A Linear Programming Approach to Construction Method Selection

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ABSTRACT

This paper deals with the development of a model for selecting an optimal construction method from the several possible alternative methods available on a project, based on the linear programming technique. The model is aimed at achieving a most effective and efficient utilisation of an organisation's resources. Its capability of being used to undertake sensitivity analysis, further enhances its usefulness as an invaluable tool for construction planning.

A numerical example, based on data collected on a "real life" project was used to assess the feasibility of the developed model. The conclusion was drawn that the model was an invaluable aid in the speedy and objective selection of reliable construction methods for optimum results, provided the input data were accurate and reliable.

KEYWORDS:

Linear Programming; Model; Construction Project; Method Selection; Sensitivity Analysis.

INTRODUCTION

The successful implementation of a construction project requires the undertaking of several varying activities at specific times using specified methods of construction. Each activity, could theoretically, be carried out in a countless number of ways, using a variety of resource combinations. Each resource combination would have associated with it a time and a cost element. A project planner is therefore invariably faced with the task of identifying an appropriate method - from the myriad of possible methods - of undertaking each activity that constitutes a project.

Even though the method selection activity is one of the key functions that must be efficiently undertaken by construction contracting organisations wishing to remain competitive and indeed survive, investigations undertaken on the subject within 51 large construction organisations in Nigeria indicated a surprisingly lackadaisical approach to the performance of the function. (7) When the 51 respondents in the organisations included in the study were asked whether they would describe their current procedures of construction method selection as "subjective" or "objective", all the respondents opted for the "subjective" label. The Chambers Twentieth Century Dictionary definition of "objective" as "uncoloured by one's own sensations or emotions" was used for the exercise. The general consensus among the respondents was that their suggested methods for the activities constituting their projects were invariably based on previously accumulated experiences on similar projects, or on intuition.

It is most unsatisfactory to rely too heavily on past experience when planning for building activities, since many new factors would have to be acknowledged and taken into consideration in the method selection process for each new project. Besides, the process should be capable of taking a global view of the problem by taking into consideration such factors as the overall resources available to the contractor, the alternative methods that could be used on the project for each activity, the effect of current decisions on activities of projects that would be running concurrently with the project under consideration, and so forth.

Other major drawbacks of the present "subjective" method of construction method selection are its inability to:

i. base the decision making process on clearly identifiable, quantifiable and stated project objective(s) which may be the minimisation of construction time or cost; maximising the use of scarce and or expensive resources, and so forth;

ii. speedily provide answers for important "what if" questions. The ability to under-

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> take such sensitivity analysis is now a "sine qua non" for any efficient and reliable decision making model.

In order to overcome the above stated drawbacks of the present "subjective" method of construction method selection, a model based on an " objective" system of construction method selection is being proposed for the construction industry. The system is based on the linear programming technique, because the technique is capable of handling the major problems that have been associated with the present "subjective" model mentioned above, namely; the resource constraint factor, the clearly stated and quantifiable objective factor, and the capability for undertaking sensitivity analysis factor.

This paper reports the outcome of a project undertaken to develop a more efficient model for construction method selection based on the linear programming technique.

A DESCRIPTION OF THE MODEL.

One of the major tasks in using the linear programming technique is the formulation of the problem in the linear programming format. This involves the identification of the variables to be used in the model, the determination of the constraints and the co-efficients for the variables and lastly the formulation of the objective function.

In the model being proposed in this paper, the various alternative methods for carrying out the activities that constitute a project are represented by the variable X. Figure 1 depicts the format for the model. The various essential features of the model will be explained by reference to Figure 1.

The rows of the model are divided into five main sections: Section A contains information necessary for identifying and working on the activity under consideration. The WORK SECTION identifies each activity with one of the work sections in the Standard Method of Measurement. The ACTIVITY DESCRIPTION sub-row of section A gives an exact description of the activity being considered. The QUANTITY sub-row will indicate the quantity of the item under consideration. The number of possible ways in which any particular activity could be carried out within the organisation, is shown as the ALTERNATIVE PROCESS NUMBERS FOR EACH ACTIVITY. The gang composition to carry out each activity, together with each gang output figure is depicted against GANG COMPOSITION and GANG OUTPUT items respectively.

Section B assigns variable names - $x_1, \ldots, x_j, \ldots, x_n$ - to each of the methods that will be used in the model. Section C will list the name of each of the resources, together with its all-in rate, that will be required to solve the model. Section D is a repetition of the activities listed in the ACTIVITY DESCRIPTION row of section A. The last section, E, contains the OBJECTIVE FUNCTION. This is the function whose value we are aiming at either maximising or minimising.

The columns of the model are divided into four major sections, namely; section W, section X, section Y and section Z. Section W of row section A gives the descriptive definitions of the input items for the model. Section X of row section A contains the basic input data that will be used for deriving the technology co-efficients as well as the co-efficient of the objective function for the model. Section Y is the RELATIONAL OPERATORS COLUMN. Each row of this column in section C and D will have at least one of the following relational operators:

"≥" indicating a greater than or equal to relationship;

"≤" indicating a less than or equal to relationship;

"=" indicating an equal relationship.

The extreme right hand side of column of the model, depicted in section Z is the RIGHT HAND SIDE CO-EFFICIENT column. The figures in this column give the limits of the resources to be used in the model.

The model described above can be put in the general linear programming form thus:

> Find a vector $(X_1, X_2, X_3, \ldots, X_n)$ that minimises (or maximises) the linear objective function F(X), where

$$F(X) = C_1X_1 + C_2X_2 + C_3X_3 + \ldots + C_jX_j + \ldots + C_nX_n$$

Subject to the linear constraints:

$$A_{11}X_1 + A_{12}X_2 + A_{13}X_3 + \ldots A_{1j}X_j + \ldots + A_{1n}X_n = B_1$$

$$A_{21}X_1 + A_{22}X_2 + A_{23}X_3 + \ldots A_{2j}X_j + \ldots + A_{2n}X_n = B_2$$

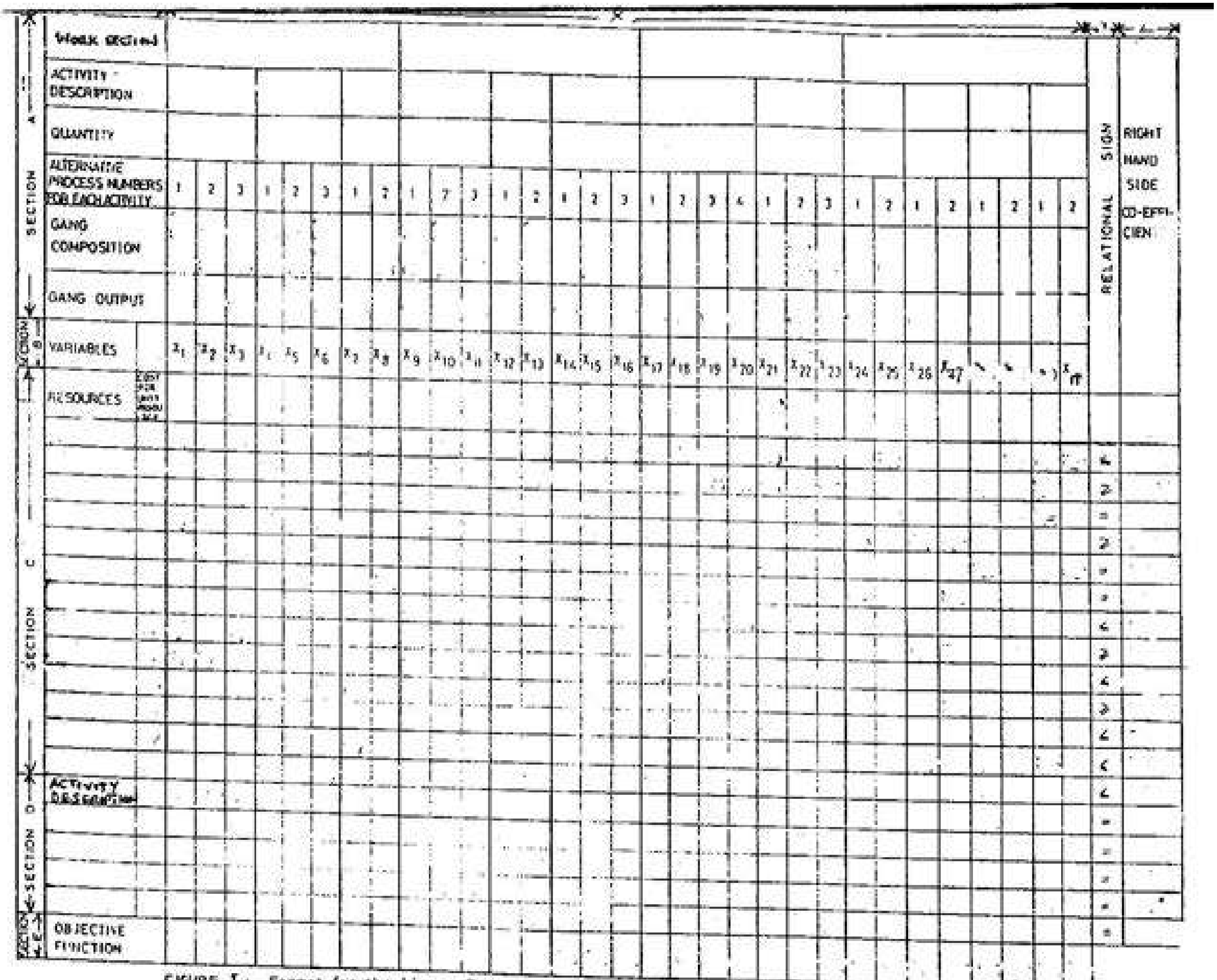


FIGURE I: Format for the Linear Programming Model

$A_{m1}X_1 + A_{m2}X_2 + A_{m3}X_3 + \dots A_{mj}X_j + \dots + A_{mn}X_n = B_m$

where A_{ij} are the input-output co-efficients;

C_j are the cost (or profit) co-efficients ;

and B_i are the capacity levels.

