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MODELLING AND DESIGN OF CONSTRUCTION PROCESSES

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MODELLING AND DESIGN OF CONSTRUTION PROCESSES AND OPERATIONS

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SYNOPSIS

The ever changing times bring in their wake the phenomena which effect human environment, lives, resources and behaviour. One of such phenomena is the ever increasing realization of and sensitivity to the human and equipment productivity. This realization in construction industry has of late, been driving the construction engineers to explore and find new ways and means for determining, anticipating, predicting, and increasing productivity of construction tools, both human and machinery.

In the recent past, mathematical modelling has become a handy tool for the analysis of some difficult problems, which required a long analysis procedure till very recently. Mathematical modelling opened new vistas of thought and some very powerful new models came into practice. One of these is the CYCLONE program developed by Prof. Daniel W. Halpin in the seventies. CYCLONE is the abbreviation of "CYCLIC OPERATIONS NETWORK". It is a very useful tool for determining/ predicting the productivity of a construction process that can be represented on a Cyclic network.

This paper presents an introduction to some of the more commonly used models and a somewhat detailed account of the more interesting, useful and effective model, the author considers the best i.e. "CYCLONE", and a few examples of its use including the actual computer analysis of a specific construction process operation, carried out during the research work as the part of a "Construction Engineering and Management Programme" at 'PURDUE' University, (U.S.A.) and verified on construction projects in the country. The "CYCLONE" Model holds a great promise and scope of applicability in the construction projects for improving process planning, productivity and financial control.

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Introduction

The modern Construction Industry- Senario

Modern society is becoming more technological in nature. Its needs are being met by an industry that is becoming more technical at a time when the time lag between scientific discovery and technical implementation is diminishing. Today we are being deluged with and are struggling to absorb the fruits of science and technology.

The demands, inventiveness, and consumption of an industrial society react heavily with a service industry like construction, and call for continuous development of new construction methods and new material handling and placement techniques as basic project needs. The equipment manufacturers are producing more and more general and special function equipment, even robots. Each new demand and situation requires the design and specification of new construction operations or the adaptation of existing methods to the specifics of the new problem.

The construction industry, however, has some unique features and structures that influence the current approach and practice to construction operations. In practice the in-depth design or analysis of a construction operation is rarely formally considered. It is either implicit in the adoption & modification of past methods or realistically solved by the Construction Agent/ Engineer in the field.

The Hierarchical Levels in Construction Management

Basically, the construction management has the following six major hierarchical levels of administration/ implementation.

- Organization - Project - Activity - Operation - Process - Work task.

These can be defined/ explained as under:

1. Organization- The organizational level is concerned with the legal and business structure of a firm, the various functional areas of management, and the interaction between head office and field agents performing these management functions.

2. Project- Project level concept of resources is defined and related to the activity as either an added descriptive attribute of the activity or for resource scheduling purposes.

3. An activity is a time and resource consumption element of a project normally defined for the purpose of time and cost control by a planner, estimator, scheduler, or cost engineer.

4. Operation and Process- The construction operation and process level is concerned with the details of how construction is performed. Generally a construction operation encompasses several distinct processes, each having its own technology and work task sequences. However, for simple single-process situations the terms are synonymous.

4 (a) A construction operation results in the placement of a definable piece of construction and has implicit in it some technological processes and work assignment structure.

4 (b) A construction process is defined as a unique collection of work tasks related to each other through a technological structure and sequence.

5. Task- The task level is concerned with the identification and assignment of elemental portions of work to field workers. A work task is the basic descriptive unit in construction practice and the basic building block of processes and operations.

The Need for Operation Analysis

Activity-oriented models do exist in construction management, but they do not address and are not responsive to the site manager's day-to-day problems regarding methods and resource commitment. Activity-oriented models that are expanded to handle resource levelling and allocation aspects of project management are projected at an upper-management level and across a time horizon of weeks or months.

Site managers need a method for modeling, analyzing, and establishing the correct design of construction operations that determines the proper quantity and sequencing of labour and equipment resources within the context of a selected field construction technology. This method must allow examination of the interaction of the committed resources to determine imbalance in resource utilization. A conceptual modeling format is required within which the site manager can "tinker" with these interactions until a smooth and productive process is achieved. This will allow the determination of system sensitivity to various policies adopted by the manager. Once the operations are designed, many criteria for evaluating performance become available. Standards of delay, idleness, and utilization can be established.

Traditionally, construction operation design has received little attention if any, in the construction industry. It has been generally accepted that construction operations and processes are unique and must be solved on the spot, using experience and engineering judgement. The concept of designing and analyzing processes before the actual construction operation commences has not gained much support. Industrial engineers confronted with more repetitive situations have given more consideration to the study of process design but such repetitive situations/processes are also common in construction project operations.

Historically, the construction industry has adopted a multilevel structure as an expedient in organizing its activities. From the construction company's viewpoint, this hierarchy begins at the foreman or junior engineer level and ascends to the President of the company.

Management viewpoints depend on the decision level and functional areas of responsibility of the manager involved in the problem under consideration. For instance, the foreman may be interested in the efficient use of crew and equipment for a given operation, while the project management is interested in levelling resources across the job and organizing supporting activities such as procurement and payroll. By contrast, the company President may be interested in labor and equipment utilization factors, cash flows, and capital investment ratios.

Top management is interested in broad project statements and gross time-cost profiles that allow comparison between actual and estimated progress of each project in the company's portfolio. At lower levels, interests focus on determination of equipment availability, suitability, and use for feasibility or efficiency analyses of project, activity, and operation technologies. At the field level, more attention is needed by the process and work task sequences of the construction operation itself.

Designing Construction Operations

In the planning phase of any construction operation, certain decisions and projections must be made about the intended development of the works, by considering a variety of scenarios that introduce the operation and resource capability in a given environment. Thus the construction manager thinks through the work task sequences associated with a given construction technology, establishes a feasible work plan, and assesses the adequacy of a source allocation to the operation. The resulting formulation of construction technology, work sequences, resource requirements, and management policies establishes the design details of the construction operation.

The Design Process

The design process is "the process of developing a plan that reduces a concept to a practical format for implementation". The design process for construction operations is characterized by a procedure consisting of four major activities.

1. The development of a feasible plan.
2. The equipment and labor selection process.
3. The development of management policies.
4. The monotoring and evaluatiuon of the construction operation performance relative to the efficient use of resources and management goals.

The development of a feasible plan for a construction operation requires the selection of a suitable construction technology and the definition of the work tasks and processes that must be performed according to the technological logic.

Modelling Viewpoints

The fact that construction management is hierarchical in nature, focuses on different problems, and requires that varying types of models and levels of information must be emphasized. The modelling viewpoint is, therefore, a function of the hierarchial level of the manager, the decision process, management function to be served by the model, and the project time horizon.

A number of modelling tools have been specifically developed or proposed for the construction management area. These include the networking techniques of the critical path method (CPM) with its many variants and computer-based information system. Certain modelling tools have been borrowed from other management fields and adapted to the construction environment. Typical examples are the GANTT or Bar Charts, originally developed for the industrial process area and now commonly used in construction. A statement depicting various aspects of different modelling viewpoints appears as Table-1.

Conceptual Models

A model is a representation of real-world situation and usually provides a framework within which an investigation and/or analysis of a specific situation can be made. Models portray data about a situation, which on interpretation according to certain rules or conventions, provide information relevant to pertinent decision processes.

Table - 1

Modelling View Points

Project Life Stage	Management Function: Planning	Scheduling	Directing (Actual Field Operations)	Reporting
Project definition	Preplanning technology modesl Estimating models Multiple activity charts Budget models	Resource availability Resource-use-time models	Site investigations Labor availability and attitude models	Bidding models Rise and fall models
Project initiation	Equipment allocation models Site layout	Procurement Inventory	Expediting access models Priority models	Reassessment of adequacy of site reasources, access and constraints
Project implementation	Work order models Crew compositions Productivity models	Crane and hoist use Schedule charts Delivery models Inventory models	Work order Crew assignments Work face layout models Labor relations	Status reports Time and cost reports Work sampling Delivery
Project completion	Contract time Project duration Risk models	Change order and variation impact models	Strategy models for settlement of claims and disputes	Predicted completion date Final budget Project summary Hisotrical data

Adopted from (7)

Models may be physical or conceptual. Physical models normally being scale models are often used in the preplan analysis of industrial projects. Conceptual models are abstractions of reality and are not intuitive to the uninstructed observer. Conceptual models are developed on a set of modeling and interpretive rules. Network models and bar charts, for example, are conceptual models that have their own individual modeling and interpretive rules. Schematic models are representations that, to some extent, portray a physical situation, so that a physical modeling reaction or perception is induced in the user through conceptualizing of the situation. Exploded drawings of a physical facility can be considered to be schematic models.

Model Categories

The main categories into which the conceptual models for construction process/operation productivity measurement and analysis can be grouped are : -

1. Deterministic Models

(a) Field Estimation Models.

(b) Theoretical Models using deterministic time and other resource attributes.

2. Simulation Models

The Field Estimation Models rely mainly on the field observations and estimates for productivity and involve only basic arithmatic. These models though not very reliable in terms of accuracy, and unrestricted applicability, can be effectively used by construction personnel of any level and do give a useful output for the benefit of the construction Manager and the Project. These are specially suited for small construction jobs and low resource managements. Some of these are : -

(a) Work Sampling.

(b) Time Rating.

(c) Delay Surveys.

(d) Questionaire Surveys etc.

(e) Time lapse photography and

(f) Crew Balance Charts.

The theoretical/mathematical models using no simulation techniques, require a good working knowledge of Mathematics and also computers in some cases, in addition to field observation programme and statistical data/record. These are more reliable and yield better results, but are expensive and require special study groups and thus more resources. These can be employed with reasonable accuracy and success on all jobs by medium resources establishments and include : -

(a) Line of Balance Models.

(b) Queuing/Markovian Models.

(c) Production Function Models.

(d) Learning Curves.

(e) Motion Analysis.

(f) Method Productivity Delay Model.

(g) Linear Programming.

(h) Dynamic Programming and

(i) Regression Analysis.

The simulation models as the name indicates, use simulation techniques to represent the process or operations under analysis, with the help of suitable net works both manually and through computers.

The manual processing takes a lot of time and is very cumbersome. This fact necessitated the development of various computer programmes for "Mainframes" and "Micros" both. The major programmes so developed and having attracted the attention of construction Industry are : -

(a) CONSTRUCTO (A forerunner of CYCLONE and Successor of "CONSTRUCTION MANAGEMENT GAMES" Ignored), 1970.

(b) CYCLONE (CYCLIC OPERATIONS NETWORKS) FOR MAINFRAMES. - 1972 - 74.

(c) MICRO-CYCLONE (CYCLONE Version

for Micro-Computers) - 1983 - 1986.

(d) SIREN (SIMULATION OF REPETITIVE NET WORKS) - 1985.

(e) INSIGHT (INTERACTIVE SIMULATION USING

GRAPHICS TECHNIQUES). - 1987

A brief introduction to some more commonly used models is presented in the following paragraphs:-

1. Line of Balance Models

Line of Balance modeling is a graphical method for productivity control and is basically derived from bar charting. It focuses on the planned verses actual progress for individual activities and provides a visual display depicting difference between the two enabling the management to achieve proper allocation of resources. Originated during World War-II, this technique was recognised in 1962, and is useful for construction planning of many repetitive processes.

Line of Balance (LOB) Models serve two fundamental purposes. The first is to control production and the second is to act as a project management aid. Each of these are interrelated through development and analysis of four LOB elements which provide the basis for progress study on critical operations. The four elements are :

(1) The Objective Chart

(2) The Program Chart

(3) The Progress Chart

(4) The Comparison

1. The Objective Chart shows cumulative number of units to be produced over a time period through a production Vs time graph. A typical objective chart is shown in Figure-1-(a).

2. The Program Chart is the basic unit of the LOB system. It is a flow process chart of all major activities, presenting their planned, sequenced interrelationships on a "lead time" basis. The development of program chart comprises the following three processes:-

1. The determination of operations to be performed.

2. The determination of the sequence of operations.

3. The determination of the processing & assembly lead time.

The program chart shown in Fig.1-(b) exhibits the production process for the 240 units mentioned in the objective chart. Each activity (A through E) has a lead time (latest start time) signified by an event starting symbol (□) and an event coordination symbol (▽) signifying its end or completion. These event coordination symbol are referred to as progress monitoring points and are labelled from top to botton and from left to right. All five activities must be completed before one unit can be ready for delivery. This takes 30 working days as shown on the program chart's lead time scale.

3. **The Progress Chart** is drawn to the same vertical scale as the objective chart with horizontal axis correspond to the progress monitoring points levelled in chronological order. Vertical bars represent the cumulative progress or status of actual perfomance at each monitoring point, usually based on a site inventory.

The progress chart in Fig. 1-(c)indicates that on a given day when inventory was taken, 120 units had passed through monitoring point # 5, or completed. This corresponds to activity E in the program chart which is the last activity in the production process.

4. **The Comparison** The objective, program, and progress charts are utilized to draw the LOB by projecting certain points from the objective chart to the progress chart. This results in a stepped line graph indicating the number of units which must be available at each monitoring point for progress to remain consistant with the objective. Figure-2 indicates the LOB and the method used to project it from the objective chart to the progress chart.

The procedure for striking the Line of Balance is :

(a) Plot the balance quantity for each control point, starting with the study date on the horizontal axis of the cumulative delivery (objective) chart. Mark off to the right number of working days (or weeks or months, as appropriate) of lead time for that control point. This information is obtained from the program chart.

(b) Draw a vertical line from that point on the horizontal axis to the cumulative objective curve.

(c) From that point draw a horizontal line to the corresponding bar on the progress chart. This is the quantity of Balance for that bar.

(d) Join the quantities of Balance to form one stair-case type line.

Analysis of the LOB reveals activities # 2 and # 5 are right on schedule while activities # 3 and # 4 show deficit units. Activity # 1 shows surplus. This surplus is the difference between the 180 units actually completed by activity # 1 and the 157 units indicated as necessary by the LOB. On the other hand, activities # 3 and # 4 are lagging by 5 and 15 units respectively.

The LOB display enables management to begin corrective action on activities # 3 and # 4 to ensure they do not impede the production rate of the remaining units.

Uses of LOB

As described above an LOB can be drawn for any day of project construction for either start or completion of activities and can be used for:-

(1) Comparison of required versus actual status,

(2) Assessing changes in the planning and scheduling of the project.

(3) Producing or checking a work schedule.

A weekly LOB evaluation delivers considerable value for the little time spent in its preparation.

Correlation with Other Tools:-

The LOB gives simple graphical information not given by a bar chart or CPM, & they, in turn, furnish data not shown by LOB. For example, the LOB will forecast delay in the delivery of a unit but not the accompanying delay in total project completion, which is an essential part of a typical C.P.M. output. The LOB makes use of the schedule of unit completion but does not use as input or produce as output a schedule of activity progress. Such information is often well presented by a Bar Chart.

The three tools are thus complementary and can be parts of a computerized information system, a manual system, or a combination of both. However their joint use is not obligatory as the use of each is dependent upon the project requirements and not the presence of other tools.

The many uses of LOB make it a practical tool for planning, scheduling, and controlling the construction of repetitive units specially the building units. It is easy to understand and useful for decisions by field personnel and is a valuable addition to the existing activity oriented project management models.

