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A Computer Model for Selecting Equipment in Earth-Fill Dam Projects

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Abstract
Optimum selection of the right equipment plays an important role in the success of any construction project. This paper presents a computer model, ESCMODEL, for selecting equipment fleet in earth-fill dam projects. The model is capable of assisting the users in making decisions to determine the size, number, type and schedule of dozers, loaders, graders, excavators, trucks, sheepsfoot rollers and smooth wheel rollers. This model contributes to the selection process through the application of an optimization technique, based on nonlinear programming. The paper concludes with a proposal to concentrate on the development of a computer model to identify the number of equipments to be bought or rented. One actual case study are presented in order to illustrate the effectiveness and performance of the model.

Keywords
Construction equipment, Equipment selection, Optimization technique, Nonlinear programming, Earth-fill dam projects

1. Introduction

One of the most important decisions confronting any construction project planner is the choice of equipment for earthmoving operational job. Careful selection of a fleet of equipment for earthmoving operations can result in substantial savings in both time and cost of a construction project (Alkass *et al*., 2003). The deterministic method for this selection is simple and can provide satisfactory results for small projects requiring a simple equipment fleet. For large projects requiring multi-equipment fleets, however, the selection process can be more complicated, and cost can fluctuate widely (Farid and Koning, 1994).

Construction Equipment Management has received broad attention in the construction literature. Optimum planning methods, algorithms and models are provided for selecting equipment for earth-moving operations: SCRAPESIM, a computer simulation for scraper selection (Clemmens and Willenbrock, 1978); ESEMPS, an expert system for earthmoving equipment selection in road construction (Alkass and Harris, 1988); INSIGHT, an integration of simulation with expert systems for selecting of earthmoving equipment (Touran, 1990); SSPE, a tool for scraper selection (Kuprenas and Henkhaus, 2000); ESTIVATE, a model for calculating hydraulic excavator productivity and output cost (Edwards and Holt, 2000); FLSELECTOR, a computer model for selecting equipment for earthmoving operation using queuing theory (Alkass *et al*., 2003). However, previous researches have limitation in some aspects: limited on the number of assessed equipment, failed to provide quantitative information on equipment selection (Estivate; Edwards *et al*., 2001), failed to reach the optimum fleet in the considerable earthmoving volume (Amirkhanian and Baker, 1992), assumed nominal productivity in calculation and it is fixed, and assumed the duration of project tasks fixed. This paper introduces a computer model to enhance the previous researches by covering the limitations.

2. Proposed Model

The ESCMODEL is a computer model, designed as a module, which assists project planners to select the optimum fleet combination of dozers, loaders, graders, excavators, trucks, sheepsfoot rollers and smooth wheel rollers which can complete an earthmoving operation in earth-fill dam projects with least cost. Based on the planner's input data regarding the project activity characteristics (Duration, earthmoving operation volume, selected equipment and working conditions) and the selected type of the equipment (Equipment models, productivity and operational cost), ESCMODEL provides the user with a list of number, type and schedule of presence of the optimum fleet. ESCMODEL can assess a hundred activities and has no limitation to assess the number of fleet. One of the most important aspects of ESCMODEL is that it can assess an activity with variable durations and find the optimum duration for each task. ESCMODEL is implemented using FORTRAN and it contributes to resolving this selection process through the application of an optimization technique, based on nonlinear programming.

3. ESCMODEL Structure

3.1 Nonlinear Programming

Model development was undertaken using the nonlinear programming. Considering the following nonlinear programming problem:

$$\begin{aligned} &\text{Minimize} && f(x) \\ &\text{Subject to} && g_i(x) \leq 0 \quad \text{for} \quad i = 1, \ldots, m \\ & && h_i(x) = 0 \quad \text{for} \quad i = 1, \ldots, l \\ & && x \in X, \end{aligned}$$

where f, g_1, …, g_m, h_1, … , h_l, are functions defined on R^n, X is a subset of R^n, and x is a vector of n components x_1, …, x_n. The above problem must be solved for the value of the variable x_1, …, x_n that satisfy the restrictions and meanwhile minimize the function f.