The above scenario completes the theoretical description of the model. A numerical example will now be used to fully explain and demonstrate the formulation, provide solutions and interpret the outputs from the model. Perhaps that might be the simplest way of demonstrating the application of the model to "real-life" problems.

A NUMERICAL EXAMPLE OF THE MODEL

Input data for the model were provided by a medium-sized construction company based in Jos, Nigeria. The project used was one for the construction of twelve two-storey blocks of flats for a big manufacturing company. The contract was based on drawings, bills of quantities and specifications.

Three senior company staff members were mandated by the company's management to fully cooperate with the author in the exercise. The participating staff members consisted of the estimator, the site manager for the project and the chief planning engineer.

A list of 56 items was randomly selected from the activities making up the project for inclusion in the exercise. The list of items together with copies of the blank charts shown in Figures 2 and 3, was despatched to each of the three participants in the exercise, for each to provide the required data. Figure 2 needed no accompanying instructions to guide the three participants in completing the charts; Figure 3 however was sent with an explanatory note spelling out what was required from them.

In Figure 3, the column under TYPE OF RESOURCE was to be used to list the labour and plant resources that were to be used on the project, and which have been included in their method statements. The TOTAL QUANTITY OF RESOURCE AVAILABLE FOR DEPLOYMENT ON THE PROJECT column was to be used to indicate the total amount of each resource available for deployment on the project. The column headed PERIOD OF DEPLOYMENT was to be used to indicate the period of time that each resource would be available for deployment on the project.

On closely scrutinizing the returned completed forms, it was noticed that significant differences existed among the resource combinations and thus resource outputs being proposed for each of the activities, by each of the three participants. Equally large differences were noticed in the figures sub-

S/No.	Activity Description	Quantity	Resource (Gang) Composition	Resource (Gang) Output per day	Description of Method

Fig. 2: Blank Method Statement Chart.

S/No.	Type of Resource	Total Quantity of Resource Available for Deployment on the Project	Period of Deployment	Remark

Fig. 3: Blank Overall Resource Deployment Chart.

mitted on the resource availability charts. The question clearly therefore was:

> "Which method do you select from amongst the three submitted by each of the participants for each activity?"

There must indeed be a sound basis for selecting any one method for each of the activities included in the exercise. Again, the fact that large differences existed in the figures submitted by each of them on the overall resource availability chart indicated that none of them was aware of the right amounts of resources available to the contractor's organisation for undertaking the project. One therefore wonders how any serious method selection activity could be undertaken with those involved in the selection process having no clear idea about the amount of the various resources available for undertaking the activities constituting a project.

Normally, in a building construction organisation, the final method selection activity is undertaken by a senior management team within the organisation. The three participants were therefore constituted into such a team to select an appropriate method for each of the activities on the activity list. The task was accomplished for each listed activity often after very protracted and heated arguments; for each participant wanted his suggested method to be the selected one for inclusion in the final or "pooled" method study document. One could therefore see clearly the problems that a building construction organisation normally faces when undertaking that aspect of its work. The importance and the need for the development of an objective method or model for undertaking the task therefore became all too glaring.

Figure 4 shows the complete information that resulted from the above-mentioned exercises.

Method No. 1 contains details of the method agreed upon by the team for undertaking an activity, while Method No. 2, Method No. 3 and Method No. 4 contain details of the suggested methods by the estimator, the site manager and the chief planning engineer respectively. Taking item No. 1 for instance on the chart, which is, "Excavate trench commencing from stripped level and not exceeding 1.50 metres deep", with a total quantity of 78 cubic metres; the pooled suggested method was to use 15 labourers with a total output of 34 cubic metres per day. The time to be taken by the gang to perform a unit amount of work, was therefore 0.24 hour. The estimator's suggested method of using a gang of 8 labourers, with an output of 20 cubic metres per day, had 0.40 hour as the time for a unit quantity. The site manager suggested using 5 labourers and a 0.25 cubic metre backacter with an output of 43 cubic metres per day, giving 0.19 hour per cubic metre. Finally the chief planning engineer's suggested method of 2 labourers and a 0.25 cubic metre backacter, with an output of 81 cubic metres per day, resulted in a unit quantity output figure of 0.10 hour per cubic metre.

A close look at the output figures on the method statement document indicated significant discrepancies in some of them. Taking item No. 1 for instance as an example, the chief planning engineer's daily output figure of 81 cubic metres for 2 labourers and a backacter, is twice as much as the site manager's daily output figure of 43 cubic metres, for 5 labourers and a backacter even though nearly the same resources were being used in both cases. One could easily conclude that the construction organisation did not have a reliable data base for such an important piece of data, and that staff in the organisation used data acquired privately from experience and other private sources.

An investigation carried out by the author to ascertain if the practice was widespread in the industry, was confirmed when 43 out of the 51 construction companies included in the study stated that they did not have reliable output data bases for use within their organisations. Since the resource output figure is a vital and critical piece of data for planning, estimating, controlling purposes, its neglect by construction companies only openly brought to the fore, the levity with which most of the organisations approached the handling of that critical issue in their organisations.

It is to be noted, before we leave the method statement document (Figure 4), that each of the methods included in the document has been denoted as an X variable.

Figure 5 shows an abridged version of the linear programming model, with the necessary input data transferred to it from Figure 4. It could be seen from the bottom part of the model that the objective function being optimised was time: time was to be minimised. Other additional pieces of information included in the chart were a listing of the resources - together with their associated daily all-in rates in Naira, to be used for the project - under the RESOURCE/ACTIVITY column; the various technology co-efficients for the X variables, and the values of the right hand side co-efficients.

