UNITED ARAB REPUBLIC

THE INSTITUTE OF NATIONAL PLANNING

التخطيط القومي

Memo. No. 900

AN INTRODUCTION TO SIMULATION

BY

ALWALID ELSHAFEI
OPERATIONS RESEARCH GROUP

JUNE 1969

CAIRO
3. MOHAMED MAZHAR - ZAMALEK

INTRODUCTION

Simulation, one of the earliest applications of general-purpose digital computers, continues to be one of the major applications of them. But even in the computer world, simulation is a word which means many things to many people: making one digital computer behave like another, for example, or studying the flight behavior of a ballistic missile by means of a numerical mock-up, or modeling a business enterprise to study the effect of certain management decisions, or the scheduling of maintenance, inventory, procurement, tracking of space vehicles. Simulation is perhaps most common in engineering, where analog computers have long been used to model continuous system dynamics. Simulation, in one sense, is identified by various terms-discrete event network, computer simulation, stochastic models, particle flow, discrete processes, Monte Carlo, etc. Discrete-systems simulation techniques are applied to problems in highway traffic flow, message handling networks, job shop manufacturing operations, computer systems, and logistics-supply systems, among others.

In this presentation, we are concerned particularly in two separate identifications of simulation:

(1) Discrete-systems simulation.

(2) Monte Carlo Simulation Technique.

1 DISCRETE SYSTEMS SIMULATION

1-1 BACKGROUND

In the past, discrete systems simulation, in various forms, has been closely connected with operations research. Originating in Game Theory, which started in the 1920's, it might be considered one of the latest skills of the operations researcher, an extension of the statistical technique known as distribution sampling. Dealing first mainly with military problems, discrete systems simulations later were applied to business and industrial systems problems. Early applications were for the most part nonengineering: scheduling of ships, trucks, and railway cars, allocating resources in job shops. But recently, the engineering sciences have begun to depend more and more on the simulation of discrete systems. The swing is evident in the growing number of simulation studies involving complex engineering designs - communication traffic flow, computer systems performance and reliability, advanced teleprocessing systems, diesel power requirements in railroad systems, to name a few. This has been due mainly to (1) the availability of large-capacity, high-speed digital computers, (2) the absolute necessity (considering the economic commitments at stake) of studying the performance of complex systems by simulation, (3) a better understanding of simulation methods and, (4) the development of computer programs, simulation languages and other techniques to aid the analyst or engineer.

1-2 DISCRETE VS. CONTINUOUS?

The simulation world seems to be divided into two camps, the discrete and the continuous, but the differences may be more apparent than real. What distinguishes continuous systems simulation from discrete systems simulation? ... the computer used, analog or digital? ... continuous or discrete behavior in the real system being simulated? ... the viewpoint of the engineer or analyst who establishes the model of the real system?

This much we know. Electronic analog computers operate continuously and simulation using them is based upon continuous measurement. On the other hand, electronic digital computer operations are discrete, sequential steps, and all computation is based on discrete measurements. The nature of the digital machine precludes continuous activity in simulation or any other task.

In the real world, all activity is continuous. Time and tide wait for no man, and ceaseless changes occur in all systems, where things grow, decay, move in space, and so on. Whether the example is fuel flow, or projectile movement through space, continuity is violated whenever we try to "pin it down" by simulating the system on a digital computer. Thus a discrete process only approximates a continuous process. The key word is approximate, which underlies the entire domain of simulation.

How may we view the real world, and what tools have we to describe it precisely? The characteristics of the real system under investigation suggest and to some extent determine the modeling approach. Many dynamic systems can be approximated by sets of differential or other mathematical equations, and we simulate such systems by solving these equations (and making some compromises, as in any approach). With extensive use, this older type of simulation has undergone a scrutiny of its logical foundation and mechanization procedures, so that a sort of "theory" exists for it.

Where mathematical equations do not apply, we describe dynamic systems in other ways: logical equations, block diagrams, flow charts, and so on, in various combinations. An adequate model for a discrete system usually requires this approach. For such purposes, there exists no polished, logical structure comparable to that in, say, the mathematical theory of functions of a complex variable. It has not been possible, so far, to reduce the operation of a logistics system or a steel mill to a concise set of mathematical equations. The approximation is rougher, in a sense, because the problem is so much more complex.

Analog simulation devices have been used in various operations research studies. The QUEUIAC, for example, was designed for the study of queueing, a class of problems usually belonging to the world of discrete systems! So in practice, we find both continuous systems and discrete systems being studied by means of both continuous and discrete machines.

The net of all this is simply how the real world is viewed by the analyst or engineer. Will he cut up space asswell as time in discrete units, or will he think in terms of continuous variables? This depends largely upon the tools available, the mathematical techniques for systems study.

1-3 COMPUTING TECHNIQUES

Computing techniques in discrete system simulation are necessarily unlike those in most continuous-system digital simulations because the systems are represented so differently. A continuous system, as noted, is often represented by differential equations, a discrete system, by less formal methods, but in both cases the independent variable is time. A digital computer model is a numerical representation of the status of the real world being simulated. As a model is moved through simulated time, or "animated," this status is modified at discrete time steps to reflect changes, i.e., one or more events which change the status of the simulated system. Here the word "status" is the clue. We examine everything "as it stands," i.e., as if it stood still or froze in its tracks when we rang a bell. The system is caught in the act, so to speak.

Continuous systems simulators ordinarily use a "snapshot" approach, recording the status of important variables at regular time intervals to provide a time history of a simulation run. In discrete systems, the approach is somewhat different. Here, a statistical summary is presented at the end of a run based upon data collected during the run, but collected at discrete steps, as we have said.