The function f is usually called the Objective Function, or the Criterion Function. Each of the constraints $g_i(x) \leq 0$ for $i = 1, \ldots, m$ is called an Inequality Constraint, and each of the constraint $h_i(x) = 0$ for $i = 1_1, \ldots, l$ is called Equality Constraint. The set X might typically include lower and upper bounds on the variables, which even if implied by the other constraints can play a useful role in some algorithms. Alternatively, this set might represent some specially structured constraints that are highlighted to be exploited by the optimization routine, or it might represent certain regional containment or other complicating constraints that are to be handled separately via a special mechanism. A vector $x \in X$ satisfying all the constraints is called a Feasible Solution to the problem. The collection of all such solutions is called a Feasible Region. The nonlinear programming, then, is to find a feasible point such that $f(x) \geq f(\bar{\mathbf{x}})$ for each feasible point x.

In the ESCMODEL, the Objective Function is: Minimize Total Operational Cost = ∑(Machine × Operational Cost)

This equation is linear. The total constraint is that the specific earthmoving operational volume must be done in the specific duration.

3.1.1 Earth excavation optimization using nonlinear programming

The following example illustrates the ESCMODEL using nonlinear programming to applications.

Consider a problem is that determine the number of trucks which work with a loader.

- Truck:
  standard body heaped *A*; dump time T_A; haul distance D_1 with V_1 ; return distance D_2 with V_2
- Loader:
  bucket capacity *B*; load time (to be used to load a bucket of loader and dump in truck) T_B

$\rightarrow$ Truck time cycle = $\dfrac{A}{B} \times T_B + T_A + \dfrac{D_1}{V_1} + \dfrac{D_2}{V_2}$

$\rightarrow$ Number of trucks = $\dfrac{Truck\ time\ cycle}{T_B \times A \times B^{-1}}$

$\Rightarrow$ Number of trucks = $\left[A \times B^{-1} \times T_B + T_A + D_1 \times V_1^{\ -1} + D_2 \times V_2^{\ 2}\right] \times \left[A \times B^{-1} \times T_B\right]^{-1}$

The final equation indicates that the Constraints are not linear; therefore, the ESCMODEL using nonlinear programming to applications.

3.2 Optimization Technique

The optimization technique used to develop ESCMODEL contains a set of changes made to increase a model's efficiency. This process is that ESCMODEL determines the location of task contact and it takes the duration which is between contact locations as a section. Figure 1 shows a sample of a project that contains 5 tasks with 9 sections.

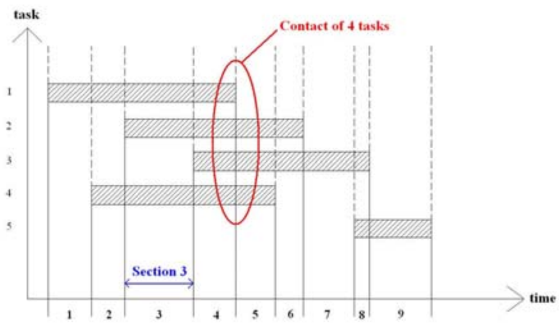

Figure 1: A Sample of Optimization Technique on a Project

As shown in the Figure 1, the number and duration of sections is variable in any project and when the duration of a task is changed, the sections are changed as well. After the sections determined, ESCMODEL assesses the type and number of equipment in each section inasmuch as the optimum allocation of equipment be occurred. A sample of unsuitable allocation indicates in Figure 2; the project has 3 tasks and assumed each task needs 1.3 dozers for completing earthmoving operation.