METHOD STATEMENT FOR THE NUMERICAL EXAMPLE

No.	ITEM DESCRIPTION	QUANTITY	METHOD No. 1 (METHOD AGREED ON BY THE CHIEF PLANNING ENGINEER, ESTIMATOR AND SITE MANAGER) RESOURCE NAME	RESOURCE (GANG) COMPOSITION	RESOURCE (GANG) OUTPUT PER DAY	TIME PER UNIT PRODUCT	METHOD No. 2 THE ESTIMATOR'S SUGGESTED METHOD RESOURCE NAME	RESOURCE (GANG) COMPOSITION	RESOURCE (GANG) OUTPUT PER DAY	TIME PER UNIT PRODUCT	METHOD No. 3 THE SITE MANAGER'S SUGGESTED METHOD RESOURCE NAME	RESOURCE (GANG) COMPOSITION	RESOURCE (GANG) OUTPUT PER DAY	TIME PER UNIT PRODUCT	METHOD No. 4 THE CHIEF PLANNING ENGINEER'S SUGGESTED METHOD RESOURCE NAME	RESOURCE (GANG) COMPOSITION	RESOURCE (GANG) OUTPUT PER DAY
[illegible]	Excavate trench commencing from stripped level and not exceeding 1.50m deep	18 m³	R1	15 Labourers	24m³	0.34hr	R3	8 Labourers	20m³	0.40hr	R5	5 Labourers 1 Backacter 0.25m³ bucket	43m³	0.19hr	R4	2 Labourers 1 Backacter (0.25m³ bucket)	8m³
2.	Excavate pit drive	5.8m³	R2	5 Labourers	3m³	2.70hr	R6	3 Labourers	3m³	4.00hr	R7	6 Labourers	12m³	0.67hr	R8	4 Labourers	5.5m³
[illegible]	Excavate to reduce levels.	8m³	R9	16 Labourers	4.4m³	0.18hr	R10	2 Labourers 1 [illegible] Bulldozer	120m³	0.07hr	R11	1 Labourer 1 [illegible] Bulldozer	13.4m³	0.06hr	R12	4 Labourers 1 [illegible] Bulldozer	44m³
[illegible]	Cartaway excess excavated material from site.	300m³	R13	5 Labourers 1 [illegible] Dumper	100m³	0.08hr	R14	2 [illegible] Dumpers 1 [illegible] tipper	330m³	0.04hr	R15	3 Labourers [illegible] dumper wagons	81m³	0.10hr	R16	4 Labourers [illegible] dumpers	33.5m³
[illegible]	Rock spalls, hardcore well rammed and consolidated, to receive concrete in 150mm thick layers 300mm thick	600m²	R17	5 Labourers 1 [illegible] Roller	32m²	0.04hr	R18	15 Labourers	140m²	0.02hr	R19	2 Labourers 1 [illegible] Roller	75m²	0.12hr	R20	12 Labourers	60m²
[illegible]	Plain mass concrete of nominal mix (1:3:6)/38mm aggregate) to develop a test strength of not less than 11N/mm² at 28 days in strip foundation over 150mm but not over 300mm thick.	33m³	R21	15 Labourers 1 Mason [illegible] mixer	30m³	0.43hr	R22	4 Labourers 2 Masons 1 crane 1 [illegible] mixer	14m³	0.57hr	R23	3 Labourers 2 Masons [illegible] mixer	18m³	0.44hr	R24	4 Labourers 2 Masons [illegible] dumper [illegible] mixer	22m³
[illegible]	Solid sandcrete blocks bedded and jointed in cement mortar (1:4), 225mm wide.	270m²	R25	2 Masons 1 Labourer	15m²	0.42hr	R26	3 Labourers 5 Masons	38m²	0.20hr	R27	6 Labourers 8 Masons	62m²	0.12hr	R28	5 Labourers 10 Masons	92m²
[illegible]	Reinforced concrete of nominal mix (1:2:4/19mm aggregate) to develop a test strength of not less than 30N/mm² at 28 days in ground floor slab 150mm thick [illegible]	270m² (30m³)	R29	15 Labourers 4 Masons [illegible] mixer	18m³	0.44hr	R30	6 Labourers 2 Masons 1 crane 1 [illegible] 2 [illegible]	14m³	0.57hr	R31	6 Labourers 3 Masons 2 Carpenters [illegible] mixer	21.5m³	0.74hr	R32	4 Labourers 2 Masons [illegible] Dumper [illegible] mixer	8m³
[illegible]	Blockwork as before described in super-structure (second storey)	1385m²	R33	4 Labourers 8 Masons [illegible] mixer	54m²	0.15hr	R34	5 Labourers 5 Masons	30m²	0.27hr	R35	2 Labourers 5 Masons 1 crane 1 [illegible] mixer	24m²	0.29hr	R36	5 Labourers 8 Masons 1 crane [illegible] mixer	67m²
2	Ditto in ground floor walls.	1216m²	R37	4 Labourers 8 Masons [illegible] mixer	16m²	0.12hr	R38	10 Labourers 5 Masons	32m²	0.25hr	R39	3 Labourers 8 Masons [illegible] [illegible] crane	45m²	0.18	R40	5 Labourers [illegible] 1 crane [illegible] mixer	66m²
[illegible]	Wrot formwork to vertical sides of columns 500mm girth	168m²	R41	1 Labourer 3 Carpenters	8m²	0.73hr	R42	1 Labourer 5 Carpenters	18m²	0.42hr	R43	1 Labourer 3 Carpenters 1 crane	36m²	0.22hr	R44	2 Labourers 8 Carpenters	48m²
[illegible]	Wrot formwork to horizontal soffit of floor slab (first floor)	534m²	R45	3 Labourers 6 Carpenters	24m²	0.24hr	R46	3 Labourers 8 Carpenters	45m²	0.15hr	R47	3 Labourers 3 Carpenters 1 crane	77m²	0.10hr	R48	8 Labourers 4 Carpenters	143m²
[illegible]	Wrot formwork to sides and soffits of horizontal beams 675 girth (first floor)	349m²	R49	8 Labourers 6 Carpenters	30m²	0.27hr	R50	3 Labourers 8 Carpenters	42m²	0.18hr	R51	2 Labourers 3 Carpenters 1 Crane	62m²	0.10hr	R52	4 Labourers 6 Carpenters	120m²
[illegible]	Wrot formwork to vertical sides of columns 500mm girth (first floor)	30m²	R53	1 Labourer 2 Carpenters	4m²	2.00hr	R54	1 Labourer 4 Carpenters	18m²	0.44hr	R55	1 Labourer 1 Carpenter	5.6m²	1.00hr	R56	4 Labourers 8 Carpenters	75m²
5	Wrot formwork to ring beams	265m²	R57	3 Labourers 4 Carpenters	17m²	0.47hr	R58	3 Labourers 6 Carpenters 1 Crane	25m²	0.32hr	R59	4 Labourers 6 Carpenters 1 Crane	24m²	0.33hr	R60	5 Labourers 5 Carpenters 1 Crane	165m²
6	Wrot formwork to sloping soffit of stairs	33m²	R61	3 Labourers 3 Carpenters	9m²	0.89hr	R62	3 Labourers 4 Carpenters	16m²	0.50hr	R63	1 Labourer 1 Carpenter	8m²	1.00hr	R64	6 Labourers 4 Carpenters	35m²
[illegible]	Mild steel reinforcement in columns (Ground floor)	892kg	R65	8 Steel fixers	763kg	0.01hr	R66	4 Steel fixers	483kg	0.02hr	R67	3 Labourers 3 Steel fixers	702kg	0.01hr	R68	3 Labourers 5 Steel fixers	1220kg
[illegible]	Mild steel bar reinforcement in slabs (first floor)	3338kg	R69	4 Labourers 6 Steel fixers	1676kg	0.005hr	R70	8 Labourers 8 Steel fixers	1897kg	0.004hr	R71	2 Labourers 8 Steel fixers 1 crane	1607kg	0.006hr	R72	4 Labourers 4 Steel fixers	2014kg
[illegible]	Mild steel bar reinforcement in stairs	1813kg	R73	4 Labourers 6 Steel fixers	2856kg	0.003hr	R74	4 Labourers 4 Steel fixers	2100kg	0.004hr	R75	3 Steel fixers	726kg	0.01hr	R76	2 Labourers 2 Steel fixers	4320kg
5	Mild steel bar reinforcement in beams	2875kg	R77	4 Labourers 6 Steel fixers	1600kg	0.005hr	R78	4 Labourers 4 Steel fixers [illegible] dumper	360kg	0.01hr	R79	2 Labourers 3 Steel fixers 1 crane	2155kg	0.003hr	R80	4 Labourers 4 Steel fixers 1 crane	3000kg
11	Mild steel bar reinforcement in columns (First floor)	877kg	R81	4 Labourers 6 Steel fixers	330kg	0.024hr	R82	4 Labourers 3 Steel fixers 1 crane	1749kg	0.005hr	R83	2 Labourers 3 Steel fixers 1 crane	2155kg	0.003hr	R84	4 Labourers 4 Steel fixers 1 crane	3000kg
12	Mild steel bar reinforcement in ring beams	1000kg	R85	4 Labourers 6 Steel fixers	1600kg	0.005hr	R86	8 Labourers 4 Steel fixers [illegible] dumper	827kg	0.009hr	R87	4 Labourers 5 Steel fixers 1 Crane	1310kg	0.007hr	R88	4 Labourers 1 set of [illegible] 1 crane	3000kg

[illegible]

Fig. 4: (cont'd) : Method Statement for the Numerical Example.

44	300 x 300 x 15mm [illegible]	1366m2	3171	2 Labourers 6 Masons	84m2	0.3 hr	3173	2 Labourers 4 Masons	80m2	0.03hr	3175	3 Labourers 3 Masons	50m2	0.15hr	3176	4 Labourers 8 Masons	220m2	0.05hr
45	225 x 225 x 3mm thermoplastic floor tiles and laying in adhesive	1866m2	3177	2 Labourers 6 Masons	150m2	0.05hr	3178	2 Labourers 4 Masons	120m2	0.07hr	3179	3 Labourers 3 Masons	160m2	0.06hr	3180	2 Labourers 8 Masons	260m2	0.02hr
46	Acoustic ceiling white regular perforated 600 x 600 x 6mm thick tiles	200m2	3181	3 Labourers 4 Carpenters	31m2	0.25hr	3182	3 Labourers 8 Carpenters	101m2	0.08hr	3183	1 Labourer 2 Carpenters	33m2	0.24hr	3184	6 Labourers 5 Carpenters	144m2	0.06hr
47	Knot, prime, stop and apply one undercoat and one finishing coat of gloss paint on general surface of wood	784m2	3185	3 Painters	130m2	0.01hr	3186	1 Labourer 5 Painters	400m2	0.02hr	3187	6 Painters	1018m2	0.01hr	3188	1 Labourer 4 Painters	836m2	0.01hr
48	Touch-up red-oxide primer, prepare and apply one undercoat and two finishing coats of gloss paint on metal work, edges not over 100mm girth.	1022m	3188	3 Painters	275m	0.03hr	3189	1 Labourer 5 Painters	395m	0.03hr	3191	6 Painters	421m	0.02hr	3192	1 Labourer 4 Painters	405m	0.03hr
49	Knot, prime, stop and apply one undercoat and one finishing coat of gloss paint on woodwork edges not over 150mm wide	1520m	3190	1 Labourer 3 Painters	424m	0.02hr	3194	1 Labourer 5 Painters	782m	0.01hr	3195	6 Painters	950m	0.008hr	3198	1 Labourer 4 Painters	850m	0.01hr
50	Rub down, prime and apply one under coat and two finishing coats of emulsion paint on rendered blockwork externally.	3430m2	3197	1 Labourer 5 Painters	315m2	0.04hr	3198	2 Labourers 8 Painters	600m2	0.02hr	3199	6 Painters	500m2	0.02hr	3200	1 Labourer 4 Painters	256m2	0.03hr
51	Ditto internally.	7882m2	3201	1 Labourer 4 Painters	240m2	0.03hr	3202	4 Painters	240m2	0.03hr	3203	6 Painters	410m2	0.01hr	3204	1 Labourer 4 Painters	225m2	0.03hr
52	400 x 550 white vitrified china washhand basin with chromium plated outlet, bottle trap, chain plug and stay, two number cantilevered brackets	48 nr	3205	3 Mates 3 Plumbers	6 nr	1.33hrs	3206	4 Mates 8 Plumbers	31 nr	0.33hr	3207	3 Plumbers	9 nr	0.73hr	3208	1 Mate 2 Plumbers	8 nr	1.00hr
53	Low-level water closet suite with 9 litre flushing cistern, plastic seat and cover, pan connector and 100mm diameter over flow.	36 nr	3209	3 Mates 3 Plumbers	3 nr	1.67hrs	3210	4 Mates 4 Plumbers	6 nr	1.33hrs	3211	6 Plumbers	6 nr	1.33hrs	3212	2 Mates 3 Plumbers	8 nr	1.00hr
54	1800mm long white porcelain bath, waste fittings, chromium plated outlet, chain plug and stay, two number pillar taps, mixer unit, telephone hand shower and bracket, grated over flow.	36 nr	3213	3 Mates 6 Plumbers	12 nr	0.83hr	3214	8 Mates 8 Plumbers	21 nr	0.38hr	3215	4 Mates 4 Plumbers	8 nr	1.00hr	3216	2 Mates 3 Plumbers	5 nr	1.60hrs
55	600 x 450 x 450mm deep laundry sink in white porcelain	24 nr	3217	2 Mates 3 Plumbers	6 nr	1.33hrs	3218	4 Mates 8 Plumbers	20 nr	0.40hr	3219	3 Plumbers	9 nr	0.89	3220	1 Mate 2 Plumbers	5 nr	1.60hrs
56	2000 x 500mm stainless steel kitchen sink single drainer two number pillar taps, chain plug and stay, chromium plated outlet, grated over flow, two number cantilevered brackets.	42 nr	3221	2 Mates 3 Plumbers	6 nr	1.33hrs	3222	4 Mates 8 Plumbers	20 nr	0.40hr	3223	3 Plumbers	11 nr	0.73hr	3224	1 Mate 2 Plumbers	5 nr	1.60hr

Fig. 4: (cont'd) : Method Statement for the Numerical Example.