In discrete simulation, a numerical description identifies each type of component (each entity) in the system, specifies it (gives its properties or attributes) and specifies the dynamics of the system, including the relationships of all entities. In addition, a numerical description includes decision rules which define the interplay between entities.

Although simulation programs can be organized in many ways, most of them have similar basic functions. A simulation is usually regulated by a central program which schedules events in regard to timing and sequence. Most simulators are built on a next-event principle, updating the "clock" when the next event is imminent. (The time increment is a function of the state of the model and is computed at each time cycle). When the time arrives, events which can take place do so, and the clock is then updated to the next event time. This, in effect, provides a mechanism for parallel computation. Since time is advanced in variable steps, an event can occur at any point in simulated time. Included in this operation is a scan of all events to select those which coincide with the present value of the clock. To facilitate scanning, most programs keep an event list ordered by time. (Another method is to use uniform intervals of time, but, since events usually occur unevenly in time, this method is less efficient).

List-processing plays an important role in the computational aspect of simulation, as in many computer programs. In programming jargon, lists are a series of words or groups of words in storage, not necessarily contiguous, but chained together, generally by pointers included in the elements to serve as links. Accordingly, computer storage is organized in an associative fashion. Queues are represented by lists of words in storage; events, by lists which are scanned at the appropriate clock times. Chaining techniques normally associate entities, lists of entities, and their attributes. Numerous subprograms are designed to manipulate these lists-to place an entity on a list or remove it, to scan a list for entities having certain attributes, to create and destroy lists, and so on. Implied is a dynamically allocated storage. Size and number of lists are not usually known before a simulation run is made; therefore, a pool of storage must be available to the program from which lists can be constructed and modified during a simulation run.

Good program design will usually include considerable logical capability. Most simulation programs aim to solve complex logical and decision-making problems, and depend on the flexibility of digital computer logic. In practice, most program steps in a simulation involve testing and data manipulation (is a queue empty ? is a facility in use?); relatively few steps involve arithmetic computations.

An underlying concept in computer simulation is statistical sampling, and statistical quantities must be computed to measure system performance. To handle the random variables in systems being simulated, most simulation programs contain mechanisms for inputting and storing various statistical distributions for these variables, and for selecting values for particular events during a simulation run. There are several techniques for generating random numbers for this purpose. Random numbers are used not only as arguments for table look-up functions, but also are used in conjunction with program decision-making. It is not uncommon that many logical decisions be made by a random choice.

The output of a simulation is composed of statistical quantities which most programs accumulate in an appropriate way, analyze, and present in a meaningful form. For instance, the output data may be queue statistics (average and maximum length of queue, the average time a unit remains in queue), or take the form of histograms providing distribution information about important system variables.

As we have seen, simulation programs are list-structured to a high degree, and operations on data sets play a major part in the overall computation. Computations involve principally decision-making and the manipulation of data, with only a minimum of arithmetic. The high degree of computational accuracy required in numerical problems is not the main purpose in simulations. A significant characteristic of many simulation programs is their high ratio of computing to input-output activity.

2- MONTE CARLO SIMULATION TECHNIQUE

WHAT IS MONTE CARLO SIMULATION? Monte Carlo simulation is a technique that aids management in making decisions involving the design and operation of physical and business systems. As is the case with all simulations, the objective is to devise a model that behaves like the real system with respect to those characteristics which are relevant to the decisions under consideration. The model has parameters that correspond to specific design and operating variables in the real system. These are analogous to parameters in other simulation models such as the curvature of the cross section of a wing in a wind tunnel, the rate of flow in a pilot plant, the resistance of an element in an analog computer, or the value of a mathematical variable "x". The model is manipulated by changing its parameters. On the basis of the observation of the behavior of the simulation model, conclusions are drawn about the real system.

2-1 Numerical model

The name Monte Carlo derives from the fact that sampling from statistical distributions is an essential part of carrying out these simulations. Some of the input variables to the model are subject to random variation. As such, a distribution of possible values instead of specific values is known. In making a Monte Carlo simulation run, values of these variables are obtained by random sampling from the specified distributions using tables of random numbers, computer subprograms that generate random numbers, or physical sampling methods such as tossing coins, throwing dice, spinning wheels or drawing cards. Mechanical failures, service times and demand rates are examples of variables which are frequently described by statistical distributions.

A Monte Carlo simulation is generally run on a digital computer, though in principle it could be performed using pencil and paper and the aid of random number tables or other physical methods of introducing random variation. In practice, the amount of sampling, data handling and bookkeeping is so large that a computer becomes indispensable.

As mentioned, making a Monte Carlo simulation run corresponds to observing the behavior of the real system. A set of numbers represents the status of each component in the real system at an instant of time. New numbers are generated through random sampling and the entire set of numbers is modified according to the logic of the model in order to represent the new status of the system. This process is repeated as often as desired, simulating the operation of the real system. During the course of the simulation appropriate statistics about the behavior of the system are collected. These statistics are subsequently used to help management evaluate alternative policies and make decisions.

2-2 Illustrative example

To illustrate the Monte Carlo simulation approach, consider the following example: A particular chemical production complex produces a range of intermediate products which are combined in specified proportions and sold as mixtures. Because of a lack of inventory space for finished products, and the peculiar specifications of each order, each mixture must be prepared immediately before shipment. In order to prepare a mixture, the intermediates are transferred in the proper proportions to the mixing tanks. For the purposes of the illustration assume that the intermediate products are always available, that the preparation of each mix requires one working day, and that each order is for a unit mix load. The average demand for the five mixtures A,B.... E is presented in Table 1, and the problem is to determine the proper number of mixers.