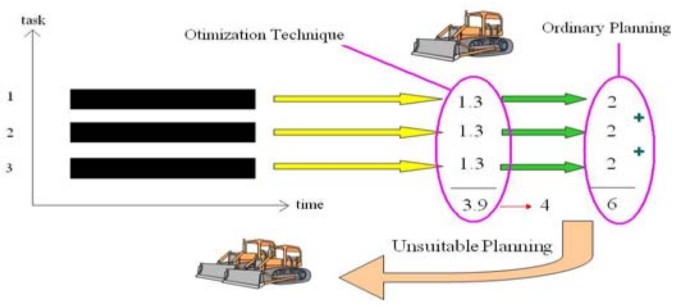

Figure 2: A Sample of Unsuitable Planning

Finally, ESCMODEL shows equipment of each section in the final answer. Obviously, the number of sections in a project may be very; therefore, ESCMODEL, at first, ask from planner to choose a number as a minimum duration of sections.

3.3 Equipment Selection

The equipment selecting process starts with entering the project and equipment information (Figure 3). Figure 4 shows a sample of entering data (project activities and equipment information). In project activities data, finish float is the difference of activity ending days (In the preliminary planning of a project, planner has no clear information about the exact duration of an activity; therefore, he can choose a day as an activity start. Then, concerning previous experience, he chooses a day as the earliest time of an activity finish with chooses some days for float. ESCMODEL is capable to find the optimum duration for activities; this means that ESCMODEL choose a day from different ending days as an activity finish day with satisfied the least operational cost of equipment.). Planner also chooses a machine by entering Y (yes) or N (no); in other word, planner can choose ideal and accord fleet for any activity. Finally, he entered a number between zero and one as a site factor that is effective in equipment productivity. In equipment entering information, as shown in the Figure 4, planner can enter any value for equipment productivity as he want; thus, this value is not fixed. Furthermore, information of each of seven equipment is entered in separately sheet (Figure 4 shows a sheet for loader). It is noticeable that the number of fleet can be assessed is very huge with no limitation. Then, equipment are selected and allocate to activities; in this selection process least operational cost should be satisfied. Following, the sections are located and the optimization process performed. The final level in the analysis process is that find the optimum duration for any activity. After that all aspects of activity durations considered, the optimum fleet with total cost and the optimum duration of activities can be listed according to the selected criterion. Figure 5 shows the flow chart of the mentioned process.

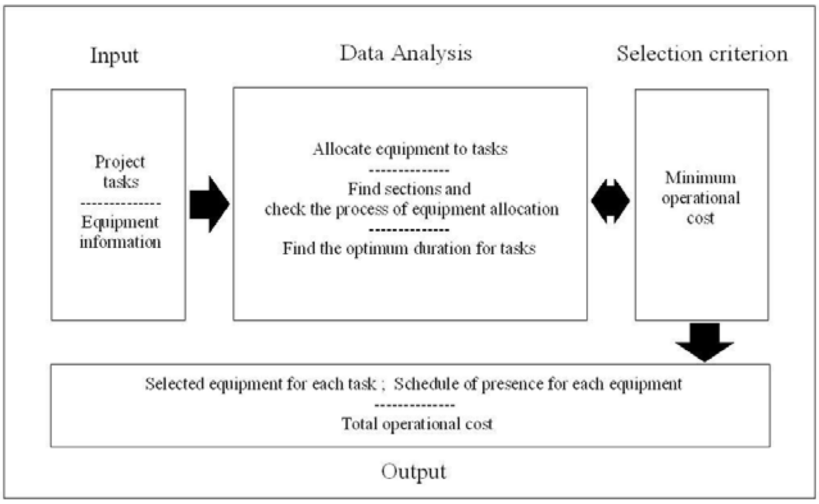

Figure 3: Equipment Selection Process and Analysis

Activity Number	Activity Code	Start	Finish Earlist	Finish Float	Earthmoving Volume	Roller Smooth	Roller Sheepfoot	Dozer	Excavator	Grader	Loader	Truck	Site Factor
1	A11	1	200	37	3530000	Y	N	Y	N	Y	Y	Y	0.8
2	A22	43	150	11	3267890	N	Y	Y	Y	Y	Y	Y	0.75
3	B12	11	70	0	3452671	N	N	Y	N	N	Y	Y	0.5