Since the various co-efficient indicated under the X variable columns are so critical to the development of the model, an explanation of how they were derived should be appropriate. The figure of 3.60 (15 labourers x 0.25 hours) for the X_1 variable indicates the total manhours taken by the 15 labourers to carry out 1 unit of trench excavations. Similarly , for variable X_3, which uses two types of resources (2 labourers and a backacter), the figure 0.95 (5 labourers x 0.19 hour) is indicated against the labourer resource, and 0.19 (1 backacter x 0.19 hour) indicated against the backacter resource under the X_3 variable column. The objective function co-efficient of 0.24 indicated under X_1 is the time taken in hours by the gang of 15 labourers to perform a unit of the operation.

Perhaps it is pertinent to emphasize at this point that the fact that a mathematical programming model involves a single objective function which is to be maximised or minimised, does not imply that problems with multiple objectives cannot be tackled. Various modelling techniques and solution strategies can be applied to such problems. Some involve reducing the model to one with a single objective. Objectives and constraints can often be interchanged. Once a model has been built, it is extremely easy to convert an objective to a constraint or vice versa. Another way of tackling a multiple objective model is through the use of a variant of the linear programming technique known as goal programming. This technique even has facilities for prioritising the goals. The reason it is not presently widely used is the limited availability of computer softwares for solving "real-life" problems.

Continuing our explanation of the technology co-efficients in Figure 5, we find that the intersections of each row and column describing each activity is given a co-efficient of 1. In linear programming problems, this is normally done when dealing with those variables normally described as having generalised upper bounds of 1. This means that the sum of these variables must be 1. The fact that the co-efficient of such variables are ones, is not very important, since scaling can always convert any constants with non-negative co-efficient into this form. What is however important is that, when a number of constants such as the above exist, the variables in them form exclusive sets. A set of variables is said to belong to a generalised upper bound set if it can belong to no others.

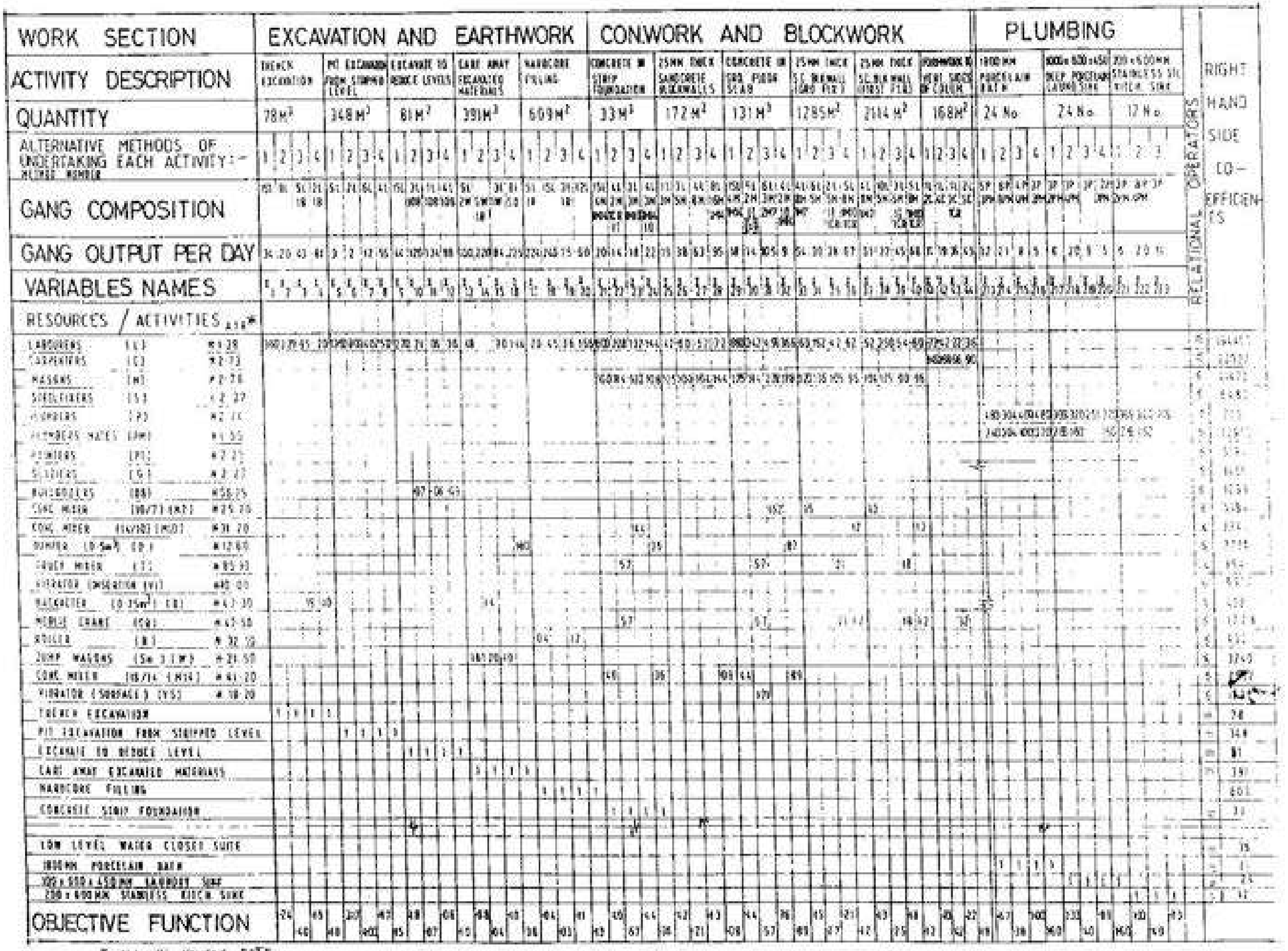
The right hand side co-efficient of 194,400 against the labourer resource was arrived at by using the figure of 45 labourers that the building organisation indicated it had available to be used on the project for a total period of 540 working days. Since the organisation had an 8-hour working day, the total labourer-hours available for the project would be 194,400 hours. Since the number of labourer-hours must not be exceeded, the relational operator linking the manhours to the labourer resource would be the "less than or equal to type". The right hand side co-efficient linking each activity description row would simply be the total quantity or amount of work involved in each item; the relational operator would in each case be the "equal" sign, since the quantity should neither be reduced nor exceeded. Thus, for the first activity on the activity description row, namely; "Trench Excavation", the right hand side co-efficient was put down as 78, which represents the total quantity of 78 cubic metres of trench excavation to be undertaken.

If instead of minimising time, we rather elected to minimise cost, then our objective function co-efficient for each of the X variables would have to be altered to reflect the change in our objective. Thus, as indicated in figure 6, the X_1 co-efficient of 0.24 would now be changed to 4.97 (N1.38 x 3.60 hours), where N1.38 is the all-in daily rate for labourers. The technology co-efficient would however remain the same as for the time optimisation model.

SOLUTION TO THE MODEL

The Sciconic Mathematical Programming computer software was used for providing solutions to the linear programming problems formulated in this paper. Abridged versions of the input data for the model with TIME and COST as the objective functions are indicated in Figures 7 and 8 respectively. First, the row variable names were entered followed by the column and the right hand side variables; each with its associated co-efficient. The variable names have been coded to comply with the computer software's specifications of limiting variable names to a maximum of eight characters. Full descriptions of a few selected coded names are given in appendix A.