2. **Queueing/Markovian Models**

Many situations in which units are processed can be considered as Queuing or Waiting line situations. Systems in which two units i.e. processor and calling units interact with each other can be presented in a Queueing Model.

The concept of Queueing Systems was first put to Mathematical Analysis by a Danish Mathematician Dr. A. Q. Erlang while studying the processing of telephone calls and developed relationships that provide mathematically correct answers to the following issues before a Project Manager : -

(i) Delay of units in the Queue.

(ii) Length of the Queue.

(iii) No. of units that can be effectively processed with Queueing delays.

(iv) Relationship of lack of service to arriving units (idleness) and inefficient use of processors.

(v) No of processors required.

Queueing situations are common in industrial and construction processes. Considering an earth moving process using trucks and loader, the arrival of trucks at the loader position is a classical example of Queueing system. Other common examples are ready mix trucks serving hoppers and hoppers serving crane buckets, wheel barrows or hoists transferring men and materials at building sites.

The response of a Queueing model is tied to the assumptions made about the unit arrival rates, the processor rates, the type of population, and the discipline of units passing through the system.

The rate of units arriving at the input side of a queueing system can be described in terms of random or constant (deterministic) time intervals. Mathematical solutions of the basic queueing model normally assume exponentially distributed interarrival times and service (processing) time. The assumption of exponentially distributed arrival times simplifies the mathematical development of the model and the model input is defined by the parameter $1/\lambda$ where :

$$1/\lambda = \int tf(t)\ dt$$

is simply the mathematical expectation of an interarrival value t. It is not difficult to establish that the probability of N arrivals in the period (0,t) is given as :

$$PN(t) = \frac{(\lambda t)^n e^{-\lambda t}}{n!} \quad \text{(Poisson distribution).}$$

A finite input population implies that, following their exit from the system, processed units may re-enter the system at a later time. The shovel-truck model described above is a finite queueing model, since a finite number of trucks, M, exist and re-enter the loader station.

Another important characteristic of queueing model is the processor or server rate. Although this rate can be either deterministic or probabilistic to include any number of distributions, the most common assumption regarding the server rate is that it is also exponential. The server rate, μ, is defined as

$$\frac{1}{\mu} = \int tf(t)\ dt$$

where f(t) is the probability density function defining the randomness of the processing times; $1/\mu$ is then the expected mean processing time.

The final distinguishing characteristic of queueing models is tghe manner in which units are sequenced while delayed in the waiting line. Most construction processes are best modeled as first-in-first-out (FIFO) systems.

System States

Queueing theory problems can be readily described in terms of states defined as the number of units delayed in the queue, whether the processor is active or idle, and so forth. Based on the assumption made regarding the queueing problem model, a set of equations can be written to describe the queueing system under investigation. The concept of "states" is used in writing equations to describe a queueing system, and these equations are called equations of state.

If in the truck and loader earth moving system we have (n) number of trucks, (n + 1) number possible system states can be identified and an equal number of equations of state can be written, and diagrams representing these states drawn.

Markovian Models

State diagrams including the transition probabilities as arcs are referred to as Markovian Models.

Markovian models are helpful in representing various situations in which a system moves from state to state based on a set of transition probabilities. Howard (1960) presented a very clear characterization of the action of a Markovian process.

Markovian concepts are helpful in analyzing queueing situations. When the graphical Markovian model is properly defined, the process of writing the equations of state for the corresponding queueing model reduces to balancing the incoming and outgoing links.

At any time t, the probability of being in S_i is specified as P_i.

In general, the probability of being in state P_n at $t + \Delta t$ is given as :

$$Pn\ (t + \Delta t) = Pn\ Tnn + P(n+1) + T(n+1)n + P(n-1)\ T(n-1)n.$$

Finite Population Queueing Models

Finite population queueing models are of interest in construction, since in many situations a finite number of resources (a fleet of trucks, a crew of masons, etc.) are served by one or more resources in a cyclic fashion. This recycling of served units leads to a finite population model. For finite population systems with exponentially distributed arrival and service times, the Markovian graphical model can also be used.

A Markovian model of the six-truck system is shown in Fig. 3. The arrival rates have been modified to indicate the effect of units outside the system of any state. Therefore, the probability of a unit arrival within Δt when the system is in S_0, is $6\ \lambda$. The comparable probability of a unit arrival when in S_5 is λ. The transit probability from S_{n+1}-----Sn remains equal to μ. Using the method of equating inflows and outflows at each state node, M + 1, or 7 (seven) equations can be written. The equations written at each node in the model are as follows :

Node	Flow Out	=	Flow in
0 (S_0)	$6\lambda P_0$	=	$\mu P1$
1 (S_1)	$(5\lambda + \mu) P_1$	=	$6\lambda P_0 + \mu P_2$
2 (S_2)	$(4\lambda + \mu) P_2$	=	$5\lambda P_1 + \mu P_3$
3 (S_3)	$(3\lambda + \mu) P_3$	=	$4\lambda P_2 + \mu P_4$
4 (S_4)	$(2\lambda + \mu) P_4$	=	$3\lambda P_3 + \mu P_5$
5 (S_5)	$(2\lambda + \mu) P_5$	=	$2\lambda P_4 + \mu P_6$
6 (S_6)	μP_6	=	λP_5

It is possible to solve for the productivity of a finite queueing model such as the shovel-truck system by determining the probability that no units are in the system, P_0. Having determined P_0, the probability that units are in the system is $(1 - P_0)$, and this establishes the expected percent of the time the system is busy (i.e., productive). The production of the system is defined as :

$$\text{Prod} = L(1 - P_0)\mu C = L\,(\text{P.I.})\,\mu C.$$

where

μ	=	the processor rate (i.e. loads per hour).
C	=	capacity of the unit loaded.
L	=	period of time considered.
P.I.	=	productivity index (i.e., the percent of the time the system contains units that are loading.

For P.I. = 0.65, the μ value = 30 loads per hour, the L value = 1.5 hours, and the hauler capacity = 15 cubic yards, the production value comes to :-

$$\text{Prod} = 1.5\,(0.65)\,30\,(15) = 438.75 \text{ cubic yards.}$$

The value of P_0 can be determined by writing the equations of state for the system and solving for the values of P_i (i = o, M).

In addition to these equations, all state probabilities must sum to 1.0 and, therefore, the additional equation.

$$\sum_{i=o}^{M} P_i = 1.0$$

is available. Since one of the node equations (last one) is redundant, this equation is substituted, providing the seventh equation required for solution of the P_i values (i = 0,6). Solving these equations in terms of P_o, the following values of the state probabilities result.

State	P_o	P_1	P_2	P_3	P_4	P_5	P_6
Probability							
Value	0.0121	0.0363	0.0906	0.1813	0.2719	0.2719	0.1359

The production of the system can be calculated using Equation

$$\text{Prod} = L\,(1 - P_o)\,\mu C.$$

Assuming $\lambda = 6$ and $\mu = 12$, the production becomes :

$$\text{Prod} = 1.5\,(1\text{-}0.0121)\ 12\ (15) = 266.73 \text{ cubic yards } (L = 1.5 \ \&\ C = 15).$$

Multiserver Finite Population Models

In the finite system explained above, only a single-server channel was defined.

If two loaders are available, the probability of transiting down from states containing two or more units ($S_n > S_2$) is 2 μ instead of μ. Similarly, if three loaders had been defined, the probability of downshifts for states containing three or more units would be 3 μ. The model for a three-server system is shown in Fig. 3.

Finite Models with Storage

In the system of six trucks serviced by one loader, the loader can either serve them directly or it can store loads in a hopper. If the capacity of the hopper is two loads (H = 2), the symbols for arrival and server rates are λ and μ, and the rate of loading afforded by the hopper is γ , the distribution of all times assumed to be exponential, are defined by the parameters $1/\lambda$, $1/\mu$,and $1/\gamma$. The number of states between which this system transits, is: (H+1) x (M+1) = 21. The Markovian model (Fig. 4) is handy in developing the state equations for this hopper system.

The highest row of the model is identical to the single-server model since when the hopper is empty (j = 0), the system is actually a single-server system. However, when there are no trucks in the system (i = 0), the loader loads the hopper (rate = μ). In the other rows, the rate of downshift and, therefore, of production is γ.

The equations of state are written again by equating inflows and outflows at each node. The 21 state probabilities are calculated using 20 node equations and the equation summing probabilities to 1.0. The expression for production of the hopper system is :

$$\text{Production} = \left\{ \mu \left(\sum_{i=0}^{M} P_{i0} \right) + \gamma \left(\sum_{j=1}^{N} \sum_{i=1}^{M} P_{ij} \right) \right\} CL$$

Nomographs are available that use the factors λ/γ and μ/γ to determine the P.I. The expression for production is :

$$\text{Production} = (\text{P.I.})\, \gamma\, CL$$

The hopper does add a small amount of production to that of the system of single server without hopper.

Although limited in scope and in the range of field problems it can handle, queueing theory does provide a good vehicle for introducing some concepts basic to modeling construction operations. The concepts of unit flows and storage, system states, delays, and processing are fundamental both to queueing systems and to the modeling of the more complex dynamics of construction processes.

Short comings of the Queueing Models

The Queueing models however suffer from the following short comings : -

- The assumption of exponentially distributed arrival and service times is not compatible with field conditions.
- Steady state operation is hardly attainable in real world processes.

3. Method Productivity Delay Model (MPDM).

This model developed by Adrian and Boyer (1); focusses on method productivity parameters that are measurable and controlable by the average construction Administration. Method productivity parameters are addressed by documenting productivity system/process operation delays. The model recognises the environments and constraints of an average construction firm, and requires only simple mathematics and process attributes, necessary to provide a means of measuring and improving productivity. This field oriented model has been evolved from : -

(i) Attributes required to provide potential for measuring, predicting and improving productivity.

(ii) Recognition of the positive attributes of other similar models.

(iii) Field observation of construction methods/process operations.

A flow chart of the model operation appears as Fig. 5.

(A) Collection of method productivity data involves : -

(i) Identification of "production unit" and 'production cycle'.

(ii) Identification of leading Resource.

(iii) Collection/observation of production cycle times and documentation of productivity delays.

The delays encountered in production cycle can be broadly assigned to the following groups : -

(a) Environmental;

(b) Equipment,

(c) Labour,

(d) Material,

(e) Management, (most common/dominant).

(f) Queueing, and,

(g) Black Box. (The types that cannot be placed in any of the groups (a) to (f) above).

These delays are observed in the field and recorded in a proper format. The procedure for collection and record of data is termed as "Production Cycle Delay Sampling (PCDS)."

(B) The processing and structuring procedure is best explained by the real world example presentd in Appendix-A.

III. Application of M.P.D.M. to variable field systems.

A study of the data and calculation sheets in conjunction with the paper titled "Modeling Method- Productivity" by Prof. J.J. Adrian & L.T. Boyer (1) reveals that the applicability of the method/model described therein is limited to the systems which do not undergo changes during the data collection period/process.

In the example of Appendix-A; the system is not in balance and one out of 4 Scrapers drops out of the system after just 3 cycles. The productivity per scraper per hour (3.875) is realistic but multiplying it by the nominal numerical value of the transit units to arrive at the system productivity is not justified. This is why the value of system production given by M.P.D.M. (15.50 loads/hr) does not agree with the field productivity of 13.89 loads/hr. If the effect of the exit of scraper No. 4 is recognised in M.P.D.M. the production of the system will come to : -

3.875 x 3.4 = 13.18 loads/hr which is very close to the field productivity.

The deterministic value of production based on manufactures characteristics/Ratings has been calculated as 25.88 loads/hr which nearly tallies with the Ideal productivity figure of 24.76 loads/hr indicating that the equipment is working almost true to the rated characteristics.

The model needs to be amended to either recognise the changes occuring in the system during the observation period or restrict/limit the use of this model to stable systems only.

Another way to handle the changing systems could be to break up the observations into two or more sets of uniform working but in such a case, none of the sets may contain a sufficient number of observation to yield results of acceptable accuracy.

4. Linear Programming Models

In some processes of repetitive nature, different parameters and constraints can be represented through Linear equations which when solved simultaneously yield quite reliable solutions. Such models can be very effectively used for;

- Material management Problems.
- Transport Problems.
- Labour Allocation Problems and
- Cost Management of resources.

The process is handled by the use of a cost concious linear model in two steps.

First, each material is allocated to an Equipment Service Area (ESA) based upon the least expensive total transport costs of all materials and is constrained by the total service area. The second step assigns each allocated material an area within the equipment service area based upon the least expensive piece of equipment. Both steps can be easily accomplished by a linear program assignement. The model requires three types of input from the field. They are the storage area requirement of the area each material will occupy, the total trips required to transport each material to the site and the cost of each trip. Normally the cost of a trip may be determined by estimating the time required to make the trip and equating it to the operating costs of the piece of equipment.

Simulation Methods

On account of the complexity of interaction among units on the job site and in the construction environment, queueing models can be applied to only a limited number of special cases. In line of balance, the output from one operation tends to be the input to following operations. This leads to the development of chains of extremely complex queues as well as situations in which many units are delayed at processors pending arrival of a required resource. Such linked situations are too complex to be modeled using queueing models. Simulation techniques alone offer the general methodology that affords a means of modeling such situations.

A variety of simulation program languages is available for the modeling of processes in which discrete units cycle through active and idle states. These simulation Languages allow the investigation of complex queueing networks that cannot be handled using the mathematical methods of queueing theory. Among the more popular of these Languages are; the General Purpose Simulation System (GPSS). SIMSCRIPT, and General All purpose situation programme. A detailed description of these simulation systems can be found in various references e.g. Gaarslev (1969), Gordon (1969) and Naylor et al. (1966) etc.

Some models utilising the simulation techniques are introduced in the following paragraphs:

1. SIREN: (SImulation of REpetitive Networks) is a computer simulation model of repetitive construction, such as the construction of multi-storey buildings etc. The user interactively inputs a precedence diagram for the repetitive unit via an IBM-PC at which point extensive error checking is carried out. The model runs on a remote mainframe computer. It simulates the various crews as they queue to carry out activities. A working schedule and cumulative cost curve are produced and statistics are gathered on crew and equipment utilization, and presented in a graphical output.

'SIREN' is essentially written is GPSS language, the PL/1 pre-processor and FORTRAN post-processor merely facilitate input and output. A deterministic analysis is done initially using mean activity durations. Data is collected on crew and equipment utilization and a working schedule is produced. Then a Monte-Carlo stochastic simulation is executed which gives confidence intervals on milestone attainment and cumulative costs and also more accurate utilization data.

A User's Manual written for SIREN, describes the system in detail. Features of the model are outlined in the following

Input

Two forms of input are required:

(a) **Global Data** - Required global data includes:

1. Network data - The number of repetitive units must be specified, as well as the event and unit that triggers each sub-net.

2. Weather - Weather is input as the expected percentage of days in each month weather-dependent activities will remain stopped.

3. Time data - Project start date, holidays, working days per week, working hours per day and basic time unit (day or hour).

4. Crew - Each crew may consist of a number of squads, e.g., a crew of Electricians might consist of three squads, each executing one activity.

5. Equipment - There may be a number of machines of each type.

(b) **Activity Data** - Required data includes

1. Duration distribution: Erlang, Uniform and Normal distributions are allowed. Each requires a mean duration and a minimum duration.

