TOPICS.

A MODEL FOR OPTIMAL BUILDING PROJECT REALISATION UNDER MULTIPLE TECHNOLOGY AND RESOURCE CONSTRAINTS

A Thesis Presented to this Department of Building, Faculty of Environmental Design, Ahmadu Bello University, Zaria, in Partial Fulfillment of the Requirements for **the** Award of the Degree of Master of Science Construction Management

BY

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SEPTEMBER, 1983

UNDER THE SUPERVISION

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ZARIA, NIGERIA

D E D I C A T E D

TO MY

WIFE - BILKISU

AND

DAUGHTER - ZAINAB

A C K N O W L E D G E M E N T

My unreserved appreciation goes to my Mentor Dr. D. A. Muazu. His advice and guideline at every stage of the thesis makes me indebted to him.

I must also thank Dr. T. O. Mosaku, and the entire staff of the Department for their various help.

I am grateful to Mr. Tom Higgins of the N.N.C.C. for his assistance in collecting my data.

Finally I thank all my classmates. I also thank Miss Hannah Gabriel and Isaac for their special help in typing and rolling.

Thank you all.

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Chapter One

INTRODUCTION

1.1 Background:

Traditional building construction in the country before the advent of the British influence tended to be made of local materials and simple technology. The technologies employed relate to the types of materials and labour available and consist mainly of local materials such as earth, bamboo, wood and thatch and local labour which used to be comminal.

At present in the country, with new and modern buildings such as hospitals, industries, large scale housing, etc. however, the rate of building project realization can be characterised using multiple technologies and resource constrainte.

The types of technologies employed in the realization of building in the country involve the important sectors of construction found in most developing countries of Africa.

Accordingly Turin D. et al (1) classified the important sectors of construction in such regions as follows:

(1) The traditional sector, estimated to be between 20 per cent to 30 per cent of the total building activity, with most of it existing in the rural areas and around rapidly expanding urban centres.

(2) The Natural Conventional is charactersed by a mixture of traditional materials and technologies, with a few modern and industrally produced materials and compoments (i.e. aluminum roofing sheets, cement blocks for walls, simple reinforced concrete beams and lintols, crude jornery and glazing).

(3) The National Modern Sector involves the use of local technical and managerial skills in handling modern technologies, imported or adopted from more industrialized countries. Most of the buildings in this sector are carried out in major urban centres.

(4) The International Modern Sector draws on the most advanced construction technology available in the world. It is controlled largely by foreign consultants. A prerequisite of the National Modern Sector.

1.2. Need for the Research:

There is need to appraise all the technologies and materials mentioned in 1.1. and try to come out with optimal technologies for building project realisation. High costs of buildings in the country, time overuns, made worse by importation of key materials and equipments, and transportation problems from the port inland makes such a need urgent. Such a model should highlight potential bottlenecks in project realization and increase efficiency of operations, and move efficient use of scant resources.

1.3. Scope and Objectives:

The objective of this work is to develop a mathematical model that will give an optimal building project realization. This model should increase efficiency in building project realization and streamline resources involved.

Linear programming technic will be used to develop this model. The modelformulated will then be solved with the aid of an electronic computer.

Date obtained from construction site of the New Nigeria Construction Company (NNCC) in Zaria, where Ahmadu Bello University Teaching Hospital is under construction will be used to illustrate the working of the model. Both time and cost will be taken as objective functions and the results analysed.

The final analysis of the results obtained from the model will be reviewed within the light of some qualitative (i.e. political, human and related problems) aspects of the problems.that were not included in the Model.

Chapter Two

2. BUILDING PROJECT TECHNOLOGIES OF COMMON USE IN NIGERIA

2.1. Manual-Oriented Technology:

2.1.1. Labour in Manual-Oriented Technology:

According to De et al (2) "the need for building in all the developing countries requires an all-out effort in moblising resources and in developing appropriate techniques which take into account the technologieal development, the skills and the materials available. As the available capital in India is limited whilst there is a large labour force it would seem more appropriate to adopt manual-oriented construction method."

Manual-oriented technology is labor-intensive. Nigeria and other developing countries have abundant labour, relatively cheap though of poor quality. The quality can greatly be improved by close supervision.

Efforts are however being made to improve this situation. Scott and Sheikh (3) reported that "efforts have been made by international agencies such as International Labour Organisation (ILO), International Bank for Reconstruction and Development (IBRD), and the World Bank, to help the developing countries utilize their local resources in a better manner by substitution of technology. The Internation Labour Organisation (ILO) in particular has undertaken studies in roadwork construction and has demonstrated that in the case of minor roads the prospect of using labour - intensive methods of construction are promising, both technically and financially."

Table: 2.1 Productivity Data for Earthmoving

Method	Operation	Team	Hourly Output (m^3)	Assumptions
CI	ELHUS	Bulldozer (D8H)	90	Haul 50m
	EL	1 Worker	0.5	L on wheel barrow bull cart.
LI	HU	1 Worker + wheelbarrow	1	H by wheelbarrow 50m.
	S	1 Worker	0.5	Soil, stiff clay

Source: ASCE Journal, June 1978.

CI = Capital-intensive E=excavation U=unloading

LI = Labor-intensive L=loading S=spreading

H=hauling

Table 2.1 shows for CI approach the hourly output is that for the whole task (ELHUS) but for the LI approach it is obtained by combining a number of smaller operations. Since S can be done at 5.0m^3/hr for the task of ELHUS for the LI appraoch.

2.1.2 Equipment in Manual-Oriented Technology:

In manual-oriented technology, most of the operations are manual and therefore the need for soplusticated equipment does not arise. Simple equipments are only needed for mixing, excavation, transportation and placing use shovel, headpans, wheelbarrows etc.

2.1.3. Materials in Manual-Oriented Technology:

"Many developing countries use predominantly imported materials in construction, according to De Graft Johnson (4). Thus, material resources in most developing countries are not fully exported. In some cases materials production plants dependent on imported raw materials have been established, and this has led to expensive products."

This solution, cannot be afforded by the poor developing countries. These countries can only afford to import the few building materials and product which they cannot produce themselves.

As Kristiansen (5) put it, "even today fewer than ten of the most industrialised countries can afford to base their construction industry on imported building products and components. Their finance does not permit this, and this is why in all coountries the civil engineering and construction industry is mainly a domestic industry. Too much money is involved (some 50 per cent of all capital investment) and therfore a construction industry cannot develop if based on imports."

2.1.4. Time in Manual-Oriented Technology:

Due to the type of labour and equipment used in this technology, the time factor in this case should be longer. The rate of out put would be minimal, but with good supervision the out put could be improved.

2.2. Semi Mechanised - Technology:

2.2.1. Labour in Semi-Mechanised Technology:

In semi-mechanised technology the ratio of skilled to unskilled labour is high. This is so because of the number of equipments involved. Here, "skilled labour" is presumed to include the following class of workers: Foreman, Mechanics, operators for equipments drivers for trucks, etc. Generally the operator for heavy equipments are the highest paid followed by mechanics, foreman, and drivers. "Unskilled labour are presume to include all those workers who are engaged in manual work that does not require any skill". (3)

Table: 2.2 Estimates of Hourly Wage Rates for Skilled Labour in Construction, in Bahts per hour:

Skilled Classification	Range of Wages B	Wage Used B
Operators for Scrapers, heavy dozers, loaders and cranes.	8.00 - 9.50	9.00
Foreman, mechanics, operators for rollers and graders	6.00 - 8.00	7.00
Drivers for trucks, farm tractors	5.00 - 6.50	6.00

Note: B 20=$1 US : B1=5¢

Source: ASCE Journal
Vol. 104 No. CO2 June, 1978.

As seen from table 2.2, operators of heavy machine are paid higher (8-9.50) than that of drivers for trucks and farm tractors (5-6.50).

In the developing countries, skilled labour are in short supply and are therefore imported. This is substianted by De Graft Johnson (4) who said, "in most developing countries, the availability of trained personel is far below requirements, and the scope of training is not sufficient to enable engineering and technology graduates to acquire skills which would facilitate the adoption of appropriate technology. Projects are planned, designed and excuted by personel from developed countries or by local staff trained using technic similar to those available in developed countries.

2.2.2. Equipment for Semi-Mechanised Technology:

Mechanisation plays an important role in industrialization and in many construction processes that must be carried out at building sites.