The computer outputs of the model indicating the selected methods with time and cost as the objective functions are indicated in Figures 9 and 10 respectively. Each output has three columns headed: "COLUMN", "AT" and "ACTIVITY". The variables in the first column indicate those that are in the solution. The second column gives an

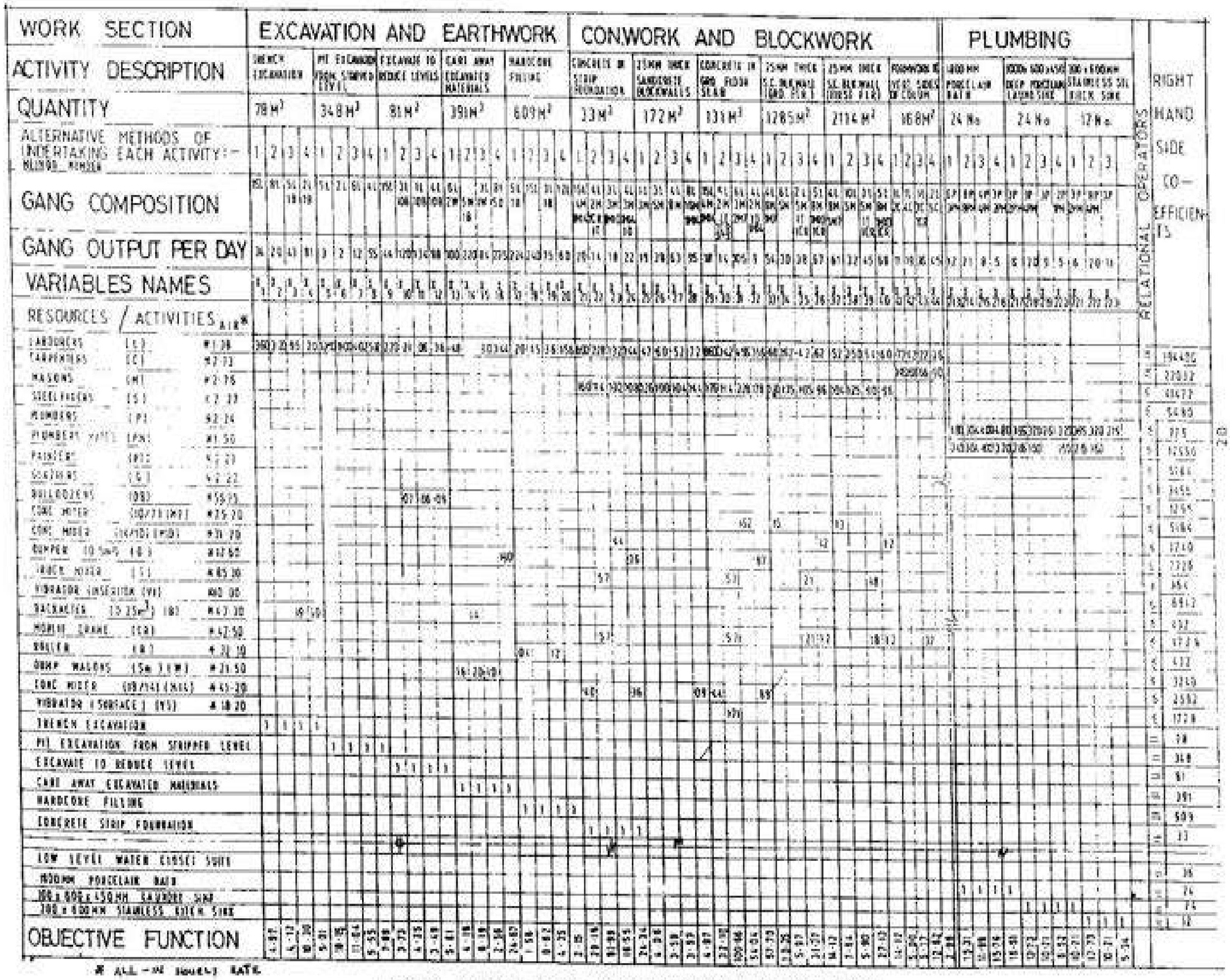


WORK SECTION	EXCAVATION AND EARTHWORK					CONWORK AND BLOCKWORK						PLUMBING		
ACTIVITY DESCRIPTION	TRENCH EXCAVATION	PIT EXCAVATION FROM STRIPPED LEVEL	EXCAVATE TO REDUCE LEVELS	CART AWAY EXCAVATED MATERIALS	HARDCORE FILLING	CONCRETE IN STRIP FOUNDATION	25MM THICK SANDCRETE BLOCKWALLS	CONCRETE IN GRD. FLOOR SLAB	25MM THICK S.C. BLKWALL (GRD. FLR.)	25MM THICK S.C. BLKWALL (FIRST FLR.)	FORMWORK TO VERT. SIDES OF COLUMN	1800 MM PORCELAIN BATH	600×450×450 DEEP PORCELAIN LAUNDRY SINK	200×600MM STAINLESS STL. KITCH. SINK
QUANTITY	78M³	348M³	61M³	391M³	609M²	33M³	172M²	131M³	1285M²	2114M²	168M²	24 No	24 No	17 No
ALTERNATIVE METHODS OF UNDERTAKING EACH ACTIVITY:- METHOD NUMBER	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3
GANG COMPOSITION	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
GANG OUTPUT PER DAY	36 20 43 61	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
VARIABLES NAMES	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

RESOURCES / ACTIVITIES		RATE*	RELATIONAL OPERATORS	RIGHT HAND SIDE CO-EFFICIENTS
LABOURERS	(L)	N1.28	≤	[illegible]
CARPENTERS	(C)	N2.73	≤	[illegible]
MASONS	(M)	N2.76	≤	4672
STEELFIXERS	(S)	N2.27	≤	8482
PLUMBERS	(P)	N2.[illegible]	≤	[illegible]
PLUMBERS MATES	(PM)	N1.55	≤	[illegible]
PAINTERS	(PT)	N2.25	≤	[illegible]
SLATERS	(SL)	N2.27	≤	[illegible]
BULLDOZERS	(BD)	N58.25	≤	[illegible]
CONC. MIXER	(10/7) (KM7)	N25.70	≤	[illegible]
CONC. MIXER	(14/10) (KM10)	N31.20	≤	[illegible]
DUMPER (0.5m³)	(D)	N12.60	≤	[illegible]
TRUCK MIXER	(T)	N85.93	≤	[illegible]
VIBRATOR (IMMERSION)	(VI)	N40.00	≤	[illegible]
BACKACTER (0.75m³)	(B)	N42.30	≤	[illegible]
MOBILE CRANE	(CR)	N47.50	≤	[illegible]
ROLLER	(R)	N32.50	≤	[illegible]
DUMP WAGONS	(5m³) (W)	N21.50	≤	[illegible]
CONC. MIXER	(18/14) (M14)	N41.20	≤	[illegible]
VIBRATOR (SURFACE)	(VS)	N18.20	≤	[illegible]
TRENCH EXCAVATION			=	78
PIT EXCAVATION FROM STRIPPED LEVEL			=	348
EXCAVATE TO REDUCE LEVEL			=	81
CART AWAY EXCAVATED MATERIALS			=	391
HARDCORE FILLING				601
CONCRETE STRIP FOUNDATION			=	33
LOW LEVEL WATER CLOSET SUITE			=	15
1800MM PORCELAIN BATH			=	1
600×450×450MM LAUNDRY SINK			=	24
200×600MM STAINLESS KITCH. SINK			=	17
OBJECTIVE FUNCTION				[illegible]

* ALL-IN HOURLY RATE

FIGURE 5: An Abridged Version of the Linear Programming Model for Optimum Construction Method Selection With Time as the Objective Function

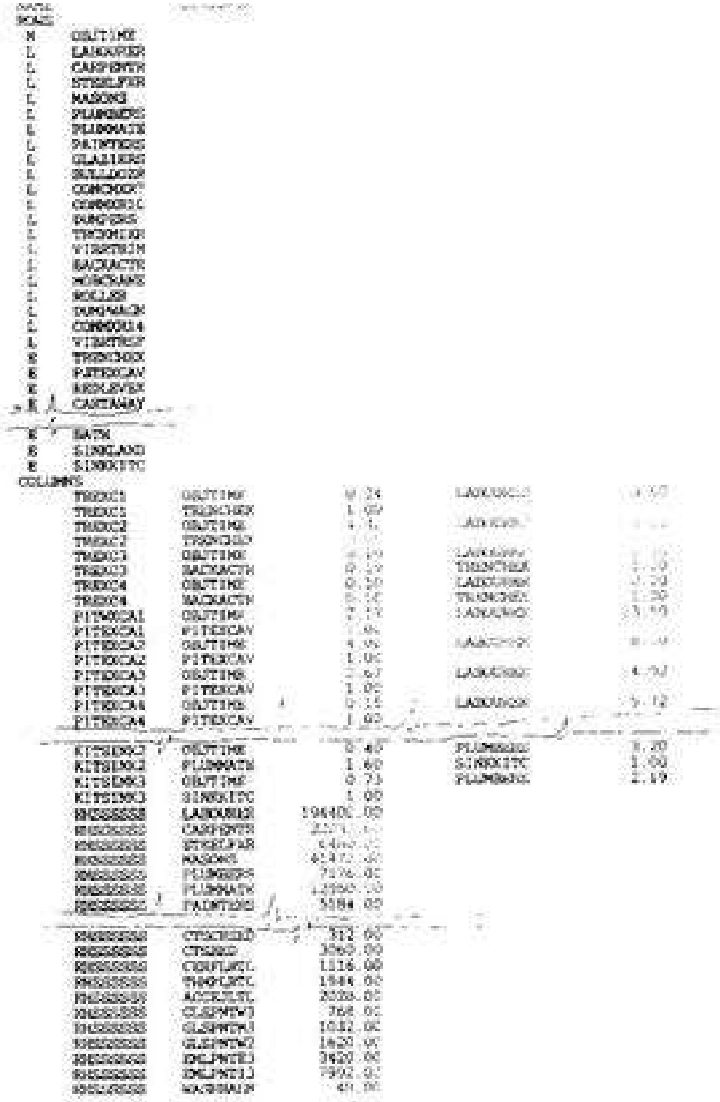


WORK SECTION	EXCAVATION AND EARTHWORK					CONWORK AND BLOCKWORK						PLUMBING		
ACTIVITY DESCRIPTION	TRENCH EXCAVATION	PIT EXCAVATION FROM STRIPPED LEVEL	EXCAVATE TO REDUCE LEVELS	CART AWAY EXCAVATED MATERIALS	HARDCORE FILLING	CONCRETE IN STRIP FOUNDATION	225MM THICK SANDCRETE BLOCKWALLS	CONCRETE IN GRD. FLOOR SLAB	225MM THICK S.C. BLKWALL (GRD FLR)	225MM THICK S.C. BLKWALL (FIRST FLR)	FORMWORK TO VERT. SIDES OF COLUMN	1800MM PORCELAIN BATH	1000x600x450 DEEP PORCELAIN LAVATORY SINK	1000x600MM STAINLESS STEEL KITCH. SINK
QUANTITY	78M³	348M³	81M³	391M³	609M³	33M³	172M²	131M³	1285M²	2114M²	168M²	24 No.	24 No.	12 No.
ALTERNATIVE METHODS OF UNDERTAKING EACH ACTIVITY	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3

