LINE OF BALANCE IN PRACTICE

A report submitted in part completion of the
Degree Master of Science in Building Science

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University of the Witwatersrand
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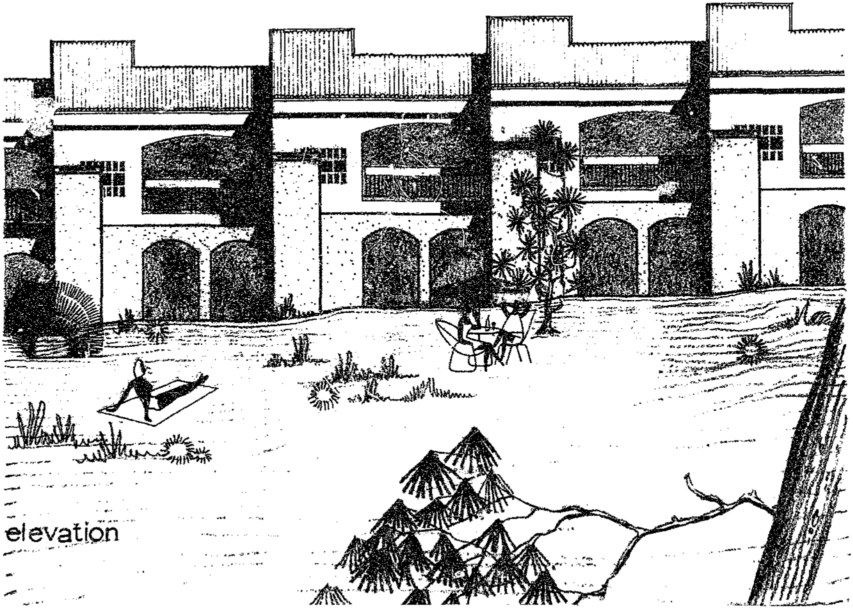


elevation

Somewhere at the back of my mind I have got a feeling that I can't quite put into words. I feel that why a building fascinates me is because, when it is completed, with the last piece of inside woodwork sand-papered and the last nail-hole filled in with putty, and the masons and carpenters and painters have left, then there has come into the world a new piece of creation. Somebody conceived a vision and the workmen gave that man's dream outward shape. In his mind a man conceived that building whole and the builders set about interpreting his conception in terms of the earth's most primitive materials of soil and stone. So that in the construction of this building what has taken place is really a magical thing. It is as though the man that got the vision cast a spell which brought about the external realisation of his dream. And from this point of view every building is enchanted, and every city is fairy.

herman charles bosman

ACKNOWLEDGEMENTS

Mr. J. P. E. Koep, Managing Director of Gallic Construction (Pty.) Limited for valuable experience and the material which forms the basis of this report.

My wife, Sandy, for typing the manuscript.

SYNOPSIS AND HISTORICAL SURVEY

The precise origin of the line of balance method is difficult to trace. From research into literature on the subject, opinions were found to differ considerably both as to the time and country of origin.

On its origin two main schools of thought exist; the one being that of the American and British writers, who claim that the method was developed in America, and the second being that of Iron Curtain countries and Germany who claim that the method was in use in Czechoslovakia long before its inception in America. *For the sake of clarity these are discussed separately.*

DEVELOPMENTS IN THE U.S.A.

Just prior to the Second World War there is evidence of a system whereby batches of work in mass production works were balanced to achieve better utilisation of labour and plant.

In 1941, George E. Fouch of the Goodyear Company developed a graphic control system based on the previous work to assist in rapid growth of the new military production programmes.

This technique was later applied in the Navy Bureau of Aeronautics procurement programme of the war years and became known as the Line of Balance method.

There appears to be limited further developments until 1963 when the Federal Government showed interest in the method as a production aid and by formation of the Line of Balance Co-ordinating Committee which was to run parallel to the existing P.E.R.T. Coordinating Committee, ensured its continued development particularly in the field of production costing.

These developments were essentially contained in the manufacturing industries and any application of the method to construction during this time was in isolation only.

Although the exact date of its application to the construction industry is not clear it would appear that it did not occur significantly before 1969. In a form, modified to suit the industry, it is now used in the programming and control of repetitive schemes such as housing and also in linear construction sites such as pipelines and roads.

DEVELOPMENTS IN GREAT BRITAIN

As with P.E.R.T. and Critical Path Scheduling, the method did not take long to cross the Atlantic and become adopted in the British manufacturing industries. It was here, however, that perhaps the most significant development of the application to repetitive housing took place. This occurred around 1967 when the National Building Agency drew on the work undertaken by the United States Department of Navy and adapted the method to suit repetitive house building in Great Britain. The findings of their research and development were recorded in a paper entitled "Programming House Building by Line of Balance" in 1967.

One of the employees of the National Building Agency, Philip Lumsden, in conjunction with Professor Trimble of Loughsbcrough University of Technology and D. Etherington, was responsible for the developments on the method described in the publication and in 1968 he published a modified approach in his book "Line of Balance in Practice". In a forward to this book the Managing Director of the National Building Agency recorded that it was the only book containing the application of the principles to building.

It is significant that shortly after this time, the interest in the method applied to construction grew in the United States of America and it can be presumed that the method in a modified form made another Atlantic crossing.

In 1972 British Standard No. 4335 recognized the developments of the method as per the National Building Agency and applied the name "Elemental Trend Analysis", while the term "Line of Balance" was retained for industrial situations.

DEVELOPMENTS IN EUROPE

Developments in Europe are difficult to define precisely as most of the work was carried out and published in Eastern European countries. The absence of literature in the Western World is borne out by the almost complete absence of any references to European developments in all the books listed in the bibliography except that of Calvert who recorded certain variations on the theme in Russia where a Cyclogram, combining an arrow diagram with a type of Line of Balance diagram, had been in use presumably during the past ten years and, in Germany, where a Building Box Network was developed which combined the precendence diagram developed in France with Line of Balance.

In a postal communication with the National Building Agency, it was clear that knowledge of the European developments was minimal and doubt was expressed about any original developments in countries behind the Iron Curtain. The National Building Agency, as stated previously, relied solely on American developments for their work.

Both the American and British claims, however, were refuted in an interview with Professor Armon, an Israeli, who had conducted research in Munich and was occupied at the C.S.I.R. and Dr. J. Nawrath of the Technical University, Munich, Germany. These two gentlemen were both aware of American and British developments but were of the opinion that there was evidence of a similar approach to the programming of pipeline, canal and railway line construction in Czechoslovakia some time before the Americans applied the method to the manufacturing industries. This fact, however, could not be substantiated by any publication, the earliest reference on the subject being a work by Professor J. Nezval of the University of Prague some time in 1950.

In 1960 Nezval produced a translation into Germany entitled "Grundlagen der Flesfertigling in der boupropuktion (Berlin)", and this appears to have sparked off interest in the method in Germany. (This conclusion is drawn from the numerous publications which appeared after that date in Germany. In the bibliographies of the four papers sent out by Dr. Nawrath, some twenty papers were listed dating from 1963 to 1972, including the four papers, while only three papers were published prior to 1960). Besides the papers there were a number of dissertations prepared on the subject. Amongst the authors are Armon, Bauer, H., and Nawrath, who was awarded a doctorate in Engineering in this field by the Technical University of Munich in 1966.

It is evident that the developments were directed more in the field of linear construction sites than in repetitive housing both in Germany and in Czechoslovakia. Rigorous mathematical models have been developed to take into account variable conditions such as weather and geological formations. The imput data has been linked to probability theory and linear programming techniques.

From these facts it can be concluded that the method developed simultaneously in all of these three regions, viz. United States of America, Great Britain and Europe, during the periods indicated and that each of these contributed a specific application of the method.

America developed in the manufacturing field and first labelled the technique, "The Line of Balance Method" in 1941. The National Building Agency in Great Britain in 1967 adapted the method to assist in the programming and control of repetitive housing schemes. The European countries have produced sophisticated models for the control of linear construction sites from the 1950's.

It should be noted that only Britain and America used the term "Line of Balance". In Europe different terms are used by different writers. Dressler refers to the diagram as a "time-velocity diagram". His choice of this name is confusing since velocity can be defined as the rate of change of distance with respect to time. Certain German writers use the term, "Speed diagrams". Perhaps this is the most appropriate with respect to roads and pipelines where the quantity produced is defined by distance travelled rather than unit numbers. Nawrath again uses the term, "time-product" diagram.

The Line of Balance method is applied in this report to the construction of a small block of duplex flats. At the time of building the flats, Line of Balance was a relatively new concept in programming in the country. The writer's interest in the subject developed while formulating a course in Production Planning for final year students at the University of the Witwatersrand during the same year.

In constructing the course, the work done by the National Building Agency was considered the most applicable to local conditions and Philip Lumsden's work was the main reference. Since the course was written up and submitted to the University of the Witwatersrand, the emphasis in this Report is more inclined to the practical problems encountered in compiling the programme and the actual control rather than detailed theory. (The Course is listed in the Bibliography).

The Report should be considered as a resumé of the problems encountered in researching and applying a relatively new concept to local construction conditions. The problems are analysed and solutions suggested.

One particular aspect requires mention here. It is noted in Chapters Two and Four that a design change was made after the project had commenced. It was stated that instead of recalculating the programme it was assumed that the same output could be achieved by increasing the relevant labour force. This was to be the major cause of an overrun on the programme. It can be argued that the programme should have been recalculated immediately and this is, in fact, correct.

The volume of work involved in costing, buying and controlling this project and three others by the writer, however, precluded this requirement. If the programming was done by a separate Department as in larger companies this would have been possible. In this case, there was only one other solution and that was the appointment of a private consultant to reprogramme the work. In terms of the value of the work, however, this was considered not warranted by the Company.

The Report commences with a background to the study and a description of the initial costing and estimating system employed.

The basics of the method are described and it is shown how the programme was constructed (Chapter One).

In Chapter Two, it is shown how the method is applied in the analysis of resources and determination of the cash flow of the project. Part of the theory in Chapter One is included in detail in this section to illustrate the effect of the rate at which units are to be delivered on the resources required on a project.

Chapter Three deals with problems of representing the diagram on site and the importance of communication with site staff, sub-contractors and suppliers.

In Chapter Four, the exercise is analysed in terms of actual performance versus programmed performance. Problems encountered during construction are discussed and recommendations made.

CHAPTER ONE : THE PROGRAMME

1.1 BACKGROUND TO THE STUDY

The project comprised the erection of sixteen duplex flat units on 2½ acres of company-owned property in Bryanston, Sandton. A site plan and a typical floor plan are shown in figures 1.1 and 1.2 respectively.

Being company owned the usual tender documents were not available to assist in the calculation of activity times and cost control. All initial estimates were done on a square metre basis.

This method of the square metre estimate is simple, quick and, as was proved on a number of schemes, accurate when comparing similar buildings. A brief description is relevant as it serves to illustrate how useful a control tool can be for tendering purposes.

When the project was undertaken, the company had been building similar but less lu[illegible]s units for about four years. During this time a r[illegible]mprehensive list of cost items for each project ha[illegible]een built up. This followed the usual system of splitting elements of the building into cost codes. For instance, labour working on excavating may be booked to a Code '2' whilst labour assisting a carpenter on the roof would be booked to say, a Code 36.

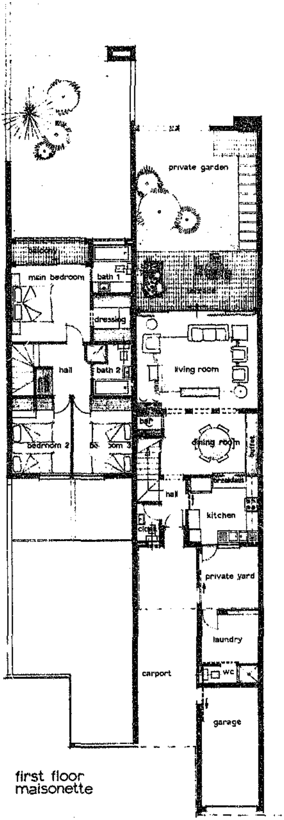


Fig 1.2.

ground floor
maisonette

These elements were further broken down where further distinction within an element was desirable, viz. 'Excavation Code 2' would be broken down into :

2a	*Bulk Excavation*
2b	Excavation in foundations
2c	Excavation to reduce levels

The site clerk had the job of walking around the site twice daily to book all labour to the respective codes.

Similarly, when invoices were paid monthly the respective items would be booked to a code, viz.

Cement	Code 6
Door Frames	Code 29, etc.

The number of codes ranging from bulk excavations and covering all cost items generally of consequence, to management fees, covered some 70 items.

Naturally this is essentially a control system and the estimates of each cost item had to be made before or just after commencement of site operations.

By comparing monthly the estimate against actual cost related to the stage of completion, a reasonable control on the budget could be kept. Being mostly development work it was important to keep costs within a limit beyond which the feasibility of the scheme would fail.

Once a cost, say foundation excavation, was exceeded it might be possible to reduce the cost somewhere else along the line and indeed desirable to do so.

In such a way, a month to month control is kept and unless the initial estimate was for some reason way out, the ultimate cost must be reasonably close to that budgeted for.

The compiling of the data is similar to the preparation of a Bill of Quantities except that the abstracting of the measurement is geared to the cost system rather than to a tender document. There are, therefore, two distinct phases, viz. the physical measurement of the drawings followed by the reshuffling of this information to form the control system.

This raises an important point on measurement of drawings in that this stage must in turn be geared to suit the abstract of the information into the various codes. It was generally found that the time involved in preparing the cost information could be significantly reduced by deviating from the Standard System of measurement. Typically the same extent of detail is not necessary.

The point is made that in practice it is not necessary or indeed desirable to adhere rigidly to established procedures, but rather to analyse and redesign the 'modes operandi' to suit the final form of the information.

For contract work where tender documents are available the procedure is similar except that the information is taken from the Bill of Quantities instead of the measurement of drawings. Here again, this method of pricing the Bill can reduce the work involved in preparing the control sheet. This is achieved by preparing a concise build up of rates showing clearly the cost of all materials and labour individually.

Consider the following Bill description :

B.	<u>CONCRETOR</u>				
	Cement concrete (1-?-6 of 40 m stone) in footings				
	Cubic meters	50	13.36	668	00

For calculation of the tender price all that is required is the rate multiplied by the number of units. This rate could be obtained from past records or experience.

It would suit the system more, however, if the following information was shown in the Bill as well.

Assume 1,6 cubic metres dry material = 1 cubic metre of mi .

1. CEM

$\frac{1}{10}$ x 1,6 = ,16m^3

Say 1500 kg/m^3

i.e. 1500 x ,16 = 240

÷ 50 add waste = 5 pockets

Total Rand = 5 x 50 x R0,90

= R225

2. SAND

$\frac{3}{10}$ x 1,6 = 0,12

Add bulking 0,60 cubic metres

Total = 0,60 x 50 x R3,00

Total Rand = R90,00

= R90,00

3 STONE

$\frac{6}{10}$ x 1,6 = ,96

Total Rand = ,96 x 50 x R3,50

= R168,20

4. <u>LABOUR</u> (Mixer in P & G)

Say 1 artisan + 6 labourers place 3 m^3/hour

Hourly Rate		R2,50
	6 at 56	R3,36
		R5,86
	Add 15%	,88
		R6,74

Cost/m^3 = $\frac{R6,74}{3}$

i.e. R2,25

Total Rand R2,25 x 50

i.e. R112,50

This *information* is *now* in a form which facilitates transfer to the cost sheet. It is a simple clerical function to page through the Bill collecting all sands, stones, etc. As this calculation is *generally done in* any case the extra work involved in presenting the information in this form is negligible.

Once the job is complete and all the costs have been entered the control sheet becomes a useful basis for estimating. The first step in the calculation is to select a scheme already completed and similar to the one on which an estimate is required.

For similarity the following points could be considered :

- Type of Accommodation
  - Luxury
  - Upper Middle Class

- Lower Middle Class
- Economic
- Sub-Economic

- Rentals or selling price required
- Area in which situated
- Age group catered for
- Type of building
  - High Rise
  - Low Rise
  - Two Storey
- Type of Apartment
  - 3 Bedroom
  - 2 Bedroom
  - Bachelor
  - Duplex
- Extent of Extras
  - Tennis Courts
  - Gardens
  - Swimming Pool

These indicate general points that could be considered but obviously due consideration must also be given to the site itself as these factors could affect the cost considerably.