2. Crew utilized: To take account of activities such as "cure slab," dummy crews may be invented.

3. Equipment utilized: This is input as the percentage of time that each piece of equipment will be used during the duration of the activity.

4. Weather-dependency: Activities may or may not be weather-dependent.

5. Mean cost: This is the cost of the activity based on a mean duration.

6. Title

7. Learning curve parameter: In production processes, a logarithmic learning curve is commonly used to represent the relationship between the number of units produced and the number of man-hours used.

8. Dependent activities: The system uses an activity on node precedence network.

9. Milestones: Particular events in sub-nets may be identified as milestones, indicating that statistical data is to be collected at these events during the Monte-Carlo simulation.

The user has some control over the output format and also on whether or not a Monte-Carlo analysis is to be done. After data verification a dataset is sent from the micro to the mainframe.

Deterministic Analysis

The model reads in both the global and activity data via a PL/a HELP routine.

In this model, the transactions are activities that queue to take control of the associated crew. Each crew has two queues of activities associated with it.

1. Unready queue: Acivities in this queue are not ready to begin, as all preceding activities are not yet completed.

2. Ready queue: Activities in this queue are ready to start as all preceding activities are complete, but the required crew is busy.

The priority system adopted is:-

1. Top priority is given to sub-network activities.

2. When an activity finishes, the same activity on another unit automatically begins, if ready, and if no sub-network activities are ready.

3. Work progresses sequentially from unit to unit in ascending order.

4. Once in the ready queue, activities queue according to unit number.

This priority system closely approximates the thinking of the site superintendent by emphasizing work continuity and job progression.

Initially all activities are in their appropriate unready queues. A scan is made after each activity finishes to find activities that may begin. These are then moved from the unready to the ready queue. After the scan is complete, the first activity in each ready queue seizes control of a squad, if available.

Once an activity seizes control of a squad, a check is made to see if the same activity on the succeeding unit is free to begin. If it is and the labor is available, a new activity is "created," gains control of the squad, and checks the next succeeding unit and so on.

Monte Carlo Simulation (Stochastic Analysis)

Once the deterministic analysis is complete, the model is reinitialized and the Monte Carlo simulation begins. This involves repeating the simulation, using a particular set of values for activity durations and weather (the random variables) in accordance with the corresponding probability distribution. During each simulation, the time to reach each milestone and the cumulative cost upto that point are recorded.

Comments

The apparent limitations are as below:-

1. In reality, activities may be executed by more than one crew.

2. A conventional critical path analysis is not carried out and no informmation is gathered on activity criticality.

3. The resource allocation routine does not give priority to critical activities nor does it delay activities that have float.

4. The model presumes that the repetitive units are essentially independent. No inter-dependency between activities in different units is allowed except that the start activtiy of a unit may be dependent on one or more activities in the preceding unit.

   Eliminating this restriction makes the model intolerably complicated.

5. 'SIREN' allows modelling of complex projects with numerous activities. It models crew and equipment availability, learning curve effects and the weather, as well as doing a Monte-Carlo simulation. However, the objective to make the model user-friendly is hindered by the inclusion of these features.

6. Before implementation, 'SIREN' has to be upgraded to allow the user to impose his plan of work on the model.

7. 'SIREN' has many features that make it attractive, but no firm conclusion on its applicability can be drawn untill it is used to model a number of projects successfully.

2 INSIGHT (Interactive Simulation using Graphics Techniques) is basically a conversion of Halpin's mainframe computer simulation programme 'CYCLONE' into an interactive DEC-PDP-II mini computer modelling system through interfacing the time lapse movies and later on video-tapes to mini computer. Further research at Stanford University enabled the research workers/programmers to establish effective communication between mini and micro computer for disc to disc data transfer. This resulted in effective transformation of the model system to a version suited to application on micro computer of IBM PC/AT category.

The 'Insight' is thus a system that combines, (1) Videotape data collection from field construction operations; (2) statistical analysis of data; and (3) computer-based simulation modelling.

As implemented, a video camera taken to the field, records data about the logical relationship between, and the cycle times of the various elements in an operation. With the aid of a computer connected to a tape player, these data can be extracted from the tape and analyzed statistically to yield estimated values for the productivity of the system and components. With the aid of a microcomputer, the user then can build a network-based simulation model which replicates the performance of the real-time system. Integration of simulation with video methods of data acquisition, linked to computer for data extraction and statistical analysis, makes it economically feasible to collect real data with which to develop and run simulation models, even for complex operations of short duration.

The system however requires verification and confirmation on real world problems to establish its credence and claimed versatility.

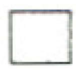
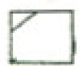
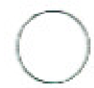
3. CYCLONE Model

The CYCLONE Model as mentioned earlier was developed by Prof. Daniel W. Halpin and introduced in 1974. The word *cyclone* is the acronym of *"Cyclic Operations Network"*. This computer programme written in a specific "Problem Oriented Language" (POL) is simpler and much more versatile than other models. A fifteen element G.P.S.S. representation can be effectively modelled with only five elements using the *Cyclone* P.O.L. The variety of symbols and functions used in GPSS leads to large models for relatively simple construction processes. Such models require a manager who is knowledgeable in simulation techniques and considerable time to develop and interpret.

The *Cyclone* computer language is designed to retain the features of the conceptual model and use many of the input procedures common to existing time scheduling network programs. In defining *Cyclone* system networks, the modeler utilizes a problem-oriented language (POL) that allows direct specification of the model developed in *Cyclone* system format without translation into a functional model. The *Cyclone* system POL uses a word set that specifies each of the *Cyclone* elements in terms understandable to both the modeler and the computer. A description of the number of work tasks involved and their attributes and interrelationships defines information that is sufficient to organize the data for simulation. The definition of logical relationships between *Cyclone* model elements is the same as was used in critical path and Pert scheduling programs employing precedence notation. In general, the design of the network specification language is such as to minimize the number of new concepts that must be learned. The *Cyclone* system POL relies on a problem specification structure similar to that already familiar to managers using time scheduling networks.

The Micro-*Cyclone* program is only an enhanced version of the original Main-Frame *Cyclone* program adjusted to run on micro-computers. The *Cyclone* model formulation is based on the construction management heirarchical levels and terms descibed in earlier paragraphs.

The six basic modeling elements used in the development of the *Cyclone* Model diagram are as under : -

ELEMENTS	NORMAL	COMBI	QUEUE	ACRS	ACCUMULATOR	FUNCTION
SYMBOL				→		

The NORMAL is an active working state node unconstrained in its starting logic. Units are processed as soon as they arrive at this node, and exit the node when the activity is completed. This element requires the user to define an intrinsic time delay for the activity being modeled.

The COMBI, or combination is similar to the NORMAL element, except that it requires all preceding nodes to have units available to them. Combi nodes must therefore always be preceded by an idle or waiting state node. The COMBI must also have a user defined time duration.

The QUEUE is an idle or waiting state node. It defines a waiting location for the units expecting to be combined in a COMBI. Delay statistics are measured at this element.

A GENERATE function may be associated with a QUEUE, whereby N units are generated for each arriving unit. There are no time delays associated with a QUEUE. Actually, a queue itself is a result of time delays.

The ACCUMULATOR, or counter, is a monitoring and control element. This node records information on the productivity of the operation, limiting further processing of units if a user-specified number of unit cycles have been reached. There must be one and only one accumulator per model.

The FUNCTION Node is inserted into the model chain to perform certain special assigned functions :

CONSOLIDATE : One unit is released for every N arrivals i.e. N units consolidated into one.

STATISTIC : Collect user specified statistics.

COUNT : Establish a counter without the capabilities of the Accumulator.

The ARC modeling element establishes only the direction of the flow of the operation Units.

The following is the precedence table for element. A preceding element B for formulation of *Cyclone* Network :

			B		
A/ELEMENTS	COMBI	NORMAL	QUEUE	FUNCT	ACCUM.
COMBI	N	I	I	I	I
NORMAL	N	I	I	I	I
QUEUE	M	N	N	N	N
FUNCT	N	I	I	I	I
ACCUM	N	I	I	I	N

M = mandatory I = immaterial N = nonfeasible

Model Formation

The process to be modelled is broken up into various work tasks and durations and resources needed are recorded. The model chains (network) for individual component cycles are then drawn using the modelling elements elucidated supra. (Refer Fig. 6.).

These are then consolidated together to yield one Model Network for the process. (Fig. 7.). The process model is the basic unit for *Cyclone* analysis, although several process models may be compiled in one overall model for the operation, activity, or even the project. However, larger the scope, the more complicated the model becomes and so the use is therefore generally restricted to processes and operations.

Based on the Model Network, an Input file is prepared which depicts the model network in a form and language acceptable to the computer. All this is very simple to achieve. A sample model and input file are presented as Fig. 7 and Table-2.

The input file is fed to the computer and processed in accordance with the directions contained in the user's Manual and the program itself because the *Cyclone* is a Menu-Driven, User-friendly program.

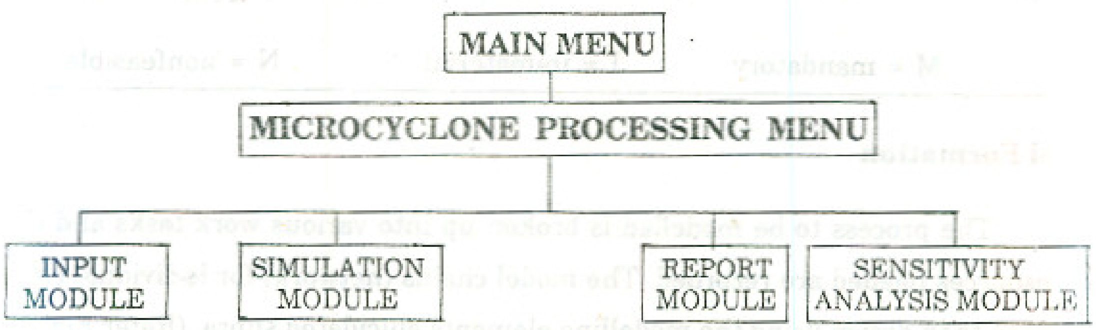
General Program Organistion

The system is composed of a series of independent modules each of which is in control of a particular segment of the overall system. There are four different types of modules :

1. Data-input module.
2. Simulation module.
3. Report generation module.
4. Sensitivity analysis module.

The system is menu driven, and its use is equally easy for the inexperienced as well as the expert user. These menus will allow the user to move within the whole program by using just the function keys to respond to the menu queries.

The program is organized as shown in the following micro-flow-chart : -



ORGANIZATION OF MICROCYCLONE PACKAGE

The computer simulation analysis provides 6 major productivity analysis reports. The sensitivity module allows the repetition of simulation with changing resources and durations without repeating the preliminaries, changes in model networks or input process and without quiting the main menu of the programe.

The sensitivity analysis yields another 9 reports which give complete data of the process analysis to enable the Manager to take necessary remedial actions in terms of changes in resources and their development to achieve the optimum productivity and cost levels for effective project control.

In elucidation/confirmation of above narration, a Micro-CYCLONE analysis for a real-world "R.C. floor slab concreting process", is presented in the following paragraphs as an example.

MICRO CYCLONE ANALYSIS OF A REAL WORLD PROCESS

PROCESS SELECTED FOR STUDY AND ALALYSIS

The process chosen for study and analysis using Micro-CYCLONE Model is "CONCRETE PLACEMENT IN RC FLOOR SLAB", at the SUBARU-ISUZU Automotive Plant, Lafayette (IN) U.S.A. The floor was laid in square panels/bays of 50ft. x 50ft. size. The slab was 6 inches thick and reinforced with 12" x 12" welded mesh of No. 4 wire placed in 9' x 6' sections. These mesh sections were laid by a rebarman as the concrete pouring progressed, from a rebar stack placed close to the panel being poured. A total of 5 bays were poured in 4-1/2 hours from 1000 AM to 0300 PM with a 1/2 hour break. The total quantity poured in this period comes to 231.48 Cyd. at a placement rate of 51.44 Cyd/workhour.

MAJOR RESOURCES USED AND TASKS INVOLVED

Resources Used

The following resources were deployed for this process operation : -

(i) **CREW**

S. No.	DESCRIPTION OF CREW	NUMBER DEPLOYED	REMARKS
1.	Chute Handler	1	
2.	Spreader	1	
3.	Screedmen	2	
4.	Vib. Screed Operator	1	
5.	Finishers	3	
6.	Rebarman	1	
7.	Spotter	1	
	Total :	10	

Equipment

The equipment used in the process under analysis included Mixers, Transit Trucks, a Vibratory screed, a small electrically driven immersion vibrator for use in tight locations like corners etc. a metal screed, a bull float, shovels, rakes, small hand floats and other tools.

CYCLONE MODEL AND ANALYSIS FOR THE PROCESS

The Model

The CYCLONE model Network developed for the process study is shown in Figure-7 and exhibits the logic and functional details of the process. The work tasks involved in constituting the model are defined and explained in the following paragraphs :

Work Tasks

(a) 2- "Load Conc Truck" The truck moves under the delivery Chute of the Mixer to be loaded, and after getting loaded moves out.

(b) 3- "Haul Concrete". The loaded truck travels to pour site, and awaits entry signal in Queue-28 from spotter.

(c) 29- "Order A Truck". The spotter available in Queue-30 causes a loaded truck waiting at Queue-28 to move into Quueu No. 4 to position itself for pour as the preceeding truck finishes its load and leaves for Queue-1 to wait to be loaded with mixed concrete.

(d) 5- "Position Concrete Truck". The loaded truck positions itself to deliver concrete through its Chute. Since the bay being poured is 50 ft. wide it cannot be covered from a single position, the truck positions itself 4 times to cover whole width of the slab. (Refer Fig. 8).

(e) 6- "Conc Avail". The truck capacity is 12 Cyd and it delivers 3 Cyd of concrete at every change of position. This 3 Cyd is broken into 3 portions of one Cyd each placed suitably through Chute to facilitate manual handling by crews.

(f) 7- "Place Rebar and Concrete". The concrete is placed in 1 Cyd portions, which have been generated earlier at Queues number 4 and 6.. The rebar mesh is placed in pieces of 9' x 6' ahead and alongwith the advancing concrete front.

(g) 11- "Spread Conc". The concrete unit placed in task No. 7 is spread by the spreader available at Queue No. 21.

(h) 13' "Rough Screed". The concrete spread in task No. 11 and having become available at Queue No. 12 is screeded by the two screedmen available at Queue No. 20.

(i) 15- "Vib and Final Screed". The thickness of the slab being small, it is vibrated and given a final screeded surface by a vibrating screed with its operator available at Queue No. 19.

(j) 17- "Finish Concrete". The final screeded concrete having become available at Queue No. 16 is given the final finish by the 3 finishers available at Queue No. 18.

(k) 25- ""Empty Truck Returns". The truck after delivering the 12 one Cyd units at 7, returns to pre-load Queue No. 1, after the function No. 24 has consolidated the 12 elements generated at Queue No. 4&6.

(l) 27- "Function Counter Quantity-1". The counter records one Cyd as each unit is released from 17 after finishing and becomes a part of the completed floor slab.

WORK TASK DURATIONS AND RESOURCES

(a) Durations

The durations fixed for each task have been established on deterministic basis after observation at site and statistical analysis for weighted averages, exhibited in the CYCLONE INPUT FILE, and are also reproduced below, for reference :

TASK NO.	2	3	5	7	11	13	15	17	25	29
Duration (mts)	1.5	4.0	0.75	0.75	0.50	0.25	0.60	1.50	2.50	0.20

(b) Resources

As enumerated in an earlier paragraph.