Project Data

Equipment Entering Data: Loader

Loader Number	Loader type	Cost ($/hr)	Productivity (m^3/hr)	Bucket Capacity (m^3)
1	VOLL150	28	160	4.2
2	VOLL180	35	210	5
3	CAT950G	27	145	3.1
4	CAT966C	33	160	3.4
5	KOMA420	30	170	4.2

Figure 4: Sample of Entering Data

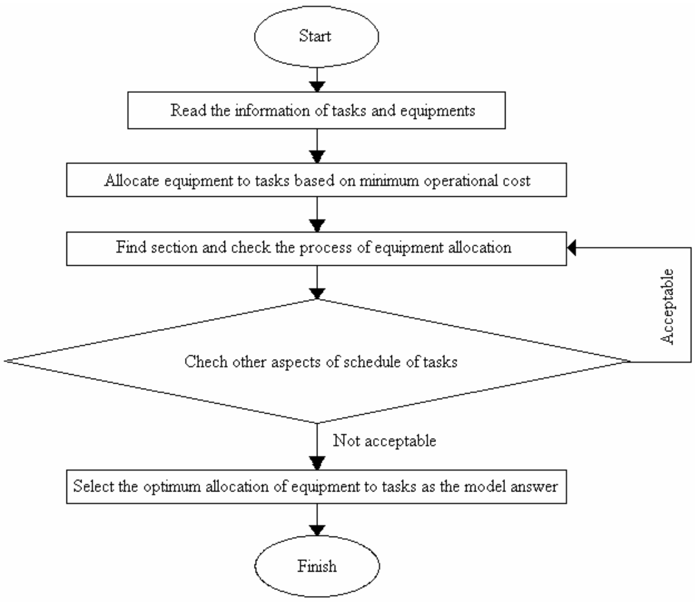

Figure 5: Flow Chart of the Equipment Matching

4. ESCMODEL Testing and Validation

Many examples are tested to verify the accuracy and efficiency of ESCMODEL. However; to illustrate the ability of the proposed model, one case study of earth-fill dam projects constructed in Iran are considered in this paper. The results are compared with the conventional method solution.

4.1 Case Study

Agh-Chay, an earth-fill dam that constructed across Agh-Chay River at Azarbayejan-Gharbi district, is considered in this section. The project was estimated to be around 9 million cubic meters of earthmoving operation. Figure 6 shows the information related to this case study. Figure 7 indicates the reduced process of total cost and figure 8 shows the reduced process of equipments whilst ESCMODEL runs; decreasing the operational cost 5% and 3.3% in the number of equipment. These reduction means that ESCMODEL reduced both of total operational cost and total number of equipment with respect to preliminary plan using conventional method. These results indicate the effectiveness of optimization technique used in ESCMODEL. Furthermore, in the final result, the finish date of some activities is changed. 348 is the ending day of activity 1. The ending day for activity 6, 11, 15, and activity 17 are obtained 211, 1302, 1214 and 821 respectively. The section diagram for all equipment shows in Figure 9. The minimum duration for sections is 10 days.

