earthwork allocation problem is formulated in terms of linear programming by defining the variables, and specifying the objective function and constraints. The variables are the quantities of earth to be moved from section i to section j, $X_{(i,j)}$. The earthwork allocation module uses the quantities of earth estimated by the Quantity Module. A section is defined as the earth volume between two stations. Earth can also be moved from a cut-section to a waste-site, or from a borrow-site to a fill-section.

The system considers the change in volume that occurs when earth is excavated or compacted by means of the haul factor S^{b-l} and compaction factor S^{b-c}. Different sections may have different factors.

The objective function is to minimize total earthmoving cost. The cost function is the sum of the cost to move earth between sections, from borrow-sites or to waste-sites. $C_{(i,j)}$ is the unit cost to move earth from section i to section j. $Cw_{(i,K)}$ is the unit cost to move earth from section i to the waste-site K. $Cb_{(p,j)}$ is the unit cost to move earth from borrow-site p to section j. These unit costs are based on loose volumes of earth. The objective function is:

$$\text{Min } Z = \Sigma_i \Sigma_j \; C_{(i,j)} \; X_{(i,j)} + \Sigma_i \Sigma_j \; Cw_{(i,K)} \; S^{b-l} \; Xw_{(i,K)} + \Sigma_p \Sigma_j \; Cb_{(p,j)} \; S^{b-c} \; Xb_{(p,j)}.$$

Z is the total cost, and Σ_i is the sum over all i, etc.. The unit costs C, Cw and Cb are estimated using simulation. Each one of the unit costs can be estimated using a different process and a different equipment combination. The system also provides for estimating the cost of within-section earthmovement. This is the earthmovement from a cut site to a fill site within a section. It usually involves short haul distances, and in many projects it can be ignored. A different process can be used to estimate this work.

The quantity constraints represent the limited amount of cut or fill volume in a given section, the size of a borrow-site, or the size of a waste-site. There is a quantity constraint for each section of cut, section of fill, borrow-site and waste-site. The formulation of the linear program requires that all variables be positive. The cut constraints are:

$$\Sigma_j \; X_{(i,j)} + \Sigma_K \; Xw_{(i,K)} = Qc_{(i)},$$

where $Qc_{(i)}$ is the quantity of earth available for cut in section i. The fill constraints are:

$$\Sigma_i \ X_{(i,j)} + \Sigma_p \ Xb_{(p,j)} = Qf_{(j)},$$

where $Qf_{(j)}$ is the quantity required as fill in section j. The quantity constraint for the borrow-site is:

$$\Sigma_i \ Xw_{(i,K)} <= Qw_{(K)},$$

where $Qw_{(K)}$ is the volume capacity of waste-site K. The constraint for the waste-site is:

$$\Sigma_j \ Xb_{(p,j)} <= Qb_{(p)},$$

where $Qb_{(p)}$ is the capacity of the borrow-site p.

The method used to solve the linear program is the revised simplex method with the product form of the inverse (16).

5. Time Analysis. Project duration is estimated using the Critical Path Method (CPM). A network is created including all the activities in the project. A sample CPM program is included with the system for illustration purposes.

Sample Problem

A following simplified, sample problem demonstrate part of the capabilities of the RACO system. A roadway contractor is planning a grading operation of a 400 meter road. Actual and final terrain elevations at 50 meters interval are available. The haul factor is 1.1 and the compaction factor in embankment is .9. There is a borrow area available 250 meters from the end of the proposed road. The only waste-site available to the contractor is located very close to the start of the project. The contractor has two scrapers and one pusher-dozer available for this job.

Table I shows volume calculations carried out by the RACO system. Productivity and unit cost estimates are to be made for three travel distances. The data entered to the CYCLONE earthmoving model is shown below:

Hours Worked per Day---------------------- 8
Hours per Day of Nonproductive Time ------ 1.25
Days Worked per Week---------------------- 5
Hours per Week Lost due to Rain----------- 5
Direct Cost of Scraper and Operator------- $72/Hr.
Direct Cost of Pusher and Operator-------- $68/Hr.
Capacity of Scraper ---------------------- 19.8 cubic meters
Number of Simulation Cycles -------------- 25

Other data entered includes scraper travel time for the three travel distances, scraper load time and pusher return-maneuver time. The productivity and unit cost estimates produced by the system are shown in Table II. Estimates for distances not shown in Table II are estimated using interpolation.