SIMULATION USING MICROCYCLONE

The input data file for computer simulation with Microcyclone appears as Table-2. This data was put to simulation with Microcyclone, and the simulation results obtained in the form of various reports detailed below are exhibited as Table-3 to 10 and Figures 9 to 10.

(i) Network input file.

(ii) Production Curve.

(iii) Cyclone Report No. 1 (By Elements).

(iv) Cyclone Report No. 2 (Cycle Monitoring Report)

(iv) Cyclone Report No. 3 (Production by Cycle).

(v) Cyclone Report No. 4 (Process Report).

(vi) Cyclone Report No. 5 (NL Dump Report).

(vii) Graphic Report for Queues & Work Tasks.

(viii) Sensitivity Analysis Reports.

- (a) Productivity and Total time for different Mixes.
- (b) Average of time Queues are occupied.
- (c) Percentage of time Queues are occupied.
- (d) Average Number of Units in Queues.
- (f) Graphical Report of Mix effect on Productivity.
- (g) Graphical Representation of Queues in Comparison.
- (h) Graphical Representation of Work Tasks in Comparison.
- (k) Graphical Report of Mix effect on Total Time.

COMPARISON OF PRODUCTIVITY

The productivity of the system obtained through cyclone Production curve and analysis is 58.67 Cyd/hr. The Means Manual gives a standard productivity figure of 34.36 Cyd/hr indicating that either the cyclone given value is too high, or the value contained in

Means Manual is too conservative. To reach a logical conclusion, the actual productivity in the field was determined from the value of concrete placed and the time consumed in doing so. The actual field data and calculation of productivity therefrom are as below : -

- No of bays poured - 5.
- Total Quantity poured = 50 x 50 x 5/2 x 27 = 231.48 Cyd.
- Time taken for this quantity = 4-1/2 hrs.
- **Therefore Productivity = 231.48/4.5 = 51.44 Cyd/hr.**

The above value of actual productivity in the field ie. 51.44 Cyd/hr. is quite close to the simulated value of 58.67 Cyd/hr, and supports the Cyclone simulation results. Means Manual is a bid preparation, and estimation guide and therefore really conservative. The above-mentioned results are tabulatd below :

TABLE - A

COMPARISON OF PRODUCTIVITY

PRODUCTIVITY FROM CYCLONE ANALYSIS	= 58.56 Cyd/hr.
PRODUCTIVITY FROM MEANS MANUAL = 10/0.291	= 34.36 Cyd/hr.
PRODUCTIVITY FROM ACTUAL FIELD DATA = 1250 x 5/27 x 4.5	= 51.44 Cyd/hr.

SENSITIVITY ANALYSIS

The Microcyclone software package also includes a Sensitivity program/module which allows the comparison of productivity for various sets of resources. One can change the resources in the model and simulate to obtain the changed productivity. The data obtained from simulation did not show any change in the system productivity in this case, when the number of trucks initialized at Queue No. 1 was reduced from 3 to 1 or increased to 6. This indicates that the system is quite insensitive. The reason for this apparent insensitivity is the fact that proximity of the on site batching plant has reduced the truck cycle time to a figure lower than that for the placement and finishing cycle, to an extent that the system's need for trucks is satisfied even if a total of two trucks is available in the system. Since one truck each is already initialized at Queue No. 4 and 23, the system behaves as if it is insensitive.

HAND SIMULTION

Hand simulation of the field data carried out over 10 cycles for the process indicates a productivity figure of 47.06 Cyd/hr, which is lower than the value indicated by Microcyclone program. This is so because the system attains a Steady State or more or less so after 60 cycles of operation. However at 5 and 10 cycles the relevant figures are in perfect agreement.

COMMENTS ON SIMULATION REPORTS

The simulation reports indicate that spreaders and finishers are clearly under utilised and one man each can be withdrawn from the two crew groups without affecting the productivity and with substantial saving of money.

Special Attributes of CYCLONE SYSTEM

The CYCLONE methodology enables construction operations to be described, modeled, analyzed, and designed in whatever level of detail is relevant to the needs of the construction engineer, head office planner, or field agent.

The CYCLONE graphical modeling concepts are simple and versatile and enable the ready portrayal of work sequences, construction technology, and conditional interrelationships among the various work tasks and processes involved in the construction operation.

The CYCLONE methodology consists of a number of sequential stages in the formulation and development of models. These stages correspond to the various levels of professional effort, decision making, and management of construction operations.

The CYCLONE methodology can be utilized at any number of different levels of involvement. Thus the first stage corresponds to a method of describing construction operations, that might be useful as a means of instructing field staff in a new operation or as a teaching methodology for construction engineering students. The second stage corresponds to the management of in-progress construction operations. The third stage focuses on the specification of a construction operation reporting system that could form the basis of a field reporting document to head office management.

The CYCLONE methodology provides the format and opportunity to the user for the repetitive sequencing of the decision phases associated with the selection of technology, design, and the assessment of the implication of a construction operation before actual work commitments are made.

The CYCLONE models may be usefully developed for the analysis and design of large unique capital intensive under-takings.

The development of CYCLONE models alerts management and field agents to features of a construction operation that affect its productivity, cycle duration, and efficiency.

The CYCLONE models for material handling processes associated with mass concrete dams, earthworks, tunneling, pipeline construction, and extensive pile driving may become imperative. In some cases work volume achieved by a particular construction operation over a number of projects is sufficient to make its analysis worthwhile on a long-term basis although, for each particular project, its impact appears small.

The CYCLONE methodology uses the work task as the elemental building component of the construction operation. While the number of work task elements in an operation may be considerable, their definition and focus on the active processing of resources is more receptive to capturing the specifics of a particular work face layout and environment.

The methodology allows for the better analysis of operations using field estimates, since the estimate data input for the procedure is based on small tasks that are relatively clearly defined in terms of resources and their participation in the process and operation.

Field agents do not think in terms of arbitrarily defined project activities related to a physical structure. Instead they think in terms of resources and their maximum utilization to achieve production on a process that may be common to many project activities.

The CYCLONE methodology talks in the same language as that used by field agents. It has the right level of abstraction and detail for field management.

The CYCLONE system allows higher management to work at work sequences and the details of construction operations through the eyes of field management and to tap their accummulated expertise. Similarly, the system can facilitate the training of candidates for field management.

Conclusion

(1) The construction industry in the Global perspective is advancing towards better productivity and innovativeness.

(2) A substantial number of mathematical models of various types are available to help the construction Managers/Engineers, who can choose and use any or a combination in accordance with the typical or unique conditions obtaining in their work areas.

(3) Simulation models are more potent, and versatile.

(4) CYCLONE system models are the most potent, versatile, simple to understand and easy to use. They are equally useful for all levels of construction Management heirarchy, right from the organisation Chief down to the Junior site engineer.

(5) CYCLONE model holds a great promise and scope of applicability to the construction projects in the country for improving process planning, productivity and financial control specially with the introduction of "Robotics" to the construction methods.

(6) Research being a continuous process, more models and programs are likely to be added to the ARRAY we already have.

(7) There is a definite need for introduction of research into our sick construction Industry which requires an early shot in the arm to save it from complete destruction and increasing foreign involvement.

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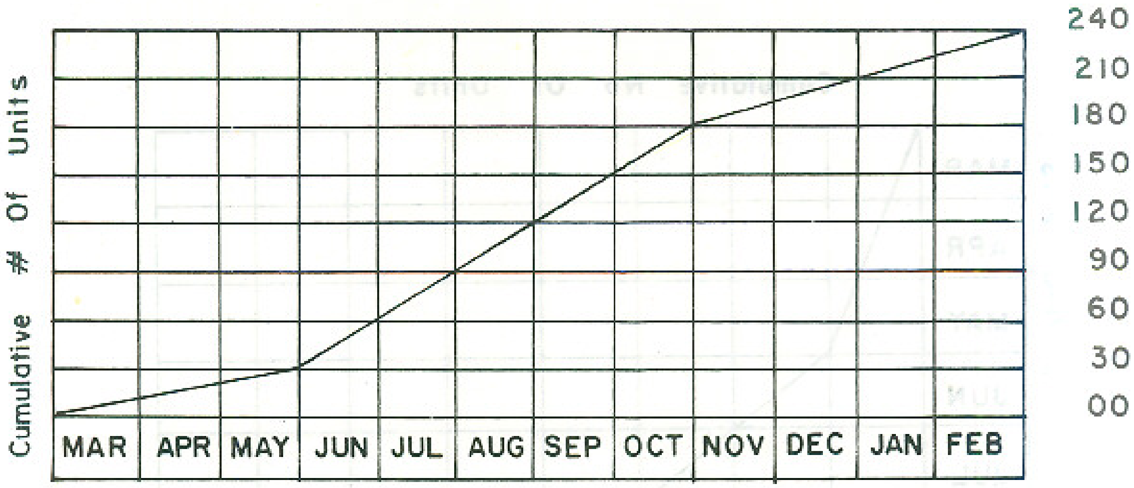
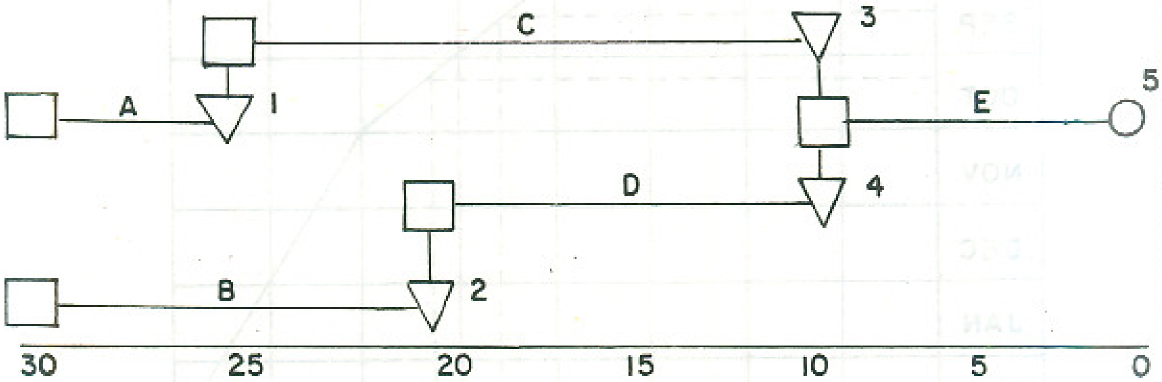
22. Zaidi, M.A. "Modelling a Construction Process" A Construction Project Field Research Report, Purdue University May, 1988.

*****

Fig. No. 1

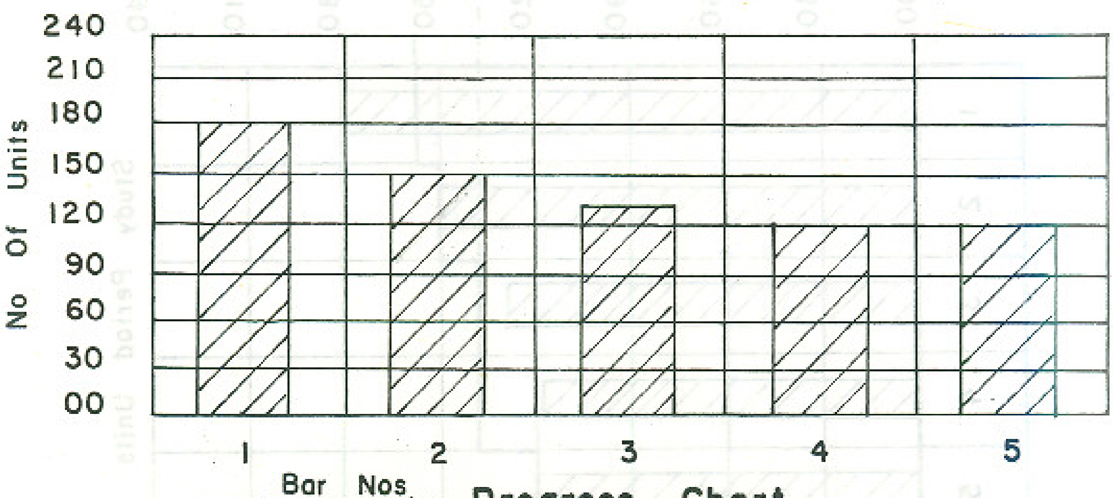


(a) **Objective Chart**

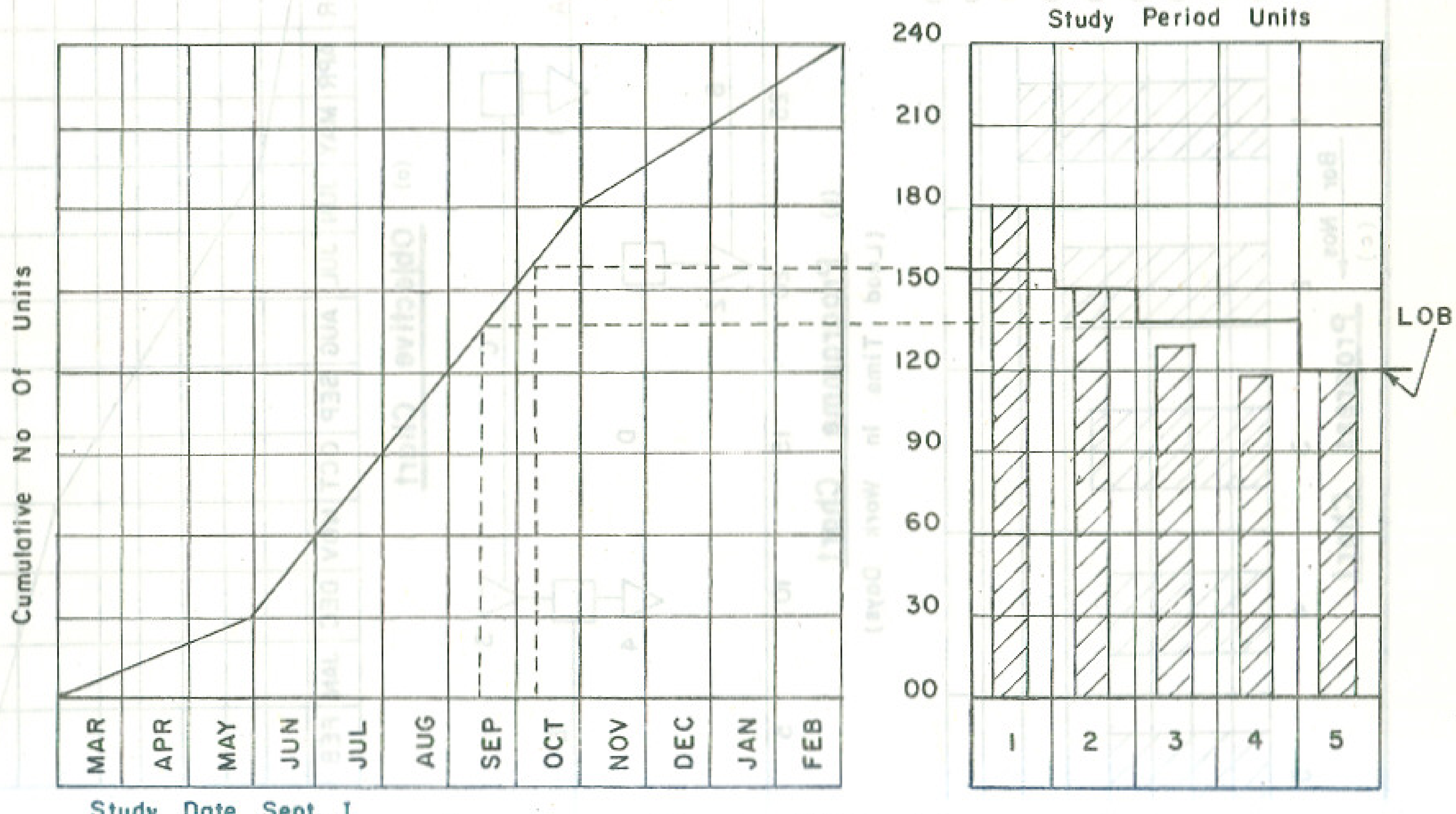


(b) **Programme Chart**

(Lead Time In Work Days)