Mechanical plants for site work are scarce and expensive. Equipments then has to be imported. The cost of importing to the developing countries is burden onto their economy. Mechanisation could both be of disadvantage and advantage to these countries. Mechanisation increases productivity but reduced the labour employment. (4)

Table: 2.3. Replacement of Human Labour with Machines:

Types of Machine	No of Labourers Replaced
Excavation, 0.15 - $3m^3$	20 - 160
Motor-Scrapers, from $6m^3$	50 - 120
Bulldozers, from 8hp	70 - 90
Motor Graders, 60 - 120	30 - 50
Machines for Earth Compaction, 4 - 25	20 - 50
Building Cranesm, 30 - 80	30 - 40
Dump-Cars, 3 - $5m^3$	20 - 30
Motor Granes, 5	10 - 20
Mixers, 250 - 750	5 - 10
Conveyors, 4 - 15	3 - 5

Sources: Building Research Nos. 2 and 3 Research Institute of the Building Industry Prague, 1963.

Table 2.3 shows the relationship of machine to human labour. By using, for example, motor scrapers, you replace 50 - 60 human labour, excavation 20 - 160 building cranes 30 - 40.

Also the selection of appropriate technology is also based on minimizing the outflow of foreign exchange. Comparing alternative technology by this criterion does not involve shadow prices; rather, foreign exchange flow can be measured in a monetary unit, and the net flow over the relevant span of years can be discounted back to the date of project initiation. But in a country where rental services are offered, firms can save money by hiring and the country will save its foreign exchange.

Table: 2.4. Estimated Rental Rates for Equipments:

Equipment Type	Life in n, Years	Hourly Rental Rates in Bahts
Wheelloaders (2.1/2cu yd)	8	340.00
Dragline	10	1032.00
Bulldozer: D 8 H	8	630.00
Crawler Mounted Loader; 920	8	485.00
Motor Scraper (Cat 621)	8	630.00
Pneumatic Roller (4T)	8	243.00
Motor Grades (Cat 12F)	8	243.00
Vibratory Rollers (4T)	5	88.00
Vibratory Plate	8	24.00
Dump Truck (5 cu yd)	4	127.00
Water Truck ($6m^3$)	4	127.00
Farm Tractor (73 hp)	4	63.00

Note B 20 = S 1 US

Source: ASCE Journal
Vol. 104 No. CO2 June 1978.

Form table 2.4, the hourly rental rate is fairly high, this could be due to high list of importation. But depending on how much a list the machine can be put at, owning or hiring decision could be arrived at.

2.2.3. Material for Semi-Mechanised Technology:

With regards to the quantity and quality of building materials available in the country, there is a small domestic production of these materials. Although the production of building materials has been insufficient in developing countries, it has gradually reached a very high level in developed countries. As a result, foreign trade in building materials started to grow in recent years with developed countries exporting to developing countries. Statistics for 1960 show that Africa had to import a total of 50 percent of its building materials, including 100 percent of its glass, consumption, 60 percent of paints and vanishes, 50 percent of brichs, tiles and ceramics, 33 percent of cement, and 33 percent of sawn wood and wood products (6).

Nigeria is fortunate to be producing some of the primary[1] building materials but had to import wholly the secondary[2] building materials. See table (2.5) and (2.6).

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1. High volume strucural materials used in most buildings (e.g. cement and reinforcing bars).

2. The lower volume, more specialised parts of the internal systems of the building (e.g. air-conditioners and sanitary fittings).

Table: 2.5. <u>Primary Construction Materials Recuirments</u>

	1979	1980	1981	1982	1983	1984	1985	1986
Cement (T)	119,600	159,900	167,700	102,000	110,100	188,600	154,600	120,300
Sand (M^3)	35,200	107,600	123,900	185,800	202,700	166,000	103,700	58,300
Aggregate (M^3)	95,700	377,900	418,300	421,900	315,200	211,400	127,900	68,900
Clay Products (T)	1,200	3,200	8,100	11,500	26,300	41,100	41,200	24,200
Rebar (T)	2,400	6,600	7,600	18,700	10,000	11,100	8,400	6,000
Structural Steel (T)	1,400	2,100	1,300	900	1,400	2,500	2,300	1,500
Lumber (M^3)	1,900	5,600	7,100	13,500	14,600	9,100	3,000	1,300
Asbestos Roofing (T)	600	1,500	2,500	5,300	6,100	3,780	1,100	500
Aluminum Roofing (T)	100	200	400	900	900	700	400	200
Asphalt Roofing (T)	40	100	70	100	300	400	400	200
Bitumen (T)	2,000	13,600	14,900	10,900	3,100	2,200	2,200	2,200

T - Metric Ton: M^3 = Cubic Meter *Brick, Hollow Clay Pots, Clay Condurt

Table: 2.6 Secondary Construction Materials Requirements:

	1979	1980	1981	1982	1983	1984	1985	1986
Ceilings, Proprietary (M^3)	200	500	1,300	1,500	3,800	6,100	6,400	3,000
Ceilings, Plaster (M^3)	50	120	10	60	250	360	310	100
Partitions, Proprietary(M^3)	200	600	1,900	3,100	8,000	14,000	14,100	8,300
Door and Frames: (No.)	6,800	15,600	20,900	43,400	54,700	41,900	21,400	10,000
(T)	150	350	475	985	1,200	950	490	250
Window and Frames: (No.)	8,300	19,800	27,100	51,400	74,200	71,400	53,000	31,000
(T)	110	170	370	700	1,000	970	720	420
Plumbing and Sanitary Fittings (T)	145	310	610	1,340	1,600	1,100	470	210
Exterior Wall Cladding (T)	70	180	410	650	1,850	3,070	3,060	1,860
Air Conditioning Equipment(T)	20	40	90	130	300	450	450	250
Electrical Equipment and Fittings (T)	30	75	160	270	400	440	380	220
Paint (T)	100	240	340	670	890	740	490	270
Steel Pipe (Large Diameter) (T)	620	5,400	5,700	4,200	600	0	0	0
Miscelaneous Installed Mechanical and Electrical Plant and Fittings (T)	770	1,350	860	980	450	120	50	20

Stone, Marble, Tile, etc.

2.2.4. Time inSemi-Mechanised Technology:

The time taken here is much less than that of manual-oriented technology. This is quite understandable due to the amount of equipment used.

2.3 Preffabrication:

Testa (7) defines "prefabrication" as a form of industrialization which, count of producing parts which, when assembled, will give a finished product, whether these parts are produced in a factory or under the open sky does not change the essence of the method. More relevant is the fact that when utilizing this form of industrialization, we have first to designed the finished product, then break it down into meaningful parts, produce these parts and finally assemble them in the correct sequence and order.

In all developing countries the problem of providing dwelling, education and health facilities is of primary importance. Logically enough, governments consider at time the possibility of introducing industrialization as a way of finding a fast and economical solution of the need of the population.

From the above definition, we can now identify several forms of industrialization currently used in the building trade. A first analysis shows four forms of industrialization used in the world at presen.

(a) Prefabrication

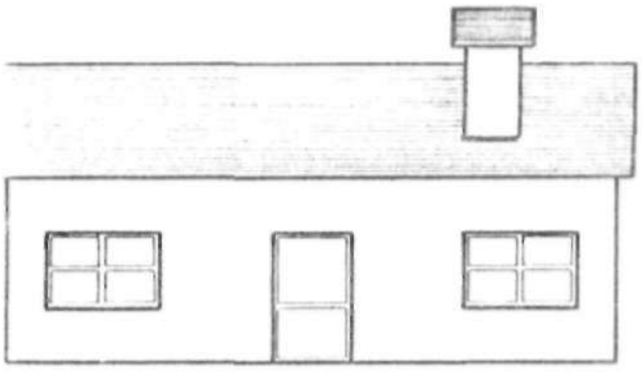
(b) Modular System Building

(c) Rationalized Building

(d) Equipment - Oriented Site - Production.