Typically, one would consider :

Type of Ground - Need for piling
Need for structural foundations
Special drainage

Presence of Rock	-	Can determine final level of building (FLL) May require blasting Difficulty with Sewerage
Slope of Ground	-	If steep may require columns and beams Drainage Landscaping features Excessive excavation
Vegetation	-	Trees to be removed or preserved Cost of clearing site Cost of encouraging growth later if ground barren

Having selected a building for comparison purposes the cost analysis sheet is subjected to a process of deductions, the aim being to arrive at a cost per square metre of the structure itself.

All cost items not directly related to the cost of the shell of the building are deducted.

Examples of deducted items are :

Plumbing
Electrical

Kitchen Fittings

Floor Finishes

Light Fittings

Sanitary Fittings

Plaster and Paint (if surface areas change considerably)

Bedroom Fittings

Sundry Bathroom Fittings - Medicine cabinets

Ironmongery

Major Earthworks (if dissimilar)

Management Fees (Generally P & G items)

Roof Structure)
) if appreciably different
Roof Covering)

Swimming Pool

Tennis Court

Landscaping

Roads and Driveways

General Joinery

Municipal Fees

One would also take cognisance of the extent of garden walling and sundry accommodation and if necessary deduct.

The net cost remaining represents that amount required for the erection of a shell of a similar nature. Divided by the total square metering this gives a basic cost per square metre.

The process is now repeated, but in reverse, for the new scheme. Naturally, an estimate has to be made at this stage of the escalation of building costs since completion of the control project. This is not as difficult as may seem for the elements in the cost per square metre are few and generally easily split into labour and material.

The increase in labour cost is simple to include as labour only items are clearly indicated in the control sheet. The calculation then merely involves increasing this figure by the relevant percentage and adding it back to the total cost.

A further distinction into skilled and unskilled would be required if the increases for the two groups differed appreciably.

In the case of materials, one could take a general escalation figure giving special attention to items which showed marked increases over the period in consideration.

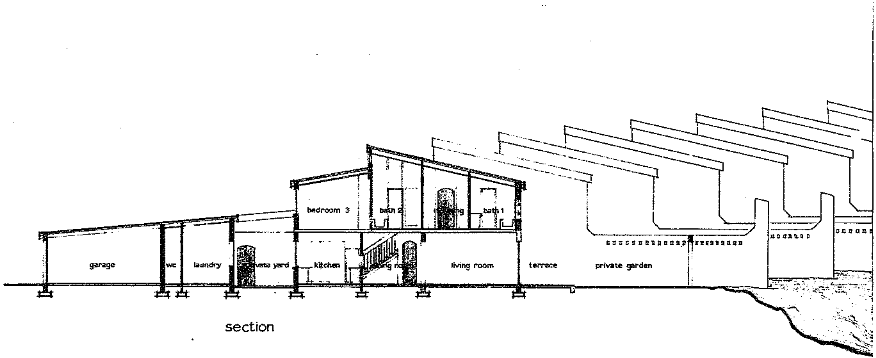
The accuracy required is naturally determined by the nature of the particular contract. If development work, the degree of accuracy required is that which defines feasibility of the scheme. A 10% increase in the cost of cement is not going to affect the overall picture. If contract work, one might argue that the client must pay for the 10% increase in cement. Each scheme will have unique factors which have to be taken into account.

The square metre and elemental method proceeds fairly rapidly and as noted previously was found to be fairly accurate. Sufficient detail is included to determine feasibility or for establishing a contract price.

For the construction of the line of balance diagram and indeed for any programme a more detailed supply of information is required and it is at this stage that the Architect's plans are physically measured to form the programme and control system.

A typical section and elevation of the scheme are included on the next two pages.

Both drawings indicate clearly the different levels across the site, the importance of which will be shown later.


bedroom 3
bath 2
bath 1
garage
wc
laundry
vate yard
kitchen
living room
terrace
private garden

section

1.2 CONSTRUCTING THE PROGRAMME

1.2.1 DESCRIPTION OF THE METHOD

The Line of Balance method operates in terms of a required delivery rate of completed units. The units described in this report are "flats". In a manufacturing field, the units could be "transformers". In a housing project, "houses" and in a pipeline scheme, "100 metres of pipe".

Once a delivery rate is determined the work content of each unit is calculated. This work is related to a time scale and the relevant time set back from the required completion date.

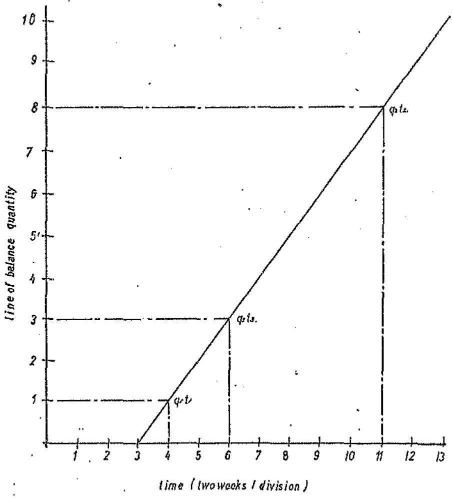
At any time T in the programme a certain amount of work must have been completed to ensure the predetermined delivery rates. This work could be in terms of delivery of materials, components or completed jobs depending on the particular activity defined by time T.

The cumulative quantities of these materials, components or completed jobs are termed "the Line of Balance Quantities".

The line of balance method assumes the rate of deliveries to be constant and therefore the relationship between the line of balance quantities and time is linear and the straight line equation of Y=MX+C applies.

Consider the delivery of kitchen units to be a ten unit housing scheme.

Assuming that the first unit is required at week 8 and each successive unit is required two weeks after the first, this information can be plotted graphically as below.



The required line of balance quantity for any point in time 't' can readily be determined. For instance, at t1 = 12 weeks, three kitchen units should have been delivered. Similarly at week 22, eight units and so on. 3 and 8 are the line of balance quantities at weeks 12 and 22 respectively.

As noted before this is a straight line equation and for Y=MX+C, Q=MT+C can be substituted where :

Q = Line of Balance quantity
M = Rate of Delivery (starts or completions)
T = Time
C = Constant being the intercept on the Y axis

Referring back to the graph two important expressions can be derived which would yield :

(a) the L.O.B. quantity that must be achieved at any time T

(b) the time T at which a line of balance quantity of Q should be achieved.

From the graph, applying the straight line equation the quantity -

$$Q1 = MT1 + C \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad 1.$$

$$Q2 = MT2 + C \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad 2.$$

subtracting "1" from "2"

$$Q2 = Q1 = M (T2 - t1) \quad \ldots\ldots\ldots\ldots 3.$$

by transposition :

$$Q2 = M (T2 - T1) + Q1 \quad \ldots\ldots\ldots\ldots 4.$$

Assume that the line of balance quantity for week 22 is required.

Substituting in the expression yields :

$$\begin{aligned} Q2 &= .5\ (22 - 8) + 1 \\ &= .5\ (14) + 1 \\ &= 8 \end{aligned}$$

Similarly the required L.O.B. quantity for any time T can be calculated.

Assume the manufacturer requires the delivery date for the eighth unit.

From equation (3)

$$\begin{aligned} Q2 - Q1 &= M\ (T2 - T1) \\ M\ (T2 - T1) &= Q2 - Q1 \\ T2 &= T1 + \frac{(Q2 - Q1)}{M} \quad \ldots\ldots\ldots\ldots (5) \end{aligned}$$

Substituting :

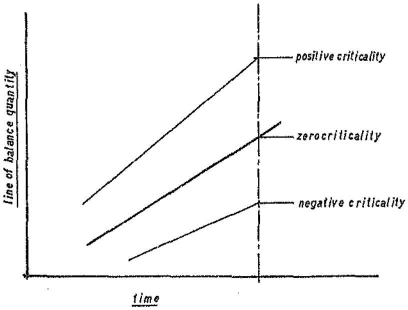
$$\begin{aligned} T2 &= 8 + \frac{(8 - 1)}{.5} \\ &= 8 + 14 \\ &= \text{Week } 22 \end{aligned}$$

CRITICALITY

Any difference between the L.O.B. quantities and the actual number of deliveries is termed criticality. Criticality can be zero, positive or negative.

Zero criticality indicates that the programme is on target in that the L.O.B.Q. and the achieved quantities are equal.

Positive criticality indicates that the programme is ahead of schedule and negative criticality indicates that the actual quantities are less than the L.O.B.Q. and the programme is behind schedule.



One of the main advantages of the method is the ease at which it can be applied and the ready reference to the criticality of any activity.

This can be done graphically or by applying the straight line equation.

USE OF L.O.B.

1. The state of delivery of materials against the programmed rate of delivery.

   Here the concern is not merely of shortages. Each case has to be studied on its respective circumstances. Over delivery of components has the effect of reducing site storage space and on a site with very little space this can be an important factor.

   Furthermore, over delivery of materials calls for payment earlier than anticipated and this affects the cash flow of the project. This can be a dangerous situation and may reduce the capital available for investments in other projects. Over delivery has no advantages if the completion dates are fixed.

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2. The date of completion of jobs.

   It is important to know how far a job has progressed so that corrective action can be taken to ensure completion. Similarly, if jobs are ahead of schedule it may be possible to slow down the rate and collect certain cost advantages. Again early completion, i.e. the rate in excess of requirements places demands on capital which may have no advantage from the completion date point of view.

3. The cumulative state of jobs completed or in progress across the whole contract at any particular time. This enables the work to be programmed in such a way as to adhere to a constant labour force.

   Line of balance is thus a planning tool and a control tool.

   In the planning stage it assists in resource allocation and deriving the correct balance. It assists in programming the rate of deliveries of materials.

Once these have been established the control is simplified.

Corrective action can be taken at the right time to ensure that all materials are on site when required which improves the morale of the men on site.

By exploiting repetitive operations the firm gets the benefit of the resultant high output. This high output is also likely to be very constant and the fixing of bonuses is facilitated. A bonus system is attractive to workmen and is likely to reduce the labour turnover. This in turn reduces office time spent on hiring and resignations.

1.2.2 CALCULATION OF THE BASIC PLAN

The first stage in the calculation is to construct a logical plan of a typical unit. The line of balance method's basic objective is to ensure that a programmed rate of delivery is met. It requires therefore that all activities prior to this event 'delivery' be arranged in a logical sequence.

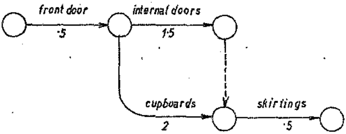
The critical path method is ideally suited to this analysis as it shows clearly activities and their interrelationships.

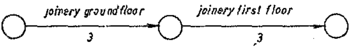
The importance of logic and accuracy at this stage connot be overstressed and it will be shown later how an assumption can affect the whole programme.

The exercise is commenced with listing of all activities of consequence and the calculation of the respective durations from the allowable rates.

At this stage a certain amount of intuition is needed as to how much detail is required. It would be possible to extract some 500 activities out of one unit but it is the writer's experience that the more complicated and detailed a programme the quicker it is outdated. In the type of unit in the scheme anyone with a few years experience could draw up a mental critical path by simply studying the drawings and a very limited amount of calculation. Generally, items with a large amount of float should be left off the programme.

Consider joinery work by way of example.
This activity could be listed in two ways :





In the first example the detail is overdone. The fact that the front door is hung before the internal doors and that the built-in cupboards completed before the skirtings is unlikely to affect the picture.

The only concern is that the joinery to ground floor is commenced on day x and completed 3 days later and similarly the first floor.

However, the detail is often required in the calculation of the total activity times, the point is only made that it should not be included on the network for the construction of the L.O.B. diagram. Sub-networks were found to be quick and accurate in the determination of activity times.

The taken off quantities play an important part of the calculation of the activity times as all times can naturally be based on only two factors, i.e. the work content of the activity and the rate allowed per unit of the work to be executed.

Generally, the quantities contained in the abstract are the total quantities for the job and an estimate must be made of the amount applicable to each unit.

It should be a simple matter of dividing the total quantity involved by the number of units. Difficulty, however, is sometimes experienced if garden walls and sundry non-typical walls have been included and for this reason the system of measuring must be adapted to suit the programming method.

This may seem obvious in the cases of seperate dwelling units but in cases like this, it is tempting to include brickwork, foundation, excavation, etc., under the same heading resulting in deductions having to be performed at a later stage. It follows, therefore, that a good idea of how the building is going to be built it is required before the measurement of drawings begins.

With reference to the typical floor plans and photographs it can be seen that the extent of the garden walling in the scheme is quite considerable. It can also be seen that these walls bear little significance to the structure. It was, therefore, decided that the work in connection with these would carry on apart from the main structure. The picture emerging would be that of a number of units having structural brickwork complete with the garden walls typically following a number of units behind. It was intended that all work in connection with these walls be used as a buffer during slack production periods on the main structure. This buffer proved invaluable during the mid period of the job when problems with the foundations were encountered and the natural flow of work assumed a slower rate. The concrete gang was effectively utilised in completing the foundations while the bricklayer could follow on behind. The only trade that was adversely affected was the plasterer who had to reduce his team size for a period.

It is for this reason that the garden walls were not indicated on the programme. The event 'complete' therefore indicates the day on which the flat could be locked having been cleaned and inspected and does not include all external works.

There was a further more important factor which determined this method and that was the extent of the external works before and after completion.

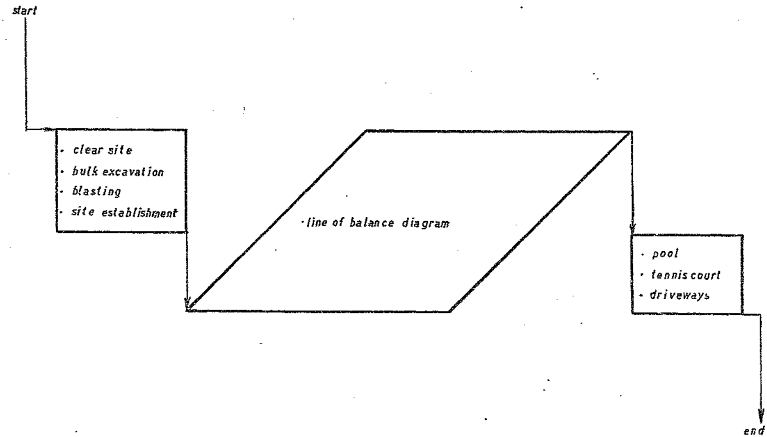
The site was previously part of a farm in Bryanston and was densely wooded. A rock outcrop was sited in the middle of the proposed block and the ground fell sharply north of this. This necessitated fairly extensive clearing and blasting operations. Under these conditions, it is not possible to include this operation as part of the line of balance programme. This occurs because the basis of line of balance is the effective utilisation of repetitive processes. Bulk Excavating, clearing and blasting in this case must be regarded as a one-off type of operation to be considered separately.

Also envisaged in the scheme was the construction of a swimming pool and tennis court as well as extensive brick paving to form driveways and parking areas. Obviously, these cannot be included being non-repetitive and must be programmed separately.

This basic logic is shown diagramatically in the figure on the next page.

There are two distinct phases in the calculation of activity times and the arrangement of them to facilitate construction of the network.

The first requires the listing of the activities and the calculation of the duration in terms of one resource unit. For instance, the calculation for the duration of excavation in garden walls would be based on only one labourer carrying out the work.


start
· clear site
· bulk excavation
· blasting
· site establishment
· line of balance diagram
· pool
· tennis court
· driveways
end

These durations are then multiplied by a factor in the second phase with due consideration to gang sizes, availability of labour and the times of other activities. This system permits flexibility and enables all durations to be brought into line with each other. At this stage the activities are grouped together to formulate the basic logic of the network.

A special form, overleaf, can be used for this purpose and when completed a clear and concise picture of the work on a typical unit emerges. This is essential where complete integration of resources occurs.

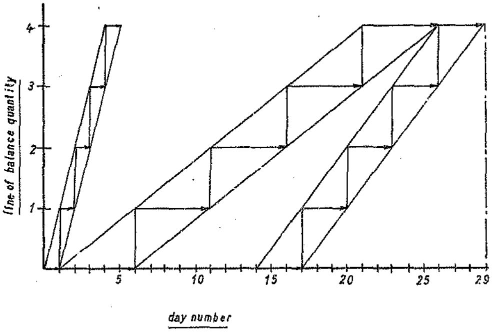
This analysis is important as activity with natural rhythms out of phase with other activities tend to increase the contract time considerably. An example will illustrate this point.