The data entered to the system for earthwork allocation is shown below:

Name of Borrow-Site ------------------ Borrow
Location of Borrow-Site -------------- Sta. 7+50.00
Capacity of Borrow-Site -------------- 99,999 cu.mts.
Compaction Factor (S^{b-c})-------------- .9
Haul Facotr (S^{b-l})-------------------- 1.1
Name of Waste-Site ------------------- Waste
Location of Waste-Site --------------- Sta. 0+00.00
Capacity of Waste-Site --------------- 99,999 cu.mts.

The earthwork allocation plan produced by RACO which minimizes total direct cost is shown in Table 2. The total estimated direct cost of the operation is $11,200.00, and the estimated duration is say 9 working days. Figure 2 illustrates the allocation plan.

Conclusion:

A microcomputer is capable of providing an interactive environment for earthwork analysis on personal computers. A system was developed for an IBM/PC (or compatible) personal computer. It applies operation research techniques to address the following: (1) Quantity Development; (2) Resource Definition; (3) Productivity Analysis; and (4) Earthwork Allocation. Most of the operation research techniques are now accessible to construction contractor on relatively low cost personal computers.

Table I. Volume Calculations Using RACO System

EARTHWORK SUMMARY DATA FOR PROJECT CIB

SECTION			CUT VOL.M.^3 COMPACTED	FILL VOL.M.^3 COMPACTED	SHR/SWL BANK-COMP	SHR/SWL BANK-LOOSE	NET VOL COMPACTED
100.0	-	150.0	6191.8	0.0	0.90	1.10	6191.75
150.0	-	200.0	8415.1	0.0	0.90	1.10	8415.05
200.0	-	250.0	2223.3	0.0	0.90	1.10	2223.25
250.0	-	300.0	0.0	4206.2	0.90	1.10	-4206.23
300.0	-	350.0	0.0	10147.5	0.90	1.10	-10147.54
350.0	-	400.0	0.0	5941.3	0.90	1.10	-5941.33
400.0	-	450.0	2558.9	0.0	0.90	1.10	2558.89
450.0	-	500.0	2558.9	0.0	0.90	1.10	2558.87
BORROW	AT	750.0	89999.1	0.0	0.90	1.10	89999.09
WASTE	AT	0.0	0.0	99999.0	0.00	0.00	-99999.00

Table II. Earthwork Allocation Plan Which Minimizes Total Direct Cost

PROJECT: CIB

EARTHWORK ALLOCATION TABLE

FROM SECTION		TO SECTION		QTY. M^3 COMPACTED	COST ($)	DURATION HOURS	PROCESS	RESOURCE CONFIGURATION
100.00	150.00	WASTE		1652.7	$842.92	4.45	CIB.CST	1-DOZ 2-SCR
150.00	200.00	300.00	350.00	8415.1	$4369.19	28.20	CIB.CST	1-DOZ 2-SCR
100.00	150.00	300.00	350.00	1732.5	$931.37	6.03	CIB.CST	1-DOZ 2-SCR
450.00	500.00	350.00	400.00	2558.9	$1281.56	8.27	CIB.CST	1-DOZ 2-SCR
200.00	250.00	250.00	300.00	1399.7	$675.28	4.37	CIB.CST	1-DOZ 2-SCR
100.00	150.00	250.00	300.00	2806.5	$1457.19	9.40	CIB.CST	1-DOZ 2-SCR
200.00	250.00	350.00	400.00	823.6	$427.61	2.76	CIB.CST	1-DOZ 2-SCR
400.00	450.00	350.00	400.00	2558.9	$1234.55	7.99	CIB.CST	1-DOZ 2-SCR
TOTAL				21947.8	$11219.67	71.47		

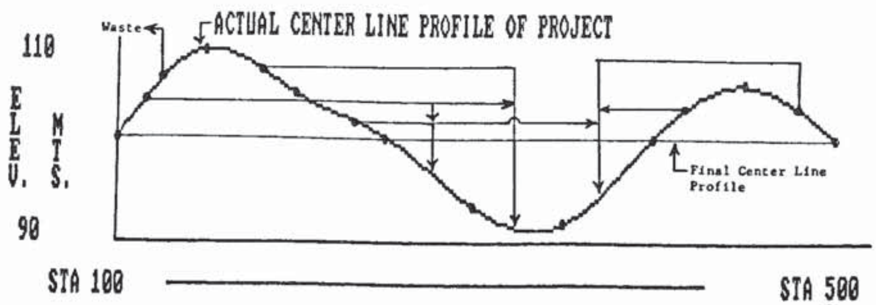

Figure 2. Center Line Profile of Project Illustrating Earthwork Allocation Plan

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