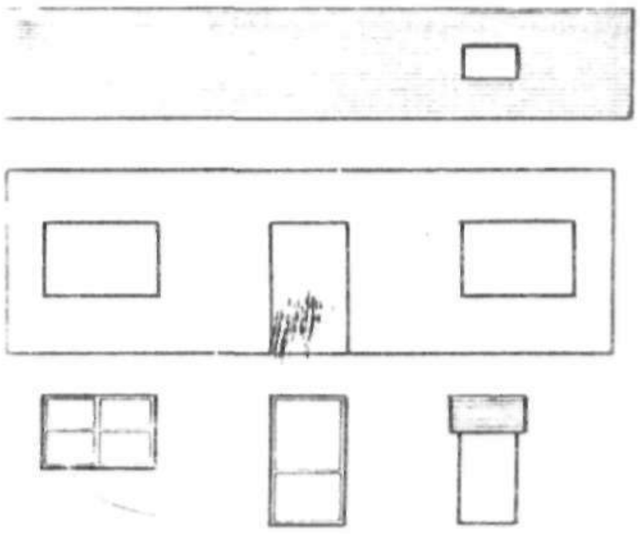
der Vorfertigung wird zunächst das Gebäude entworfen, dann wird es für Produktion in sinnvolle Teile unterteilt und schließlich werden die Teile der Baustelle montiert

prefabrication you first design the building and then you decompose it in meaningful parts for production and finally the parts are assembled on site



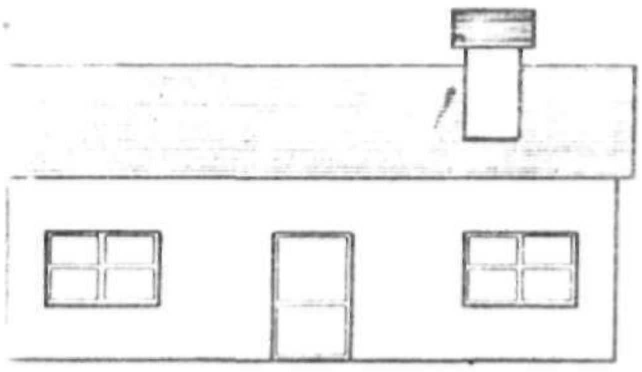
ursprüngliche Entwurf

original design



Bauwerk wird in seine Komponenten zerlegt, die dann in der Fabrik gefertigt werden

building is decomposed in its components and then the components factory produced



montierte Bauwerk

reassembled building

▶

opan Ltd. England. Ein sehr fortschrittliches Beispiel der Vorfertigung. ständige Sektionen eines Gebäudes werden in der Fabrik gefertigt, zur stelle transportiert und in wenigen Stunden montiert

opan Ltd. England. A very sophisticated case of prefabrication. Complete ions of a building are produced in the factory, transported to the site assembled in a few hours

(a) Prefabrication:

This form of industrialization consist of producing parts which when assenbled will give a finished product.

(b) Modular System:

It operates according to the opposite conceptual process of prefabrication. Here we first design a set of dimensionally and functionally inter-related compoments, we establish general rules of how these components may be connected together and with these components we then design a product. The components can be produced on a factory or several factories, but can hardly be produced on site without abourdoning the conceptual basis of this form of industrialization.

(c) Rationalised Building:

Is based not on a production form (prefabrication) or on a dimensional discipline (modular system) but on an attempt to increase productivity and performance by the application of all possible measures for streamlining production, for ensuring the best utilization of materials, equipments, and labour on the building site and in the production process. A project where considerable effort has been given to planning, scheduling, quality control and information flow can compete well in production time, cost and quality with prefabrication and modular system.

(d) Equipment - Oriented Site Production:

Here the objective of achieving productivity is achieved by the utilization on site of highly sophisticated equipments which can and with little human intervention produce complete building.

The main objective of the development of the industrialization process, according to Sebestye'n (6) are as follows: "to increase the productivity of labour; to increase the output of the construction industry; to make good use of local resources, including local raw materials, and agricultural and industrial wastes, to reduce the weight of the building structure and as a complimentary objective to decrease the volume of materials to be transported in relation to building volume; and to transfer as many process as possible from the changing building sites to off-site factories."

2.3.1 Labour in Prefabrication:

The main advantage of this technique has been the high productivity of labour: practically the same number of workers, as mentioned by Sebestye'n (6) produce twice as many flats."

Prefabrication does not require as much skilled-labour as the other technologies on the site but the managerial and planning stages need a lot move. "One large-scale European industrialized housing producer prefers to start with unskilled-labour, according to Dietz (8): he can train operatives in the simple manipulation needed in short order, and they need not unlearn anything. Building agencies in

Eastern Europe say that erection requires not more than 25 percent skilled labour, the rest can be unskilled."

Although numerous different jobs are found throughout the factory, the personnel may be divided into four main groups: operators, technicians, office staff and managers. Operators are normally semi-skilled or unskilled workers performing all manipulative operations both in production, maintenance or transportation. Technicians are skilled workers performing such operations requiring a spercialization e.g. maintenance of equipment, setting up machines, etc. Office staff performs all administrative work supporting the manufacturing process e.g. planning, purchasing, accounting etc. Managers, technical or administrative are responsible for all planning, executive and controlling activities at all levels (9).

2.3.2. Materials for Prefabrication:

The materials are almost the same as in the conventional method. In few cases, it is found that a mixture of more than one materials is needed. For example (8), "the wall of the Greater London Council were not made of only one material, nor was any one material preponderant. Their use therefore does not coincide with the primary interest of any one manufacturer, and no materials manufacturer took on either their development or fabrication."

Delayed delivery can cause considerable setback. To some extend industrialized buildings are more affected by a delayed delivery than conventional buildings.

Considerable savings could be achieved by exact [illegible] dimensioning of the components, a tighter quality control and employment of semi-skilled labour on site.

2.3.3. Equipment in Prefabrication:

Machinery acquisition by a construction firm can be a problem in this country. The manufacture of building machines requires a certain overall experience in machine building, existing production facilities for crucial parts (electric and diesel engines, ball bearings, etc.) and a market of sufficent size for such machines. Most developing countries do not meet all these requirements, and therefore have no building machines-industry. The pace of industrialization is illustrated by the number and sizes of plants for producing light to heavy prefabricated building components that are now in operation or under construction (Table 2.7).

Table: 2.7 Data on Plants for Prefabricated Building Components:

Type of Components	No of Plants in Operation	Annual Production Capacity (1,000m²)	No of Plants under Constr.	Annual Prod² Capacity (1,000m²)
Heavy	15	812	11	3465
Light	33	900	10	250
Total	48	1712	21	3715

Source: UNIDO Technology Program No 12 Vienna, 1980.

The technological development tends to give us very specialised equipment(7): automatic drills which will drill at 32mm interval only, foam spraying equipment which can be use only in connection with a specific mould, etc. Obviously a specific piece of equipment can perform beautifully a certain duty but nothing else. The consequence is that it becomes a limiting factor for future developments. All new design will have to take into consideration the capabilities of the equipment or heavy financial penalties will be paid.

After few years of operation firms are cluttered with a very specialised equipment and skills and can hardly follow the evelution of the market. The alternative of using very flexible equipment is not always satisfactory either.

As wish all tools designed to do a wide range of jobs it may prove that flexible equipment is never optimally utilized, is slow in operating and as a result expensive.

Clearly, the same rules apply on building - site: the correct kind of equipment must be utilized but at times the identification of the correct equipment is not an easy task.

2.3.4 Time in Prefabrication:

Of all the technologices, prefabrication has the shortest duration in terms of building project realisation.

A hypothetical mathematical model would be proposed using the technologies in building project realization. The technologies together with the resource constrints: would be applied to the different stages of construction in the model to find an eptimal cost and duration for an optimal building project realisation.

3. DEVELOPMENT OF MATHEMATICAL OPTIMIZATION MODEL FOR BUILDING PROJECT REALISATION

3.1. Nature of Models:

Accoding to Williams (9) the term "model" is usually used for a structure which has been built purposely to exhibit features and characteristics of some other object". Generally only some of the features and characteristics will be retained in the model depending upon the use to which it is to be put.

The models are usually mathematical in that algebraic symbolism will be used to minor the internal relationships in the object being modelled. It is important to realise that a model is really defined by the relationship which it incoporates. A model may be used on many different occasions with differing data e.g. costs. technological coefficients, resource availabilities etc

The quality of the answers which a model produces obviously depends on the accuracy of the structure and data of the model. For mathematical programming, models the defination of the objective clearly affect the answers as well.

A model should be used as one of a number of tools for decisions.

The specification of another objective function in the case of mathematical programming model might result in a different option. By successive questioning of the answers and altering the model or its objective, it should be possible to clarify the optious available and obtain a greater understanding of what is possible. A model cast in linear programming format will be adopted for building project realisation.

3.2. Linear Programming:

3.2.1. Linear Programming Problems:

According to Luenberger[a], "a linear programming problem is characterised, as the name implies, by the linear functions of the unknowns; the objective is the linear in the unknowns and the constraints are linear equalities or linear unequalities in the unknowns."

The problem of building project realisation is formulated as alinear programming problem. In the following section given is a brief review of the linear programming result that will be needed for the understanding of the proposed model.