Consider the three activities below :

Activity	Duration
1 - 2	1 day
2 - 3	5 days
4 - 6	3 days

If only one gang were employed on each activity the resultant L.O.B. diagram is :

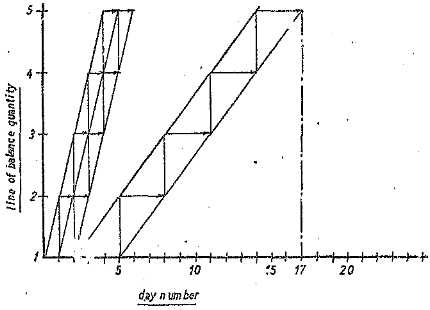
ACTIVITY	QUANTITY	RATE	GANG SIZE	COST/GANG/HOUR	TIME/GANG	RMF	TIME-DAYS
<u>E.G.</u> formwork slab	$80m^2$	r1,50	6	r 3,00	40	1	5
concrete surface beds	$24m^3$	r1,03	6	r 2,75	9	1	1



Activity 1 - 2 has a natural rhythm of 5 per week , 2 - 3 one per week and 4 - 6 1,67 per week.

The completion date is subject to that activity having the smallest natural rhythm.

If now 5 labourers were employed reducing the second activity duration to, say, 1 day, the diagram becomes :



Note that here no additional gangs have been employed - only the structure of the gang changed. Where extra gangs have to be employed becomes relevant at a later stage.

The balancing of operation times in the basic network is an essential part of its construction and in fact is the basis of the method. Unbalanced activities, not only tend to increase the total time of the contract, but also lead to under-utilization of resources resulting in extra costs.

In general practice it is not possible to balance all activities exactly. This is evident from the table on page 28, where the formwork gang has an activity time of 5 days of 8 hours, while the concrete gang has an activity time of 1 day of 9 hours. If these two activities were to be programmed strictly on an hourly basis, the resultant curves would not be parallel but have slightly different slopes.

This occurs particularly where a pre-determined rate of delivery has been set. For example, the gang size G to achieve a rate of n activities per week is typically :

$$G = \frac{n\,m}{h}$$

where m is the work content of the activity in man hours and h is the available working hours per week. It follows that G is likely to contain a fraction, say 3,5. Since labour is not divisible, the gang size would either have to be increased to 4 units or reduced to 3.

The resultant rate of delivery of that activity would be different from the pre-determined rate.

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The resultant rate of delivery of that activity would be different from the pre-determined rate.

There are two methods to take this into consideration.

Firstly, the activities can be programmed to run parallel to each other. In this case, the actual rate will be slightly different to that programmed, although the overall project time need not be significantly changed. This occurs because the errors will generally be compensatory. The cost, however, is likely to increase because of idle time caused by under-utilization and possible compensation having to be paid to sub-contractors.

The second method, which results in complete utilization of resources and no related cost implications, is to programme the activities according to the nearest whole number as in the example, in which case the activities would not run parallel to each other. This tends to increase the overall project time and implicates increases in P and G costs, bond interest and other related costs.

The choice of the method is dependent on the cost benefit to the company. While deliberately programming for under-utilized resources might not be in accordance with strict programming theory, the effect must be considered in relation to the overall feasibility.

The calculation of idle time and its resultant cost implications is discussed in detail in Chapter Two on the analysis of the programme. As will be shown, the original basis may have to be altered as a result of the analysis.

In a paper by M. J. DARLOW of the Department of Civil Engineering, University of Loughborough (Investigation into Line of Balance Scheduling for House Building, University of Loughborough, 1968), the conclusion was drawn that parallel programming proved more economical provided that the contractor could recruit men of the appropriate trades, at the right time and in the right numbers. If this proviso could not be fulfilled, then non-parallel programming would result.

It is unlikely that in this country with an inherent shortage of skilled labour, the proviso for parallel programming could be met. In this situation, the analysis described in Chapter Two would be more accurate than the Loughborough generalisation.

The Line of Balance diagram on the project (Figure 1.5) was drawn up on the basis of 11 activities. The rate of completion was determined at 1 unit per week as follows.

Because of blasting and clearing operations typical work could only commence at the beginning of April. It was desirable to complete the scheme by the December recess of the same year. The extent of landscaping, brick-paving and sundry structures (servants' quarters, pool & tennis court), most of which occurred in the area between unit numbers 8 and 16, required two months work.

The network calculation revealed that the first unit could (with no buffers) be completed by mid-June. The available time to hand over 16 units allowing October and November for landscaping was 16 weeks - a rate of one unit per week.

It was obvious from an early stage that while the company labour was well trained in this type of operation, the co-ordination and supervision of sub-contractors was to be a formidable task.

The company labour was allocated in terms of gang size and activity combinations to achieve a work cycle as close as possible to one week per unit. This was to reduce the idle time inherent in non-parallel programming to a minimum.

The work content of the network was divided between six gangs as follows:-

GANG 1 CLEARING, PREPARING LEVELS, BRICK-PAVING

This gang proceeded ahead of the typical work, reducing levels, removing rocks and tree stumps, and formed the work force of the first phase in the diagram on page 26.

Once the whole area to be occupied by the flats was completed, they continued on preparing for gardens and brick-paving.

GANG 2 FOUNDATIONS

The gang size was calculated as that size which could complete the foundation excavation and concreting at a pre-determined rand rate in 5 days.

For Example :

Let the allowable rate for excavation be Re and the volume of excavation per flat be, Ve. Let the allowable rate for concreting be Rl and the volume of concreting be Vc. If the current labour cost is Rl per hour than the gang size is :

$$G = \frac{ReVe + RcVc}{R1M}$$

Where M is the available number of hours for the activity (in this case, 5 days).

This was in fact a departure from the traditional system of the team, whereby one gang did all the excavation work and another the concrete work. But it was by this means of combining activities and calculating the gang size that this team and most of the subsequent teams were able to achieve a one week work cycle. These activities are labelled 1 - 2 and 2 - 3 on figure 1.3.

GANG 3 BACKFILLING AND CONSOLIDATING SURFACE BEDS AND CONCRETING SURFACE BEDS

In a similar manner to that described above, these two activities were combined to produce a one week cycle. These are labelled 4 - 5 and 7 - 8 on figure 1.3.

GANG 4 'ORK

The for... the slab was arranged in two stages to allow for a start to be made before load bearing brickwork was complete. It was possible to score two days per unit by this means. The total activity time was again calculated at one week, and is shown as activity 9 - 14 (2 days) and activity 14 - 15 (3 days) on figure 1.3. This gang also erected the formwork to the front beam (activity 9 - 13) and the staircase of the previous unit (activity 19 - 20) at the same time.

GANG 5 ROOF STRUCTURE AND ROOF COVER

The roof structure which consisted of simply supported 150 x 75 laminated pine beams was erected in two days, while the covering (I.B.R. sheeting) required 3 days. These were grouped to be completed by gang number 5 in 5 days (activities 32 - 33 and 33 - 37, figure 1.3).

GANG 6 ROOF TILING, CLEANING

As the roof was completely waterproofed by means of the I.B.R. sheeting, the tiling was an unskilled operation which was planned to be carried out by the general cleaning gang rather than have a separate gang for this purpose. This activity (38 - 39) was thus combined with the 3 cleaning stages shown as activities 46 - 47, 49 - 50 and 48 - 50.

The cleaning described here consisted only of cleaning the flats themselves and did not include removal of rubble and surplus material. This was done by gang number one prior to laying the paving.

In this manner the company's own labour was allocated to keep the losses inherent in parallel programming to a minimum.

A similar approach was adopted with sub-contractors even though their losses did not directly affect the company.

The approach was adopted, however, on the basis that,were the sub-contractor placed under financial strain in having to move his labour to and fro from the site, he would be reluctant to do so and the progress would be likely to suffer.

The sub-contract work for this purpose could be divided into two categories:

A Those required sporadically on site

B Those required permanently on site

Category A included plumber and electrician while Category B included the bricklayer, plasterer and painter.

With the A type sub-contract work, it was standard practice for them to arrive on site to carry out work of a very short duration - usually one day or less. Consequently, no special consideration was required to be given to the natural rhythm of the activities. They were, however, briefed in the importance of their being on site as and when required, prior to the signing of their contracts. Note that this was of consequence only in the beginning of the contract in the case of both these sub-contractors. This occurs because as the contract progresses, the number of times that these sub-contractors are required on site increases. For example, for approximately the first four weeks the electrician is only required on site for 1 day per week. Thereafter, until about week 6, 2 days per week increasing to just about full-time on site.

A reasonably even labour distribution was achieved for the 3 sub-contractors under category B by using the non-critical external works as a buffer. On each flat the bricklayer had about 5 days work externally while the plasterer had 4 days and the painter 3 days work. The emphasis was, therefore, on programming the bulk of their work, e.g. load bearing brickwork activities 8 - 9 and 8 - 10 to conform as closely as possible to the one week cycle. As the external works were not critical to the extent of the internal works, the men on these works cyuld carry out the more sporadic activities, e.g. brickwork foundations (activity 3 - 4).

In the case of these sub-contractors the activity durations should be calculated in much the same way as the Company's own activities. This enables realistic times to be set and at the same time a check made on how many tradesmen each sub-contractor would be required to have on site. The latter is particularly important as the smaller sub-contractor (as these generally are) can only effectively supervise a certain number of men himself. Once he is required to employ more than that number inefficiency developes with the consequent losses.

Under these conditions, he has two alternatives - one, to ignore the programme and constantly report that he cannot get more men (which usually happens in practice) as he could either employ supervision staff or sublet part of the work.

The calculation of his profitable output can be calculated directly from the price he is being paid. e.g. Assume a brickwork sub-contract has been awarded on an all-in rate of R35-00 per thousand bricks, the required output per man to ensure 20% for overheads and profit is calculated from :

Let 1 gang consist of 1 bricklayer and 2 labourers. Assume the cost of this to be R4-00 per hour. For budgeted profit

Cost = Earnings

Let O = required output per hour

$$\text{Then } O = \frac{R4\text{-}00 \times 1000}{R35 \times 0{,}8}$$

$$\simeq 140 \text{ bricks per hour}$$

Relating this to the measured quantities and the required cycle would rapidly indicate the sub-contractor's resource requirements and degree of utilization.

Experience on other sites showed that it was essential to have a working knowledge of the sub-contractor's expected profit. The cost of a sub-contractor leaving a contract either because of insolvency or merely running away was large both in terms of cash and loss of time. In certain cases, it might be wise to pay a bit more to keep the sub-contractor alive.

+The foregoing considerations were all included in the compiling of the master line of balance diagram which appears at the end of this chapter (Figure 11.5).

The network which appears in the top right-hand corner of the diagram is the same as Figure 1.3 except that certain modifications in drafting were made to facilit te identification of all activities. It will be noticed that no buffers are included in the diagram. These were not written into the program on the following assumptions.

- Time was critical in terms of the proposed handover date. Any significant buffers would have extended the contract time which was not desirable.

\+ The details of constructing a typical diagram as well as other relevant theory is not discussed in great depth in this report as this is covered in a previous work, "A course in Advanced Planning", which has been submitted to the University of the Witwatersrand.

- The time scale was related to a five day working week. Any activity not completed during the week could have been completed on the Saturday. The six company gangs had, therefore, a buffer of about 20% on their work.

  In the case of sub-contractors, the 5 days week was also adopted even though it was generally accepted that their tradesmen worked on Saturdays. This assumption created an activity buffer rather than a stage buffer.

- A quasi stage buffer was written in, that being activity 18 - 19 which was a five day period during which the slab was cured and stripped. The fact that no other work on the unit was programmed to run concurrently with this activity was deliberate and intended as a buffer.

Further remarks on buffers are made in Chapter Four.

Both figures 1.3 and 1.5 were issued to the site foreman who charted his progress on figure 1.5.

CHAPTER TWO : ANALYSIS OF THE PROGRAMME

2.1 RESOURCE REQUIREMENTS

This is the most important step in the construction of the programme and involves the analysis of resource requirements over the duration of the contract and terminates in the critical decision of at what rate to produce the units.

If the question were to be raized as to why the project was not completed on time then in all honesty one must reply that a design change was not fully analysed at this critical stage. Reference will be made to this in a later section on the performance of the project compared to the programme. The effect on the programme had the design change been taken into account is also shown but to fully grasp the significance and importance of this stage in the programme a bit of theory is relevant as it illustrates how useful the line of balance method can be in this regard.

Consider the network below:

Assume that this is a network applicable to a typical unit of which ten are required and an intuitive decision is made to deliver these at a rate of two per week.

The resultant line of balance diagram is shown on the next page.

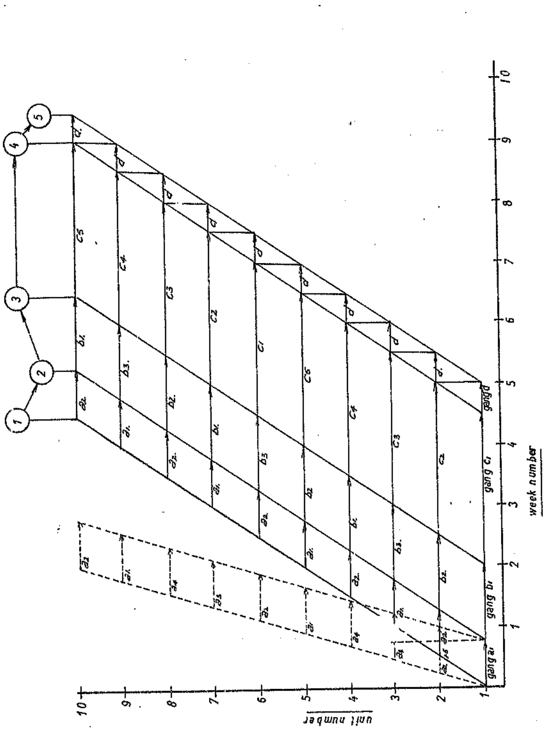
Consider activity No. 1 - 2.

If the allocation of the resource requirement was an ideal one then these resources cannot be employed elsewhere on the project.

Projecting upwards on the 'unit' scale after completion of the activity shows that the resources only become available for the same activity on unit two, 1,5 days after its scheduled start.

It follows therefore that a further allocation would have to be made to this activity if the required rate of delivery is to be maintained.

Projecting further upwards shows that gang 'A1' becomes available one day before the scheduled start of


week number
unit number
gang a1
gang b1
gang c1
gang d

activity 1 - 2 on unit number three. An allocation of two gangs 'type A' is therefore sufficient, gang 'A1' working on units 1, 3, 5, 7, 9 respectively and gang 'A2' on units 2, 4, 6, 8, 10.

Activity 1 - 2 is said to have a resource multiplication factor of 2.

DEFINITION

The factor by which a resource allocation on any activity is to be multiplied in order to achieve a predetermined rate of delivery is known as the resource multiplication factor.

A table can be drawn up for the required factors.

Activity	R M F
1 - 2	2
2 - 3	3
3 - 4	5
4 - 5	1

Consider the decision to increase the rate of delivery to 5 units per week.

Gang 'A' completes activity 1 - 2 after the scheduled starts of units 2, 3 and 4 and is only available again for unit 5. Further gangs would be required for these units and the resource multiplication factor is 4.

The table is completed thus :

Activity	R M F
1 - 2	4
2 - 3	6
3 - 4	10
4 - 5	3

If resource 'A1' was a R40 000 mobile crane (as could be the case with an industrialised building scheme) the required investment is doubled. This might not be economically feasible or it may have to be hired at a rate of some R125 per day.

Activity 3 - 4 may be a team of carpenters. By increasing the rate, the requirement is increased from 5 to 10 and the labour market particularly if the project is away from the major centres may not be able to supply the additional requirement. Alternatively, incentives and higher wages would have to be offered to ensure the labour requirement is fulfilled.

Both the above would affect the cost of the contract and the point is made that it is only by careful analysis of all resource requirements that these factors become apparent and can then be taken into account either by reducing the rate again or by adding them in as an extra cost in calculating the feasibility of the scheme. It could also assist in the basic question of whether to tender or not to tender.

A further point of useful information can be extracted from the diagram that being the degree of utilization of each resource.

Consider activity 2 - 3 on unit number 2. If only one allocation is made then unit 2 must wait 1,5 days for the completion of activity 1 - 2. The effect of this is to increase the duration from 6 days to 7,5 and results in the resources on that activity being underutilized by $\frac{1,5}{7,5} \times 100 = 20\%$

Under these circumstances, it would be wise to increase the duration of activity 2 - 3 to coincide with that of activity 1 - 2 and so by ensuring the elimination of the 1,5 day delay. Note that this would continue throughout the contract.

The cost of activity 2 - 3 would increase proportionately, i.e. by 25%.

Considering the first allocation again, it can be seen that gang 'A1' have to wait one day for the scheduled start of activity 1 - 2 on unit number 3. The calculated duration was 4 days but the labour is employed for 5 days resulting again in an increase in cost of 25%.