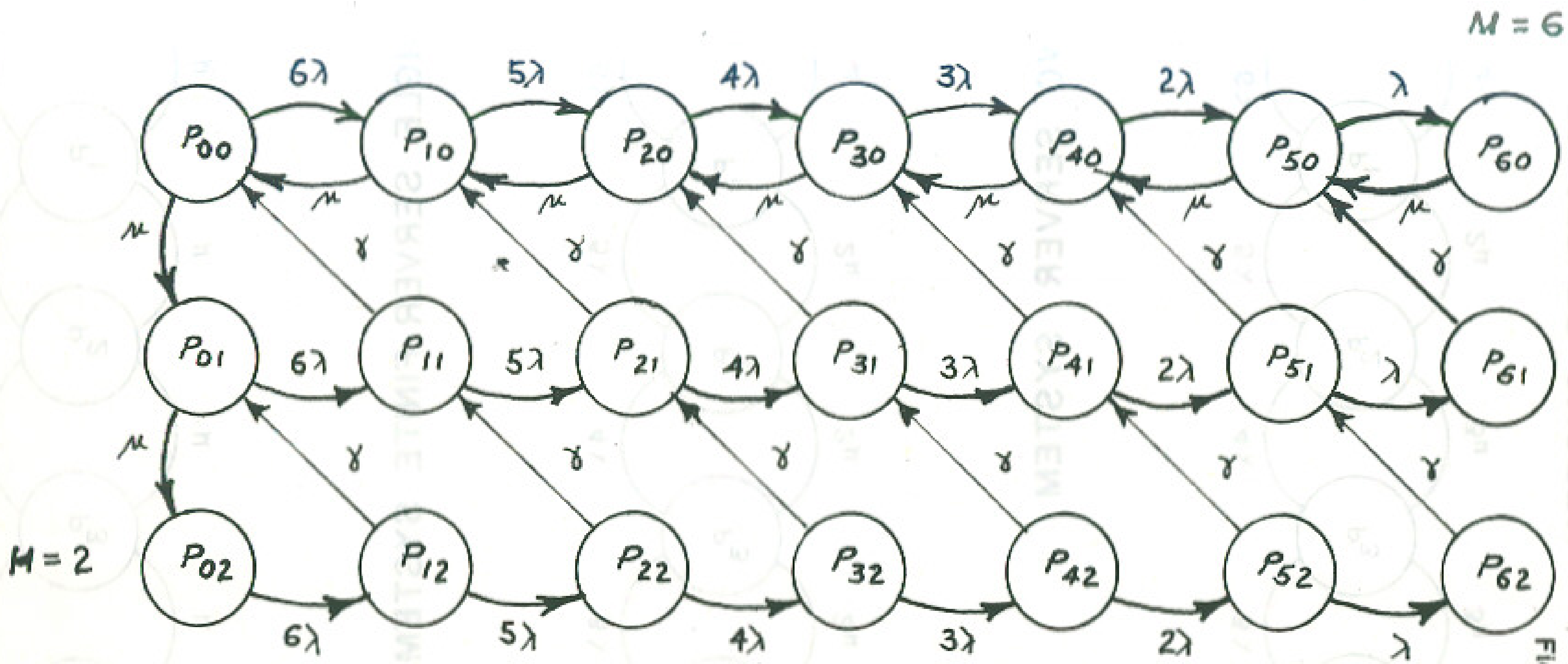


(c) **Progress Chart**



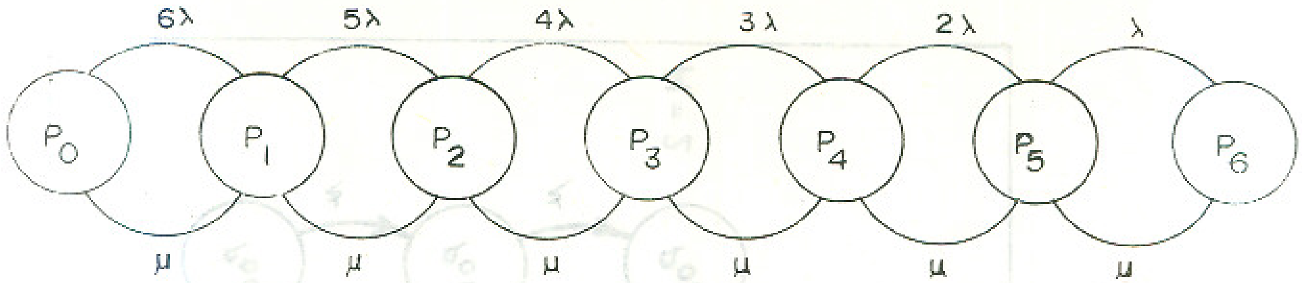
Progress Chart With Line Of Balance

Fig. No. 2

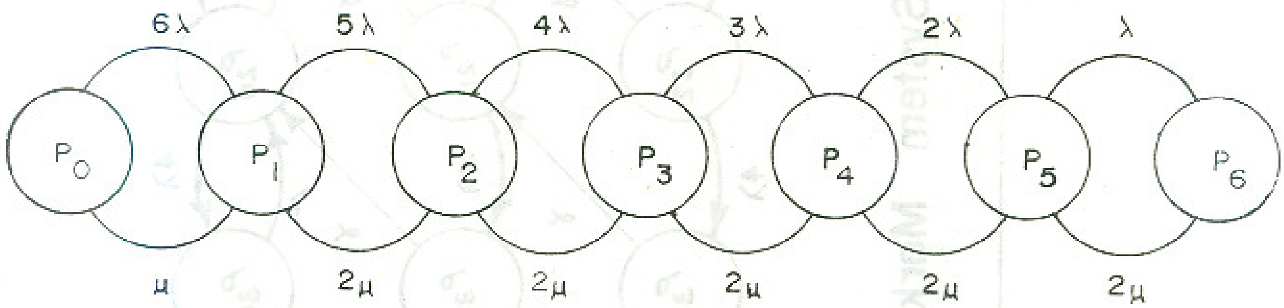


Hopper System Markovian Model. (7)

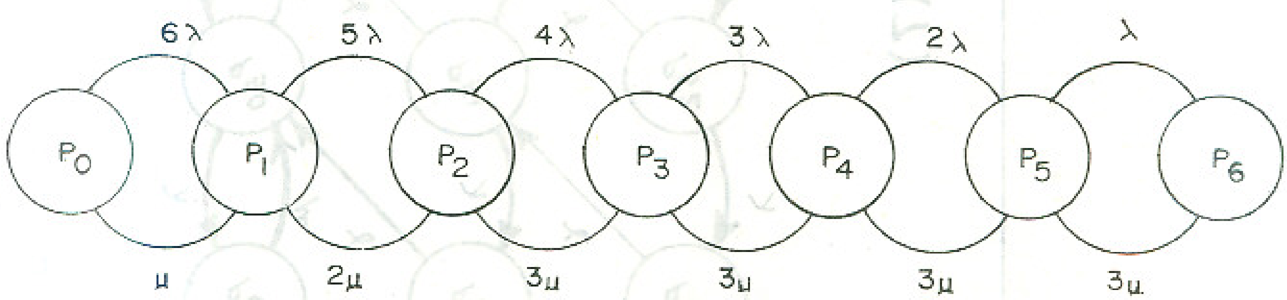
Fig: No. 4



(a) SINGLE SERVER FINITE SYSTEM (M=6)

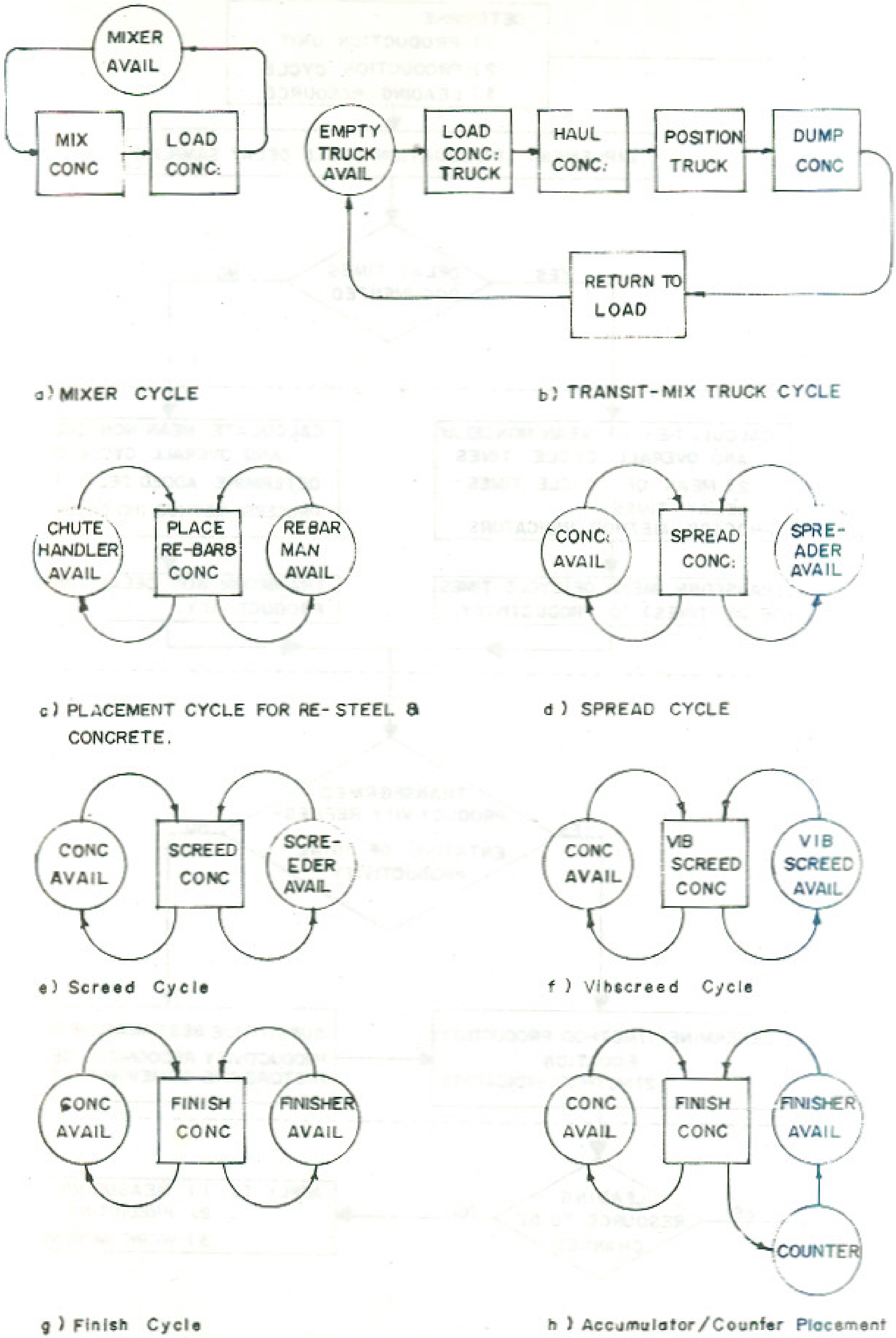


(b) TWO SERVER SYSTEM



(c) THREE SERVER SYSTEM

TYPICAL MARKOVIAN MODELS FOR 1,2,& 3 SERVER SYSTEMS. (7)



INDIVIDUAL CYCLES FOR COMPONENT WORK TASKS

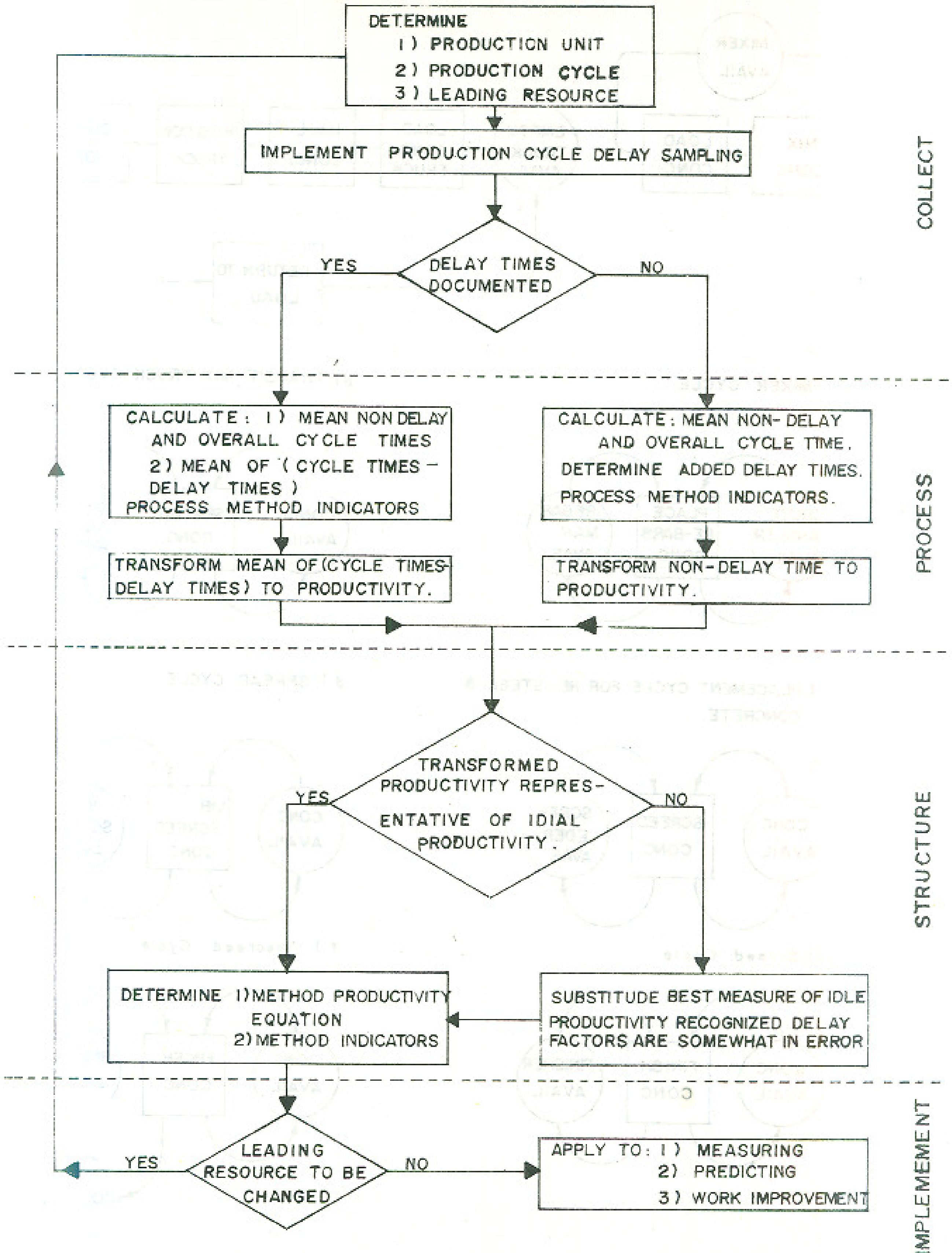


FIG: METHOD PRODUCTIVITY DELAY MODEL (I)

CYCLONE MODEL FOR POURING RC FLOOR SLAB.