Table 1. Average orders per day for mixtures.

MIXTURE	AVERAGE ORDERS PER DAY
A	3.5
B	2.35
C	3.5
D	1.4
E	1.75
Total for all mixtures	12.50

The average daily demand is 12.5 mixtures. Therefore, at first glance 13 mixers might seem adequate. However, the average figure for demand does not present the entire picture, for some days there will be more than 12.5 orders and some days less. In the former case, the excess orders will become back orders which will hamper service. It is, therefore, necessary to consider a distribution of the demand. Table 2 presents the frequency distribution of orders/day for each mixture, indicating that even though the average daily demand is 12.5, there will still be significant variations around this average.

Table 2, Frequency distribution of orders per day.

PERCENTAGE OF DAYS

No. of orders	A	B	C	D	E
1	2.1	14.3	0.4	2.1	36.7
2	20.3	49.0	8.7	58.7	53.9
3	34.6	26.6	43.7	37.1	8.7
4	22.4	8.7	37.4	2.1	0.7
5	12.9	1.4	8.7		
6	4.6		1.1		
7	2.7				
8	0.4				

Next consider a criterion for an adequate design. One approach might be to decide to have a number of mixers which is greater than the demand for 95% of the days. A Monte Carlo procedure could then be used to calculate the proper number of mixers based on this criterion.

To do this, it is necessary to pick random samples from the distributions of order rates. To illustrate a possible sampling procedure, first prepare cumulative frequency distributions and a procedure for generating random numbers from 000 to 999 (by using a random number table, computer program; or drawing numbers from a hat). If the numbers from 000 to 999 are assigned to the different order levels in proportion to the percentage of days with that order level (see Table 3), a random sample of a number from 000 to 999 will generate a sample from the order distribution. Table 4 illustrates the results of this sampling procedure for one day.

Table 3. Cumulative frequency distribution of orders per day for each mixture, and the assignment of the numbers 000-999 to different order levels.

No. of Orders.	MIXTURE A		MIXTURE B		MIXTURE C		MIXTURE D		MIXTURE E	
	Cum. FREQ., %	ASSIGNED Nos.	CUM. FREQ., %	ASSIGNED Nos.	CUM. FREQ., %	ASSIGNED Nos.	CUM. FREQ., %	ASSIGNED Nos.	CUM. FREQ., %	ASSIGNED Nos.
1	2.1	000-020	14.3	000-142	0.4	000-003	2.1	000-020	36.7	000-366
2	22.4	021-223	63.3	143-632	9.1	004-090	60.8	021-607	90.6	367-905
3	57.0	224-569	89.9	633-898	52.8	091-527	97.9	608-978	99.3	906-992
4	79.4	570-793	98.6	899-985	90.2	528-901	100.0	979-999	100.0	993-999
5	92.3	794-924	100.0	986-999	98.9	902-988				
6	96.9	925-968			100.0	989-999				
7	99.6	969-995								
8	100.0	996-999								

Table 4. Random sample of a day's activity.

PRODUCT	RANDOM DIG.	No. OF ORDERS
A	392	3
B	480	2
C	923	5
D	102	2
E	684	2
		14

This process has been carried out on a computer using the distributions of the demand for mixtures A, B, ... E given above. A computer program has generated 2,000 days of demand and prepared the cumulative frequency-distribution of the total demand seen in Table 5.

It can be seen that for 97.35% of the days there are 16 or less orders. On only 2.65% of the days there are more than 16 orders. However, with 16 mixers, the percentage of days in which all the orders arising in that day could be handled immediately would be smaller than 97.35% because of back orders. These back orders occur whenever the number of orders is greater than the number of mixers (or if orders plus back orders is greater than the number of mixers).

It is, therefore, necessary to maintain a list of unfilled orders during the simulation in order to evaluate the percentage of orders which will not have to wait or the percentage of days during which there would be no backlogs. In order to do this, several simulation runs must be made, each assuming a definite number of mixers (i.e., with the number of mixers as a parameter). In each run daily orders are generated using the Monte Carlo sampling procedure explained above and the system simulated for a large number of days (such as 2,000). Table 6 illustrates the results of a simulation run with 15 mixers. Table 7 summarizes the results of a series of runs with varying numbers of mixers.

Table 5. Distribution of total orders per day for a sample of 2,000 days.

No. OF ORDERS	No. OF DAYS	%	CUMULATIVE %
5	1	0.05	0.05
6	1	0.05	0.10
7	7	0.35	0.45
8	25	1.25	1.70
9	92	4.60	6.30
10	221	11.05	17.35
11	315	15.75	33.10
12	370	18.50	51.60
13	350	17.50	69.10
14	292	14.60	83.70
15	188	9.40	93.10
16	85	4.25	97.35
17	36	1.80	99.15
18	11	0.55	99.70
19	6	0.30	100.00
	2,000		

Table 6, Comulative distribution of orders and back orders per day for 15 mixers (a sample of 2,000 days). There were no delays 91.45% of the days.

No. OF ORDERS + BACK ORDERS	NO. OF Days	%	CUMULATIVE %
6	3	0.15	0.15
7	5	0.25	0.40
8	22	1.10	1.50
9	69	3.45	4.95
10	169	8.45	13.40
11	335	16.75	30.15
12	387	19.35	49.50
13	365	18.25	67.75
14	289	14.45	82.20
15	185	9.25	91.45
16	83	4.15	95.60
17	55	2.75	98.35
18	24	1.20	99.55
19	6	0.30	99.85
20	1	0.05	99.90
21	2	0.10	100.00

Table 7. Summary of results with different numbers of mixers.