Note that the scheduled start is still governed by the decision to deliver 2 units per week and on this basis the start of subsequent units cannot be brought forward. The significance of this idle time is made more apparent by completing the exercise with gang sizes assumed and the activity considered in terms of man weeks, i.e.

ACTIVITY	DURATION	GANG SIZE	MANWEEKS
1 - 2	0,8	10	8
2 - 3	1,2	8	9,6
3 - 4	2,5	11	27,5
4 - 5	0,5	7	3,5
TOTAL	5,0	36	48,6

The total resource requirement for the project on this basis would be 48,6 x 10 equal to 486 man weeks.

Looking at the situation more closely, however, will yield a different solution.

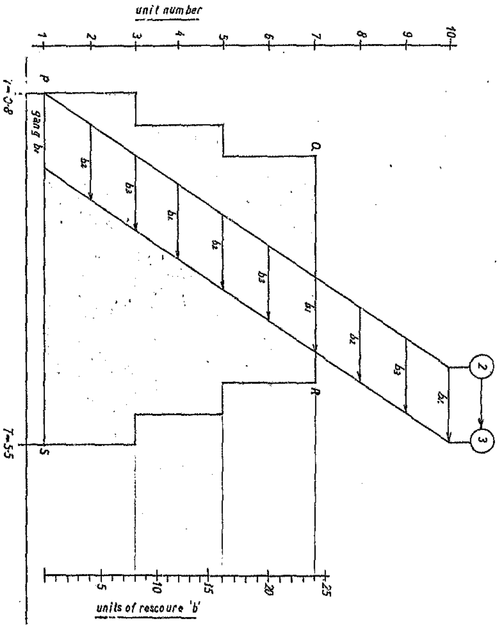
Consider activity 2 - 3 plotted on the diagram overleaf. The activity commences at t = 0,8. On this day 8 men are brought onto the site to commence unit one.

At t= 1,25 the same activity on unit two is scheduled to start and another gang must be brought on and the same occurs at t = 2 on unit number 3.

By the time unit 4 is to be started gang B2 has completed unit one and can thus move over.

The labour force has increased in a step-like fashion to the commencement of unit number 3 and now remains constant at 24 labourers.

By continuing the set of allocations it can be seen that after completion of unit number 8, gang 'B2' is no longer required. Similarly with gang 'B3' on unit 9 and gang '[illegible]' on unit 10.



unit number
units of rescoure 'b'
P
Q
R
S
T=5·5
gang b1

The labour force remains constant therefore until the completion of unit number 8 after which a 'run down' takes place to equal zero gangs at the completion of the activity.

This series of events is shown by the shaded in histogram. The scale is shown on the left hand side of the diagram.

The effective work content c. the activity can now be calculated and since time and number of men were plotted on the two axis this would simply be the area of the histogram, i.e. area P.Q.R.S.

As the rate of building is constant it follows that labour will be employed and deployed at the same rate and the histogram will be symmetrical about its central axis.

The area and consequently the activity resource is equal to the peak labour requirement multiplied by the time calculated from either :

- the start of the build up of labour on an activity to the start of the run down, or

The labour force remains constant therefore until the completion of unit number 8 after which a 'run down' takes place to equal zero gangs at the completion of the activity.

This series of events is shown by the shaded in histogram. The scale is shown on the left hand side of the diagram.

The effective work content of the activity can now be calculated and since time and number of men were plotted on the two axis this would simply be the area of the histogram, i.e. area P.Q.R.S.

As the rate of building is constant it follows that labour will be employed and deployed at the same rate and the histogram will be symmetrical about its central axis.

The area and consequently the activity resource is equal to the peak labour requirement multiplied by the time calculated from either :

- the start of the build up of labour on an activity to the start of the run down, or

- the time at which full allocation occurs to the time at which zero allocation occurs.

For activity 2 - 3 this would be :

Peak labour force	=	24
Start of build up	=	0,8
Start of run down	=	5,5
Area histogram	=	24 (5,5 - 0,8)
	=	112,8 units

Effective work content is therefore 112,8 man weeks as against 96 man weeks previously calculated. This difference occurs because the actual time on site is now calculated instead of merely the gang size times the total duration.

Lumsden+ has defined this time scale as the 'equivalent base of the histogram' as is formulated :

$$Eb = \frac{Q - RMF}{M} + A$$

Philip Lumsden - The Line of Balance Method, Pergamon Press Ltd., Industrial Training Division, 1968, London.

Q_r = Number of units

RMF = Activity Resource Multiplication Factor

A = Activity Duration

M = Delivery Rate

For Activity 1 - 2 $\quad Eb = \dfrac{(10 - 2)}{2} + 8$

$= 4,8$ weeks

The exercise is extended for the remaining activities in the table below :

ACTIVITY	E.b. HISTOGRAM	PEAK REQUIREMENT	EFFECTIVE WORK
1 - 2	4,8	20	96
2 - 3	4,7	24	112,8
3 - 4	5	55	275
4 - 5	5	7	35
			578,8

Effective work constant is now 578,8 as against 486 previously calculated and the direct effect would be to have underpriced the labour on the project by :

$$\frac{(518,8 - 486)}{486} \times 100$$

6,75%

I ··'ence later gained by the writer on much larger p: as endorsed the significance of this idle t . and its resultant losses. The question arises as to who pays for it? Is the contractor foregoing part of his profits or is he writing some contingency based on past experience into his tender price thereby passing the cost onto the client?

Not wishing to delve into the ethics of tendering procedure consider a situation from the contractors point of view.

The writer is currently engaged in the construction of a multi-storey office block, a typical floor plan of which is shown overleaf.

Each floor requires the erection of some 2200 square meters of vertical formwork and some 1500 metres of horizontal formwork.

In terms of the contract period and the cranage available a cycle of 4 weeks per floor has been programmed. From this and given a bill rate of say, R2-50 per metre for vertical formwork and R1-50 for horizontal formwork the number of carpenters required per floor can be calculated so that at least the budgeted profit is achieved.

A. Income per Floor (4 weeks)

Vertical	2200	x	R2-50	=	R5 500
Horizontal	1500	x	R1-50	=	R2 250
					R7 750

B. Expenditure per Floor (4 weeks)

Gang distribution = 1 artisan + 2 labourers

Cost to Company, say R4-00 per hour

Expenditure per 4 weeks = R4-00 x 44 x 4

i.e. R704 per gang

C. Number of Gangs

$$\frac{\text{Income per 4 weeks}}{\text{Expenditure per gang per 4 weeks}}$$

i.e. $\frac{R7\ 750}{R\ \ 704}$

i.e. 11 gangs

or 11 carpenters 2 labourers

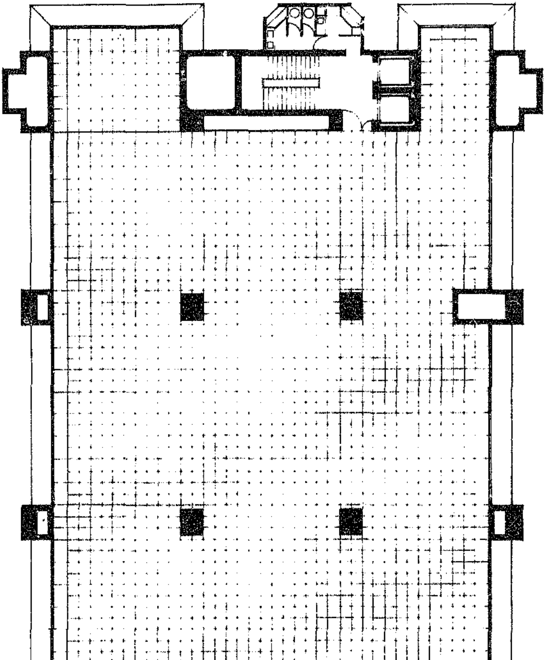
Provided then that each floor takes no longer than 4 weeks the budgeted profit on labour will be achieved irrespective of any idle time incurred during the 4 week cycle.

However, this is not quite as simple in practice. If the job was allowed to proceed ad lib there would be certain periods in the month where more than the required number of carpenters would be required and other periods where fewer carpenters are required. The tendency would be for the site supervision to engage that amount of men that would tide them over their peak periods resulting in under utilisation during slack periods causing the total number of carpenters to settle at a level in excess of that number actually required.

On a project of this size, (37 floors) the resultant loss of underutilisation can be high and can only be minimised by effective resource allocation.

The effect of this is illustrated with reference to the 3 large shafts C, D and E.

In the initial planning stage, it was decided that to ensure a four week cycle per floor, these shafts should be constructed so as to remain a couple of floors ahead of the slab itself.


C.
D.
E.

Rather than delay the slab while these shafts went ahead it was decided to reduce the cycle time of the shafts until such time as they were the desired number of floors ahead.

The way it was actually programmed on site is shown in the diagram overleaf together with the resultant resource histogram which shows a peak requirement of 3 carpenters while certain periods acquired zero carpenters. If during these times of less than peak requirements it was possible to move the men to some other productive function no loss would be incurred but this is practically not possible. However, for the sake of getting the shafts ahead this was desirable.

Once these shafts were two floors ahead it was possible to reprogramme and reallocate.

At this stage the one carpenter who had been mostly employed on the shafts was more skilled in the operation and this was immediately utilised.

Basically the shafts were programmed to proceed at the same rate as the floors and by effective utilisation considering factors such as crane time and steelfixing time, the work is now carried out by only one man.

The network and resultant histogram is illustrated. To ensure the timeous completion so as not to delay the slabs following up behind a simple bonus scheme was designed.

The standard time for the work on one complete shaft was calculated at 26 working days, i.e. four weeks at six days per week.

Standard time was naturally that time which would yield the budgeted profit plus an extra few per cent. For completion in standard time the carpenter receives a certain sum of money and for every day saved on standard time an additional amount is paid.

The scheme was communicated to the carpenter by letter translated to the Portuguese language as well as the provisos which are :

- The work must be carried out to the satisfaction of the architects and structural engineers failing which the bonus would be forfeited.

- The assistance allowed was fixed at four labourers.
- Management would be the sole judge as to the award of the bonus.

The e... ...t has been encouraging. The artisan no longer s...nds idle awaiting the steel fixer but complains until steelfixing is commenced.

- Previously the stripping gang was blamed for lack of output. He now supervises this himself.
- Erection of scaffolds previously caused delays. He now ensures via the foreman that scaffolds are erected well ahead of time.

Basically the man has changed from one indifferent to his output to one anxious to get the work done as quickly and as accurately as possible.

While still on the same project and as this work is basically planning in practice an enlargement on the presentation and control of the programme is relevant.

One of the major problems encountered in programming in practice is controlling and maintaining the interest of all parties to the programme.

nis in the writer's opinion occurs because of the optimistic approach by management that a detailed programme (and indeed detail is often carried to the nth degree) drawn up at the beginning of a job will be enthusiastically adhered to by the parties concerned and will be sufficient for the duration of the contract.

A boast was heard that the critical path network for a certain restaurant section of a building in town covered some 4 sheets of double elephant size drawing paper. Questioning revealed what was to be expected. The network was outdated not long after site operations began and was soon not worth the paper it was drafted on.

This attitude is largely responsible for the reluctance by many contractors to use the critical path method.

Strangely enough one of the basic requirements of a plan that it must be flexible is generally ignored and to programme the whole of a contract in fine detail does not permit flexibility.

The solution can be found in the construction of different programmes for different purposes.

The Bill of Quantities generally requires that a programme be subm ed to the architects a few weeks after taking over the site. One must examine the reason for this requirement.

Is it required by the architect so that he can decide whether the programme is fair on his nominated sub-contractors as he advocates or does he require it to quickly finalise certain details which are shown to be urgent?

The programme is stated to be subject to the architect's approval. Would it not be convenient for him to disapprove of a programme which regarded as urgent certain sections for which documentation was not nearly complete?

Under these circumstances it is felt that this programme must be as simple and as broad as possible. Basic cycles must be calculated so as to ensure completion on time.

To include float on this programme has been found to be undesirable as the architect generally believes float belongs to him. As many activities as possible should be shown as critical.

The structure on this programme on high rise buildings should show no more detail than floor one, floor two, etc.

Once the job has started this broad plan must be translated into one of action to achieve the predetermined cycles. Here detail is required and structure is treated separately from finishes.

The job should be broken down into manageable sections and treated separately with the overall picture in mind.

An effective method used by the writer is to programme the structural programme on a monthly basis. This generally tends to hold enthusiasm for if, towards the

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An effective method used by the writer is to programme the structural programme on a monthly basis. This generally tends to hold enthusiasm for if, towards the end of the month the programme is running behind, the site supervision know that a fresh programme is due and a fresh start will be made with due regard to catching up on lost time. The advantage of this is that the catching up of lost time is in the hands of the programmer and will be reflected (although not necessarily noticed by site supervision) in the next monthly programme.

This programme is updated and discussed daily. A typical monthly programme is enclosed in the back of this report.

The main feature of the programme is that it is basic network form but instead of listing starting times in the usual way the whole network is on a time scale.

The network is updated daily by a senior student who does so in the presence of the foreman and charge hand.

To highlight the state of the work compared to programme, a simple colour code is used.

If an activity were due to commence on a particular day and was in fact commenced the line is coloured in red.

If the programmed activity has not yet started it is coloured in blue and if it is commenced ahead of programme green is used.

Each activity must therefore be considered every day.

The effect of this method has been that a chargehand with an education level of about Standard 6 and a foreman fully understand a basic critical path network.

The interest and response generated by using a time scale and colour code has been encouraging and its overall effectiveness is far superior to that of a bar chart which has been advocated as the only means of representing a programme to site staff.

The morale on site is governed by the colours prominent on the programme. If the predominant colour is blue a general sense of urgency exists. If towards the end of the month the programme is showing green the charge hand and foreman convey a sense of relief and look forward to the last Saturday of the month when the site closes down.

The effect of the glaring colours is in fact so important on morale that if significant time is lost due to say, rain (which is claimed for) the whole of the time scale is shifted back by the relevant amount to maintain interest.

This programme is drawn up by the writer and requires for calculation and drafting, one day.

This programme is not submitted to the architects as it does not concern them in that it is a means to achieving or bettering dates already submitted to them in the general programme.

Returning to the discussion on the analysis of the programme at the beginning of this section, it may seem as if in carrying out this analysis that the horse is being put before the cart. This, however, will not be the case if this analysis is considered to be an integral part of the calculation of the final programme.

A programme is useless if the rate of building (intuitively decided) is such that the company has not the resources with which to carry out the programme.

In summary, therefore, the exercise is carried out in two parts.

Firstly, the network in taken and plotted on a diagram to an assumed rate. This rate should naturally conform as closely as possible to the required delivery date for even with development work this is generally defined.

The resources are then analysed, adjustments made and the programme finalised.

It can be argued that this exercise is unnecessary with tender work as the completion date or dates of separate landowners in the case of housing schemes is predefined.

This is in certain cases true but then the assumption is that the tendering company has adequate resources for the work on which it tenders.

However, where the resources of the company are limited, this exercise could be a valuable aid in the decision of whether to tender or not.

The resource histogram for the line of balance programme (Fig. 1.5) is shown overleaf.

2.2 THE CASH FLOW

The method permits ready calculation of a statement of income and expenditure and the timing thereof. From this can be calculated the contract breakeven point and, which follows, the total working capital required and the length of time for which it is required.

The basic procedure is simply to place a cost estimate next to each activity and to add these at various time intervals as they become payable. This cost estimate is available from the original 'take off' and so the cash flow calculation is merely an arithmetical exercise.

In the calculation, cognisance must be taken of the timing of the flow which will depend on the accuracy required. The amount of detail required should also be taken into account.

On the scheme the cash flow was calculated firstly on the basis of labour and sub-contract only. This was done because labourers and subcontractors were paid weekly. No distinction was made between a subcontractor who submitted a draw every week and one who was known to draw every two to three weeks.

The cash flow diagram, therefore, tended to produce a picture less optimistic than that which would actually occur.

The decision as to which sub-contractors to include on a weekly basis would on larger contracts depend mainly on the normal procedure for payment and this should be taken into account. The generally accepted form is monthly on work certified by the Quantity Surveyor.

Typically each case will depend on its own set of circumstances, the basic objective being simply to time the cash payment as closely as possible to that which is likely to occur during the construction period.

Suppliers naturally have to be treated separately and again the timing of the flow will depend on credit arrangements with the supplier.

On the project, accounts were paid monthly - an average of 6 weeks after receipt of the goods and the cash flow was drawn up on this basis.

Once the information has been collected (which is straightforward from the quantities) the overall expenditure calculation can proceed very rapidly by simply moving the different amounts to the time scale corresponding to the assumptions made.