RESOURCES / ACTIVITIES		AIR*	RELATIONAL OPERATORS	RIGHT HAND SIDE CO-EFFICIENTS
LABOURERS	(L)	₦1.28	≤	194436
CARPENTERS	(C)	₦2.73	≤	27032
MASONS	(M)	₦2.76	≤	40477
STEEL FIXERS	(S)	₦2.37	≤	5480
PLUMBERS	(P)	₦2.24	≤	775
PLUMBERS' MATES	(PM)	₦1.50	≤	12550
PAINTERS	(PT)	₦2.27	≤	5184
SCAFFOLDERS	(S)	₦2.22	≤	3455
BULLDOZERS	(DB)	₦55.75	≤	1255
CONC. MIXER	(10/7) (M7)	₦25.20	≤	5484
CONC. MIXER	(14/10) (M10)	₦31.20	≤	1740
DUMPER (0.5m³)	(D)	₦12.60	≤	7720
TRUCK MIXER	(T)	₦85.30	≤	864
VIBRATOR (INSERTION)	(VI)	₦10.00	≤	6912
BACKACTER (0.25m³)	(B)	₦47.30	≤	432
MOBILE CRANE	(CR)	₦42.50	≤	1724
ROLLER	(R)	₦31.10	≤	432
DUMP WAGONS (5m³)	(W)	₦21.50	≤	3240
CONC. MIXER	(18/14) (M14)	₦45.20	≤	2592
VIBRATOR (SURFACE)	(VS)	₦18.20	≤	1728
TRENCH EXCAVATION			=	78
PIT EXCAVATION FROM STRIPPED LEVEL			=	348
EXCAVATE TO REDUCE LEVEL			=	81
CART AWAY EXCAVATED MATERIALS			=	391
HARDCORE FILLING			=	609
CONCRETE STRIP FOUNDATION			=	33
LOW LEVEL WATER CLOSET SUITE			=	36
1800MM PORCELAIN BATH			=	24
100 x 600 x 450MM LAVATORY SINK			=	24
100 x 600MM STAINLESS KITCH. SINK			=	12
OBJECTIVE FUNCTION				

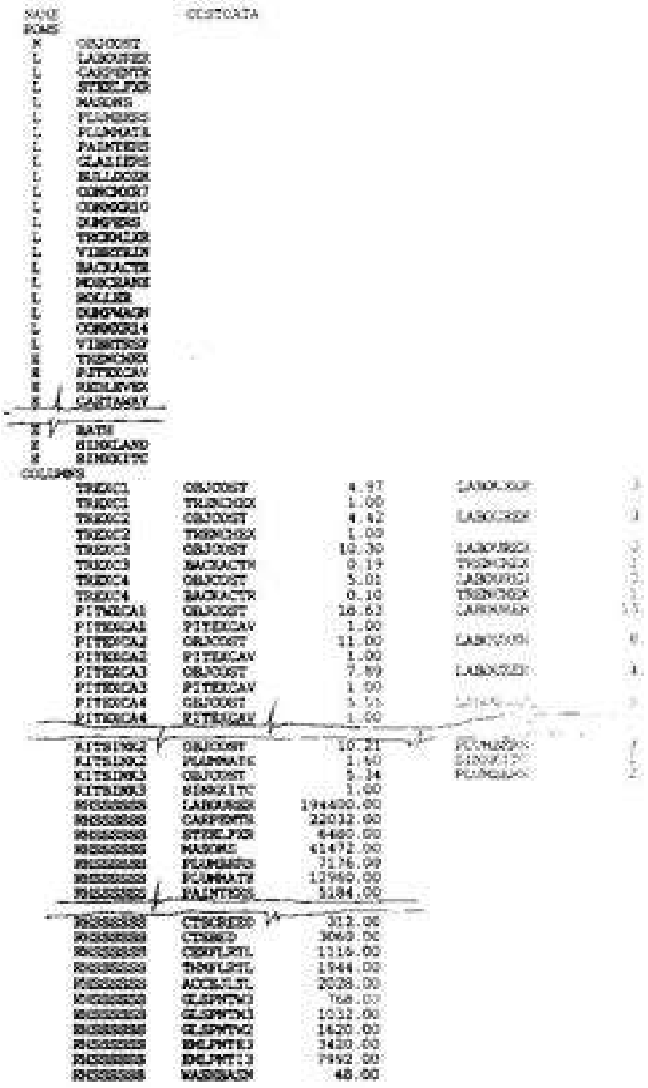
* ALL-IN HOURLY RATE

FIGURE 6: An Abridged Version of the Linear Programming Model for Optimum Construction Method Selection With Cost as the Objective Function.



```
NAME          [illegible]
ROWS
 N  OBJTIME
 L  LABOURER
 L  CARPENTR
 L  STEELFXR
 L  MASONS
 L  PLUMBERS
 L  PLUMMATE
 L  PAINTERS
 L  GLAZIERS
 L  BULLDOZR
 L  CONCMXR7
 L  CONMXR10
 L  DUMPERS
 L  TRCKMIXR
 L  VIBRTRIN
 L  BACKACTR
 L  MOBCRANE
 L  ROLLER
 L  DUMPWAGN
 L  CONMXR14
 L  VIBRTRSP
 E  TRENCHEX
 E  PITEXCAV
 E  REDLEVEX
 E  CARTAWAY
 E  BATH
 E  SINKLAND
 E  SINKKITC
COLUMNS
    TREXC1    OBJTIME        0.24   LABOURER     [illegible]
    TREXC1    TRENCHEX       1.00
    TREXC2    OBJTIME   [illegible]  LABOURER    [illegible]
    TREXC2    TRENCHEX  [illegible]
    TREXC3    OBJTIME   [illegible]  LABOURER    [illegible]
    TREXC3    BACKACTR  [illegible]  TRENCHEX    [illegible]
    TREXC4    OBJTIME        0.30   LABOURER     [illegible]
    TREXC4    BACKACTR  [illegible]  TRENCHEX    [illegible]
    PITEXCA1  OBJTIME   [illegible]  LABOURER    [illegible]
    PITEXCA1  PITEXCAV  [illegible]
    PITEXCA2  OBJTIME   [illegible]  LABOURER    [illegible]
    PITEXCA2  PITEXCAV       1.00
    PITEXCA3  OBJTIME   [illegible]  LABOURER    [illegible]
    PITEXCA3  PITEXCAV       1.00
    PITEXCA4  OBJTIME   [illegible]  LABOURER    [illegible]
    PITEXCA4  PITEXCAV       1.00
    KITSINK2  OBJTIME        0.40   PLUMBERS         3.20
    KITSINK2  PLUMMATE       1.60   SINKKITC         1.00
    KITSINK3  OBJTIME        0.73   PLUMBERS         2.19
    KITSINK3  SINKKITC       1.00
    RHSSSSSS  LABOURER  194400.00
    RHSSSSSS  CARPENTR  [illegible]
    RHSSSSSS  STEELFXR  [illegible]
    RHSSSSSS  MASONS    [illegible]
    RHSSSSSS  PLUMBERS  [illegible]
    RHSSSSSS  PLUMMATE  [illegible]
    RHSSSSSS  PAINTERS    5184.00
    RHSSSSSS  CTSCREED     312.00
    RHSSSSSS  CTSBED      3060.00
    RHSSSSSS  CSBFLRTL    1116.00
    RHSSSSSS  TMBFLRTL    1944.00
    RHSSSSSS  ACCRLSTL    2028.00
    RHSSSSSS  GLSPNTW3     768.00
    RHSSSSSS  GLSPNTW1    1032.00
    RHSSSSSS  GLSPNTW2    1620.00
    RHSSSSSS  EMLPNTE3    3420.00
    RHSSSSSS  EMLPNT13    7992.00
    RHSSSSSS  WASHBASN      48.00
```