Activity Number	Activity Code	Start	Finish Earlist	Finish Float	Earthmoving Volume	Roller Smooth	Roller Sheepfoot	Dozer	Excavator	Grader	Loader	Truck	Site Factor
1	AA1	1	335	16	407081	N	N	N	Y	N	Y	Y	0.67
2	AA2	482	666	8	36300	N	N	N	Y	N	Y	Y	0.67
3	AB1	664	820	0	238000	N	N	Y	N	N	Y	Y	0.75
4	AB2	1	235	0	472610	N	N	Y	N	N	Y	Y	0.75
5	AB3	253	448	0	100000	N	N	Y	N	N	Y	Y	0.75
6	AC1	1	210	20	378074	Y	N	Y	N	Y	Y	Y	0.75
7	AC2	331	586	15	405080	Y	N	Y	N	Y	Y	Y	0.75
8	AC3	646	810	0	226845	Y	N	Y	N	Y	Y	Y	0.75
9	AD1	684	864	0	1058824	Y	N	Y	N	Y	Y	Y	0.75
10	AD2	938	1115	0	1041176	Y	N	Y	N	Y	Y	Y	0.75
11	AE1	1120	1296	18	1785281	Y	N	Y	N	Y	Y	Y	0.83
12	AE2	1434	1630	0	1988154	Y	N	Y	N	Y	Y	Y	0.75
13	AF1	637	817	10	478230	N	Y	Y	N	Y	Y	Y	0.83
14	AF2	1028	1119	0	241771	N	Y	Y	N	Y	Y	Y	0.83
15	AG1	1120	1204	12	301854	N	Y	Y	N	Y	Y	Y	0.83
16	AG2	1381	1543	0	584126	N	Y	Y	N	Y	Y	Y	0.75
17	AH1	637	817	14	171920	Y	N	Y	N	Y	Y	Y	0.83
18	AH2	1028	1224	12	168100	Y	N	Y	N	Y	Y	Y	0.83
19	AH3	1381	1543	0	154730	Y	N	Y	N	Y	Y	Y	0.75
20	AI1	381	431	9	28140	Y	N	Y	N	Y	Y	Y	0.83
21	AI2	522	581	0	33206	Y	N	Y	N	Y	Y	Y	0.83
22	AI3	1106	1196	0	50653	Y	N	Y	N	Y	Y	Y	0.83
23	AJ1	600	780	10	5000	Y	N	Y	N	Y	Y	Y	0.75
24	AK2	1114	1640	0	51550	Y	N	Y	N	Y	Y	Y	0.83
25	AL1	1047	1640	0	125750	Y	N	Y	N	Y	Y	Y	0.83