An example will illustrate this point.

Consider an operation with a delivery rate of one unit per week.

Expenses averaged out are :

Labour	R2000	per month
Sub-Contract.	R5000	per month
Suppliers	R3000	per month

Three methods of payment are tabulated on the next pages with their resulting cash flow curves.

TABLE A

All expenditure assumed to take place in week during which the work executed.

WEEK	1	2	3	4	5	6	7	8	9	10	11	12
Labour	500	1000	1500	2000	2500	3000	3500	4000	4000	5000	5500	6000
Sub-Contr.	1250	2500	3750	5000	6250	7500	8750	10000	11250	12500	13750	15000
Supplier	750	1500	2250	3000	3750	4500	5250	6000	6750	7500	8250	9000
TOTAL	2500	5000	7500	10000	12500	15000	17500	20000	22500	25000	27500	30000

TABLE B

Labour - Weekly
Sub-Contractors - Bi-Weekly
Suppliers - Monthly

	1	2	3	4	5	6	7	8	9	10	11	12
Labour	500	1000	1500	2000	2500	3000	3500	4000	4500	5000	5500	6000
Sub Contr.		2500		5000		7500		10000		12500		15000
Supplier								3000				6000
TOTAL	500	3500	4000	7000	7500	10500	11000	17000	17500	20500	26000	27000

TABLE C

Labour paid weekly
Sub-Contractors Monthly
Suppliers 60 Days

WEEK	1	2	3	4	5	6	7	8	9	10	11	12
Labour	500	1000	1500	2000	2500	3000	3500	4000	4500	5000	5500	6000
Sub-Contr.								2500				5000
Supplier												3000
TOTAL	500	1000	1500	2000	2500	3000	3500	6500	7000	7500	8000	14000

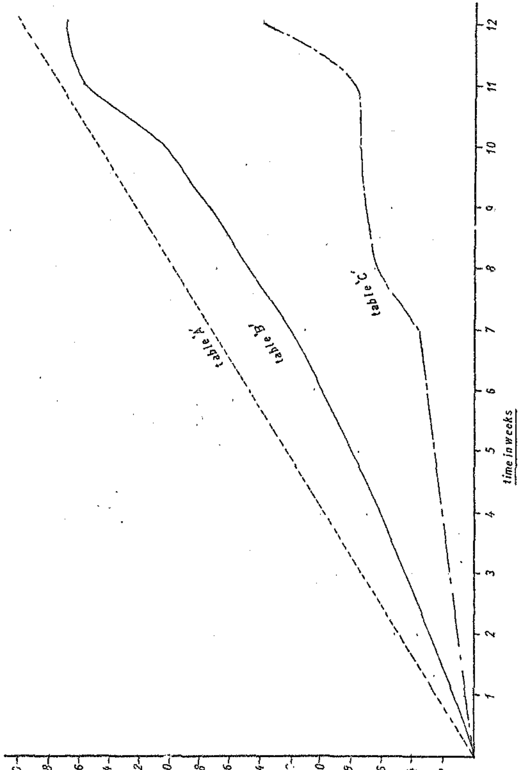
table 'A'
table 'B'
table 'C'
time in weeks
1 2 3 4 5 6 7 8 9 10 11 12
2 4 6 8 10 14 16 18 20 22 24 26 28 30

Clearly shown is the behavior of the cash flow curve in relation to the credit period available.

The second factor to be considered in the calculation is the amount of detail required. In this regard it is wise to consider the effect on the overall picture of carrying detail to the nth degree.

In the case of the flats, had each activity on each unit been calculated as with the hypothetical case, this would have resulted in some 816 additions to carry out.

A simpler method and one that would not affect the accuracy at all is to group convenient sections of the work into 'packages'. The expenditure that occurs within this 'package' is totalled and this figure used in the calculation of the cash flow.

Here it is wise to construct the 'cost package' by grouping activities by time intervals dependent on the method of payment of wages, sub-contractors and suppliers.

It can be seen from the critical path of the typical unit that certain activities take one day only. It would be unwise to plot these individually as very seldom, if not never, are disimbursements made on a daily basis.

The cost packages used in determining the cash flow on the project were grouped mainly according to the section in which they occurred.

These were:

1. Foundations up to and including surface beds.
2. Ground Floor superstructure and slab
3. Upstairs superstructure and downstairs finishes
4. Roof structure,covering and finishes
5. Painting, Final Cleaning and Clearing

The calculation of each cost package then merely requires the summation of the cost of the activities within the cost package.

This calculation in terms of labour and weekly paid sub-contractors is shown.

1. FOUNDATIONS

Act	Description	Rands
1 - 2	Foundation Excavation	130-00
2 - 3	Concrete Foundation	30-00
3 - 4	Brickwork Foundation	150-00
6 - 7	Concrete Surface Beds	35-00
		345-00

2. GROUND FLOOR

7 - 8	Load Bearing Stocks (10 000 at R30)	300-00
8 - 9	Load Bearing Fairface (4 500 at R40)	180-00
8 - 11 8 - 10 10 - 11	Formwork	100-00
16 - 17	Pour	30-00
		610-00

3. 1ST FLOOR SUPERSTRUCTURE & GROUND FLOOR FINISHES

18 - 19	Staircase (Formwork & Concrete)	30-00
18 - 22	Internal Brickwork 3200 at R30-00	96-00
21 - 27	Brickwork 1st Floor 4500 at R40 + 10000 at R30	480-00
24 - 26	Plaster Ground Floor $\frac{R600}{2}$	300-00

24 - 25	Wall Tiles	$\frac{R210}{2}$	105-00
26 - 37	Floor Screeds		130-00
	Build in Frames		25-00
			1 166-00

4. *ROOF*

27 - 28	Roof Structure & 1st Floor finishes	50-00
30 - 31	Wall Tiles	104-00
30 - 32	Plaster	300-00
32 - 33	Screeds	70-00
33 - 34	Roof Covering	80-00
37 - 38	Ceiling (Timber)	100-00
38 - 39	Joinery Ground Floor	112-00
33 - 36	Joinery 1st Floor	113-00
	External Brickwork 1600 at R40 2250 at R30	135-00
	Garden brickwork 4500 at R40	180-00
	Cement wash external	75-00
	External Floors	100-00
		1 419-00

5. FINAL FINISHES

40 - 43)		
40 - 42)		
42 - 45)	Paint	600-00
43 - 44)		
46 - 47)		

45 - 48	Final Clean - Ground	60-00
47 - 48	Final Clean - 1st Floor	50-00
		......
		R 710-00

The resultant curve is shown in figure 2.1.

The income curve is naturally dependent on arrangements made with the relative financ(house or is defined by the contract.

Whatever the arrangements, the problem remains one of determining at what point in time draws will be paid and the extent of these draws.

Typically work is measured monthly and a certificate issued monthly. Knowing the value of each section, the estimated draws can then be related to the programme and the timing thereof evaluated.

Naturally in contract work the normal retention must be deducted from each draw to arrive at the net expected amount.

Again as with the expenditure curve the expected valuations will be grouped into 'packages' to reduce the amount of detail and to simplify calculation. Once these packages have been valued the calculation proceeds in precisely the same way as the previous curve.

These curves are also useful to the financial institutions who often require advance information on the expected draws for the duration of the contract to facilitate the planning of their finances.

The income curve plotted on figure 2.1 is a hypothetical curve to illustrate the principle and the contract breakeven point.

In constructing these curves care must be taken not to overlook expenditure which may not appear on the line of balance diagram. Activities generally not appearing would be :

Major Earthworks
Swimming Pools
Tennis Court
Roads and Driveways
Local Fees

The nature of these requires that they be programmed separately from the line of balance diagram as being of a 'one off' nature having no natural rhythm as with typical activities.

The treatment of these will vary depending on how the expenditure or income is treated.

In the case of P and G items, these should be apportioned to each unit for the time period that the units are under construction. If a long period is required for site preparation then it would be more accurate to apportion the expected P and G to that period and divide the balance between units on a specific time scale.

Major earthworks on the other hand are not likely to be paid over the contract period but rather as a lump sum in the beginning of the job. Similarly, extra work such as a swimming pool and tennis court on the scheme would have to show the expenditure when it is likely to occur - in this case at the end of the contract.

These two factors are taken into account on the curve.

THREE : PROGRAMME CONTROL DURING CONSTRUCTION

3.1 REPRESENTATION

The representation of the programme as in Figure 1.5 is simple and easily understood by site supervision. Provided the activities are clearly labelled and the related critical path network (which could be a bar chart) available for reference then there is no problem in the foreman understanding what activities are required for any particular day.

The diagram is also useful as he can readily establish which activities must be commenced shortly and he can ensure that he has the resources with which to carry them out.

One problem has come out of the study, however, and that is actual recording of progress on site. It has become apparent that site personnel require a system whereby they can see exactly where they stand from day to day. It can be argued that by analysing the programme this information can be readily extracted but it was found that the foreman was reluctant to do so. On this score, the writer agrees that a better designed visual aid is of advantage.

The mere posting up of figure 1.5 on site did in fact prove unsatisfactory.

Lumsden advocates shading all activities completed. Theoretically these should all be to the left of a particular point in time. This appears to be successful but the examples he uses are all greatly simplified.

The system of shading in was attempted on site but became extremely complicated as certain activities and/or units fell behind schedule.

A system of cumulative totals seems a logical solution. With this system the weekly total of each activity is plotted against that actually achieved. However, the writer does not hold out much hope for the success of this system at foreman level. Furthermore, on larger schemes these weekly computations would almost certainly require the use of a computer. This would tend to increase the cost of this reporting which is not likely to be read by the foreman.

But, somehow the state of the job must be communicated to the site and although not used on the particular scheme, two methods are put forward.

These are the shading to the left of the current day advocated by Lumsden but on a simplified network and a weekly histogram based on plan vs. actual cumulatives.

In the first method, the first step would be to group certain stages similar to the way in which their activities were grouped for the calculation of the expenditure curve in 2.

These groupings could also allow for differences in natural rhythms and also assist in the introduction of stage buffers.

A new diagram is drawn up on this basis and posted in the site office or wherever convenient.

The stages are updated weekly in the presence of the foreman and any overrun on the completion or starts of stages is analysed with reference to the detailed programme. All units commenced to the left of time t are shaded in and the foreman has now his visual reminder as to the state of the job.

Regarding the second method, the information required is the same as the cumulative weekly totals previously discussed except that in this case the information is committed to histogram form.

The histogram is prepared in the office and delivered to the site to be discussed with the foreman. Two curves are required being the cumulative requirements of the programme at time t and the actual completion at t.

A simple colour code can be used to describe the criticality of the work. Should the actual completion be ahead of that required, the area between the two curves could be coloured in red while blue could be used for the opposite situation.

These two methods are shown diagramatically in figures 3.1 and 3.2 respectively. The stage of completion in each case is the same.

Naturally, presentation will vary with the intended recipient of the information. In a large company even the detail described in figures 3.1 and 3.2 would be too detailed for the board. The concern here, however, is more on site control and as such the importance of visual aids for control cannot be over-emphasized.

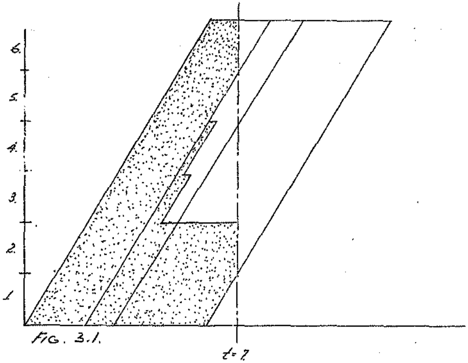

FIG. 3.1.

both methods show delays on:

activity 2 units 3 and 4

activity 3 unit 2

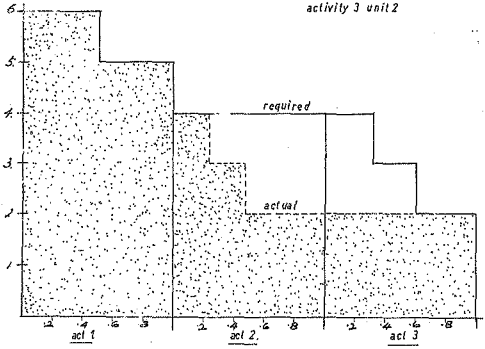

FIG 3.2.

3.2 SITE CONTROL

Control, however, does not end with the solution of the presentation problem. As stated previously a programme cannot be expected to be received eagerly by the site who would then adhere rigidly to every planned activity for management to simply collect the rewards at the end.

The drafting of a programme is an academic exercise. The implementation of that programme is a dynamic progress which continues to completion of the project.

The site control on the project can be conveniently broken down and discussed under three categories, viz :

Foreman and staff
Sub-Contractors A
Sub-Contractors B

3.2.1 FOREMAN AND STAFF

All contact with site staff, i.e. artisans and labourers was made via the foreman.

Meetings were held weekly to discuss programme and costs. These meetings were quite distinct (and should be) from the normal site meetings at which more senior staff and the architects were present.

These meetings were specifically directed at discussing progress and costs and were generally (unless problems were encountered with sub-contractors) only attended by the writer and the foreman.

A vertical line would be drawn across the particular time and the activities and units to the left of that time were discussed. For any activity behind time corrective action would be discussed and formulated.

At the same time, the next few weeks ahead would be considered and a note made of sub-contractors to be notified and manufacturers required to deliver. These were merely notifications to commence work or instructions to deliver as all sub-contracts and orders had been placed at an early stage.

Labour strengths compared to that allowed were discussed and all shortages reported to ensure that the flow of work was maintained.

These meetings proved to be the essence of the control. Unlike the general site meeting which was more formal with the typical nature of people having to rush off, problems were discussed and solved immediately. Suppliers were phoned, design details queried and construction details sorted out.

Held on site, it was convenient to visit any section that required attention.

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Held on site, it was convenient to visit any section that required attention.

The discipline of the tedious process of going through each activity ensured that at least every unit got off to a good start and in this regard the temptation to allow less and less detail to be paid to the programme as the job proceeds is not to be recommended.

Referring to figure 1.5   t = 30 days, the first unit is completed while the tenth has not yet commenced. Is there any reason to believe that unit 10 during the execution of its some 50 activities is going to give a great degree less trouble than the first? Certainly output is likely to be higher because of the effect of the learning curve but not all problems are necessarily labour orientated.

It is tempting to believe that once the first unit is complete the rest of the units will 'build themselves'.

So far as construction details go, yes, but as far as the day to day activities are concerned, these meetings and the discipline of going through the units stage by stage should remain until completion of the job.

It is the writer's experience that once a job starts falling behind programme, the less the foreman is reminded of a programme the better it suits him and he ends up doing the job his way. If this was to be, then the money spent on the original programme was wasted.

3.2.2 SUB-CONTRACTORS A

Under this heading are included those sub-contractors of a reasonable standing and generally include the plumber, electrician, plant hire companies, etc. The reason for the distinction will become clear as the discussion of the two types proceeds.
The handling of this category is in two stages. The first bein[illegible] in the contract as possible to ens[illegible] orders are placed for materials. How often has the excuse been given by the plumber for lack of output that he cannot get cast iron piping or storm water piping? This must be avoided and minutes of all discussions regarding deliveries and starting dates should be kept in the company files.

The site monitoring of their progress is much the same as described in 3.2.1 regarding the foreman except that in this case it is not necessary to include every sub-contractor at every meeting. Typically, he will attend the first few and then gradually his attendance will taper off.

It is, however, essential for him to be present at all meetings when the work commences as this will determine his modis operandi for the rest of the contract. It must be made clear to him that he cannot wait until four flats are ready for him but that only one can be fixed at a time.

They must also be made aware that they will be required to work in different sections of the job at the same time and must fully understand the implication of any extension of their planned activity .

Generally, these larger sub-contractors did not give much trouble and their comments at meetings were limited to the usual instances of where they were being held up, etc.

It is important, however, to encourage discussion on service route layout to consider all possible clashes which could delay the project at a later stage. These are not often apparent from the architects drawings.

He is expected to give warning of any likely material shortages and problems.

SUB-CONTRACTORS B

Under these are included the many small firms or partnerships generally owned by Portuguese tradesmen and performing such functions as bricklaying, plastering, painting, floor finishes, etc.

Control of this group has different problems than that of the two previously discussed. These problems arise mainly because of communication problems and the level of education or development is not as high as the previous cases.

In the case of the majority of these people, it is useless to invite them to a formal meeting. They tend to agree to everything discussed and then go off and do the opposite as they understood nothing of what was discussed but were afraid to say so.