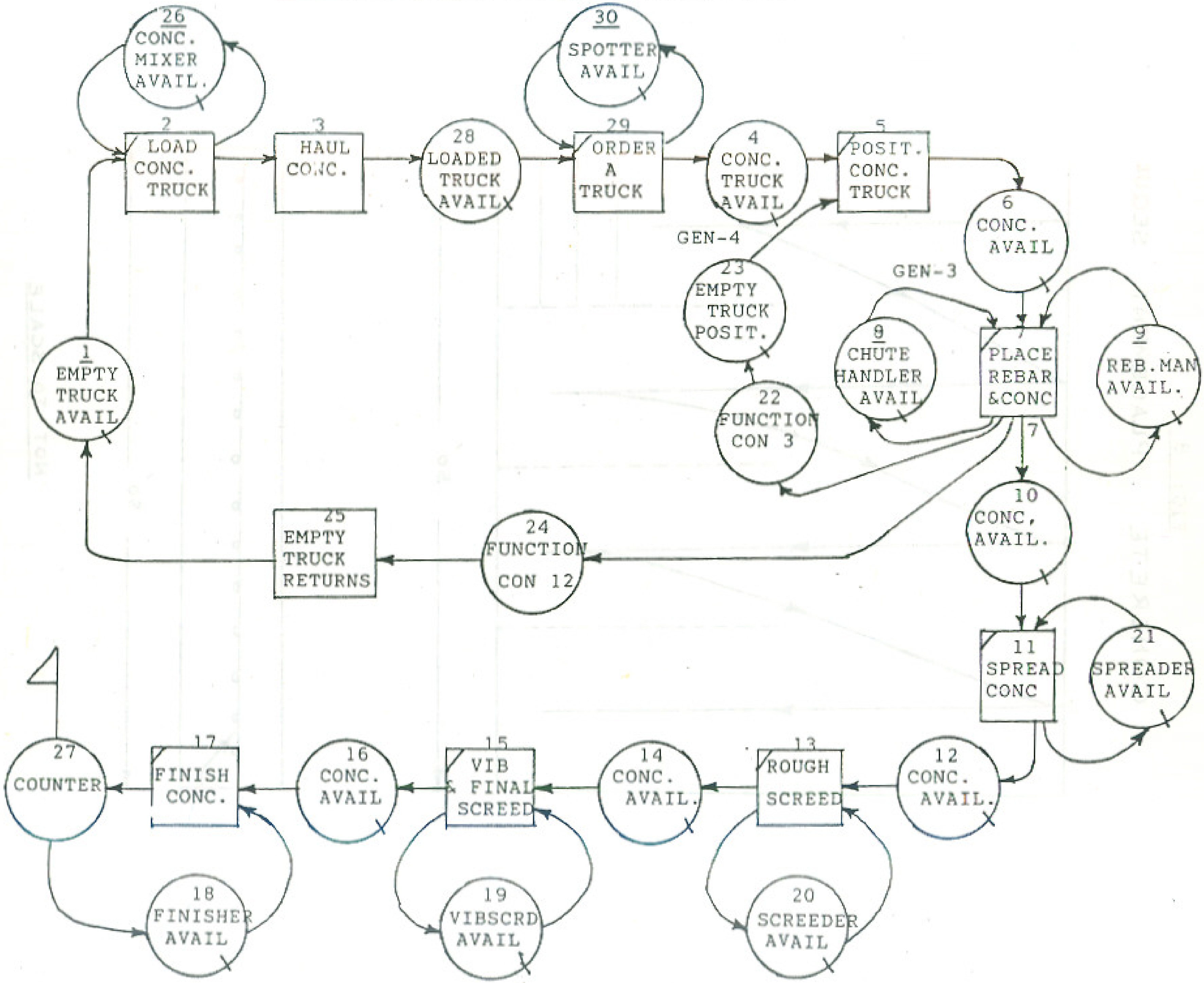
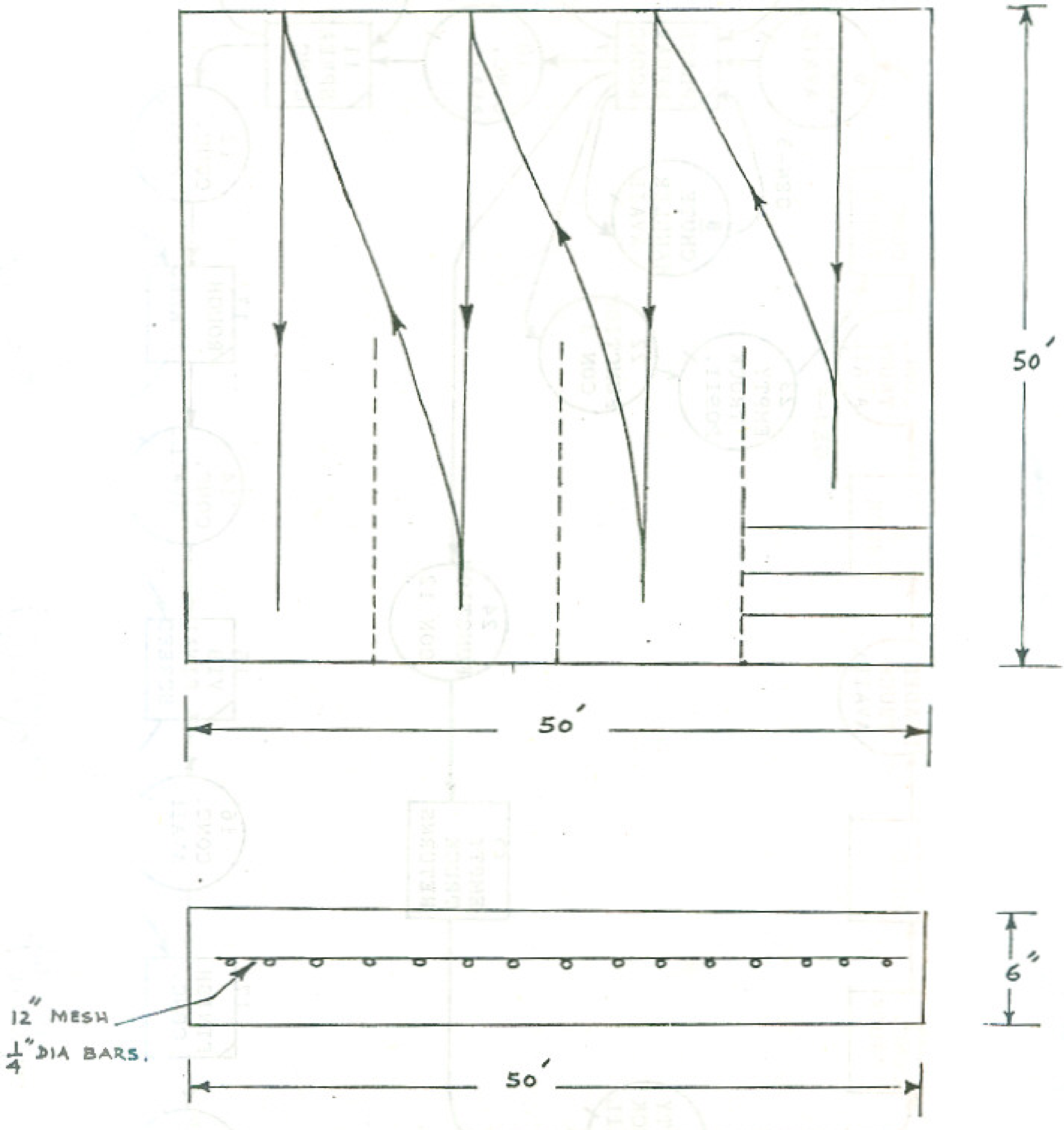


FIG:- 8

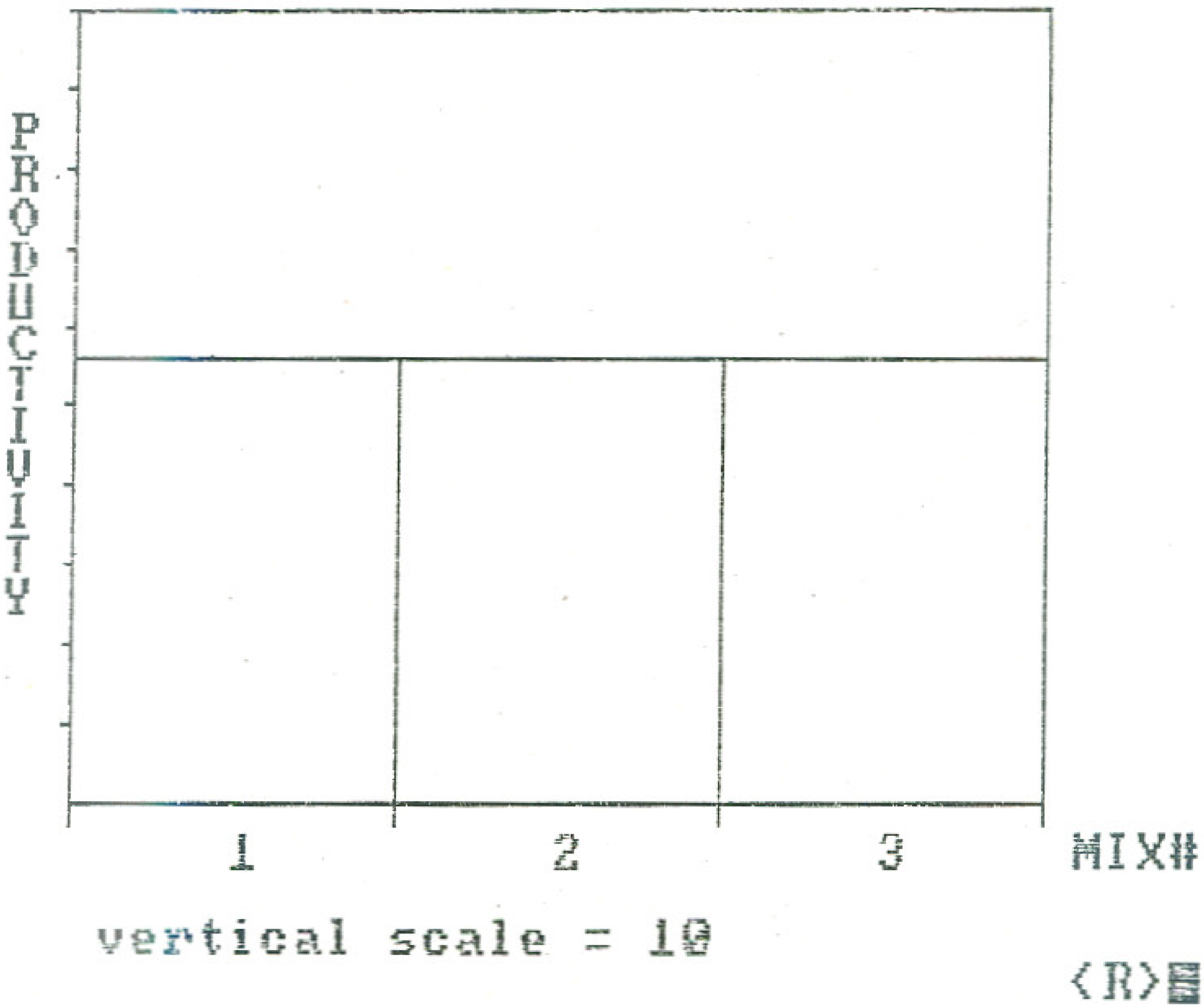
CONCRETE PLACEMENT SEQUENCE



NOT TO SCALE

Fig. No.

MIX #	TOTAL TIME	PRODUCTIVITY	TOTAL COST	UNIT COST	DESCRIPTION
1	102.00	58.82	0.00	0.00	TRY1
2	102.00	58.82	0.00	0.00	TRY1
3	102.00	58.82	0.00	0.00	TRY1

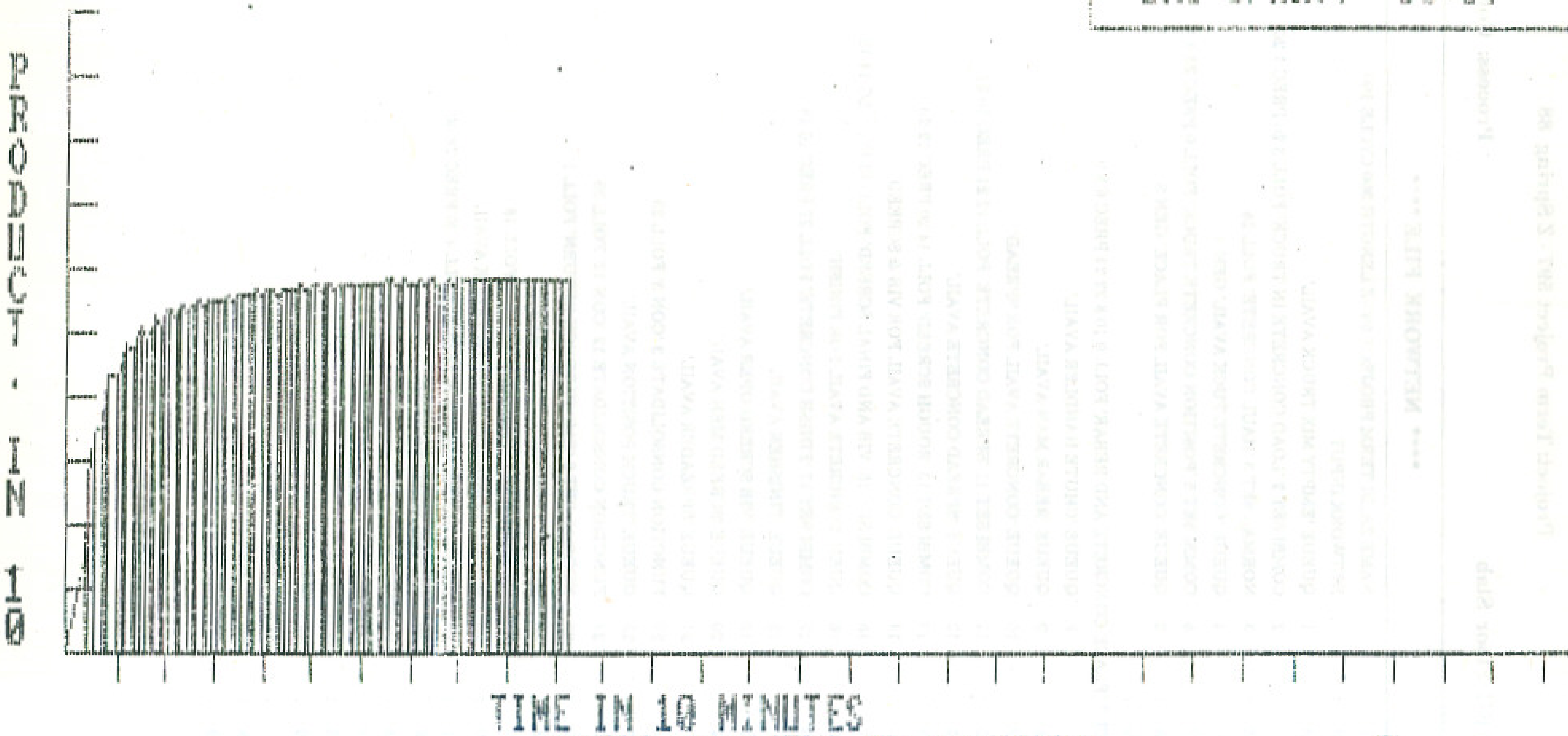


PRODUCTION CURVE FOR PROCESS: CONCRETE PLACEMENT 04-20-1988

COMMENT: ************

UNITS PROD.	CLOCK
96	102.75

UNITS/HR.: 58.67



PRESS <RETURN> TO CONTINUE.