No. OF MIXERS	NO. OF DAYS WITH NO DELAY	NO. OF ORDERS WITH NO DELAY
13	38.5	81.0
14	79.3	96.4
15	91.4	99.2
16	97.2	99.6
17	99.2	99.9
18	99.7	99.99
19	99.9	99.999
20	100.0	100.000

2-3 DEMAND SATISFACTION:

With 13 mixers, there are backlogs at the start of 38.5% of the days. To provide service with backlogs for only 5% of the days would require 16 mixers. Similarly, 13 mixers immediately satisfy only 81% of the orders-whereas 16 mixers satisfy 99.6% of the orders with no delay. It is necessary to have 18 mixers in order to satisfy 99.99% of the demand with no delay. The importance of the back order effect can be seen by comparing Tables 5 and 7. There are 13 or less orders 69.10% of the days, but with 13 mixers there are delays 61.5% of the days. Of course with more mixers the back order effect is not as great.

The decision regarding the proper number of mixers would depend on considerations of their cost, the definition of adequate service and the penalties and risks associated with inadequate service. In this instance, the simulation is a tool that can estimate the service obtained with different numbers of mixers.

The above example was simplified for illustrative purposes. However with modifications it would approximate many realistic systems. Consider the following:

1. Uncertainty in availability of raw material because of demand fluctuations and limited production capability.

2. Variations in batch size and mixing time for different mixtures.

3. Variations in clean-up time dependent on scheduling sequences.

4. Availability of limited final product storage space.

If these considerations were included in the model, the result might represent a realistic chemicals production unit. With a Monte Carlo simulation of this unit the following questions might be answered:

1. What is the proper balance between increased production capacity and increased storage facilities (raw material, intermediate and final product)? Between mixers and storage facilities?

2. How is the system affected by changes in demand characteristics?

3. What is the effect of an increase of mixing rate?

2-4 SIMULATION CHARACTERISTICS

There are two essential characteristics of the situations in which Monte Carlo simulation is useful.

1. It is believed that the real system cannot be studied satisfactorily without considering the variation which is inherent in some of its variables. The system must, consequently, be represented by a model which contains some variables described as statistical distributions. In the previous example, the distribution of demand for each mixture was such a variable.

2. The relationships between variables are usually quite complex. It may not be possible to describe some of these relations by simple algebraic equations. Often this complexity arises because of considerations of priority and scheduling rules at facilities where the demand for service is considerable. In the above example, the consideration of back orders added complexity to the model. The necessity to have two or more facilities available simultaneously may be important in a real life system, and this could introduce complexity in the corresponding model.

Either of the above characteristics alone will seldom require the use of a Monte Carlo simulation. If only the statistical nature of the variables is important and the logical relationships among variables is not complex, the analytical methods of statistics and queuing theory are quite effective. If only the complex relationships are involved, the ingenious definition of mathematical variables can lead to the formulation of an integer or linear programming model. However, when the relationships between variables are complex and variability is important, Monte Carlo simulation is often the easiest method of solution.

2-5 SOURCE OF DATA:

In many situations the distribution of the statistical variables is determined empirically by examining historical data. Statistical analysis, on the other hand, usually deals with distributions that can be described by simple mathematical expressions such as normal, Poisson, and exponential distributions. Consequently, at times Monte Carlo simulation becomes necessary even for systems with somewhat simple logical relationships among variables, for a simulation can deal with arbitrary empirical distributions.

2-6 DEVELOPMENT OF A MODEL:

In general, the Monte Carlo simulation model consists of a computer program. The identification and selection of the significant input variables and a formal specification of the relationships among them are the first activities in the development of the model. It is not necessary that the model be similar to the system in every respect as long as its behaviour is similar. Often, as a by-product of model building, previously unnoticed problem areas are discovered and valuable insights are gained into the real operation of the system. Only the variables that are believed to significantly influence the behavior of the criticial areas of the system should be included as input variables. Because physical phenomena may often be described in several ways, the input variables in the model which reflect such phenomena should be defined in ways which minimize data collection difficulties. Another approach to reducing these difficulties is to describe the distribution of some of the statistical variables analytically by fitting algebraic equations to historical data.

Besides the selection of significant variables, the model also requires identification of the relationships among these variables. The selection of the input variables should be such that the relationships among them can be specified exactly and completely. This formalization of the system is a necessary feature of any model building.

The selection of the criteria for evaluating the behavior of the system is also an integral part of the model building stage. In the illustrative example, it was possible to use percent of orders. In some situations it may be necessary to maintain a certain service level regardless of cost (within limits, of course). The selection of the variables and the relationships described in the model as well as the specifications for developing the computer program are influenced by the evaluation criteria.

2-7 AN EXPERIMENTAL TOOL

A Monte Carlo simulation model can be viewed as an experimental device. A single run representing an experiment and the output of the simulation representing a single observation. Since the input to the simulation model contains some random variables, the output would vary even if the simulation run were to be repeated with the same values of model parameters. In this sense, the result of a simulation run is not reproducible. The variability in the results depends on the following factors:

1. The sequences of random numbers used in making a simulation run.
2. The length of the run (sample size) during which data are collected (a simulated year, decade, or century).
3. The duration of the initialization period during which the simulation is run but data are not collected (presumably the system will reach some kind of equilibrium during this period).

4. The initial or the starting values of the system variables at the beginning of the simulation run.

The variability which is caused by these factors should be reduced as much as possible. However, some variation in the results is a natural characteristic of the system and often the very purpose of running a simulation is to examine the cause and the magnitude of this inherent variation.