Their firms are typically under capitalised and they tend to follow a rate of output which earns them a living only and it is difficult to make them realise that their output is determined by the contractor and not themselves.

These were handled on a more informal basis than the type A sub-contractor. Whenever the foreman had trouble, the relevant sub-contractor would be called in and the problem solved on an informal basis.

Control of this group can be divided into three categories :

Quality Control
Output Control
Draw Control

Under Quality Control, there is basically only one solution. Their work must be carefully checked and where the quality is unacceptable, the work is broken down and repaired at the sub-contractor's expense.

Output control is probably the most difficult as the sub-contractor also suffers from the inherent artisan shortage. Furthermore, the more men he has on a job the more he has to control and the more dispute he has with them in terms of wages and working hours. He, therefore, tends to keep the minimum number possible on the job and any request by the contractor to get more men is met by the statement that he cannot.

The problem is that not much can be done about it if the contract is already underway for he is entitled to a draw on completed work less say a 10% retention. Provided his draw covers his weekly cost with an amount for himself he is reluctant to increase his own risk.

One way to avoid this is to write his activity durations into his contract document with a penalty for non-performance.

The number of bricklayers required can be calculated from the programme and thus embodied in his document. Whatever the system, however, it must be made to form part of his contract document.

Again control must be continuous and any lack of output must not be allowed to go unnoticed.

The control of draws is perhaps the only real hold on this class of sub-contractor.

It is essential that he be paid no more than for work actually carried out less a reasonable retention. (By reasonable is meant reasonable to the main contractor not the sub-contractor). The reason for this is that should he have underpriced the work or should he be instructed to repair defective work or even, should he find a more lucrative contract, and, he is well drawn up on the job, he is likely to disappear. This, in turn, results in loss of production on the contract and the expense of having to employ another contractor to complete the work who, realising the predicament, loads his price.

This occurrence is not exaggerated and has been found to occur in a number of cases.

Legal action is generally not worth the time and the money.

One solution is to stipulate his retention in his contract and then measure his work carefully before paying him his weekly draw.

These three aspects again require control throughout the contract and not merely at the beginning.

3.3 SUPPLIERS AND MANUFACTURERS

The method requires a flow of work from unit to unit and as such any delay in the delivery of items such as window and door frames, kitchen units and joinery items results in serious bottlenecks.

The effect of this snowballs as sub-contractors tend to move their men to other jobs and when the item causing the delay finally is solved there is invariably a lapse of time before the sub-contractors can be brought back onto site.

On a similar block with the same company the entire ground floor of 16 units had been completed before the window frames arrived in spite of these having been ordered some three months ahead of requirements.

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On a similar block with the same company the entire ground floor of 16 units had been completed before the window frames arrived in spite of these having been ordered some three months ahead of requirements.

The manufacturer claimed that he had been instructed by the company to give preference to another job and consequently the work had not been scheduled for delivery until some time later. This claim he did not have in writing but nevertheless it would not be worth doing anything more than cutting the offending company from the order book. The cliche 'prevention is better than cure' is most appropriate.

It must be stressed that these problems have more severe consequences on contracts programmed by the line of balance method. This is because line of balance is not just another programming tool such as a bar chart or critical path but rather a concept of arranging the work to utilise the repetitive nature of operations which must result in savings in time and reduced cost because of the higher output.

To illustrate, consider two systems transferring electrical power from a power station to a city.

If a multi cable system is used the voltage drop will probably be higher due to the increased resistance ($r \propto \frac{1}{A}$). But if an earthmoving contractor rips up a cable only part of the system is put out of commission.

If a single cable system were used the voltage drop would be less but the same earthmoving contractor could, with a similar effort, cause the whole system to fail.

The method was found to be of great assistance in fixing delivery dates for suppliers.
Once an order had been finalised the system of delivery would be discussed. A system is essential as, say, with kitchen units. These were required over a period of 16 weeks.
Site storage did not permit delivery of all 16 kitchen sets and the manufacturer was loathe to deliver 1 set per week for 16 weeks. The arrangement was, therefore, that he deliver 4 kitchen units every month.

This must be written into his order or communicated by registered post.

Similarly with roof tiles, frames, joinery fittings, sanitary fittings and others could schedules be swiftly compiled and then given to manufacturers who could plan their own production to meet the requirements.

A delivery schedule can be given to site and it becomes the foreman's responsibility to see that the goods arrive on site and any problems he has should be discussed at the weekly meetings.

As stated before however control does not end with the issuing of schedules. These must be followed up for the duration of the contract.

A good system is to phone or write to the manufacturer a week or two in advance to confirm that delivery is required. Should there be any problem at that stage it would be more feasible to move men around to avert a crisis than if a delay was only discovered when delivery was expected.

It has generally been found that manufacturers are loathe to advise in advance of an expected delay. It seems as if they prefer to keep quiet hoping that something will crop up to relieve them of their predicament.

Not all materials and services are going to arrive on site on time but by effective control the effect of these delays can be minimised and the contract adhered more closely to the programme.

CHAPTER FOUR : CONTRACT PERFORMANCE COMPARED WITH PROGRAMME AND CONCLUSIONS

This is the most significant part of this report for the foregoing would be meaningless without a statement of performance. And a statement of performance would be meaningless if it were merely a factual statement of finishing times compared to planned finishing times.

This statement would suit the layman whose only concern is if the job finished on time or not and if not, then the system would be considered useless.

The professional requires more than a mere factual statement. He requires analysis of conditions which may have caused overruns and uses this analysis to build for the future. This analysis must be objective which can be difficult under certain circumstances.

Consider the statement ' we have tried critical path/line of balance/computer reporting but found it did not work'.

This statement has been heard by the writer in work situations, at informal discussion and seminars. The statement as such is completely meaningless as it does not convey anymore than an abortive attempt to apply a planning technique.

What would be significant would be information on how skilled the compiler of the programme was, how much control was envisaged during its implementation and a very important question of how would the job have fared had the method not been used.

This is perhaps the most difficult question to answer, yet it is the only way to convince the layman that a method works. To prove the point however, one would have to take two very similar projects, let them run on exactly the same resources and see who finishes first. Obviously, a fair degree of bias would creep in and the exercise would break down.

The problem in answering the question is complicated because the planning method attempts to eliminate and control those factors which could adversely affect the completion of the project. The question becomes one of an attempt to speculate on what could have gone wrong had the particular method not been applied.

The factual statement of performance against programme is that the flats themselves were to be completed by the end of September and the whole scheme handed over by the end of the year recess in mid-December.

This did not occur. The items included in the Line of Balance diagram (refer diagram page 26) overran by a total of four weeks or 16%. External works, however, were not subject to any disturbance and, as work proceeded as programmed, the overall project was completed on schedule, i.e. by the December recess. Limited maintenance and final clearing around the East end of the site was completed within two weeks of the new year.

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4.1 PERSONAL REACTIONS

Perhaps the most difficult task the young graduate has in introducing a technique is to overcome the reactions of persons with whom he will be dealing. The reactions on this project were no different.

Management was sceptical and sub-contractors who had been working with the firm since it started (i.e. Type A sub-contractors) even more so. It was, indeed, embarrassing to be told by the plumber in front of the foreman and electrician to use the network as toilet paper (and not in such mild tones either).

The reaction of the foreman was encouraging. A youngish Englishman who was then studying part time at a technical college and who had been introduced to critical path scheduling. He was keen to adopt a scientific approach to the work and was always enthusiastic at meetings and discussions on the programme. If his interest did waive towards the end then it is the fault of the compiler for not maintaining interest.

Once again the importance of carrying through until the end must be stressed for if the men on site lose enthusiasm then who will carry the programme through to completion.

In this case, enthusiasm (in the programme not the work itself) was lost because the job fell behind programme for reasons indicated later in this section.

The remedy is simple. Once a programme loses its effectiveness by being out of date, it must be re-drawn to suit the existing circumstances. One cannot expect to have the foresight to anticipate every problem over the life of the project. Re-drawing a programme is not admitting defeat, and, even if it is an admission of incorrect assumptions, then it is still better to start afresh and continue with a programme which is not the case if the original programme is so out of date that it is ignored by all who find it convenient to do so.

This admission in re-drafting a programme is at least ensuring that the remainder of the work is programmed.

This reasoning has led to the writer's belief that structural work on large projects should be programmed on a monthly basis as discussed in chapter two.

The project manager of a large contract in Johannesburg joked about the fact that a competitor chose to re-draw his programme every time it fell behind, which, admittedly was quite frequently. The competitor could perhaps be critised for his optimistic assumptions but he at least deserved credit for analysing the situation frequently, admitting his mistakes and thereby holding the interest of his staff who were after all executing the work.

Tommy Armour the great American golfer (born a Scot) who has been labelled the greatest golf

t. cher of all time has this advice for the golfer :

+'When you miss a shot, never think of what you did wrong. Come up to the next shot thinking of what you must do right'.

While the analytical approach is essential in evaluating a system, the day to day running of site operations must be with an eye to the future if it is to maintain the effectiveness for which it was intended.

The attitudes of sub-contractors improved as the contract proceeded.

This was largely due to the fact that they realised that it was advantageous to the running

+ Armour T., How to play your best golf all the time, Hodder Paper backs Ltd., London, 1972.

of their own businesses to know that they were required on the site on certain days of the week and not others even though this was against their normal method of working where they required a reasonable production run.

From their performance and attitudes it was obvious that a fair degree of coordination between themselves and the foreman had been done and very few instances of their not being on site when required were recorded.

It is difficult to comment on the reaction from management. Perhaps all that can be said is that the writer was assigned to the task of completing the scheme in a reasonable time period at a cost equal to or better than that budgeted for. Neither of these drew a negative response from management and it must be assumed that from their point of view the contract was a success.

If management believes that t [illegible] ect would have been equally successful without these methods then there must be the qualification that the work would have been controlled by a more experienced individual.

The graduate has not experience to offer. But he has a trained mind with which to evaluate and apply techniques that are available to him and if he is not given the opportunity to develop these techniques to suit the company's requirements then it is better to employ a more experienced man and continue with more established procedures.

4.2 DESIGN CHANGES

The importance of analysing the programme in terms of the rate of building and the effect on resources has been discussed at length in Section Two.

After construction and analysis of the original programme a major change was made in that the fair-face work externally was changed to a rock-face finish using a brick that because of its irregular shape proved more time consuming to lay than a normal face brick.

Instead of recalculating the relevant activity times, the assumption was made that the sub-contractor would have to employ more men to compensate for his lower output. This was in fact discussed with him and he agreed that it was possible.

This assumption proved to be the major cause of the overrun for it was the only trade which could not maintain the rate. The result was a systematic slippage which disrupted the natural rhythm of the following activities.

The correct procedure would have been to recalculate the activity time then applying a resource multiplication factor to bring the natural rhythm in line with the rest of the programme. If this factor was unrealistic then it should have been adjusted so as to coincide as closely as was feasible and the start of subsequent activities delayed so avoiding the bottlenecks which did in fact occur.

This principle is illustrated in figures 4.1, 4.2 and 4.3. In 4.1 all activities are programmed to a natural rhythm of one per week. All resources are fully utilised and there is no idle time. Each activity requires only one resource unit.

In figures 4.2 and 4.3 the duration of activity two has increased to three weeks instead of one.

The programme can be adjusted in two ways.

In figure 4.2 the resources on activity 2 have been trebled and the result is that the programme is extended only by the additional time for activity two, i.e. 2 weeks.

In figure 4.3 activity two is programmed at its new natural rhythm. The subsequent activities are delayed so as to eliminate bottlenecks and the overrun is now 17 weeks.

This is basically what occurred on the project.

The solution in 4.2 was impossible because of the sub-contractor being reluctant or unable to obtain the required number of bricklayers. The result was slippage which took the form of a new natural rhythm as in 4.3 and an overrun on the contract. It might be argued that a sub-contractor should not determine the pace of construction but in this case he was building two other blocks for the company which were contracts with a specific completion date and could not be delayed.

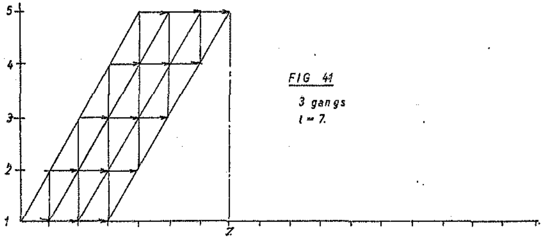


FIG 4.1

3 gangs

t = 7.

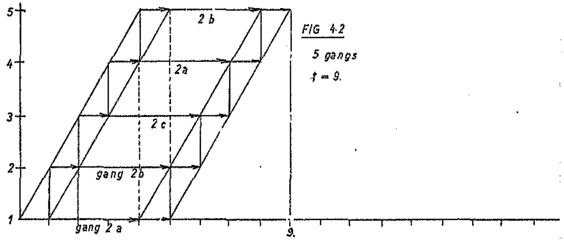


FIG 4.2

5 gangs

t = 9.

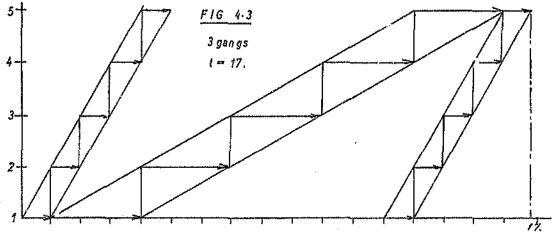


FIG 4.3

3 gangs

t = 17.

He was then employing about 10 bricklayers which was *about all he could control*. Furthermore, the nature of the work was such that to have placed any more men on the project would have caused the law of diminishing returns to take effect. To maintain the rate would have required nearly *double the amount* of bricklayers which would have been impossible to accommodate.

The change in natural rhythm affected mainly those activities occurring after the *slab was cast*.+ This occurred because the slab was supported by the lateral walls which were mainly constructed of stock bricks as opposed to the more labour consuming rockface bricks. (+Activity 17-18, Figure 1.3).

The painter and plasterer were forced to leave site for a short period. The Company's own labour was not similarly affected as the roofing crew (gang no. 5, Chapter 1) were *utilized* in formwork to columns and beams on the extreme east of the site. This formwork occurred due to the sharp drop in the site at this point which necessitated structural foundations. Gang no. 6 (page 37) was *utilized in clearing* and removal of rubble with gang no. 1.

There were other minor design changes. A balcony was added to the master bedroom on the *first floor*. The effect of this was negligible compared to the delay caused by brickwork and was not taken into account.

4.3 GENERAL

Problems were also encountered with foundations and extra blasting had to be done to reduce levels.

It was apparent from the outset that the east end of the site would give problems. Rock outcrops on the one side and a sharp fall on the other. For this reason building work was commenced in the centre, i.e. on unit number 8 and continued to unit number 1 at the west end. Unit number 12 would then start working up the slope to number 9 and finally 16 to 13. The system of working up the slope (each unit had a difference in F.F.C. of about 350 mm) was to facilitate the erection of the floor slabs.

It was intended that while the foundation work was being completed on units 8 - 1, the problems on the east site 12 - 9, 16 - 13 would be overcome. This was not to be the case as resources were fully employed on units 8 - 1 and to overcome the problems with rock and the slope would have required the employment of additional labour.

As a result, a delay occurred due to the rock and structural foundation which had to be constructed.

This could have been overcome if a stage buffer had been written into the programme after the activity 'foundation excavation'. This would have allowed for an overrun and the programme would have retained its effectiveness all other things being equal.

It would probably have been even more effective to regard foundatio as a 'stage' (as in the cash flow calculation) and ·serted a buffer between that and the rest of the wo.

The writer suggests this as standard procedure as foundations are generally unpredictable. Unforeseen blasting or compacting in large volumes to say, 90% on a Procter scale can seriously effect progress and are typically tedious and time consuming operations. A buffer is a simple and effective means of overcoming this problem even though it may appear to be giving the site 'leeway'. The point is that if the buffer was not required once that stage had been passed, the time scale on the programme can simply be adjusted to take into account the new condition.

Other problems were of so minor a nature as not to warrant discussion with the exception of purchasers' requirements. This was not a real problem on this contract mainly because the company adopted a policy that purchasers must take what they get. It is mentioned, however, as this can be a problem if purchasers are allowed a free hand in deciding how the unit must be altered to suit their individual tastes.

This is difficult to programme and each flat must be taken as a separate unit and the alterations carried out with the stipulation that it will cause a delay in the hand-over date and naturally the company must cover itself more than adequately price-wise. The rates applicable to these changes cannot be the same as the original estimate rates as firstly the work tends to be costly and secondly, the resources are being employed on work at the expense of say another scheme where the output and return would be higher. This occurs mainly because the supervision must be more effective to avoid damage to existing work and the cost of this supervision will be high in relation to the return on the work.