Figure 6: Project Activities Characteristics

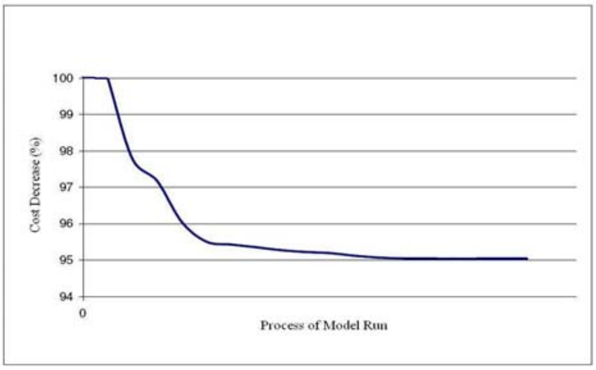

Figure 7: Chart of Cost Reduction

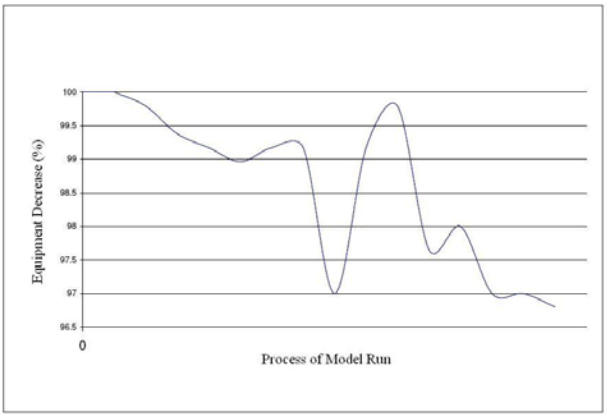

Figure 8: Chart of Number of Equipment Reduction

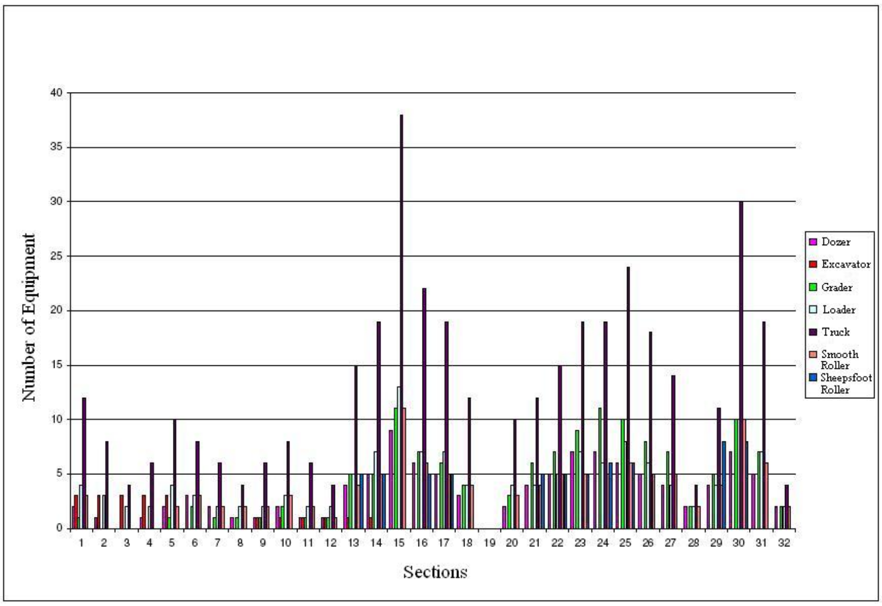

Figure 9: Section Diagram of Equipment

5. Diagram of Schedule of Equipment

The process shown in the Figure 10 indicates if the section diagram is considered for one machine, the final result is the schedule of presence of the machine. The final diagram, as indicated in Figure 10, is obtained by changing the scale of horizontal and vertical axes. In the final diagram, the planner can obtain the number of machines in duration by adding the number on vertical axis. I.e. in the figure 10, the number of machines needed for project between 605th and 615th days (section 4) is 53 (6+13+4+2+2+4+1+1+1+6+3+11=53). This diagram is the most important result of ESCMODEL.