3.2.2. Linear Programming Characteristies:

A linear programming problem in general appears as (10):

Maximise or Minimize

$$Z = c_1 x_1 + c_2 x_2 + \ldots\ldots + c_n x_n \text{ ------------(I)}$$

Subject to

$$a_{11} x_1 + a_{12} x_2 + \ldots\ldots = a_{1n} x_n = b_1 \text{ -------(II)}$$

$$a_{21} x_1 + a_{22} x_2 + \ldots\ldots + a_{2n} x_n = b_2$$

$$\vdots$$

$$am_1 x_1 + am_2 x_2 + \ldots\ldots + a_{mn} x_n = b_m \text{ ------(III)}$$

and $x1 \geq 0$, $x_2 \geq 0$, ... $x_n \geq 0$.

where the bi's, Ci's and aij's are fixed real constants, and the Xi's a re real numbers to be determined. It is always assumed that each equation has been multiplied by minus unity so that each bi. 0

Here (I) the expression in relation is called the objective function. The objective function is required to be optimised values of the unknowns X1, X2, ... Xn has to be found so that the value of 3 is optimised.

Consider the problem:

Minimize

$$Z = c_1 x_1 + c_2 x_2 + \dots\dots\dots + c_n x_n$$

Subject to

$$a_{11} x_1 + a_{12} x_2 + \dots\dots + a_{1n} x_n \leq b_1$$

$$a_{21} x_1 + a_{22} x_2 + \dots\dots\dots + a_{2n} x_n \leq b_2$$

:

:

$$a_{m1} x_1 + a_{m2} x_2 + \dots\dots\dots + a_{mn} x_n \leq b_m$$

and

$$x_1 \geq 0, \quad x_2 \geq 0, \dots\dots\dots x_n \geq 0$$

In this case the constraints set is determined entirely by linear inequalities. The problem may be alternatively expressed as

Minimize

$$Z = c_1 x_1 + c_2 x_2 + \dots\dots\dots + c_n x_n$$

Subject to

$$a_{11} x_1 + a_{12} x_2 + \dots\dots\dots + a_{1n} x_n + y_1 = b_1$$

$$a_{21} x_1 + a_{22} x_2 + \dots\dots + a_{2n} x_n + y_2 = b_2$$

:

$$a_{m1} x_1 + a_{m2} x_2 + \dots\dots\dots + a_{mn} x_n + y_m = b_m$$

and $x_1 \geq 0$, $x_2 \geq 0$, ... $x_n \geq 0$

and $y_1 \geq 0$, $y_2 \geq 0$, ... $y_n \geq 0$

The new positive variables yi introduced to convert the inequalities to equalities are called "slack variables". By considering the problem as one having n + m unknwons, X1, X2, ..., Xn, y1, y2, ... yn, the problem takes the standard form.

If the linear unequalities of the last problem are reversed so that a typical inequality is

$$ai_1\, x_1 + ai_2\, x_2 + \dots\dots\dots + ai_n\, x_n \geq bi$$

it is clear that this is equivalent to

$$ai_1\, x_1 + ai_2\, x_2 + \dots\dots\dots + ai_n\, x_n - y = bi$$

with yi $\geq$ 0. Variables, such as yi adjoined in this fashion to convert a "greater than or equal to" inequality to equality are called" surplus Variables".

It should be clear that by suitably multiplying by minus unity, and adjoining slack and surplus variables, any set of linear inequality can be converted to standard from if the unknown variables are restricted to be non-regative.

3.3. The Dual Problem:

Every linear programming problem has what is termed a "dual problem". This is the "other way" of the original problem which is called the "primal problem".

Experienced users of linear programming pay particular attention to the dual problem.[11] From it, answers to important optimality questions may be obtained which are not otherwise conveniently answered. Answers to questions about the permissable range of fluctuatives of coefficients of constraints are facilitated by examining the dual, so are answers to questions about adding, or deleting, some variables or constraint to the problem. The dual problem is concerned with the efficient use of resource.

3.4. Shadow Prices:

One very important use of the optimal dual solution is the final values of the original dual variable (excluding dual slack variables) in the final solution. These values are termed shadow prices. They show how much the objective can be inproved by obtaining one more unit of the associated resource provided the solution remains bam. (11)

3.5. Using Computer to Solve the Model:

Although very simple linear mathematical models can be solved manually this approach is inappropriate for practical sized models. The amount of calculation involved in solving real life models always necessitates the use of an electronic computers.

Practical linear programming models can be very large. Most models have a few hundreds constraints and variables and could be solved in a matter of minutes on most computers. A sizeable number of large models involving thousands of constrants and variables have also been built with these models the solution times are usually measured in hours.

3.6. A Description of a Mathematical Optimization Model for Building Project Realisation:

Multiple technology and resource constraints problems encountered in building project realisation could be solved using a linear programming model as these problems exhibit linear relations.

The whole building project is broken down into five stages for the purpose of illustration, (clear and survey, sub-structure, super-structure, roof and finishes). Three types of technologies are proposed here, (manual oriented, semi-mechanised and prefabrication).

One variant is used in the time allocation. Six variant in machinery allocation which shall give thirty decision variables. Six variants are used in the allocation of labour; giving thirty decision variables in the model. Five variants in material allocation giving twenty-five decision variables.

Decision variables for "clear and survey" are taken to be two. This means that the only two types of technology can be applied. Two decision variables are in sub-structure, but in the case of super-structure, roofing and finishes, three decision variables are taken.

The criteria adopted in this model to solve the problem is by making use of mathematical method of optimization which make it possible to determine an optimal combination of technologies to achieve building project realisation within a given set of resource constraints.

Though the model is broken down into five stages only, it is possible to break it down further if need arise. Also the variables could be more than those indicated in the model (time, machinery, men, materials) or they can be broken down into more units. The relation, is used to show that the limit should not be exceeded.

3.6.1. Decision Variables (Technology Constraints):

Fig. 3.1. Breakdown of the Project.

FIG. 3.1 BREAKDOWN OF THE PROJECT

DIVISION VARIABLES	CLEAR & SURVEY		SUB STRUCTURE		SUPER STRUCTURE			ROOF			FINISHES			RELATIVE	LIMIT
RESOURCE	X_1^I	X_2^{II}	X_3^I	X_4^{II}	X_5^I	X_6^{II}	X_7^{III}	X_8^I	X_9^{II}	X_{10}^{III}	X_{11}^I	X_{12}^{II}	X_{13}^{III}		

Here the building project is brokendown into five stages. These are clear and survey, sub-structure, super-structure, roof and finishes.

These stages are in turn brokendown into the appropriate technologies to be employed, is manual-oriented, semi-mechanise, and prefabrication, depicted in the model as I, II, III respectively. The numbers 1, 2, 3, 4. Then, 13 differentiate the different decision variables in different stages of construction. For example, X_1 represent decision variables applied in "clear and survey" stages, X_3 decision variable applied in sub-structure stage, X_5 decision variable applied in super-structure state etc.

If for example, "clear and survey" is taken, then only two technologies are applicable here, i.e. manual-oriented and semi-mechanised. "Clear and Survey", X_1^I denotes decision variable for manual-oriented technology during the clear and survey stage. Decision variable X_2^{II} here represents semi-mechanised technology during the "clear and survey" stage. In the case of "Super-structure" stage, three proposed technologies are all applicable. X^I, X^{II}, X^{III}, are decision variable representing manual-oriented technology, semi-mechanised and prefabrication in the super-structure stage.

3.6.2. Resource Constraints:

Time, labour, equipment and material are the resources used in this model. In figure 3.2; the different resources are allocated accordingly in the stages of construction. Resource coefficients depicting appropriate decision variable are denoted by small letters as against the capital letters used as limits for the resources.

Fig. 3.2. Resource Allocation:

FIG. 3.2 RESOURCE ALLOCATION.

DECISION VARIABLES / RESOURCES	CLEAR & SURVEY		SUB STRUCTURE		SUPER STRUCTURE			ROOF			FINISHES			RELATION	LIMIT
	x_1^I	x_2^{II}	x_3^I	x_4^{II}	x_5^I	x_6^{II}	x_7^{III}	x_8^I	x_9^{II}	x_{10}^{III}	x_{11}^I	x_{12}^{II}	x_{13}^{III}		
TIME:	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8	t_9	t_{10}	t_{11}	t_{12}	t_{13}	$\leq$	T
LABOUR															
L_1	l_1	l_2	l_3	l_4	l_5	l_6	l_7	l_8	l_9	l_{10}	l_{11}	l_{12}	l_{13}	$\leq$	L
⋮															
EQUIPMENT	e_1	e_2	e_3	e_4	e_5	e_6	e_7	e_8	e_9	e_{10}	e_{11}	e_{12}	e_{13}	$\leq$	E
⋮															
MATERIALS	m_1	m_2	m_3	m_4	m_5	m_6	m_7	m_8	m_9	m_{10}	m_{11}	m_{12}	m_{13}	$\leq$	M
⋮															

For example:

$$t_1 + t_3 + t_5 + \dots\dots\dots\dots + t_{13} \leq T \text{ ——— } (1)$$

$$l_1 + l_3 + l_5 + \dots\dots\dots\dots + l_{13} \leq L \text{ ——— } (2)$$

$$e_1 + l_2 + l_3 + \dots\dots\dots\dots + l_{13} \leq E \text{ ——— } (3)$$

$$m_1 + m_3 + m_4 + \dots\dots\dots\dots + m_{12} \leq M \text{ ——— } (4)$$

In (1) the total time allocated, t_1, t_2, t_3, ... etc to different technologies at the stages should not exceed the total project duration.