Fig. 7: *Print out of Parts of the Input Data for the Model with Time as the Objective Function.*



```
NAME          COSTDATA
ROWS
 N  OBJCOST
 L  LABOURER
 L  CARPENTR
 L  STEELFXR
 L  MASONS
 L  PLUMBERS
 L  PLUMMATE
 L  PAINTERS
 L  GLAZIERS
 L  BULLDOZR
 L  CONCMXR7
 L  CONMXR10
 L  DUMPERS
 L  TRCKMIXR
 L  VIBRTRIN
 L  BACKACTR
 L  MOBCRANE
 L  ROLLER
 L  DUMPWAGN
 L  CONMXR14
 L  VIBRTRSP
 E  TRENCHEX
 E  PITEXCAV
 E  REDLEVEX
 E  CARTAWAY
 E  BATH
 E  SINKLAND
 E  SINKKITC
COLUMNS
    TREXC1    OBJCOST        4.97   LABOURER     [illegible]
    TREXC1    TRENCHEX       1.00
    TREXC2    OBJCOST        4.42   LABOURER     [illegible]
    TREXC2    TRENCHEX       1.00
    TREXC3    OBJCOST       10.30   LABOURER     [illegible]
    TREXC3    BACKACTR       0.19   TRENCHEX     [illegible]
    TREXC4    OBJCOST        5.01   LABOURER     [illegible]
    TREXC4    BACKACTR       0.10   TRENCHEX     [illegible]
    PITEXCA1  OBJCOST       18.63   LABOURER     [illegible]
    PITEXCA1  PITEXCAV       1.00
    PITEXCA2  OBJCOST       11.00   LABOURER     [illegible]
    PITEXCA2  PITEXCAV       1.00
    PITEXCA3  OBJCOST        7.89   LABOURER     [illegible]
    PITEXCA3  PITEXCAV       1.00
    PITEXCA4  OBJCOST   [illegible]  LABOURER    [illegible]
    PITEXCA4  PITEXCAV       1.00
    KITSINK2  OBJCOST       10.21   PLUMBERS     [illegible]
    KITSINK2  PLUMMATE       1.60   SINKKITC     [illegible]
    KITSINK3  OBJCOST        5.34   PLUMBERS     [illegible]
    KITSINK3  SINKKITC       1.00
    RHSSSSSS  LABOURER  194400.00
    RHSSSSSS  CARPENTR   22032.00
    RHSSSSSS  STEELFXR    6480.00
    RHSSSSSS  MASONS     41472.00
    RHSSSSSS  PLUMBERS    7176.00
    RHSSSSSS  PLUMMATE   12960.00
    RHSSSSSS  PAINTERS    5184.00
    RHSSSSSS  CTSCREED     312.00
    RHSSSSSS  CTSBED      3060.00
    RHSSSSSS  CSBFLRTL    1116.00
    RHSSSSSS  TMBFLRTL    1944.00
    RHSSSSSS  ACCRLSTL    2028.00
    RHSSSSSS  GLSPNTW3     768.00
    RHSSSSSS  GLSPNTW1    1032.00
    RHSSSSSS  GLSPNTW2    1620.00
    RHSSSSSS  EMLPNTE3    3420.00
    RHSSSSSS  EMLPNT13    7992.00
    RHSSSSSS  WASHBASN      48.00
```

Fig. 8: *Print out of Parts of the Input Data for the Model With Cost as the Objective Function.*

Fig. 9. *Print out of the Output of the Model indicating the Selected Methods with Time as the Objective Function.*

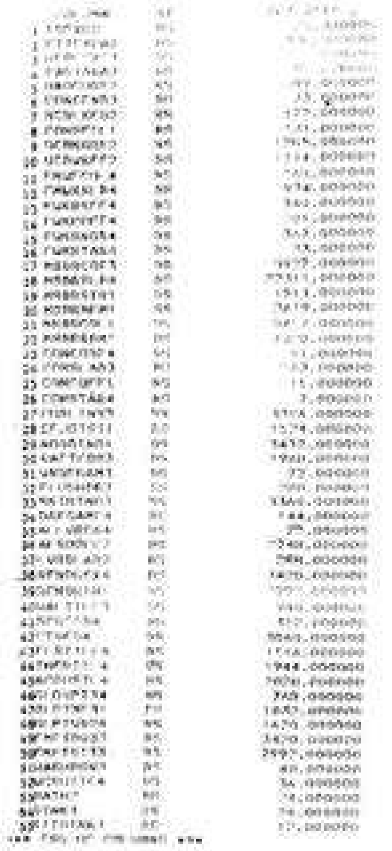


Fig. 10: *Print out of the Output of the Model indicating the Selected Methods with Cost as the Objective Function.*

PARTICIPANTS	OBJECTIVE FUNCTION	
	COST	TIME
POOLED (1)	11	10
ESTIMATOR (2)	7	12
SITE MANAGER (3)	17	10
CHIEF PLANNING ENGINEER (4)	21	24
TOTAL	56	56

Fig. 11: *Number of each Participant's Models Selected by the Model according to Specified Objective Functions.*

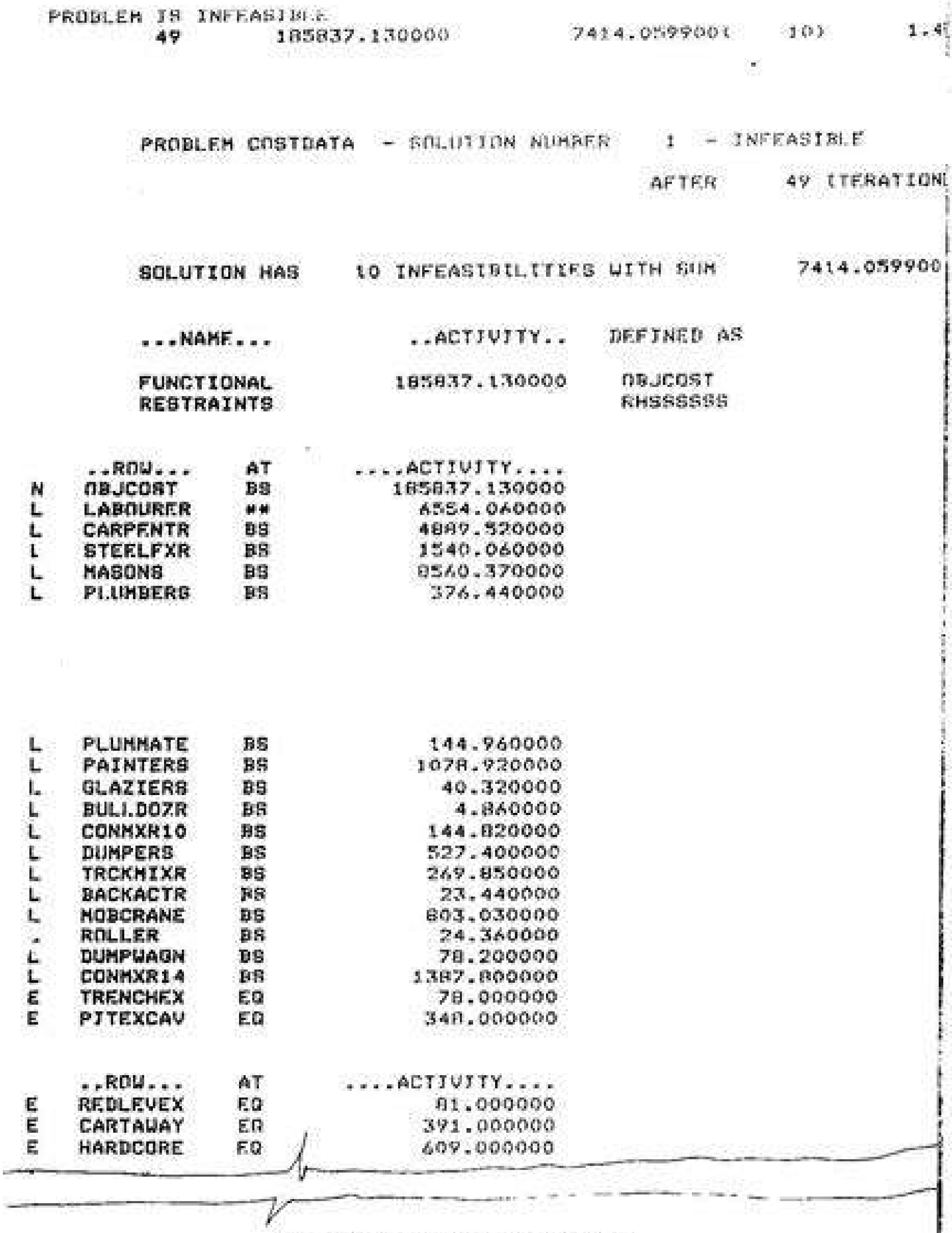
shadow price. Three of the resources fall into this category: Backacter, Roller and Surface Vibrator. Figure 13 provides the same type of information but with time as the objective function. The information indicates that the minimum work content, if the selected methods were used, would be 2868.32 hours; any other combination of methods would have a higher work content than the above mentioned figure. The respective slack values are also shown. Here, three resources, namely: Concrete Mixer (14/10), Roller and Surface Vibrator have been fully utilised. These will therefore have shadow prices associated with them.

Figure 14 provides a summary of the slack values (in percentages) available, with both time and cost as objective functions. While some of the resources had zero slack values in both cases - roller, surface vibrator - others, such as the 18/14 concrete mixer, carpenters, steel fixers, masons and painters had very high slack values, also in both cases. The high slack values produced by the model indicated that the planning team had been very generous with its allocation of resources to the project. The model was run again with the amount of each resource reduced to half of its original value, and the outcome of the exercise is depicted in Figure 15. The project in this particular case was found to be infeasible, indicating that at least one of the resources - labourer-hours at that stage - allocated to the project was not adequate. That was a very important revelation since it clearly demonstrated one of the important features of the model, namely, its capacity for indicating the adequacy or otherwise of the resources constructors would want to deploy on specific projects at the planning stages of such projects.

The value of linear optimisation models to the user is not simply in obtaining an optimal solution to a problem, but in interacting with the model and its variations to obtain information and insights. The heart of the managerial function is focused in the interpretation of results and in decision-making. While the solution output has obvious value for the user, the power of the results is greatly enhanced by the sensitivity or post-optimal analysis. Sensitivity or post-optimal analysis enables information to be generated for the "what-if" questions that the user would want to find answers for before arriving at the final decision on implementation. A detailed treatment of the subject will form the subject matter of another paper.