Fig. No. 9

Table - 2

Project: Term Project 597 - Z Spring 88

Activity: RC Floor Slab **Process: Concrete Placement**

****** NETWORK FILE ******

```
LINE   1 -:      NAME ZAIDI TERM PROJECT 597-Z LENGTH 300 CYCLE 100
LINE   2  :      NETWORK INPUT
LINE   3  :   1  QUEUE 'EMPTY MIX TRUCK AVAIL'
LINE   4  :   2  COMBI SET 2 'LOAD CONCRETE IN TRUCK' FOLL 3 26 PREC 1 26
LINE   5  :   3  NORMAL SET 3 'HAUL CONCRETE' FOLL 28
LINE   6  :   4  QUEUE 'CONCRETE TUCK AVAIL' GEN 4
LINE   7  :   5  COMBI SET 5 'POSITION CONCRETE TRUCK' FOLL 6 PREC 23 4
LINE   8  :   6  QUEUE 'CONCRETE AVAIL FOR PLACE' GEN 3
LINE   9  :
7 COMBI SET 7 'PLACE CONCRETE AND REBAR' FOLL 9 10 8 22 24 PREC 6 8 9
LINE  10  :   8  QUEUE 'CHUTE HANDLER AVAIL'
LINE  11  :   9  QUEUE 'REBAR MAN AVAIL'
LINE  12  :  10  QUEUE 'CONCRETE AVAIL FOR SPREAD'
LINE  13  :  11  COMBI SET 11 'SPREAD CONCRETE' FOLL 12 21 PREC 10 21
LINE  14  :  12  QUEUE 'SPREAD CONCRETE AVAIL'
LINE  15  :  13  COMBI SET 13 'ROUGH SCREED' FOLL 14 20 PREC 12 20
LINE  16  :  14  QUEUE 'CONCRETE AVAIL FOR VIB & SCREED'
LINE  17  :  15  COMBI SET 15 'VIB AND FINAL SCREED' FOLL 16 19 PREC 14 19
LINE  18  :  16  QUEU 'CONCRETE AVAIL FOR FINISH'
LINE  19  :  17  COMBI SET 17 'FINISH CONCRETE' FOLL 27 PREC 16 18
LINE  20  :  18  QUEUE 'FINISHER AVAIL'
LINE  21  :  19  QUEUE 'VIB SCREED OPER AVAIL'
LINE  22  :  20  QUEUE 'SCREED MEN AVAIL'
LINE  23  :  21  QUEUE 'SPREADER AVAIL'
LINE  24  :  22  FUNCTION CONSOLIDATE 3 'CON 3' FOLL 23
LINE  25  :  23  QUEUE 'TRUCK POSITION AVAIL'
LINE  26  :  24  FUNCTION CONSOLIDATE 12 'CON 12' FOLL 25
LINE  27  :  25  NORMAL SET 2 'EMPTY TRUCK RETURN' FOLL 1
LINE  28  :  26  QUEUE 'CONCRETE MIXER AVAIL'
LINE  29  :  27  FUNCTION COUNTER QUANTITY 1 FOLL 18
LINE  30  :  28  QUEUE 'LOADED CONCRETE TRUCK AVAIL'
LINE  31  :  29  COMBI SET 29 'ORDER A TRUCK' FOLL 4 30 PREC 28 30
LINE  32  :  30  QUEUE 'SPOTTER AVAIL'
LINE  33  :  DURATION INPUT
LINE  34  :  SET  2 1.50
LINE  35  :  SET  3 4.0
LINE  36  :  SET  5 0.75
LINE  37  :  SET  7 0.75
LINE  38  :  SET 11 0.5
LINE  39  :  SET 13 0.25
```

```
LINE    40  :   SET 15 0.6
LINE    41  :   SET 17 1.50
LINE    42  :   SET 25 2.50
LINE    43  :   SET 29 0.2
LINE    44  :   RESOURCE INPUT
LINE    45  :   3  'MIX TRUCKS' AT 1
LINE    46  :   1  'MIX TRUCK' AT 4
LINE    47  :   1  'CHUTE HANDLER' AT 8
LINE    48  :   1  'REBAR MAN' AT 9
LINE    49  :   3  'FINISHERS' AT 18
LINE    50  :   1  'VIB SCREED OPER' AT 19
LINE    51  :   2  'SCREED MEN' AT 20
LINE    52  :   1  'SPREADER' AT 21
LINE    53  :   1  'TRUCK POSITION' AT 23
LINE    54  :   1  'CONCRETE MIXER' AT 26
LNE     55  :   1  'SPOTTER' AT 30
LINE    56  :   ENDDATA
```

Table - 3

Cyclone report # 1 (Report by Element)

TYPE	LABEL	DESCRIPTION	STATISTICS Count	Mean Dur	Ar. Time	Av. Num	% Busy
COMBI	2	LOAD CONCRETE IN	11	1.50	9.09	0.16	16.1
NORMAL	3	HAUL CONCRETE	10	4.00	9.20	0.39	34.1
COMBI	5	POSITION CONCRET	35	0.75	2.94	0.26	25.5
COMBI	7	PLACE CONCRETE A	102	0.75	1.00	0.74	74.5
COMBI	11	SPREAD CONCRETE	102	0.50	1.00	0.50	49.6
COMBI	13	ROUGH SCREED	102	0.25	1.01	0.25	24.8
COMBI	15	VIB AND FINAL SC	101	0.00	1.01	0.00	0.0
COMBI	17	FINISH CONCRETE	100	1.50	1.03	1.46	97.8
NORMAL	25	EMPTY TRUCK RETU	8	2.50	12.31	0.19	19.5
COMBI	29	ORDER A TRUCK	10	0.20	9.22	0.02	1.9

TYPE	LABEL	DESCRIPTION	STATISTICS AVG. WAIT	AVT. UNIT	UNITS END	% OCCUPIED
QUE	1	EMPTY MIX TRUCK	0.41	0.0	0	2.9
QUE-GEN	4	CONCRETE TRUCK A	23.86	10.2	9	100.0
QUE-GEN	6	CONCRETE AVAIL F	0.73	0.7	3	49.6
QUE	8	CHUTE HANDLER AV	0.25	0.3	1	25.5
QUE	9	REBAR MAN AVAIL	0.25	0.3	1	25.5
QUE	10	CONCRETE AVAIL F	0.00	0.0	0	0.0
QUE	12	SPREAD CONCRETE	0.00	0.0	0	0.0
QUE	14	CONCRETE AVAIL F	0.00	0.0	1	0.0
QUE	16	CONCRETE AVAIL F	0.00	0.0	0	0.0
QUE	18	FINISHER AVAIL	1.53	1.5	2	100.0
QUE	19	VIB SCREED OPER	1.01	1.0	1	100.0
QUE	20	SCREED MEN AVAIL	1.73	1.8	2	100.0
QUE	21	SPREADER AVAIL	0.50	0.5	1	50.4
QUE	23	TRUCK POSITION A	0.00	0.0	0	0.0
QUE	26	CONCRETE MIXER A	7.19	0.8	1	83.9
QUE	28	LOADED CONCRETE	0.00	0.0	0	0.0
QUE	30	SPOTTER AVAIL	9.16	1.0	1	98.1

Table - 4

Cyclone report # 2 (Cycle Monitoring Report)

DESCRIPTION	LABEL	T - NOW	COUNTER
POSITION CONCRETE TRUCK	5	0.8	1
PLACE CONCRETE AND REBAR	7	1.5	1
LOAD CONCRETE IN TRUCK	2	1.5	1
SPREAD CONCRETE	11	2.0	1
ROUGH SCREED	13	2.3	1
PLACE CONCRETEA DN REBAR	7	2.3	2
VIB AND FINAL SCREED	15	2.3	1
SPREAD CONCRETE	11	2.8	2
ROUGH SCREED	13	3.0	2
PLACE CONCRETE AND REBAR	7	3.0	3
LOAD CONCRETE INTRUCK	2	3.0	2
VIB AND FINAL SCREED	15	3.0	2
SPREAD CONCRETE	11	3.5	3
ROUGH SCREED	13	3.8	3
POSITION CONCRETE TRUCK	5	3.8	2
FINISH CONCRETE	17	3.8	1
VIB AND FINAL SCREED	15	3.8	3
PLACVE CONCRETE AND REBAR	7	4.5	4
INISH CONCRETE	17	4.5	2
LOAD CONCRETE IN TRUCK	2	4.5	3
SPREAD CONCRETE	11	5.0	4
ROUGH SCREED	13	5.3	4
PLACE CONCRETE AND REBAR	7	5.3	5
FINISH CONCRETE	17	5.3	3
VIB AND FINAL SCREED	15	5.3	4
HAUL CONCRETE	3	5.5	1
ORDER A TRUCK	29	5.7	1
SPREAD CONCRETE	11	5.8	5
ROUGH SCREED	13	6.0	5
PLACE CONCRETE AND REBAR	7	6.0	6
VIB AND FINAL SCREED	15	6.0	5

DESCRIPTION	LABEL	T - NOW	COUNTER
SPREAD CONCRETE	11	6.5	6
ROUGH SCREED	13	6.8	6
POSITION CONCRETE TRUCK	5	6.8	3
FINISH CONCRETE	17	6.8	4
VIB AND FINAL SCREED	15	6.8	6
HAUL CONCRETE	3	7.0	2
ORDER A TRUCK	29	7.2	2
PLACE CONCRETE AND REBAR	7	7.5	7
FINISH CONCRETE	17	7.5	5
SPREAD CONCRETE	11	8.0	7
ROUGH SCREED	13	8.3	7
PLACE CONCRETE AND REBAR	7	8.3	8
FINISH CONCRETE	17	8.3	6
VIB AND FINAL SCREED	15	8.3	7
HAUL CONCRETE	3	8.5	3
ORDER A TRUCK	29	8.7	3
SPREAD CONCRETE	11	8.8	8
ROUGH SCREED	13	9.0	8
PLACE CONCRETE AND REBAR	7	9.0	9
VIB AND FINAL SCREED	15	9.0	8
SPREAD CONCRETE	11	9.5	9
ROUGH SCREED	13	9.8	9
POSITION CONCRETE TRUCK	5	9.8	4
FINISH CONCRETE	17	9.8	7
VIB AND FINAL SCREED	15	9.8	9
PLACE CONCRETE AND REBAR	7	10.5	10
FINISH CONCRETE	17	10.5	8
SPREAD CONCRETE	11	11.0	10
ROUGH SCREED	13	11.3	10
PLACE CONCRETE AND REBAR	7	11.3	11
FINISH CONCRETE	17	11.3	9
VIB AND FINAL SCREED	15	11.3	10
SPREAD CONCRETE	11	11.8	11
ROUGH SCREED	13	12.0	11
PLACE CONCRETE AND REBAR	7	12.0	12

DESCRIPTION	LABEL	T - NOW	COUNTER
VIB AND FINAL SCREED	15	12.0	11
SPREAD CONCRETE	11	12.5	12
ROUGH SCREED	13	12.8	12
POSITION CONCRETE TRUCK	5	12.8	5
FINISH CONCRETE	17	12.8	10
VIB AND FINAL SCREED	15	12.8	12
PLACE CONCRETE AND REBAR	7	13.5	13
FINISH CONCRETE	17	13.5	11
SPREAD CONCRETE	11	14.0	13
ROUGH SCREED	13	14.3	13
PLACE CONCRETE AND REBAR	7	14.3	14
FINISH CONCRETE	17	14.3	12
VIB AND FINAL SCREED	15	14.3	13
EMTY TRUCK RETURN	25	14.5	1
SPREAD CONCRETE	11	14.8	14
ROUGH SCREED	13	15.0	14
PLACE CONCRETE AND REBAR	7	15.0	15
VIB AND FINAL SCREED	15	15.0	14
SPREAD CONCRETE	11	15.5	15
ROUGH SCREED	13	15.8	15
POSITION CONCRETE TRUCK	5	15.8	6
FINSH CONCRETE	17	15.8	13
VIB AND FINAL SCREED	15	15.8	15
LOAD CONCRETE IN TRUCK	2	16.0	4
PLACE CONCRETE AND REBAR	7	16.5	16
FINISH CONCRETE	17	16.5	14
SPREAD CONCRETE	11	17.0	16
ROUGH SCREED	13	17.3	16
PLACE CONCRETE AND REBAR	7	17.3	17
FINISH CONCRETE	17	17.3	15
VIB AND FINAL SCREED	15	17.3	16
SPREAD CONCRETE	11	17.8	17
ROUGH SCREED	13	18.0	17
PLACE CONCRETE AND REBAR	7	18.0	18

Table - 5

Cyclone Report # 3 (Production by Cycle)

SIMULA. TIME	CYCLE NUMB.	PRODUCTIVITY (UNITS/HOUR)
3.8	1	16.0000
4.5	2	26.6667
5.3	3	34.2857
6.8	4	35.5556
7.5	5	40.0000
8.3	6	43.6364
9.8	7	43.0769
10.5	8	45.7143
11.3	9	48.0000
12.8	10	47.0588
13.5	11	48.8889
14.3	12	50.5263
15.8	13	49.5238
16.5	14	50.9091
17.3	15	52.1739
18.8	16	51.2000
19.5	17	52.3077
20.3	18	53.3333
21.8	19	52.4138
22.5	20	53.3333
23.3	21	54.1935
24.8	22	53.3333
25.5	23	54.1176
26.3	24	54.8571
27.8	25	54.0541
28.5	26	54.7368
29.3	27	55.3846
30.8	28	54.6341
31.5	29	55.2381

SIMULA. TIME	CYCLE NUMB.	PRODUCTIVITY (UNITS/HOUR)
32.3	30	55.8140
33.8	31	55.1111
34.5	32	55.6522
35.3	33	56.1702
36.8	34	55.5102
37.5	35	56.0000
38.3	36	56.4706
39.8	37	55.8491
40.5	38	56.2963
41.3	39	56.7273
42.8	40	56.1404
43.5	41	56.5517
44.3	42	56.9492
45.8	43	56.3934
46.5	44	56.7742
47.3	45	57.1429
48.8	46	56.6154
49.5	47	56.9697
50.3	48	57.3134
51.8	49	56.8116
52.5	50	57.1429
53.3	51	57.4648
54.8	52	56.9863
55.5	53	57.2973
56.3	54	57.6000
57.8	55	57.1429
58.5	56	57.4359
59.3	57	57.7215
60.8	58	57.2840
61.5	59	57.5610
62.3	60	57.8313
63.8	61	57.4118
64.5	62	57.6744
65.3	63	57.9310