In (2) the total labour (labourers, carpenters, masons, etc) needed to complete the work stage should not exceed the total labour resource needed for the project completion.

The same explanation applies to (3) and (4).

3.3. Relationship of Technologies to the Stages of Construction:

FIG. 3.3 RELATIONSHIP OF TECHNOLOGIES TO THE STAGES OF CONSTRUCTIO

DECISION VARIABLES / STAGES	CLEAR & SURVEY		SUB STRUCTURE		SUPER STRUCTURE			ROOF			FINISHES			RELATION	LIMIT
	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	x_{13}		
CLEAR & SURVEY	1	1												=	1
SUB STRUCTURE			1	1										=	1
SUPER STRUCTURE					1	1	1							=	1
ROOF								1	1	1				=	1
FINISHES											1	1	1	=	1

Figure 3.3. shows the relationship of technologies to the stages of construction that can be applied to the different stages of construction. Unity is used to show the application of the technologies at the stages. The technologies applied are in percentage and they add up to 100 percent or unity.

For example

Clear and Survey, $= X_1 + X_2 = 1$

Sub-structure, $= X_3 + X_4 = 1$

Super-structure, $= X_5 + X_6 + X_7 = 1$

Roof $= X_8 + X_9 + X_{10} = 1$

Finishes $= X_{11} + X_{12} + X_{13} = 1$

For example, in (5) a certain percentage of X is applied and the remaining percentage to add up to unity is used of X. This is so because only to different technologies are applied at this stage.

In (7), the percentage is shared between X, X and X.

The higher the percentage, the more favourable the technology. Those which favours are those chosen for the optimality.

3.6.4. Objective Function:

Fig. 3.4. Total costs as objective function

Figure 3.3. shows the relationship of technologies to the stages of construction that can be applied to the different stages of construction. Unity is used to show the application of the technologies at the stages. The technologies applied are in percentage and they add up to 100 percent or unity.

For example

Clear and Survey, $= X_1 + X_2 = 1$

Sub-structure, $= X_3 + X_4 = 1$

Super-structure, $= X_5 + X_6 + X_7 = 1$

Roof $= X_8 + X_9 + X_{10} = 1$

Finishes $= X_{11} + X_{12} + X_{13} = 1$

For example, in (5) a certain percentage of X is applied and the remaining percentage to add up to unity is used of X. This is so because only two different technologies are applied at this stage.

In (7), the percentage is shared between X, X and X.

The higher the percentage, the more favourable the technology. Those which favours are those chosen for the optimality.

3.6.4. Objective Function:

Fig. 3.4. Total costs as objective function

FIG. 3.4 TOTAL COST AS OBJECTIVE FUNCTION.

DECISION VARIABLES / RESOURCE	CLEAR & SURVEY		SUB STRUCTURE		SUPER STRUCTURE			ROOF			FINISHES			RELATION	LIMIT
RESOURCE	X_1^{I}	X_2^{II}	X_3^{I}	X_4^{II}	X_5^{I}	X_6^{II}	X_7^{III}	X_8^{I}	X_9^{II}	X_{10}^{III}	X_{11}^{I}	X_{12}^{II}	X_{13}		
[OB]JECTIVE [FU]NCTION	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	$\leq$	C

The objective function was taken as optimisation criterion the cost per resource applied in building project realisation.

In the objective function column, cost, ci, are used to denote the thirteen types of decisions variables, and the total project cost is denoted, C.

The optimal cost coefficient in each construction stage are considered. The relationship should be kept in mind that the total cost should not exceed the project cost. So the different technologies chosen should also have a relationship to the optimal cost to be chosen. For example, if decision variable, X^{I}, (Manual-oriented technology) in "clear and survey" stage is chosen, the decision variable, X (semi-mechanised technology) also at "clear and survey" stage should not be added to achieve the building project cost. To show it mathematically, assume,

Clear and Survey Stage, X^{I} is chosen
Sub-structure Stage, X^{II} is chosen
Super-structure Stage X^{II} is chosen
Roof X^{III} is chosen
Finishes X^{III} is chosen

then the total project cost relation should be, mathematically,

Always the totals of the different decision variables chosen, should not exceed the total project costs, to give an optimal decision.

The completed model described above is then given as in Figure 3.5:

Fig. 3.5. A Model for Optimal Building Project Realization under Multiple Technology and Resource Constraints.

FIG. 3.5 A MODEL FOR OPTIMAL BUILDING PROJECT REALIZATION UNDER MULTIPLE TECH. AND RESOURCE CONSTRAINTS

DECISION VARIABLES / RESOURCE	CLEAR & SURVEY		SUB STRUCTURE		SUPER STRUCTION			ROOF			FINISHES			RELATION	LIMIT
	x_1^{I}	x_2^{II}	x_3^{I}	x_4^{II}	x_5^{I}	x_6^{II}	x_7^{III}	x_8^{I}	x_9^{II}	x_{10}^{III}	x_{11}^{I}	x_{12}^{II}	x_{13}^{III}		
TIME T	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8	t_9	t_{10}	t_{11}	t_{12}	t_{13}	≤	T
LABOURERS L	l_1	l_2	l_3	l_4	l_5	l_6	l_7	l_8	l_9	l_{10}	l_{11}	l_{12}	l_{13}	≤	L
CARPENTERS K	k_1	k_2	k_3	k_4	k_5	k_6	k_7	k_8	k_9	k_{10}	k_{11}	k_{12}	k_{13}	≤	K
BRICKLAYERS B	b_1	b_2	b_3	b_4	b_5	b_6	b_7	b_8	b_9	b_{10}	b_{11}	b_{12}	b_{13}	≤	B
STEEL FIXERS S	s_1	s_2	s_3	s_4	s_5	s_6	s_7	s_8	s_9	s_{10}	s_{11}	s_{12}	s_{13}	≤	S
SCAFFOLDERS F	f_1	f_2	f_3	f_4	f_5	f_6	f_7	f_8	f_9	f_{10}	f_{11}	f_{12}	f_{13}	≤	F
CEMENT N	n_1	n_2	n_3	n_4	n_5	n_6	n_7	n_8	n_9	n_{10}	n_{11}	n_{12}	n_{13}	≤	N
SAND D	d_1	d_2	d_3	d_4	d_5	d_6	d_7	d_8	d_9	d_{10}	d_{11}	d_{12}	d_{13}	≤	D
STONE G	g_1	g_2	g_3	g_4	g_5	g_6	g_7	g_8	g_9	g_{10}	g_{11}	g_{12}	g_{13}	≤	G
STEEL R	r_1	r_2	r_3	r_4	r_5	r_6	r_7	r_8	r_9	r_{10}	r_{11}	r_{12}	r_{13}	≤	R
TIMBER H	h_1	h_2	h_3	h_4	h_5	h_6	h_7	h_8	h_9	h_{10}	h_{11}	h_{12}	h_{13}	≤	H
CRANES J	j_1	j_2	j_3	j_4	j_5	j_6	j_7	j_8	j_9	j_{10}	j_{11}	j_{12}	j_{13}	≤	J
MIXERS Q	q_1	q_2	q_3	q_4	q_5	q_6	q_7	q_8	q_9	q_{10}	q_{11}	q_{12}	q_{13}	≤	Q
DUMPERS P	p_1	p_2	p_3	p_4	p_5	p_6	p_7	p_8	p_9	p_{10}	p_{11}	p_{12}	p_{13}	≤	P
TIMPERS A	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_{10}	a_{11}	a_{12}	a_{13}	≤	A
VIBRATORS M	m_1	m_2	m_3	m_4	m_5	m_6	m_7	m_8	m_9	m_{10}	m_{11}	m_{12}	m_{13}	≤	M
EXCAVATORS E	e_1	e_2	e_3	e_4	e_5	e_6	e_7	e_8	e_9	e_{10}	e_{11}	e_{12}	e_{13}	≤	E
CLEAR & SURVEY	1	1												=	1
SUB STRUCTURE			1	1										=	1
SUPER STRUCTURE					1	1	1							=	1
ROOF								1	1	1				=	1
FINISHES											1	1	1	=	1
OBJECTIVE FUNCTION	c_1	c_2	c_3	c_4	c_5	c_6	c_7	c_8	c_9	c_{10}	c_{11}	c_{12}	c_{13}	≤	C

3.6.5. Analysis of the Utilisation of the Mathematical Model:

The model depicted in Figure 3.5. for optimal building project realisation under multiple technology and resource constraints, makes it possible for the selection of the most appropriate variant for building project realisation under total project cost.