The great majority of problems encountered in using a simulation are those regularly dealt with by a statistician or quality control engineer. The integration of statistical technique and model building ability its, therefore, the prerequisite for a successful Monte Carlo simulation.

2-8 MODEL TESTING:

Besides the question of the reproducibility of the results from a single simulation run, there also exists a question of the validity of the entire simulation model as a decision making tool. A possible approach towards verification is to test the model with historical data. The behavior of the model is then compared with the historical performance. Such an evaluation, however, should be made with due consideration to the fact that both the result of a simulation and the historical operation of the real system are statistical samples. These problems often make any direct verification of the model almost impossible. In such cases one may examine the various components of the model carefully and verify that their behavior at any particular time is consistent with the conditions in the remainder of the system. For example, is the production scheduling component performing correctly with respect to the current inventory levels, orders on hand, and expected demand? This is the only procedure to use when there is no historical data for comparison.

It has been emphasized above that a simulation run is a specific experiment. After determining the proper experimental procedures (Initial conditions, run length, etc.) it is necessary to design the complete set of simulation runs which are required for arriving at specific conclusions. Recognizing the variability of results from a simulation run, the principles of the design of experiments developed by statisticians should be used in planning simulation runs and in interpreting their results. An advantage of a simulation experiment is that it can be closely controlled. In addition, the model is an extremely flexible experimental laboratory, for normally it is not difficult to modify parameter values or the computer program. Even though a Monte Carlo simulation will not optimize the operation of a system, the model should be flexible enough to evaluate the reasonable range of possible policy (i.e., scheduling rules or inventory control procedures).

2-9. COMPUTERS AND SIMULATION

Even though it is possible to conduct small Monte Carlo simulations using a table of random numbers and a hand calculator, the use of Monte Carlo simulation as a decision making tool has become more and more restricted to computers. Since simulation computer models are complex and difficult to program, and since many elements of these models are logically similar, the need for special purpose computer simulation languages became apparent. Many different individuals and companies saw this need and have developed simulation languages. All of these languages provide a simulator clock or timing routine and provide facilities for sampling from distributions collecting statistics. However, none of these languages remove the necessity for having programming skill to convert a flow diagram of a model into a computer program.

2-10 PROGRAMMING LANGUAGES

Before any system, large or small, can be simulated, it must be described, and-as we suggested before-this is a major problem for engineers, systems analysts, and others who use digital simulation to study systems. In a sense, the description is initial simulation. Lacking a precise language for his model, the engineer cannot describe his system adequately to other people or to the computer whose help he needs. Usually, a system description develops slowly as the model is formulated, combining block diagrams, flow charts, equations, and sufficient text to explain how the system operates. A next step, if the model is to be "run" on a computer, would be to somehow translate this description to the language of a digital computer. This is a major step in the total simulation process.

Now, one way of making this translation would be to have a professional programmer study the problem in every detail before he started programming. This obviously means a close working relationship between engineer and programmer. The writing of such a program is an intricate and complex process which requires a great amount of patience, special skills, and time. This approach is often characterized and sometimes marred by a long delay before any simulation results become available, by high costs due to salaries and debugging time, and also by mutual difficulties in understanding the important aspects of both systems-the one being simulated and the one doing the simulating.

This procedure can be improved if a program is automatically created directly from a model description. Simply stated, the engineer would spend a short time getting a grasp of a problem-oriented programming language by which he could describe his system. His description would automatically generate a machine code to produce a complete simulation program ready to run. This ideal is being approximated in some languages now which offer the engineer a more direct communication path to the computer. This is no small gain, as we realize when we remember that simulation is inherently an interative procedure requiring continual modification of the model, feedback, analysis, redesign, and reruns. Furthermore, to accomplish its purpose (e.g., saving time and money in the system simulated), a simulation must be carried out quickly and be adaptable to change.

Several programming languages have been designed especially to ease the programming requirements for discrete systems simulation. Like their counterparts in continuous systems simulation (DSL/90, PACTOLUS, MIDAS, IBM's 1130 CSMP, and others), each helps solve part of the problem of communication between engineer (user) and programmer-a problem not unique to simulation, of course. These languages are being used successfully by many who are not professional programmers. Programming is the simplified and programming errors reduced, and-equally important-these languages provide a communication vehicle by which complex systems can be described and thus clarified for other purposes than simulation.

Early attempts to generalize computer programs for discrete systems simulation were limited to "programming packages" such as job shop simulators and inventory management simulators, written for a variety of computers. Usually designed for very specific application areas, and successful within their limits, these attempts were important first steps toward the development of more generalized programming systems for simulation. Out of these efforts evolved many general discrete-systems simulation programs-GPSS (General Purpose Systems Simulator), SIMSCRIPT (A Simulation Programming Language), SOL (Simulation Oriented Language), CSL (Control and Simulation Language), SIMULA (SIMUlation LAnguage), and many others. These languages and their associated programs are powerful tools for solving a large class of problems, but each requires the user to view the "real world" in a slightly different way, and there is as yet no standardization of these languages. But one system widely used - the General Purpose Systems Simulator - seems to be earning its name, and suggests the direction in which standardization may go without sacrificing the necessary orientation to a wide range of real problems.

or; $\sum_{i=j=1}^{n} h^*_j y_i + hy$ (10)

Similarly we can derive the direct, indirect and total of direct and indirect household income per unit of a particular final demand.