The policy of 'take what you get'is the most convenient and only two purchasers succeeded in having alterations done and both of these were architects.

The effect of site morale is adverse as men do not enjoy altering work already completed. Apathy reigns and the cost tends to be high.

The line of balance method is a new concept in planning in South Africa.

At the moment it is suffering from the same inertia which took critical path scheduling so long to become part of the planning process in this country.

It is significant that in the writer's three years of post graduate study with the Department of Mechanical Engineering, the critical path method and operations research techniques such as decision theory, linear programming and statistical methods were covered in detail while only a brief mention was made of the line of balance method.

Yet since its introduction in Great Britain cost savings that would enable the output of houses to be increased by 10 - 20% with the same input have been reported.

The lack of interest in the method could perhaps be attributed to the modis operandi of the local housing industry where a great deal of the skilled operation, such as brickwork, plastering and joinery have been sub-contracted out leaving the main contractor with a largely unskilled labour force under his direct control.

This labour force in turn is of a far lower cost than would be the case in England and their effective utilisation tends to be overlooked.

The earnings differential, however, is tending to close. At the time this project was undertaken the minimum wage paid to labourers was gazetted at

24 cents per hour. At the moment it is 41 cents with a further increase due in November which will put the minimum in the region of 46 cents per hour - nearly double that of three years ago.

The current economic climate has caused a slight recession in the housing market. But this is mainly in the middle to upper income groups and cannot cloud the real issue that there is a considerable shortage of housing particularly for the lower income groups.

Immigration policies and apprentice training will not be able to keep pace with the industry's requirements. Faced with increasing costs of labour, a shortage of housing and lack of skills the industry has no alternative but to consider better means of utilising the resources available.

The success of the method in Great Britain cannot be ignored.

The description of the method in this report and analysis that can be applied as shown in chapter two indicate that it is a simple method which can supply a great deal of information fairly rapidly.

Although the full benefit could not be obtained on this project, mainly because of the structure of the labour force and the extensive use of sub-contractors, the application has been a success and a great deal has been achieved in fully understanding the working of the method.

It is the writer's opinion that the use of the method will increase albeit slowly. It is felt that local research institutions should follow the example of the National Building Agency in Great Britain and assist in educating industry in the understanding and benefits of the method.

BIBLIOGRAPHY

Archibald, R. & Villoria, R. — Network based Management Systems (P.E.R.T./C.P.M.), John Wiley & Sons Inc., London, 1967.

Beech, E.F.L. — Construction Management in Principle and Practice, Management Study Series, Londman, London, 1971.

Burman, P.J. — Procedure Networks for Project Planning and Control, McGraw-Hill Publications, London, 1972.

Calvert, R.E. — Introduction to Building Management, Newnes-Butterworth, London, 1970.

Levin, R.I. and Kirkpatrick, C.A. — Planning and Control with P.E.R.T./C.P.M., McGraw-Hill Publications, New York, 1966.

Lock, D — Project Management, Gower Press, London, 1968.

Lumsden, P. — The Line of Balance Method, Pergamon Press Ltd., Exeter, 1968.

Miller, R.W. — Schedule, Cost and Profit Control with P.E.R.T., McGraw-Hill Publications, Inc., 1963.

Thornley, G. (Editor) — Critical Path Analysis in Practice : Collected Papers on Project Control, Travistock Publications, London, 1968.

PAPERS AND PUBLICATIONS

Nawrath, J. — Uber die Analyse und Steuerung eines gestörten Bauablaufs, Baubetriebswirtschaft Baurecht, Munich, 3/1967.

Nawrath, J. — Planung von Baustellen mit variablen Produktionsbedingungen, Baumaschine und Bautechnik, Munich, 1968.

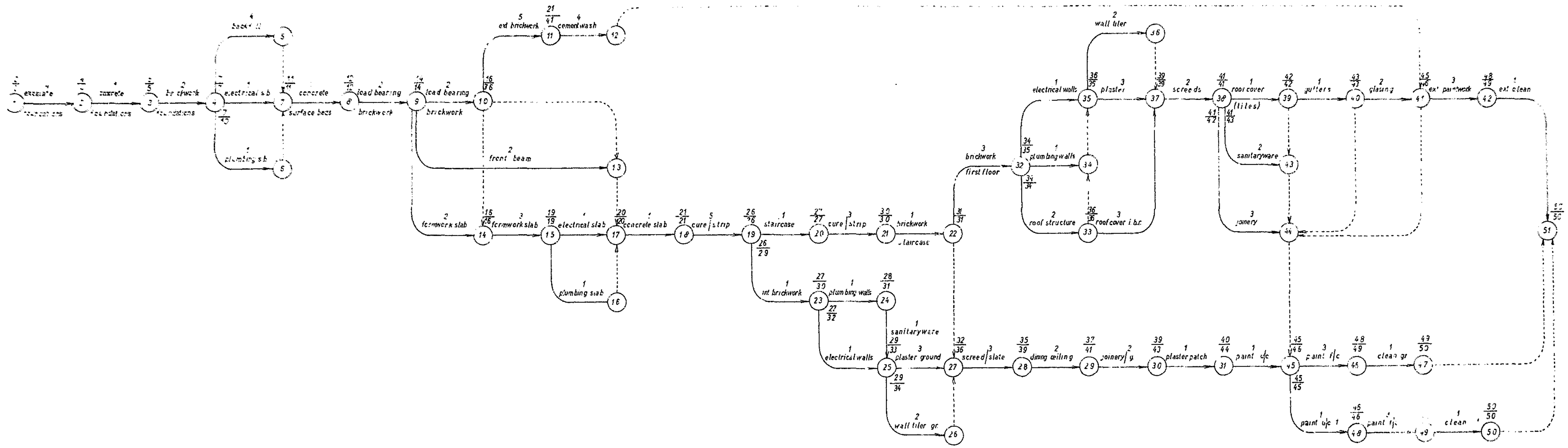
Dressler, J — Berücksichtigung stochastischer Ausgangsdaten in der Ablaufplanung von Linienbaustellen, Baumaschine und Bautechnik, Munich, 1972.

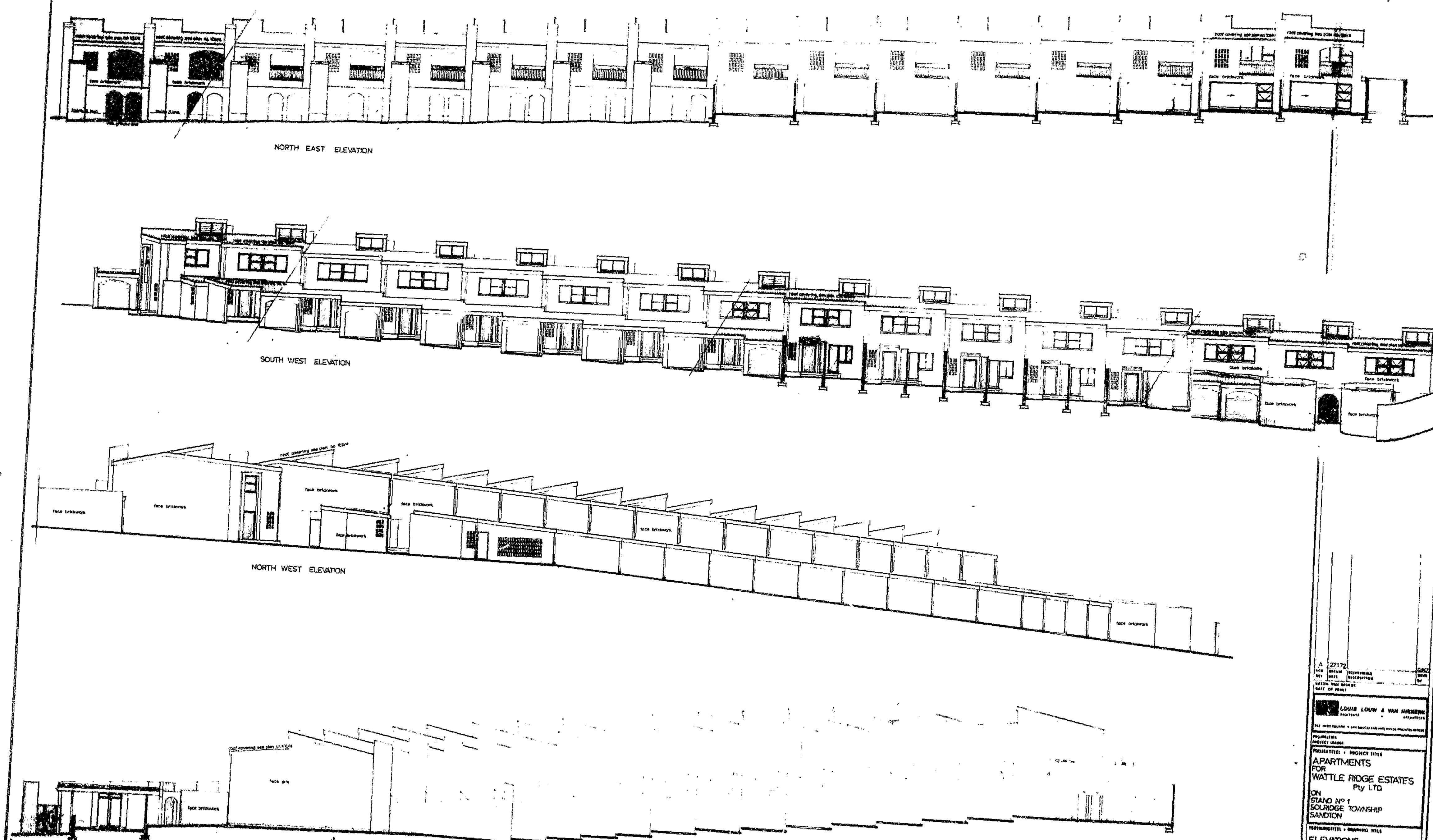
Steffen, U. — Ablaufplanung von Linienbaustellen mit veränderlichen Produktionsbedingungen unter dem Gesichtspunkt der Kostenminimierung, Baumaschine und Bautechnik, Munich, 1969.

BIBLIOGRAPHY (Continued)

Chan, W.W.	Line of Balance Charts, Contract Journal, London, May 16, 1968.
The National Building Agency	Programming House Building by Line of Balance, London, 1970
Khisty, C. J.	The application of the "Line of Balance" technique to the construction industry, U.S.A., July 1970.
Davey, A. J.	Course in Advanced Planning, University of the Witwatersrand, 1973.

FIGURE 4.3 NETWORK TYPICAL UNIT





NORTH EAST ELEVATION

SOUTH WEST ELEVATION

NORTH WEST ELEVATION

SOUTH EAST ELEVATION

A 27172

DATE

DESCRIPTION

DATE OF PRINT

LOUIS LOUW & VAN NIEKERK

ARCHITECTS

PROJECT LEADER

PROJEKTITEL · PROJECT TITLE

APARTMENTS
FOR
WATTLE RIDGE ESTATES
Pty LTD
ON
STAND Nº 1
SOLRIDGE TOWNSHIP
SANDTON

DRAWING TITLE

ELEVATIONS

SCALE 1/8" 1'0"

DATE 12.71

PROJECT Nº J 103

DRG. NO. 3

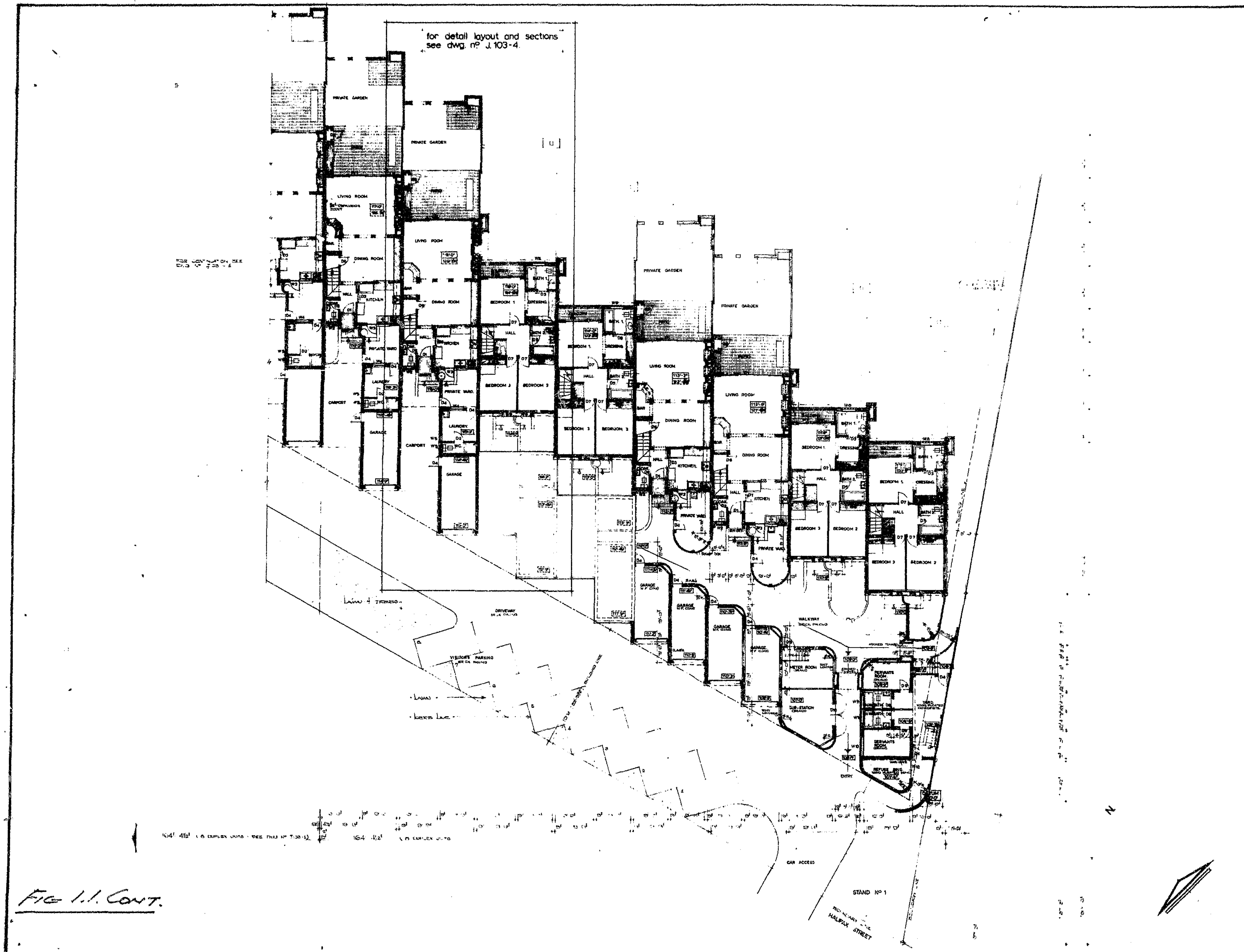


FIG 1.1. CONT.