It also gives the optimal solution the realisation that multiple technology could be used to different stages of construction. It makes it possible to see that single technology is not optimally the best to use in construction and makes it possible to chose the best combination of technology at different stages.

A demonstration of the use of the model developed will subsequently be attempted using data obtained from a building project for the new Ahmadu Bello University Teaching Hospital (ABUTH) undertaken by the New Nigeria Construction Company Limited (NNCC). The data will be fed into the computer. The results obtained from such analysis will give us the optimal solution to our model.

4. ILLUSTRATION OF OPTIMAL BUILDING PROJECT OPTIMIZATION MODEL USING AS AN EXAMPLE THE AHMADU BELLO UNIVERSITY TEACHING HOSPITAL PROJECT.

4.1. The Ahmadu Bello University Teaching Hospital (ABUTH) project is a Federal Government Project. The construction is undertaken in phases. For our model, Phase 1(a) is chosen. The construction cost is ₦20m with New Nigeria Construction Company (NNCC) as the main constractors.

The Physical Medicine segment is taken for illustration purposes in this model (See Dig. 4.1 and 4.2).

4.2. Numerical Application of the Model:

The model is brokendown into five stages using three technologies. The stages are, "clear and survey", "sub-structure," "super-structure", "roof" and "finishes". The technologies are manual-oriented, semi-mechanised and prefabrication. In all we have thirteen variables and thirteen constraints.

A stmuctural description of our formulated mathematical model for building project realisation was given in figure 3.5. A numerical application of this model is presented here in the form of ABUTH model. Numerical values of right-hand sides (of the matix) and coefficients of ABUTH building programme were substituted into the model. The solution procedure and results obtained are describedand analysed here.

It is stressed here that the ABUTH building programme has a fixed production programme, thus we cannot select the type of materials, but only the technologies of their construction.

Fig. 4.1. ABUTH Model:

FIG. 4 A. B. U. TEACHING HOSPITAL NUMERICAL — MODEL

DECISION VARIABLES / RESOURCES	CLEAR & SURVEY		SUB STRUCTURE		SUPER STRUCTURE			ROOF			FINISHES			RELATION	LIMIT
	X_1^{I}	X_2^{II}	X_3^{I}	X_4^{II}	X_5^{I}	X_6^{II}	X_7^{III}	X_8^{I}	X_9^{II}	X_{10}^{III}	X_{11}^{I}	X_{12}^{II}	X_{13}^{III}	–	
TIME (WKS)	25	1	36	18	36	12	5	10	5	4	53	52	45	≤	160
LABOURES (HRS)	1000	40	272	136	408	136	30	48	48	32	48	48	48	≤	1776
CARPENTERS (HRS)	0	0	24	24	64	64	8	0	0	0	64	64	48	≤	156
MASONS (HRS)	0	0	48	48	96	96	40	16	16	16	16	16	16	≤	176
CONCRETE (YD^3)	0	0	73	73	2852	2852	2852	0	0	0	0	0	0	≤	2952
TIMBER (FT^2)	0	0	111	111	3058	3058	3058	0	0	0	0	0	0	≤	3169
CONC. MIXERS (HRS)	0	0	0	720	0	480	0	0	0	0	0	0	0	≥	0
CRANES	0	0	0	0	0	0	200	0	0	160	0	0	0	≥	0
CLEAR & SURVEY	1	1												=	1
SUB STRUCTURE			1	1										=	1
SUPER STRUCTURE					1	1	1							=	1
ROOF								1	1	1				=	1
FINISHES											1	1	1	=	1
OBJECTIVE FUNCTION (₦)	28050	2652	65061	64775	132858	125727	125369	31840	31560	33685	376572	376516	375906	≤	636,226

The above figure shows the ABUTH model numerically. The building project, as you can see is brokendown into five stages with thirteen variable and thirteen constraints.

The varibales are the different technologies applied to different stages, while the constraints are labour, time, materials and equipment. The objective function, is taken as cost.

There is a relationship between the constraints to the total allowed in the programme. For example, let us take time (wks). The total time for the project given should not exceed 160 weeks. So the optimal solution should be related, such that the total time allowed should not be exceeded. That is why the relation sign is used. The other relation used,   0, will help the 10 find out from the model the optimal time needed for those constraints, that is why we left it open. The objective function is taken as the total project cost.

4.3. Data Preparation:

The matrix of ABUTH model was solved at the Computer Centre of Ahmadu Bello University, Zaria. The computer utilized to obtain the solution has the following configuration.

Name: Control Data Cyber 72

Memory: 64k

Magnetic Tape: 2 Tape Drivers

Peripheral Device: 1 Card Reader; 1 Line Printer
4 Card Disc Drivers.

The ABUTH model was solved using conventional linear programming with the following limitations:

STP 6 77/12/26 11: 32: 37

This program solves a linear programming problem using the revised Simplex algonthus. The problem is stated in the customary algebraic manner stated in section 3.2.

The program can accomodate a maximum of 30 variables (including slack and surplus variables) and 15 constraints.

The variable must be designated X, X, X, ... One of the three signs, , = ; , must be used in each constraints, whose right-hand side must be a non-negative number.

Slacks and surplus variables are added automatically by the program to the constraints if they do not appear where necessary in the algebraic formulation of the problem.

The data from our matrix was Read into the computer using the teletype. The optimal solution is in the form of a Simplex tableau turned out by the computer by way of the line printer.

4.4.1. Analysis of Solution Obtained Using Cost as Objective Function:

The optimal solution obtained is in the format shown below: (See Appendix, Page). Optimal value of objective function is ₦562011.7034 using.

Variable	01	at	level	0.2974291994
"	02	"	"	0.7025708006
"	03	"	"	1
"	04	"	"	0
"	05	"	"	0.9986537905
"	07	"	"	0.00134620497
"	08	"	"	0.9835130886
"	10	"	"	0.01648691136
"	13	"	"	1
"	14	"	"	27.29710071
"	16	"	"	20.00791521
"	18	"	"	27
"	19	"	"	2.574051635 E-13
"	22	"	"	7.608394658 E-13

This shows the level at which each variable is chosen.

At the "clear and survey" stage, the two variables are chosen. 30 percent of X (manual-oriented) and 70 percent of X (semi-mechanised) technologies are used for the optimality.

At the "sub-structure" stage, only X_3 (manual-oriented technology) is chosen, the other technology, X_4, (semi-mechanised) completely discarded.

The "super-structure has two variables chosen, though the second one is negligible. 99.87 percent of X_5 (manual-oriented) and 0.13 percent of 1/6 (semi-mechanised) technologies are employed. Practically, here X_5 could simple be used.

At the "roof" stage, two variables are chosen, X_8 (manual-oriented) and X_{10} (semi-mechanised) X_9 (semi-mechanised) completely rejected. 98.4 percent X_8 and 1.6 percent of X_{10} (prefabrication).

The "finishes" stage rejected both X_{11} (manual-oriented) and X_{12} (semi-mechanised) technologies. It only chose X_{13} (prefabrication).

The remaining variables are the slacks and surplus variables added automatically by the computer (X 14-22).

To explain these slacks and surplus variables, if you multiply the variables chosen with the level at which they are chosen and add the slack or surplus variable the result should be equal to the right-hand side.

For example, in the case of variable X_{14} in the case of time,

$$30\% X_1 + 70\% X_2 + 100\% X_3 + 99.9\% X_5 + 0.1\% X_7$$
$$198\% X_8 + 2\% X_{10} + 100\% X_{13} + X_{14} \text{ (surplus or slack)}$$
$$= 160.$$

4.4.2. Analysis of Solution Obtained Using Time as the Objective Function:

Before using time as the objective function, we add more to the optimal cost obtained from section 4.4.1. Now we shall obtain an optimal time for the project realization at the given cost.

Below is the optimal solution obtained in the format shown below (See Appendix, Page).

Optimal value of objective function is 101.354564 weeks

Variable	at	02	at	level	0.9983044723
"	"	04	"	"	0.7060367454
"	"	05	"	"	1
"	"	10	"	"	1
"	"	13	"	"	1

Variable	at	14	at	level	46672.30247
"	"	15	"	"	1136.223999
"	"	17	"	"	14.11023622
"	"	19	"	"	32.62992126
"	"	20	"	"	508.3464567
"	"	22	"	"	80.57480446
"	"	25	"	"	25.69685039
"	"	27	"	"	48.45931759
"	"	32	"	"	0.2939632546

Then shows the level at which each variable is chosen.