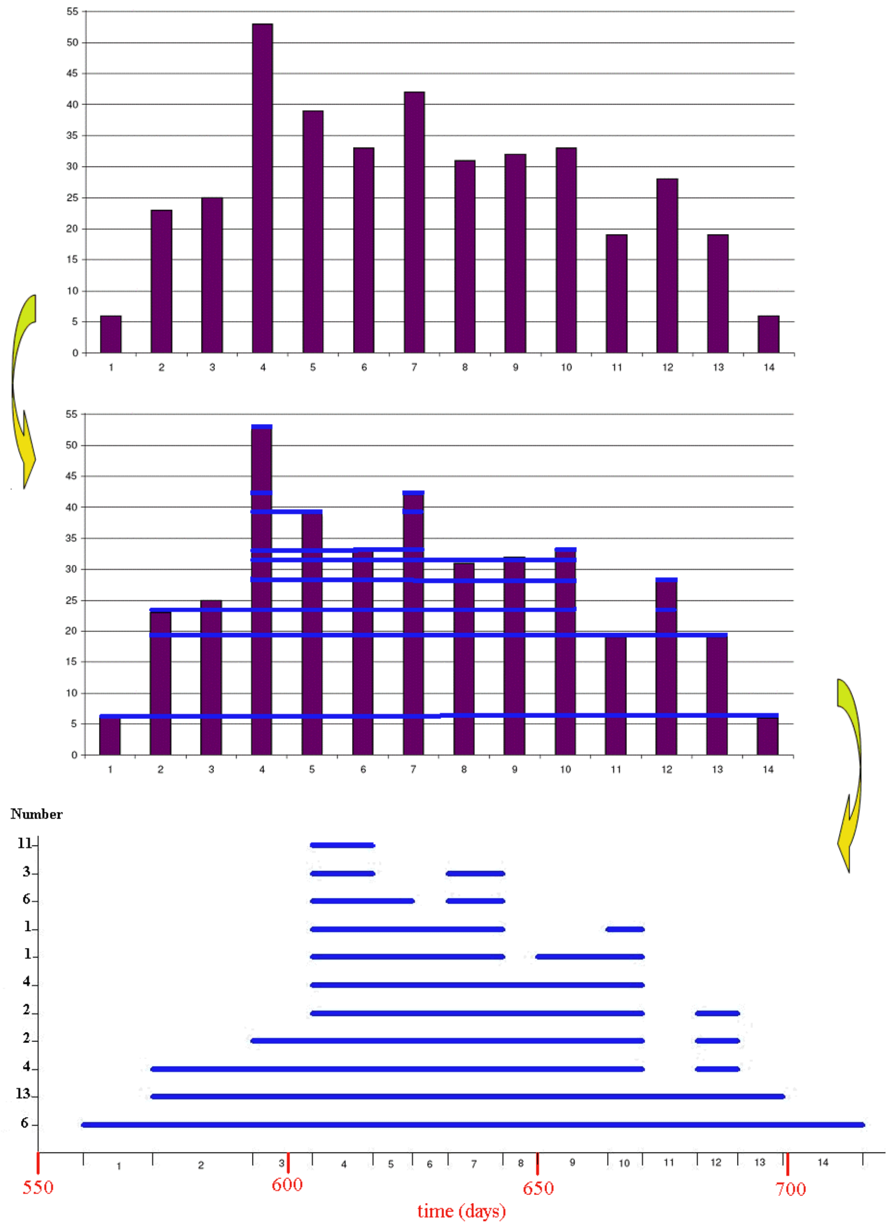

Figure 10: Process of Developing a Diagram of Schedule of a Machine

6. Future Research Work

While ESCMODEL exhibits potential for improving current methods of equipment selection, there remain of area of the decision process which requires further attention. As shown in the Figure 11, the section diagram, considered for a machine (Figure 10), can help a planner to choose the number of equipments to be bought or rented. For example, in Figure 11 line 1 is a choice that a planner can buy 18 machines and rent the remainder. Therefore, future research works can concentrate on development of a computer model that would be a subroutine for this model to identify the exact number of equipments to be bought or rented.

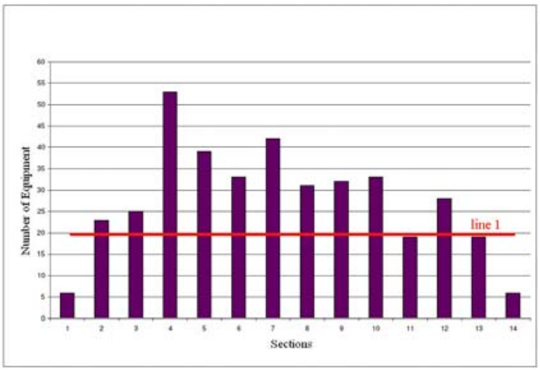

Figure 11: A Sample of Using Section Diagram in Future Research Works

7. Conclusion

This paper presented a computer model for selecting equipment for earthmoving operations using nonlinear programming with optimization technique in earth-fill dam projects. The developed model is designed to assist construction planners in selecting the best equipment that can complete the tasks in minimum total operational cost. In addition, it provides the optimum duration for each tasks. The model also enhances the previous researches; the number of assessed equipment can be very huge, can provide quantitative information on equipment selection, can reach the optimum fleet in the considerable earthmoving volume and can find the optimum duration for project tasks. Future research is however required to consider the methodology involved for selecting the appropriate machine in ESCMODEL in order to develop a software package to identify the number of equipment to be bought or rented.

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