RESOURCES	OBJECTIVE FUNCTION	
	COST (%)	TIME (%)
LABOURER	6.4	10.0
CARPENTER	28.1	25.5
STEELFIXER	24.2	14.9
MASON	20.9	23.8
PLUMBER	5.9	5.3
PLUMBER' MATE	2.1	3.1
PAINTER	23.5	20.2
GLAZIER	0.7	0.7
BULLDOZER	0.4	0.4
CONCRETE MIXER (10/7)		0.3
CONCRETE MIXER (14/10)		0.2
DUMPER	7.0	1.7
TRUCKMIXER	3.2	2.5
VIBRATOR (INSERTION)	1.6	1.6
BACKACTER	5.4	
MOBILE CRANE	18.1	1.1
ROLLER		
DUMPWAGON	2.4	1.2
CONCRETE MIXER (18/14	67.9	10.1
VIBRATOR (SURFACE)		

Fig. 14: Slack Time of the Resources used in the Model as a Percentage of the Total Resource Availability Times.



```
PROBLEM IS INFEASIBLE
        49        185837.130000          7414.0599001    10)      1.4

        PROBLEM COSTDATA  - SOLUTION NUMBER    1  - INFEASIBLE
                                                    AFTER     49 ITERATION

        SOLUTION HAS    10 INFEASIBILITIES WITH SUM          7414.059900

        ...NAME...            ..ACTIVITY..   DEFINED AS

        FUNCTIONAL            185837.130000   OBJCOST
        RESTRAINTS                            RHSSSSSS

      ..ROW...     AT       ....ACTIVITY....
N     OBJCOST      BS          185837.130000
L     LABOURER     **            6554.040000
L     CARPENTR     BS            4889.520000
L     STEELFXR     BS            1540.060000
L     MASONS       BS            8540.370000
L     PLUMBERS     BS             376.440000




L     PLUMMATE     BS             144.960000
L     PAINTERS     BS            1078.920000
L     GLAZIERS     BS              40.320000
L     BULLDOZR     BS               4.840000
L     CONMXR10     BS             144.820000
L     DUMPERS      BS             527.400000
L     TRCKMIXR     BS             269.850000
L     BACKACTR     BS              23.440000
L     MOBCRANE     BS             803.030000
.     ROLLER       BS              24.360000
L     DUMPWAGN     BS              78.200000
L     CONMXR14     BS            1387.800000
E     TRENCHEX     EQ              78.000000
E     PITEXCAV     EQ             348.000000

      ..ROW...     AT       ....ACTIVITY....
E     REDLEVEX     EQ              81.000000
E     CARTAWAY     EQ             391.000000
E     HARDCORE     EQ             609.000000
```

Fig. 15: Print out of the Output of the Model when the Original Resources were reduced by 50%.

This successful application of the model to construction method selection problems should open the floodgates for its use in modelling many similar problems in the construction industry, such as determining the "best" mix of building types for speculative development projects, the selection of the "best" design schemes put forward by design consultants, the modelling of a contractor's entire workload for a defined period of time to determine the feasibility of such a workload "vis-a-vis" the resources at the contractor's disposal, and so forth.

Furthermore, the use of the model in conjunction with the network analysis technique - that is, using the model for selecting optimal construction methods which will subsequently be used for producing network diagrams for projects - will considerately enhance the practice of project planning in the construction industry.

CONCLUSION

We have succeeded in this research project in developing a model for selecting appropriate construction methods from the myriad of possible methods that could be used in undertaking a construction project. The fact that the model takes cognisance of the type, amount, cost, output, et cetera, of the constructor's resources, and a specific objective in the selection process, makes the model a more reliable tool than most of the present ones used for selecting construction methods.

Its capability as a tool for undertaking sensitivity analysis, makes it particularly useful for testing the effects of several alternative policy decisions, before their actual implementation on the project. It is capable of company-wide application, that is, capable of being used to determine the methods that would result in the best use of a company's resources on all its projects simultaneously.

The reliability and accuracy of the model's output are very much dependent on the accuracy of the input data. It is important for the model's users to realise that, the development of a reliable data base, - using such techniques as work study, assignment, transportation, queuing and decision theories, and so forth - is a "sine qua non" for its successful application.

REFERENCES

1. **Chung, A.**, *Linear Programming*, Merrill, Columbus, Ohio, 1963.
2. **Dantzig, G.B.**, *Linear Programming and Extensions*, Princeton University Press, Princeton, 1969.
3. **Gaddie, W.**, *Chambers' Twentieth Century Dictionary*, W. & R. Chambers, Ltd., London, 1971.
4. **Gupta, J.P.**, *Building Site Activity: An Input/Output* Model, Unpublished Ph.D. Thesis, University of Manchester, Manchester, 1966.
5. **Hull, J., Mabes, J. and Wheeler, B.**, *Model Building Techniques for Management*; Saxon House, Teakfield Ltd., Westmead, 1976.
6. **Katzan, H.**, *Fortran 77*, Van Nostrand, Reinhold Co. New York, 1978.
7. **Manteau, K.A.**, *Factors Affecting Construction Cost Estimating in Nigeria-Based Construction Companies*, Faculty of Environmental Sciences Seminar Paper, University of Jos, July, 1986.
8. **Parker, H.W. and Oglesby, G.H.**, *Methods Improvement for Construction Managers*, McGraw-Hill Company, New York, 1972.
9. **Price, A.D. and Harris, F.C.**, *Methods of Measuring Production Times for Construction Work*, Technical Information Service Paper No. 49, from the Chartered Institute of Building, Ascot. 1983.
10. **Said, M.E. and Can, E.K.**, *Optimisation Model for Aggregate Blending*, Journal of Construction Engineering and Management, III, (3), 1985.

APPENDIX A1

Key to Computer Codes: "Input Data"*

ACCEJLTL	Acoustic Ceiling tiles
BACKACTR	Backacter
BATH	Porcelain Bath
BULLDOZR	Bulldozer
CARPENTR	Carpenter
CARTAWAY	Cart away excavated material
CERFLRTL	Ceramic floor tiles
CONCMXR7	10/7 Concrete mixer
CONMXR10	14/10 Concrete mixer
CONMXR14	18/14 Concrete mixer
CTSBED	Cement and sand bed
CTSCREED	Cement and sand screed .
DUMPWAGN	Dumpwagon
EMLPNTE3	Three coats of emulsion paint on blockwalls (externally)
EMLPNT13	Three coats of emulsion paint on blockwalls (internally)
GLSPNTM3	Three coats of gloss paint on metal surfaces
GLSPNTW2	Two coasts of gloss paint on wood surfaces
KITSINKI	Stainless steel kitchen sink (Method 1)
MOBCRANE	Mobile crane
OBJCOST	Objective - Minimize cost
OBJTIME	Objective - Minimize time
PITEXCAV	Pit excavation
PITEXCA1	Pit exacavation (Method 1)
PLUMMATE	Plumber's mate
REDLEVEX	Reduced level excavation
RHSSSSSS	Right-hand-side co-efficient
SINKKITC	Stainless steel kitchen sink
SINKLAND	Porcelain laundry sink
STEELFXR	Steelfixer
THMFLRTL	Thermoplastic floor tiles
TRCKMIXR	Truck mixer
TRENCHEX	Trench excavation
TREXC1	Trench excavation (Method 1)
VIBRTRIN	Insertion vibrator
VIBRTRSF	Surface vibrator
WALLTILE	Glazed wall tile
WASHBASIN	Wash basin
WC	Water closet

* See Method Statement (Figure 4) for Detailed Description of items

APPENDIX A2

Key to Computer Codes. "Output Data"*

ACOUST14	Acoustic Ceiling tiles
ALLVRCA4	Aluminium louvre carriers
ALROOFG3	Corrugated aluminium roofing sheet
BACKING4	Cement and sand backing
CARTAWA2	Cart away excavated material
CEJOIST2	Hardwood ceiling joist
CONCFND4	Concrete in foundations
CONCOFF2	Reinforced concrete in columns (First floor)
CONCOGF4	Reinforced concrete in columns (Ground floor)
CONGFSI1	Concrete in ground floor slab
CONSIAB3	Reinforced concrete in slabs
CONSTAR4	Concrete in stairs
CTBED4	Cement and sand bed
DRFRAME3	Mild steel door frames
EMPTBI33	Three coats of emulsion paint on blockwall (internally)
EMPTBW32	Three coats of emulsion paint on blockwall (externally)
FLRTILE4	Ceramic floor tiles
FLUSDR4	Plywood flush door
FMWFCOL4	Formwork to columns (ground floor)
FMWKSLB4	Formwork to floor slab (first floor)
FWKBSFF4	Formwork to beams (first floor)
FWKCOFF4	Formwork to columns (first floor)
FWKRNGB4	Formwork to ring beam
FWKSTAR4	Formwork to soffit of stairs
GLOSPT33	Three coats of gloss paint on wood surfaces

GLPTME31	Three coats of gloss paint on metal surfaces
GLPTWD22	Two coats of gloss paint on wood surfaces
HADCORE2	Hardcore filling
KITSINK2	Stainless steel kitchen sink
LVRBLAD2	Sheet glass louvre blades
MSBRBEMI	Mild steel reinforcement in beams
MSBRRBMI	Mild steel reinforcement in ring beams
MSBRCGF1	Mild steel reinforcement in columns (ground floor)
MSBRCOL1	Mild steel reinforcement in columns (first floor)
MSBRSLB3	Mild steel reinforcement in slabs (first floor)
MSBRSTR3	Mild steel reinforcement in stairs
REDLEXC3	Reduced level excavation
RENDREX4	Cement and sand rendering (externally)
RENDRIN4	Cement and sand rendering (internally)
SCBKGRF4	Sandcrete blockwork (ground floor)
SCBLKFF4	Sandcrete blockwork (foundations)
SCBWKFF4	Sandcrete blockwork (first floor)
SKIRTNGA	Hardwork skirting
THERTIL4	Thermoplastic floor tiles
WALTILE3	Glazed wall tiles
WASHBSN2	Washhand basin
WCSUITE4	Water closet suite
WNDFRAM3	Hardwood window frame

* See Method Statement (Figure 4) for Detailed Description of items.

Note: Figures at the end of codes indicate selected method numbers.