The "clear and survey" stage is roughly X_2 (semi-mechanised) technology. 99.8 percent X_2 and only 0.2 percent X (manual-oriented). This is expected since time is the objective function.

Two variables are chosen in the "sub-structure" stage. 70 percent X_4 (semi-mechanised) and 30 percent X_3 (manual-oriented) technologies. Here also the result is expected. Though it could have been assumed that more percentage could have been for X_4 (semi-mechanised).

At the "super-structure" stage only X_5 (manual-oriented) technology in chosen. This is unexpected. This is so because it has the maximum duration compared to other technologies employed. One could have expected that the technology, with least time to be chosen.

The "roof" and "finishes" stages, X_{10} and X_{13} (all prefabrication) is chosen. But this is expected since they have the least time duration.

4.4.3. Comparison of the Results Obtained Using Cost and Time as Objective Functions:

The results obtained using cost and time as objective functions shows some similarities. Again in some places it does not agree completely. This is expected because of their differece as objective functions.

The "clear and survey" stage shows that the result obtained when cost is used as objective function, roughly 100 percent X_2 (semi-mechanised) while the result obtained using cost is 70 percent X_2 and 30 percent X_1 (manual-oriented). The solution using time is expected because we need the shortest possible duration to complete our project.

At the "sub -structure" stage the case is different from that of "clear and survey". Here the cost solution chose only the X_3 technology (manual-oriented). The time solution chose both technology is manual-oriented and semi-mechanised 70 percent X_4 (semi-mechanised) and 30 percent X_3 (manual-oriented). The cost solution is not expected if you look at the objective function at X_3. The cost at X_3 (manual-oriented) is higher than that of X_4 (₦65,061 and 64 775 respectively).

The solution both agree at the "super-structure" stage. They both chose X_5 technology (manual-oriented). But in the case of time one would expect the model to chose the least time for optimality. Also the cost solution could have chosen X_7 (prefabrication) because it has the lower cost.

The solution at the "roof" stage do not agree. While the time solution chose only X_{10} (prefabrication), the cost solution chose 98 percent X_8 (manual-oriented) and 2 percent

X_{10} (prefabrication). Considering cost as objective function one could have expected X_8 (semi-mechanised) to be chosen. The time solution is what one could expect, since it has the least duration.

At the "finishes" stage, they both agree to one solution. They both chose X_{13} (prefabrication) as the only solution (prefabrication). This solution satisties the cost and time solution. X_{10} (prefabrication) has both the least time and cost and is therefore a result expected in both cases.

The second result i.e. using time as the objective function is what could be expected. The solution shows a reduction of time as a result of increase in the cost of project. When the optimal cost is used the project duration is 160 weeks, but when the cost is increased, the optimal time is now 101 weeks. In other words, by increasing the cost, one expediating the project and shorter time should be expected. Again the slack and surplus variables could be termed the float[3] of individual activities. One can choose to use the float or ignore it as the case may be but it indicates the possiblity of working within the contracted sum and the possibility of executing the project within both the duration and cost. This shows the working of our model and the possibility of its being used in any other project. It proves its practicability to be used anywhere no matter how much you breakdown your variables or your constraints.

(ii) The model shows it could be used in determining float. So it could be used to cross-check the float in the Critical Path Method (CPM). There is need for further investigation though in this area.

(iii) The relation between the constraints and the limit could either be

Though the model could accommodate any of them.

Chapter Five

5. CONCLUSION

5.1. Summary:

(i) The result found out shows that the proposed/developed model is practicable as demonstrated by the solution printout in Appendix. The answers obtained from the model is within what would normally be expected.

(ii) This also shows that building project realization can best be achieved using multiple technology under. Different resource constraints different objective functions could be used depending on what one wants to minimize or maximize as in our ABUTH model, cost and time.

(iii) The result could also be used in determining which of the constraints could be increased or decreased as required i.e. either to relax it or excute it as that, in short, the result also gives the float in each case.

(iv) This model could be applied in building projects realizations in projects in the country and also in some Civil Engineering works where there are possible choices of technologies to be employed and competing demands for scarce resources.

5.2. Recommendation for Further Research:

(i) The model could accommodate more variables. Therefore, depending on how much there is need to breakdown the construction, one could have as much as variables as one wishes within certain practical parameters. Similarly one could have as many constraints as so wishes.

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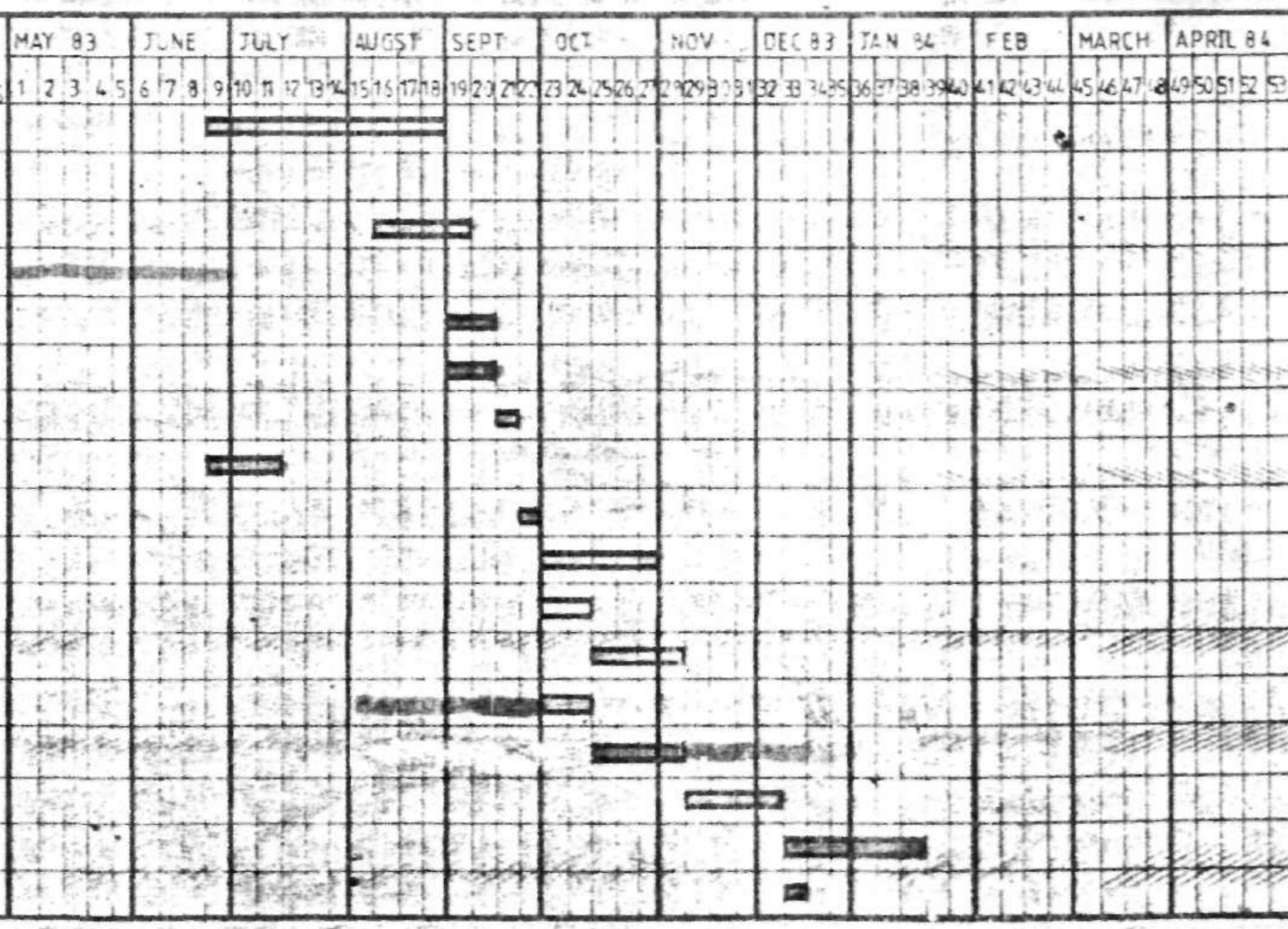
ACC NO	DESCRIPTION	TOTAL QUANTITY	ESTIMATED DURATION IN WEEKS
0 — 1	Excavate	2395 YD^3	10 WKS
0 — 2	Cut reinforcement to site		—
1 — 2	Building	1985 YD^2	4 WKS
1 — 6	Invite quotation for struct steel roof		
2 — 3	Formwork in foundation	133 YD^2	2 WKS
2 — 4	Reinforcement in foundation	10 CWT	2 WKS
4 — 5	Concrete in foundation	73 YD^3	1 WK
4 — 9	Prefab formwork for columns	154 SY	3 WKS
5 — 7	Blockwork in foundations	197 YD^2	1 WK
6 — 11	Prefab struct steel roof & delivery	338 CWT	5 WKS
7 — 8	Laterite filling	500 CY	2 WKS
8 — 9	Ground floor slab	1369 YD^2	4 WKS
9 — 10	Columns ground floor to roof	11 CY	2 WKS
10 — 11	Roof beams and slab	2841 CY	4 WKS
11 — 12	Struct steel roof	338 CWT	4 WKS
11 — 13	Super blockwork	2178 SY	6 WKS
12 — 13	Roof screed	392 SY	1 WK