The direct and indirect householdincome per unit of a particular final demand will be

$$\frac{\sum_{i=j=1}^{n} h^*_j y_i + hy}{y} \qquad (11)$$

The indirect household income per unit of that particular final demand would be

$$\frac{\sum_{i=j=1}^{n} h^*_j y_i}{y} \qquad (12)$$

and the direct household income per unit of that demand would be

$$\frac{hy}{y} \qquad (13)$$

Having the deliveries from the productive sectors from the 31 different final demand columns as projected for 1960-61 and having the V^*j and h^*j we were able to calculate the impact, direct and indirect, of these different final demands on value added and household income. The results are presented in Table 8. The table shows that only two final demand sectors contained direct inputs from value added. These are household consumption and government consumption. In the case of the first sector, the direct value added represents domestic services and in the case of the second sector, i.e. government consumption, it represents wages and salaries paid by the government. The table also shows that total value added created by final consumption and exports is by far higher than that created by the investment channels. In the meantime the total of direct and indirect value added created by the individual investment channels vary from one type of investment to the other reaching the highest figure in the case of horizontal investment in agriculture and the lowest figure in the investment of the High Dam. The figure for the High Dam, however, should not be taken without reservation as the projected investment in the High Dam for the year 1960-61 is but a fraction of the total investment and therefore the figure presented represents only the impact of that portion of investment on value added.

E. PRELIMINARY NATIONAL BUDGET FOR THE EGYPTIAN ECONOMY FOR THE YEAR 1960-61

Having computed these sets of coefficients we were in a position to construct a rough national budget for the year 1960-61. As we mentioned before, changes in final demand between the years 1959-60 and 1960-61 were taken as our starting point. These changes were, as far as possible, in conformity with the figures included in the preliminary drafts of the Plan Frame. Some adjustments of these figures, however, were essential in order to carry out our input-output calculations. For the eight different types of final demand included in Table 9 total requirements of imports to meet the change in each of the final demands was calculated by means of the coefficients in Table 7. Also by the means of the coefficients in Table 8 value added and household income created as a result of these changes in final demand were also calculated.

Table 9 shows that a change in final demand of 181 million Egyptian pounds would require total inputs of 84 million pounds. On the other hand the value added created would be 97 million pounds. The depressing feature about these results, however, is the fact that whereas the preliminary estimates of the increase in private consumption is 42.4 million Egyptian pounds we found that household income would increase by 76.5 millions. Unless a drastic increase in taxes is anticipated, these results seem very inconsistent. The inconsistency of the figures may be due, besides other reasons, to the underestimation of the import increases for consumption purposes. One reason for that was the assumption that agricultural production is determined by demand whereas it is in fact limited by capacity. However it must be mentioned that better results could have been achieved had we reviewed our preliminary assumptions about private consumption as it should be the case when carrying out such calculations.

m/z.

Table 1.

Direct and Indirect Requirements of Imports Per Unit of Final Demand from each of the Productive Sectores.

Sectors	Direct imports per unit of production	Indirect import requirements per unit of final demand	Direct and indirect requirements per unit of final demand
Agriculture	0.041	0.018	0.059
Mining and quarrying	0.068	0.029	0.097
Electricity	0.158	0.043	0.201
Basic metallurgical industry	0.225	0.062	0.287
Metal products	0.221	0.071	0.292
Cement industry	0.131	0.063	0.194
Petroleum refining	0.132	0.051	0.183
Manufacture & repair of machiney	0.166	0.097	0.263
Basic chemicals	0.076	0.048	0.124
Other basic industies	0.146	0.047	0.193
Construction	0.143	0.067	0.210
Slaughtering & meat production	0.026	0.050	0.076
Dairy products	0.028	0.054	0.082
Grinding & processing of grain	0.027	0.057	0.084
Bread & bakery products	0.064	0.065	0.129
Sugar industry	0.032	0.034	0.066
Oils & fats	0.052	0.019	0.071
Other food products	0.080	0.063	0.143
Spinning & weaving	0.055	0.072	0.127
Ginning & pressing of cotton	0.006	0.060	0.066
Manufactue of ready made clothes	0.049	0.095	0.144
Paper & paper products	0.236	0.090	0.326
Tobacco & cigarettes	0.059	0.078	0.137
Wood & furniture	0.186	0.064	0.250
Fertilizers	0.075	0.026	0.101
Other industries	0.162	0.068	0.230
Transportation & Communication	0.085	0.027	0.112
Suez Canal	0.015	0.007	0.022
Education	0.034	0.027	0.061
Medical services	0.143	0.052	0.195
Trade & financial services	0.017	0.020	0.037
Banking & insurance	0.012	0.026	0.038
Other services	0.006	0.106	0.112

Table 2.

Direct and Indirect Value Added Created Per Unit of Final Demand from each of the Productive Sectors.