ALL DIMENSION WITH POINTS TO BE CALCULATED

A 27172

LOUIS LOUW & VAN NIEKERK ARCHITECTS

APARTMENTS FOR WATTLE RIDGE ESTATES Pty LTD ON STAND Nº 1 SOLRIDGE TOWNSHIP SANDTON

PLAN

1/8" : 10'

J 103

2

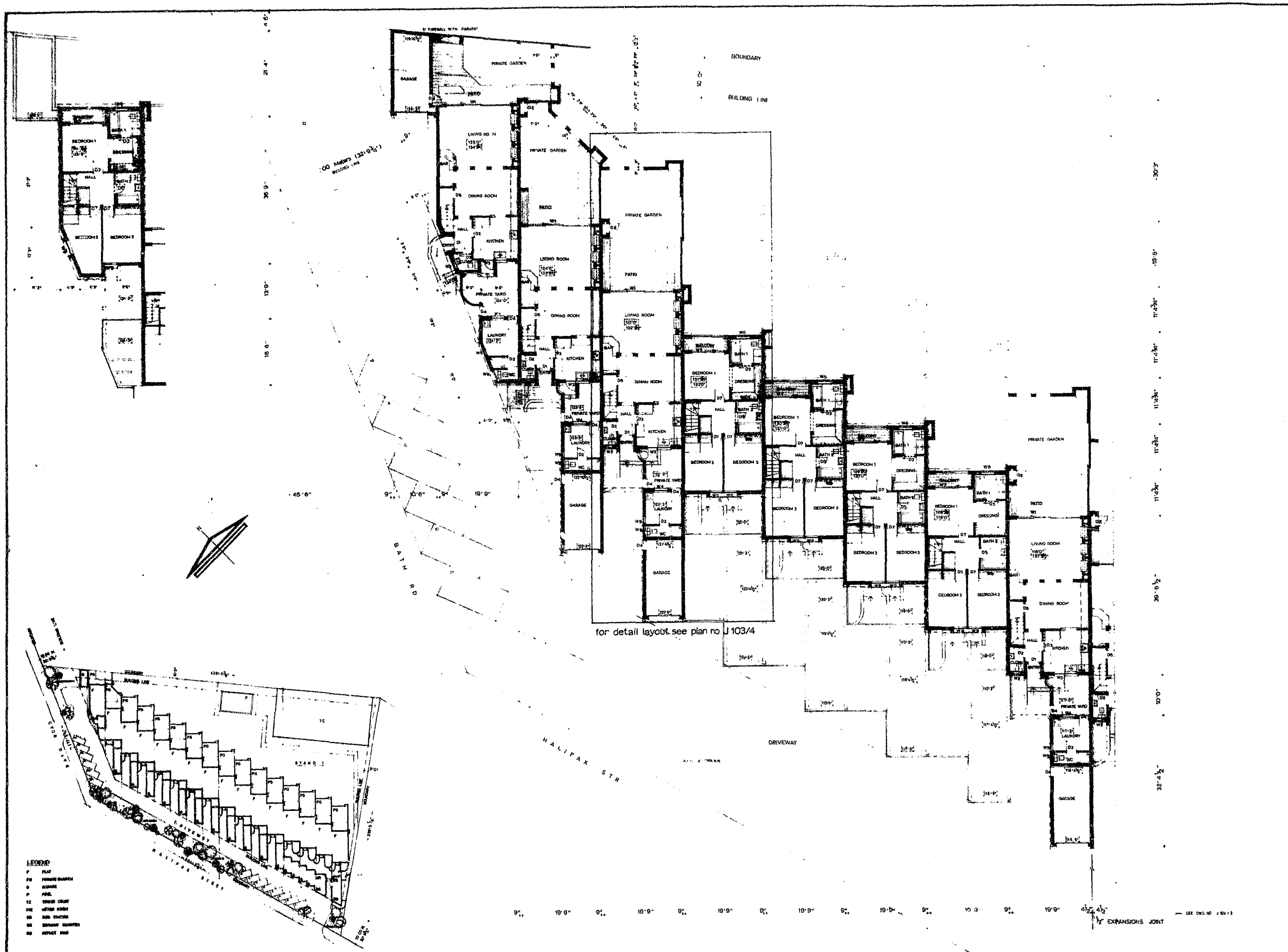


Fig 1.1. SITE PLAN

ALL DIMENSIONS WITH POINTS TO BE CALCULATED

LOUIS LOUW & VAN NIEKERK

APARTMENTS
FOR
WATTLE RIDGE ESTATES
Pty LTD
ON
STAND No 1
SOLRIDGE TOWNSHIP
SANDTON

PLAN
SITE PLAN

J 103 | 1

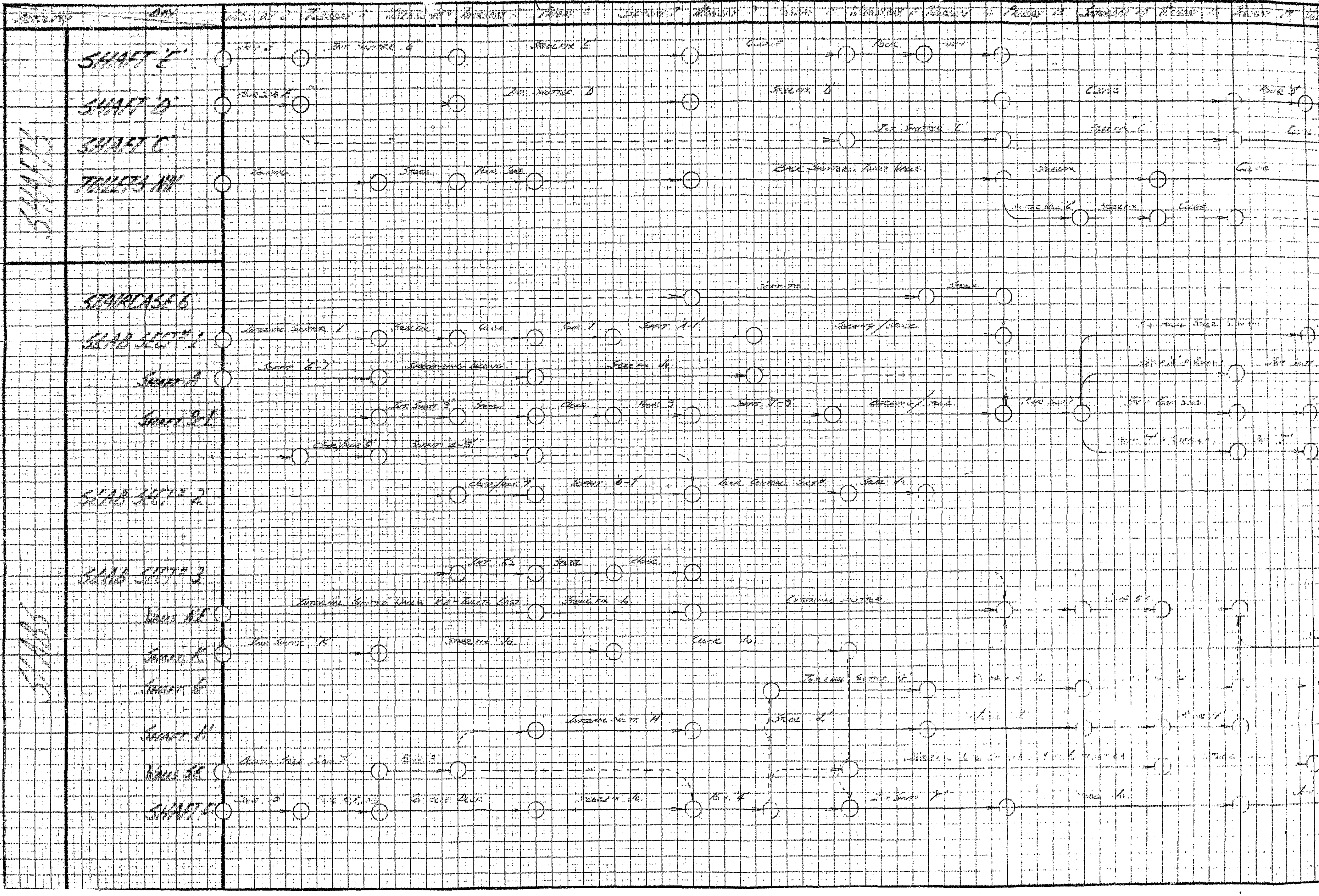
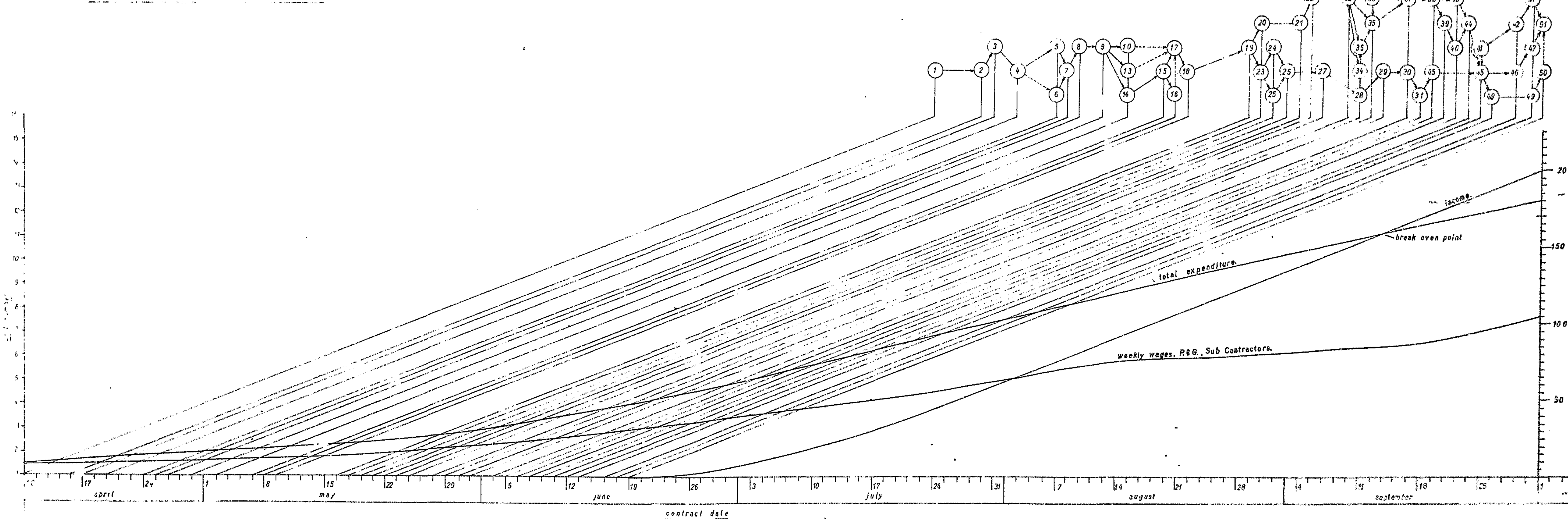
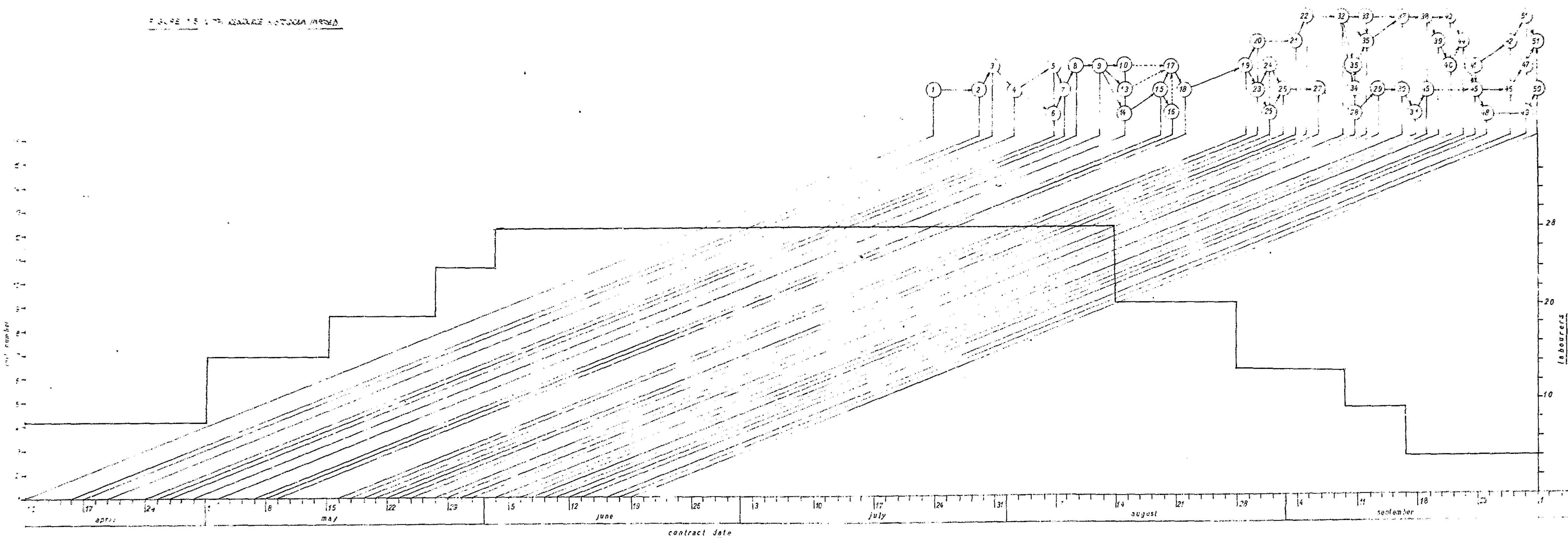
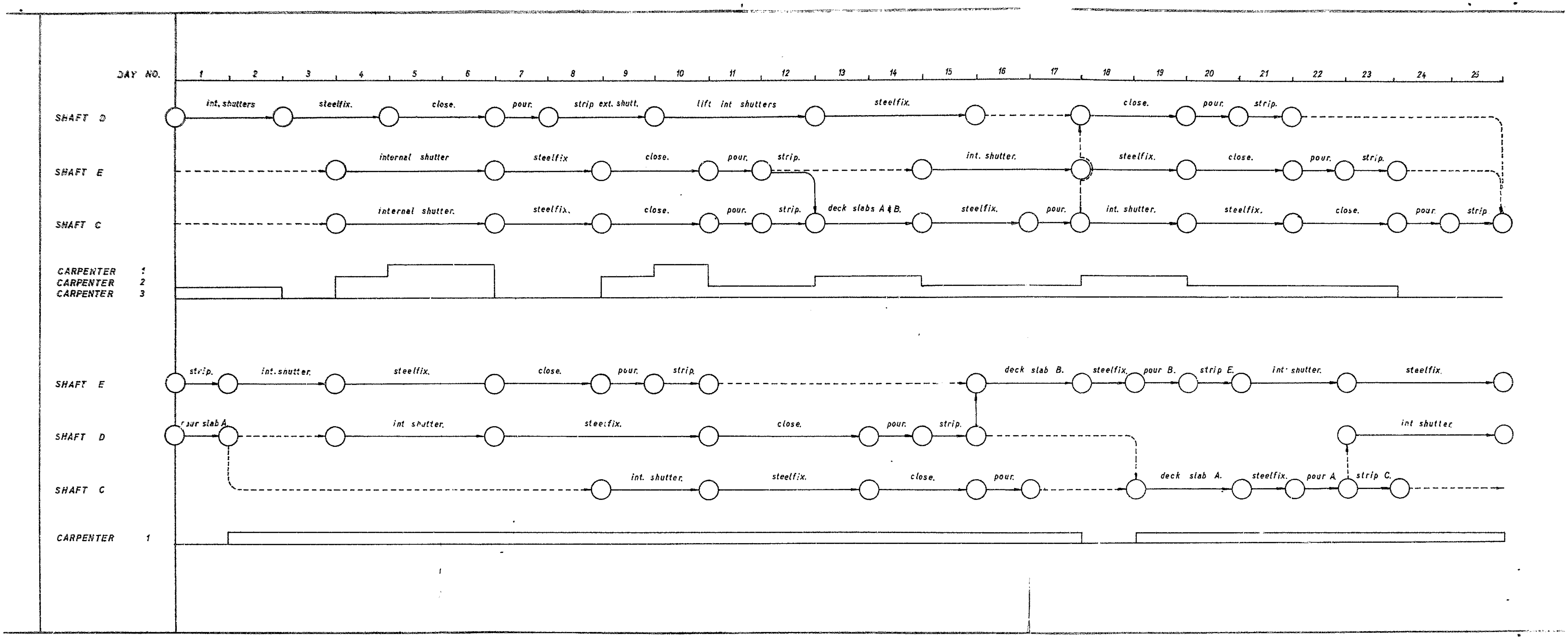

SHAFTS
SHAFT 'E'
SHAFT 'D'
SHAFT 'C'
TOILETS NW
STAIRCASE 6
SLABS
SLAB SECT 2
SLAB SECT 3

FIGURE 2.1.12. FIGURE 1.5 WITH CASH FLOW CURVES IMPOSED.





labourers
28
20
10
april
may
june
july
august
september
contract date



DAY NO.
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
SHAFT D
int. shutters
steelfix.
close.
pour.
strip ext. shutt.
lift int shutters
steelfix.
close.
pour.
strip.
SHAFT E
internal shutter
steelfix
close.
pour.
strip.
int. shutter.
steelfix.
close.
pour.
strip.
SHAFT C
internal shutter.
steelfix.
close.
pour.
strip.
deck slabs A & B.
steelfix.
pour.
int. shutter.
steelfix.
close.
pour.
strip
CARPENTER 1
CARPENTER 2
CARPENTER 3
SHAFT E
strip.
int. shutter.
steelfix.
close.
pour.
strip.
deck slab B.
steelfix.
pour B.
strip E.
int. shutter.
steelfix.
SHAFT D
pour slab A.
int shutter.
steelfix.
close.
pour.
strip.
int shutter.
SHAFT C
int. shutter.
steelfix.
close.
pour.
deck slab A.
steelfix.
pour A.
strip C.
CARPENTER 1

FIGURE 15 LINE OF BALANCE PROGRAMME