SCHEDULE OF COMPLETION — PHYSICAL MEDICINE (group 3)

CONVERSATIONAL LINEAR PROGRAMMING

DO YOU WISH ANY DESCRIPTION OF THE PROGRAM?
YES

THIS PROGRAM SOLVES A LINEAR PROGRAMMING PROBLEM USING THE REVISED SIMPLEX ALGORITHM. THE PROBLEM IS STATED IN THE CUSTOMARY ALGEBRAIC MANNER FOUND IN MOST TEXTBOOKS ON LINEAR PROGRAMMING. THE PROGRAM CAN ACCOMODATE A MAXIMUM OF 30 VARIABLES (INCLUDING SLACK AND SURPLUS VARIABLES) AND 15 CONSTRAINTS.

DO YOU WISH MORE DESCRIPTION?
YES

LET US CONSIDER THE EXAMPLE ON PAGE 16 OF
AN INTRODUCTION
TO LINEAR PROGRAMMING,
IBM DATA PROCESSING APPLICATION,E20-8171.
THIS PROBLEM SHOULD BE ENTERED IN THE FOLLOWING MANNER:

```
        MAXIMIZE
              Z=3X1+2X2+2.5X3
        SUBJECT TO
              4X1+2X2+2X3≤12
               X1     + X3≤2
                    X2+3X3≤4
        END
```

ANY NUMBER OF SPACES MAY BE LEFT WITHIN EACH LINE, AND ANY NUMBER OF BLANK LINES MAY SEPARATE EACH LINE OF INPUT. HOWEVER, THE ORDER OF INPUT MUST BE THE FOLLOWING:

1) MAXIMIZE OR MINIMIZE
2) OBJECTIVE FUNCTION Z=
3) SUBJECT TO
4) CONSTRAINTS , IN ANY ORDER
5) END

THE VARIABLES MUST BE DESIGNATED X1, X2, X3,...
ONE OF THE THREE SIGNS,≤,=,≥, MUST BE USED IN EACH CONSTRAINT,WHOSE RIGHT-HAND SIDE MUST BE A NON-NEGATIVE NUMBER.

SLACK AND SURPLUS VARIABLES ARE ADDED AUTOMATICALLY BY THE PROGRAM TO THE CONSTRAINTS IF THEY DO NOT APPEAR, WHERE NECESSARY, IN THE ALGEBRAIC FORMULATION OF THE PROBLEM.

AFTER END HAS BEEN ENTERED,THE OPTIMAL SOLUTION WILL BE COMPUTED USING THE REVISED SIMPLEX ALGORITHM RSIM AND THE RESULTS TYPED. IF THERE IS EITHER NO FEASIBLE SOLUTION OR AN UNBOUNDED SOLUTION, AN INDICATION OF THIS CONDITION WILL BE GIVEN.

THEN ANY MORE PROBLEMS?
WILL BE TYPED. IF THE ANSWER IS YES,
THEN THE PROGRAM IS READY TO ACCEPT THE NEXT PROBLEM.
IF THE ANSWER IS NO,
THEN AN EXIT IS MADE FROM THE PROGRAM.

INPUT OF ANY LINE MAY BE TERMINATED BY TYPING / AS THE LAST CHARACTER IN THE LINE. THE NEXT LINE TYPED REPLACES THE LINE THAT WAS TERMINATED. INPUT OF ANY PROBLEM MAY BE TERMINATED AT ANY STAGE BY ENTERING STOP AS A SEPARATE LINE OF INPUT. COMPUTATION WILL BE BYPASSED, AND CONTROL WILL PASS TO THE STAGE DESCRIBED IN THE PREVIOUS PARAGRAPH.

```
CONVERSATIONAL LINEAR PROGRAMMING

 DO YOU WISH ANY DESCRIPTION OF THE PROGRAM?
NO
MINIMIZE
Z=28050X1+2652X2+65061X3+64775X4+132358X5+125727X6+125359X7+31840X8+3150+33685X10+376572X11+376516X12+375906X13
SUBJECT TO
25X1+1X2+36X3+18X4+36X5+12X6+5X7+10X8+5X9+4X10+53X11+52X12+45X13≤160
1000X1+40X2+272X3+136X4+408X5+136X6+80X7+48X8+48X9+32X10+48X11+48X12+48X1776
24X3+24X4+64X5+64X6+8X7+64X11+6+X12+48X13≤156
48X3+48X4+96X5+96X6+40X716X8+16X9+16X10+16X11+16X12+16X13≤176
ERROR IN LAST LINE. RETYPE
48X3+48X4+96X5+96X6+40X7+16X8+16X9+16X10+16X11+16X12+16X13≤176
73X3+73X4+2852X5+2852X6+2852X7≤2952
111X3+111X4+3058X5+3058X6+3058X7≤3169
720X4+480X6≥0
200X7+160X10≥0
X1+X2=1
X3+X4=1
X5+X6+X7=1
X8+X9+X10=1
X11+X12+X13=1
END


OPTIMAL VALUE OF OBJECTIVE FUNCTION IS  562011.7034

VARIABLE 01 AT LEVEL  0.2974291994
VARIABLE 02 AT LEVEL  0.7025708006
VARIABLE 03 AT LEVEL  1
VARIABLE 04 AT LEVEL  0
VARIABLE 05 AT LEVEL  0.9986537905
VARIABLE 07 AT LEVEL  0.001346209497
VARIABLE 08 AT LEVEL  0.9835130886
VARIABLE 10 AT LEVEL  0.01648691136
VARIABLE 13 AT LEVEL  1
VARIABLE 14 AT LEVEL  27.29710071
VARIABLE 16 AT LEVEL  20.00791521
VARIABLE 18 AT LEVEL  27
VARIABLE 19 AT LEVEL  2.574051635E¯13
VARIABLE 22 AT LEVEL  7.608394653E¯13


ANY MORE PROBLEMS?
```

```
ILLEVAL NOT~POJ ..[.

IN THE PREVIOUS PARAGRAPH.

MINIMIZE
Z=25X1+1X2+36X3+18X4+36X5+12X6+5X7+10X8+5X9+4X10+53X11+52X12+45X13
SUBJECT TO
28050X1+2652X2+65061X3+64775X4+132858X5+125727X6+125369X7+31840X8+31560X9+33685X10+378572X11+376.1.X12+375906X13≤636226
1000X1+40X2+272X3+136X4+408X5+136X6+80X7×
                                        +48X8+48X9+32X10+48X11+48X12+48X13≤1776
ERROR IN LAST LINE. RETYPE
1000X1+40X2+272X3+136X4+408X5+136X6+80X7+48X8+48X9+32X10+48X11+48X12+48X13≤1776
24X3+24X4+6+X5+64X6-8X7+6-X11+64X12+48X13≤156
48X3+48X4+96X5-96X6+40X7+16X8+16X9+16X10+16X11+16X12+16X13≤176
73X3+73X4+2352X5+2352X6+2852X7≤2952
111X3+111X4+3058X5+3058X6+3058X7≤3169
720X4+430X6≥0
200X7+160X1.≥0
X1+X2=1
X3+X4=1
X5+X6+X7=1
X8+X9+X10=1
X11+X12+X13=1
END

OPTIMAL VALUE OF OBJECTIVE FUNCTION IS  101.305453+

VARIABLE 02 AT LEVEL  0.9383044723
VARIABLE 04 AT LEVEL  0.7060367454
VARIABLE 05 AT LEVEL  1
VARIABLE 10 AT LEVEL  1
VARIABLE 13 AT LEVEL  1
VARIABLE 14 AT LEVEL  46772.30247
VARIABLE 15 AT LEVEL  1136.223999
VARIABLE 17 AT LEVEL  14.11023622
VARIABLE 19 AT LEVEL  32.62992126
VARIABLE 20 AT LEVEL  538.3464567
VARIABLE 22 AT LEVEL  80.57480446
VARIABLE 25 AT LEVEL  25.69685039
VARIABLE 27 AT LEVEL  43.45831759
VARIABLE 32 AT LEVEL  0.2[illegible]98325+8
```