Sectors	Direct imports per unit of production	Indirect import requirements per unit of final demand	Direct and indirect requirements per unit of final demand
Agriculture	0.431	0.510	0.941
Mining & quarrying	0.659	0.244	0.903
Electricity	0.524	0.275	0.799
Basic metallurgical	0.434	0.279	0.713
Metal products	0.416	0.292	0.708
Cement industry	0.419	0.387	0.806
Petroleum refining	0.318	0.499	0.817
Manufacture & repair of machinery	0.337	0.400	0.737
Basic chemicals	0.432	0.444	0.876
Other basic industries	0.371	0.435	0.806
Construction	0.446	0.344	0.790
Slaughtering & meat production	0.105	0.819	0.924
Dairy products	0.261	0.657	0.918
Grinding & processing grains	0.052	0.864	0.916
Bread & bakery products	0.166	0.705	0.871
Sugar industry	0.451	0.483	0.934
Oils & fats	0.759	0.170	0.929
Other food products	0.078	0.779	0.857
Spinning & weaving	0.164	0.709	0.873
Ginning & pressing of cotton	0.025	0.909	0.934
Manufacturing of ready made clothes	0.271	0.583	0.854
Paper & paper products	0.177	0.407	0.674
Tobacco & cigarettes	0.119	0.744	0.863
Wood & furniture	0.464	0.284	0.748
Fertilizers	0.630	0.269	0.899
Other industries	0.393	0.377	0.770
Transportation & Communication	0.704	0.184	0.888
Suez Canal	0.879	0.099	0.978
Education	0.696	0.243	0.939
Medical services	0.395	0.400	0.795
Trade & financial services	0.759	0.212	0.971
Banking & insurance	0.727	0.235	0.962
Other services	0.947	0.041	0.988

Table 3.

Direct and Indirect Household Income[x] Per Unit of Final Demand from each of the Productive Sectors.

Sectors	Household income per unit of production	Indirect household per unit of final demand	Direct and indirect household income per unit of final demand
Agriculture	0.406	0.402	0.808
Mining & quarrying	0.236	0.197	0.433
Electricity	0.214	0.143	0.357
Basic metallurgical	0.301	0.174	0.475
Metal products	0.360	0.194	0.554
Cement industry	0.256	0.222	0.478
Petroleum refining	0.127	0.288	0.415
Manufacture & repair of machinery	0.304	0.293	0.597
Basic chemicals	0.297	0.291	0.588
Other basic industries	0.254	0.279	0.533
Construction	0.374	0.217	0.591
Slaughtering & meat production	0.109	0.674	0.783
Dairy products	0.265	0.550	0.815
Grinding & processing of grains	0.051	0.726	0.777
Bread & bakery products	0.166	0.576	0.742
Sugar industry	0.060	0.349	0.409
Oils & fats	0.563	0.119	0.682
Other food products	0.075	0.523	0.598
Spinning & weaving	0.164	0.514	0.678
Ginning & processing of cotton	0.018	0.771	0.789
Manufacture of ready made clothes	0.215	0.428	0.643
Paper & paper products	0.152	0.381	0.533
Tobacco & cigarettes	0.060	0.379	0.439
Wood & furniture	0.455	0.187	0.642
Fertilizers	0.499	0.168	0.667
Other industries	0.361	0.262	0.623
Transportation & Communication	0.694	0.113	0.807
Suez Canal	0.503	0.078	0.581
Education	0.675	0.186	0.861
Medical services	0.316	0.290	0.606
Trade & financial services	0.288	0.164	0.452
Banking & insurance	0.417	0.170	0.587
Other services	0.790	0.032	0.822

x Wages, salaries and distributed profits.

Table 4.

Direct and Indirect Imports Per Unit
of Four Different Categories of Final Demand.

Final demand categories	Direct imports to final demand	Indirect imports required by a unit of final demand	Direct and indirect imports required per unit of final demand
Investment in fixed capital	0.327	0.138	0.465
Household consumption	0.053	0.094	0.147
Government consumption	0.075	0.040	0.115
Exports	0.000	0.074	0.074

Table 5.

Projected Deliveries to Final Demand for the Fiscal Year 1960/61.

Deliveries from	Household consumption	Government consumption	Exports	Total investment in fixed capital	Total final demand (excluding changes in inventories)
Agriculture	136.3	4.0	6.1	1.0	147.4
Mining & quarrying	-	0.1	6.4	-	6.5
Electricity	4.3	0.6	-	-	4.9
Basic metallurgical	-	0.1	-	-	0.1
Metal products	0.8	3.3	0.7	-	4.8
Cement industry	-	-	2.8	-	2.8
Petroleum refining	7.9	3.1	1.9	-	12.9
Manufacture and repair of machinery	2.6	2.3	-	26.3	31.2
Basic chemical industry	10.2	1.7	-	-	11.9
Other chemical industries	1.6	0.6	-	-	2.2
Construction	-	3.8	-	138.4	142.2
Slaughtering and meat products	69.0	2.1	-	-	71.1
Dairy products	57.9	2.4	-	-	60.3
Grinding and processing of grains	51.4	1.2	4.0	-	56.6
Bread and bakery products	84.8	2.5	-	-	87.3
Sugar industry	22.5	0.3	-	-	22.8
Oils and fats industry	12.0	0.4	-	-	12.4
Other food industry	14.4	1.0	3.3	-	18.7
Spinning and weaving	80.3	4.2	25.4	-	109.9
Ginning and processing of cotton	-	-	103.9	-	103.9
Manufacture of ready made clothes	17.9	3.5	-	-	21.4
Paper and paper products	2.0	1.4	-	-	3.4
Tobacco and cigarettes	40.8	0.2	-	-	41.0
Food and furniture	7.1	-	-	-	7.1
Fertilizers	-	-	-	-	-
Other industries	15.8	0.6	8.7	-	25.1
Transportation and Communication	44.1	3.5	13.0	-	60.6
Suez Canal	-	-	46.5	-	46.5
Education	7.6	-	-	-	7.6
Medical services	13.9	-	-	-	13.9
Trade and financial services	85.1	6.2	21.0	8.3	120.6
Banking and insurance	0.9	-	0.6	-	1.5
Other services	205.2	2.7	3.0	-	210.9

(cont.)

(cont. of Table 5).