SIMULA. TIME	CYCLE NUMB.	PRODUCTIVITY (UNITS/HOUR)
66.8	64	57.5281
67.5	65	57.7778
68.3	66	58.0220
69.8	67	57.6344
70.5	68	57.8723
71.3	69	58.1053
72.8	70	57.7320
73.5	71	57.9592
74.3	72	58.1818
75.8	73	57.8218
76.5	74	58.0392
77.3	75	58.2524
78.8	76	57.9048
79.5	77	58.1132
80.3	78	58.3178
81.8	79	57.9817
82.5	80	58.1818
83.3	81	58.3784
83.8	82	58.0531
85.5	83	58.2456
86.3	84	58.4348
87.8	85	58.1197
88.5	86	58.3051
89.3	87	58.4874
90.8	88	58.1818
91.5	89	58.3607
92.3	90	58.5366
93.8	91	58.2400
94.5	92	58.4127
95.3	93	58.5827
96.8	94	58.2946
97.5	95	58.4615
98.3	96	58.6260
99.8	97	58.3459
100.5	98	58.5075
101.3	99	58.6667

CYCLONE REPORT # 4 (PROCESS REPORT)

RUN LENGTH	102.75
NUMBER OF CYCLES	100.00
UNITS PRODUCED PER CYCLE	1.00
TOTAL PRODUCTION	100.00
UNITS PRODUCED PER DAY	58.39

COST SUMMARY DATA

DAILY PRODUCTION	58.39
TOTAL COST (VAR + FIXED)	0.00
COST PER UNIT	0.00

Table - 6

CYCLONE REPORT # 5
(NETWORK LOGIC DUMP REPORT)

WORK TASK CONTENT DUMP REPORT

NODE	2	COMBI	PRECED	1	26		FOLL	3	26			
NODE	3	NORMAL	FOLL	28								
NODE	5	COMBI	PRECED	23	4		FOLL	6				
NODE	7	COMBI	PRECED	6	8	9	FOLL	9	10	8	22	24
NODE	11	COMBI	PRECED	10		21	FOLL	12	21			
NODE	13	COMBI	PRECED	12		20	FOLL	14	20			
NODE	15	COMBI	PRECED	14		19	FOLL	16	19			
NODE	17	COMBI	PRECED	16		18	FOLL	27				
NODE	32	FUNCTION	FOLL	23								
NODE	24	FUNCTION	FOLL	25								
NODE	25	NORMAL	FOLL	1								
NODE	27	FUNCTION	FOLL	18								
NODE	29	COMBI	PRECED	28		30	FOLL	4	30			

QUE CONTENT DUMP REPORT

QUE	1	HAS	0	UNITS.	IT	IS	INITIALIZED	WITH	3	UNITS
QUE	4	HAS	9	UNITS.	IT	IS	INITIALIZED	WITH	1	UNITS
QUE	6	HAS	3	UNITS.	IT	IS	INITIALIZED	WITH	0	UNITS
QUE	8	HAS	1	UNITS.	IT	IS	INITIALIZED	WITH	1	UNITS
QUE	9	HAS	1	UNITS.	IT	IS	INITIALIZED	WITH	1	UNITS
QUE	10	HAS	0	UNITS.	IT	IS	INITIALIZED	WITH	O	UNITS
QUE	12	HAS	O	UNITS.	IT	IS	INITIALIZED	WITH	0	UNITS
QUE	14	HAS	1	UNITS.	IT	IS	INITIALIZED	WITH	0	UNITS
QUE	15	HAS	0	UNITS.	IT	IS	INITIALIZED	WITH	0	UNITS
QUE	18	HAS	2	UNITS.	IT	IS	INITIALIZED	WITH	3	UNITS
QUE	19	HAS	1	UNITS.	IT	IS	INITIALIZED	WITH	1	UNITS
QUE	20	HAS	2	UNITS.	IT	IS	INITIALIZED	WITH	2	UNITS
QUE	21	HAS	1	UNITS.	IT	IS	INITIALIZED	WITH	1	UNITS

QUE	23	HAS	0	UNITS.	IT	IS	INITIALIZED	WITH	1	UNITS
QUE	26	HAS	1	UNITS.	IT	IS	INITIALIZED	WITH	1	UNITS
QUE	28	HAS	0	UNITS.	IT	IS	INITIALIZED	WITH	0	UNITS
QUE	30	HAS	1	UNITS.	IT	IS	INITIALIZED	WITH	1	UNITS

Table - 7

Process Name: RC Fcon

Percent of Time work Tasks are Busy

LABEL	MIX # 1	MIX # 2	MIX # 3
2	12.75	14.71	15.69
3	31.84	32.84	34.83
5	25.49	25.49	25.49
7	75.06	75.06	75.06
11	50.75	50.75	50.75
13	25.00	25.00	25.00
15	0.00	0.00	0.00
17	100.00	100.00	100.00
25	22.22	22.22	22.22
29	1.55	1.76	1.97

Table - 8

Process Name: RC Fcon

Percent of Time ques are Occupied

LABEL	MIX # 1	MIX # 2	MIX # 3
1	0.00	1.47	2.94
4	100.00	100.00	100.00
6	50.00	50.00	50.00
8	25.49	25.49	25.49
10	0.00	0.00	0.00
12	0.00	0.00	0.00
14	0.00	0.00	0.00
16	0.00	0.00	0.00
18	100.00	100.00	100.00
19	100.00	100.00	100.00
20	100.00	100.00	100.00
21	50.00	50.00	50.00
23	0.00	0.00	0.00
26	87.25	85.29	84.31
28	0.00	0.00	0.00
30	99.02	98.04	98.04

Table - 9

Process Name: RC Fcon
Average Number of Units in Ques

LABEL	MIX # 1	MIX # 2	MIX # 3
1	0.00	0.01	0.04
4	2.85	6.60	1.02
6	0.75	0.75	0.75
8	0.25	0.25	0.25
9.	0.25	0.25	0.25
10	0.00	0.00	0.00
12	0.00	0.00	0.00
14	0.00	0.00	0.00
16	0.00	0.00	0.00
18	1.54	1.54	1.54
19	1.00	1.00	1.00
20	1.76	1.76	1.76
21	0.50	0.50	0.50
23	0.00	0.00	0.00
26	0.87	0.85	0.84
28	0.00	0.00	0.00
30	0.99	0.98	0.98

Table - 10

Process Name: C Fcon

Average Waiting Time in Ques

LABEL	MIX # 1	MIX # 2	MIX # 3
1	0.00	0.15	0.41
4	8.08	6.83	2.36
6	0.72	0.72	0.72
8	0.25	0.25	0.25
9	0.25	0.25	0.25
10	0.00	0.00	0.00
12	0.00	0.00	0.00
14	0.00	0.00	0.00
16	0.00	0.00	0.00
18	1.52	1.52	1.52
19	1.00	1.00	1.00
20	1.73	1.73	1.73
21	0.50	0.50	0.50
23	0.00	0.00	0.00
26	8.90	7.91	7.17
28	0.00	0.00	0.00
30	11.22	10.00	9.09

APPENDIX - A

M.P.D.M. Analysis

of

A Real World Process

APPENDIX - A
PRODUCTION CYCLE DELAY SAMPLING FOR M.P.D.M.
TABLE - A

Process - Excavation & Haul of Earth | **Time Unit: Minute**
Method: Dozer Scraper Combination | **Production Unit: Scraper Load**

Prod Cycle	Scraper No.	Production Cycle Time	Delay - Type and Duration				Queue Time if Queue Exists	Minus Non-Delay Time	Non-Delay Cycle	Remarks
			Labour	Environ-mental	Manage-ment	Equip-ment				
1	2	11.38	0.50	--	--	--	2.00	1.68		
2	1	14.75	--	1.50	--	--	3.55	5.95		
3	3	16.43	--	--	2.48	--	4.25	6.73		
4	4	16.62	--	--	--	--	4.37	6.92		
5	2	18.70	--	--	--	--	4.36	9.00		
6	1	37.25	6.89	--	21.66	--	--	27.55		
7	3	15.17	--	--	3.32	--	2.15	5.47		
8	4	13.97	--	2.00	--	--	2.35	4.27		
9	2	9.71	--	--	--	--	--	0.01	0	
10	3	13.10	--	--	3.40	--	--	3.40		
11	4	44.61	8.73	--	26.18	--	--	34.91		
12	2	17.96	3.00	--	--	--	5.38	8.26		
13	3	13.10	--	--	--	--	1.80	3.40		
14	1	13.20	--	3.50	--	--	--	3.50		
15	2	8.92	--	--	--	--	--	0.78	0	
16	3	11.00	--	--	--	--	--	1.30	0	
17	1	13.10	--	--	--	--	2.76	3.40		
18	2	8.66	--	--	--	--	--	1.04	0	
19	3	11.20	1.5	--	--	--	--	1.50		
20	2	38.67	7.25	--	21.73	--	--	28.97		

Prod Cycle	Scraper No.	Production Cycle Time	Labour	Delay - Type and Duration			Queue Time if Queue Exists	Minus Non-Delay Time	Non-Delay Cycle	Remarks
				Environ-mental	Manage-ment	Equip-ment				
21	1	10.80	1.10	--	--	--	--	1.10		
22	3	11.83	--	--	--	--	--	2.13	0	
23	1	8.19	--	--	--	--	--	1.51	0	
24	3	12.50	2.80	--	--	--	--	2.80		
25	1	9.60	--	--	--	--	--	0.10	0	
Total:-		402.92	31.77	7.00	78.77	--	32.97	164.78		for NDC=6.87

M.P.D.M. PROCESSING

TABLE - B

ITEMS	TOTAL PRODUCTION TIME	NUMBER OF CYCLES	MEAN CYCLE TIME	THIS UNDELLING & THE LONGER DSAK IS A MATHEMATICAL REQUIREMENT & MAY PLEASE BE INTRODUCED
(1)	(2)	(3)	(4)	(5)
Non-Delayed Production Cycles	67.91	7	9.70	6.87/7 = 0.98
Overall Production Cycles	402.92	25	16.12	164.78/25 = 6.59

DELAY INFORMATION

TABLE - C

S. No. or Row No.	TIME VARIANCE	LABOUR	ENVIRON-MENTAL	MANAGE-MENT	EQUIP-MENT	QUEUE	REMARKS
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1	Occurances	8	3	6	0	10	
2	Total Added time of delay	31.77	7.00	78.77	0	32.97	
*3	Probability of Occurances	0.32	0.12	0.24	0	0.40	
**4	Relative Severity	0.24	0.14	0.81	0	0.20	
***5	Expected % age of delayed time per total production time	7.88	1.70	19.60	0	8.20	

* Probability of occurance = $\frac{\text{\# of Occurances}}{\text{Total number of cycles.}} = \frac{\text{ROW1}}{25}$ as decimal fraction.

** Relative Severity = $\frac{\text{Mean Delay time}}{\text{Mean overall cycle time}} = \frac{\text{ROW2}}{\text{ROW1}} \times \frac{1}{16.12}$

*** Expected percentage of delay time per total production time. = $\frac{\text{Total delay time}}{\text{Total production time or Production cycle times}} = \frac{\text{ROW2}}{402.92} \times 100$

Ideal cycle variability = $\frac{\text{Mean variation (Non delay cycles}}{\text{Mean non delay cycle time}} = \frac{\text{ROW1, Col-5 Table-B}}{\text{ROW1, Col-4 Table -B}}$

$= \frac{0.98}{9.7} = 0.101$

Overall cycle variability = $\frac{\text{Mean variation (Non delay cycles}}{\text{Mean non delay cycle time}} = \frac{\text{ROW1, Col-5 Table-B}}{\text{ROW1, Col-4 Table -B}}$

$= \frac{6.59}{16.12} = 0.409$ .... (Variability is considered indicator or a poor performance.

Ideal Producivity = $\frac{60}{9.70} = 6.19$ loads/Hr/scraper = $\frac{\text{(Minutes in one hr)}}{\text{(Ideal cycle time)}}$

Ideal productivity of the system = 6.19 x 4 = 24.76 loads/hr.

Actual productivity = (Ideal productivity) $\left(1 - \sum_{J=1}^{m} E_j\right)$

Where $\sum_{J=1}$ EJ is the sum of all types of delays expressed as decimal fraction of the total production time.

Here $\sum_{J=1}^{m} EJ = E_{Lab} + E_{env} + E_{mgt} + E_{eqp} + E_{que}$

$= 0.079 + 0.017 + 0.196 + 0.0 + 0.082$

$= 0.374$

Actual Productivity = 6.19 (1-0.374) = 6.19 x 0.625

= 3.875 Loads/Hr/scraper

& Actual productivity of the system = 3.875 x 4 = 15.50 loads/hr.

Sources and Magnitude of Delays

(i)	Labour	=	7.9%
(ii)	Environment	=	1.7%
(iii)	Management	=	19.6%
(iv)	Queue	=	8.2%

Actual field production $= \dfrac{25 \times 60}{108} =$ 13.89 Loads/hr.

II. Deterministic Production Computations

Relevant Equipment;

(i) Scraper - Cat-621-B - Wheeled - 4
(ii) Buldozer (Pusher) - Cat D.9.G - Track - 1
Haul Distance = 1100 meters
Haul Resistances:
(i) Rolling = 5.0%
(ii) Grade = 3.0%
Total Resistance = 8.0%

(a) Productivity

Scraper cycle time = Total of load, Haul, Dump/Spread and Return Time

(i)	Load Time	=	0.7 minute......................	(Page - 14 Section - II)*
(ii)	Haul Time	=	3.8 Minutes......................	(Page - 32 Section - II)*
(iii)	Dump/spread time		0.9 Minutes......................	(Page - 14 Section - II)*
(iv)	Return time	=	2.5 Minutes......................	(Page - 23 Section - II)*

Total cycle time = 7.7 minutes
and scraper cycles/hr = 60/7.7 = 7.8

Correcting for Efficiency coefficient:
Productivity per Scraper hr = 7.8 x 0.83** = 6.47 loads

and System productivity = 6.47 x 4 = 25.88 loads/hrs.

(b) System Balancing:

Pusher cycle time = Manouvre time + Boost time + Contact Time + Load Time

(i)	Manouvre time	=	0.28 Minutes (Assumed as 40% of load time)
(ii)	Boost time	=	0.10 minutes ***
(iii)	Contact time	=	0.10 minutes G.M. Terex Manual P-28
(iv)	Load time	=	0.7 minute.... (Page 14 Section - II)*

Total cycle time = 1.18 minutes say 1.2 minutes.

No of scrapers required for Balanced Working $= \dfrac{\text{Scraper cycle time}}{\text{Pusher cycle time}}$

$$= \frac{7.7}{1.2} = 6.42 \quad \text{Say} = 6$$

As we have only 4 scrapers in the system, the system requires 2 more scrapers to reach the balance point.

Refrence Notes for Sheet 1 to 2

- * Refers to Caterpillar Performance Hand Book - 7th Edition.
- ** Refers to Means Manual, 1987 - 355.
- *** Refers to G.M. Terex Manual (Revised)