Total deliveries from domestic sectors	996.4	51.8	247.3	174.0	1469.5
Imports directly to final demand	56.6	14.2	-	124.0	194.8
Total deliveries	1053.0	66.0	247.3	298.0	1664.3
Value added directly created by final demand	19.0	154.7	-	-	173.7
Sum of final demand	1072.0	220.7	247.3	298.0	1828.0

Table 6.

The Required Deliveries to the Projected Investment for the Year 1960/61

(in million £ E)

Type of investment	Total of investment	Required deliveries from: Construction	Domestic production of machinery and equipment	Agriculture	Trade and financial services	Total deliveries from domestic sectors	Imports directly to investment
Vertical investment in agriculture	12.3	5.6	1.9	0.4	0.6	8.5	3.8
Horizontal " " "	29.7	18.7	3.9	0.6	1.3	24.5	5.2
Irrigation and drainage	25.9	19.9	-	-	-	19.9	6.0
High dam	9.0	1.4	-	-	-	1.4	7.6
Mining and quarrying	3.2	0.5	0.8	-	0.3	1.6	1.6
Electricity	13.5	3.0	2.0	-	0.7	5.7	7.8
Basic metallurgical	6.7	2.0	0.2	-	-	2.2	4.5
Metal products	0.9	0.3	0.1	-	-	0.4	0.5
Petroleum refining	14.8	1.1	3.9	-	1.2	6.2	8.6
Chemical and pharmaceutical	13.1	3.0	1.3	-	0.4	4.7	8.4
Manufacture of machinery	12.5	2.6	2.4	-	0.8	5.8	6.7
Rural industries	1.0	0.3	0.4	-	0.1	0.8	0.2
Food, beverages and tobacco	4.8	2.2	0.9	-	0.3	3.4	1.4
Textiles and clothing	9.8	1.7	1.7	-	0.5	3.9	5.9
Paper products and printing	3.8	1.5	0.5	-	0.1	2.1	1.7
Wood and furniture	0.5	0.1	0.1	-	-	0.2	0.3
Non metallurgical	0.3	0.1	0.1	-	-	0.2	0.1
Other industries	3.0	0.7	-	-	-	0.7	2.3
Vocational training	2.0	0.6	0.5	-	0.2	1.3	0.7
Replacement	3.4	-	-	-	-	-	3.4
Transportation and Communication	56.4	25.1	5.1	-	1.6	31.8	24.6
Suez Canal	14.9	6.8	-	-	-	6.8	8.1
Housing	28.0	22.3	-	-	-	22.3	5.7
Public utilities	14.6	9.3	-	-	-	9.3	5.3
Services	13.9	9.6	0.5	-	0.2	10.3	3.6
Total	298.0	138.4	26.3	1.0	8.3	174.0	124.0

Table 7.

Direct and Indirect Import Requirements as Percentage of Different Categories of Final Demand for Year 1960/61.

	Direct imports	Direct and indirect imports
Household consumption	5	14
Government consumption	6	10
Total exports	-	7
Total investment in fixed capital	42	54
Exports of cotton	-	7
Exports of yarn and cloth	-	13
Suez Canal	-	2
Other exports	-	10
Investments in		
Vertical investment in agriculture	31	45
Horizontal investment in agriculture	18	34
Irrigation and drainage	23	39
High dam	85	88
Mining and quarrying	50	59
Electricity	58	67
Basic metallurgical	67	75
Metal products	56	67
Petroleum refining	58	67
Chemical and pharmaceutical	64	72
Manufacturing of machinery	54	63
Rural industries	20	40
Food, beverages and tobacco	29	44
Textiles and clothing	60	68
Paper and printing	45	57
Wood and furniture	60	80
Non metallurgical industries	33	67
Other industries	77	80
Vocational training	35	50
Replacement	100	100
Transport and Communication	44	55
Suez Canal	54	64
Housing	20	37
Public utilities	36	50
Services	26	42
Total investment in construction	-	21
Total investment in domestically produced machinery and equipment	-	26

Table 8.

Direct and Indirect Value Added and Household Income as Percentages of Different Final Demands for the Year 1960/61.

Type of Fianl Demand	Value added directly created by final demand	Direct & indirect value added created by final demand	Direct household income created by final demand	Direct and indirect household income created by final demand
Household consumption	2	86	2	68
Government consumption	70	90	67	82
Total exports	-	93	-	69
Total investment in fixed capital	-	46	-	34
Exports of cotton	-	93	-	79
Exports of yarn	-	87	-	68
Suez Canal	-	98	-	58
Other exports	-	90	-	61
Investments in				
Vertical investment in agriculture	-	55	-	41
Horizontal investment in agriculture	-	66	-	49
Irrigation and drainage	-	61	-	46
High dam	-	12	-	9
Mining and quarrying	-	41	-	28
Electricity	-	33	-	24
Basic metallurgical industries	-	25	-	19
Metal products	-	33	-	22
Petroleum refining	-	33	-	24
Chemical and pharmaceutical	-	28	-	21
Manufacturing of machinery	-	37	-	26
Rural industries	-	60	-	60
Food, beverages and tobacco	-	56	-	42
Textiles and clothing	-	32	-	22
Paper and printing	-	44	-	32
Wood and furniture	-	20	-	20
Non metallurgical industries	-	33	-	33
Other industries	-	20	-	13

(cont.)

(cont. of Table 8).

Vocational training	-	50	-	35
Replacement	-	-	-	-
Transport and Communication	-	45	-	33
Suez Canal	-	36	-	27
Housing	-	63	-	47
Public utilities	-	50	-	38
Services	-	58	-	44
Total investment in construction	-	79	-	59
Total investment in domestically produced machinery and equipment	-	74	-	60