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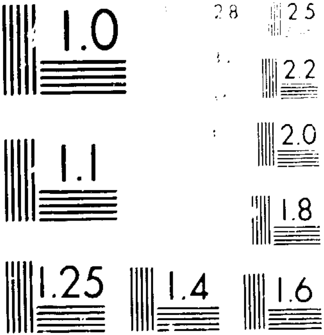
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APPLICATION OF NETWORK MODELS TO INDUSTRIAL PROJECT DEVELOPMENT IN DEVELOPING COUNTRIES

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PREFACE

This description of the application of network models to industrial project development in developing countries has been prepared by Mohamed Dessouky of the University of Illinois, Urbana, Illinois, United States of America, and Rustam Lalkaka, Senior Industrial Development Field Adviser, United Nations Development Programme, Ankara, Turkey. The booklet is issued by UNIDO in pursuance of the guidelines established by the Industrial Development Board, which requested that "the operational activities of the United Nations Industrial Development Organization should be widely publicized and brought specifically to the attention of the Governments of developing countries in order to assist them in formulating their requests under the operational programme of the organization in the immediate future".

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Introduction

A substantial part of the literature of operations research concerns network models which include distance networks, flow networks and signal flow charts. Of particular interest here are project or activity networks, together with the techniques developed around them, namely, the Critical Path Method (CPM) and Project Evaluation and Review Techniques (PERT), and their application to industrial project development. These techniques are basically distance networks, with distance being interpreted as time. The CPM and PERT techniques were developed in the late 1950s in the United States of America as tools for planning and controlling the development of large-scale system projects–the Polaris nuclear submarine, in the case of PERT. In the 1960s their application in industrialized countries extended to industry, construction and military installations, among others. Their application in developing countries began in the late 1960s, mainly in construction and industry. Here the authors discuss their use in industrial project development, examine the problems that arise and propose some means for overcoming such problems.

The application of network models, as of any other mathematical model, requires formulation of the problem or the study in question, collection of data, construction of the model, testing and evaluation. Each one of these steps is examined as it pertains to industrial projects in developing countries.

Formulation

A prerequisite for the application of a mathematical model to any study is an explicit definition of the objectives of the study and of its scope. In project development it often happens that the application of network modeling is not preceded by a clear definition of the scope of the project, the level of management responsibility over the various aspects covered by the project, and the order of priority of the objectives being sought. In a project for constructing an industrial port in a developing country, one of the authors of this paper, as a United Nations expert, observed that the project manager, a civil engineer, included in his plan of the project only those aspects covered by engineering drawings and physical facilities and excluded other management functions integral to the project such as developing an organization for operating the port and hiring and training people to staff it. He did not recognize the need for certain support facilities such as maintenance shops and employee cafeterias, which were necessary for the functioning of the port. Another shortcoming was his failure to provide a mechanism to follow up on the construction of support facilities, such as an access road and a water supply line which were to be provided by government departments. This experience demonstrated the pointlessness of applying elaborate techniques of planning in the absence of a complete definition of the project.

Data collection

Many project planners have shied away from the use of network models because they have judged the data available to them to be inadequate for the models. On the other hand, without some model to serve as a frame of reference, the collection of data becomes an aimless exercise. One important feature of the use of activity networks is that they force the project planner to list the project's detailed activities and their precedence relationships. The information provided by this exercise is a significant improvement on past planning practices which recognized only aggregate activities such as the construction of plant and the installation of equipment with a minimum identification of their precedence relationships. An important use of the detailed activity list is in determining all the activities for which parameters are to be estimated. Parameters include activity durations and their resource requirements and costs, and any additional considerations such as environmental conditions. Determination of these parameters is a difficult task for project planners in developing countries since they generally have little or no experience in many of the activities listed. However, much information can be obtained from equipment manufacturers, construction contractors, design engineers, international references and other sources which can help them to achieve more realistic estimates. In the absence of any such source, a crude estimate would be better than no estimate at all, so long as it is recognized as such.

One plausible approach is to start with as broad and aggregate a model as is appropriate for the data available at the beginning stages of project planning. Subsequently, the model can be sharpened and detailed as fresh data arrive, and plans can be elaborated accordingly. The use of stratified network modeling is common. A good example is that used by the Bokaro Steel project in India which was constructed over a period of ten years.[1] The project required about $US 1 billion in initial investment and envisaged a production capacity of 1.7 million tons of steel ingots. Its detailed plan consisted of 357 sub-networks covering about 60,000 activities. Stratified network modeling was applied, using as initial inputs aggregate and crude data which were later replaced with more detailed and reliable data. Layout drawings, cross sections and equipment erection drawings were used for initial estimates of activity duration and costs.

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[1] C. B. Patel, *Organizing Network Planning for Large Projects in a Developing Economy* (Calcutta, India, M. N. Dastur and Company).

A number of problems arose at the design stage in this project. While the project was designed in the Union of Soviet Socialist Republics, about two thirds of the equipment was to be manufactured in India, thus entailing a substantial adaptation of the drawings to Indian materials and fabrication capabilities. These modifications, in turn, had to be meshed with the fundamentally unchanged specifications. As the design process in the USSR was highly centralized, Indian designers and consultants had to travel frequently to Moscow to finalize and clear the engineering drawings and specifications of the plant. As this was a new experience for the project planners and designers, it was extremely difficult from the beginning to estimate the time required for design and construction. In comparison with a situation in which the developing country imports all the technology and most of the equipment with it, however, the Indian project certainly contributed to the development of Indian technology and led to greater self-reliance in design and construction. The relevance of this experience to the subject of this booklet is that in planning the implementation of a project in a manner that draws more heavily on local rather than on imported technology in a new field, allowance must be made in the estimates for the delays and additional costs associated with the learning process involved.

The effect of the lack of data can be exaggerated. A project for establishing a cement plant in an African country was initially estimated to require nearly two years for design, construction and start-up. However, using the data available to the personnel connected with the project, a global [illegible]0-activity network was constructed which showed that the minimum time to develop the plant was four and one-half years. The actual time even exceeded that estimate. The underestimation of project duration, which usually accompanies the use of crude planning methods, results in an underestimation of budget requirements. This, in turn, precipitates fund shortages and causes delays in project implementation while new funds are being sought.

Construction of a model

The construction of an activity network model for CPM/PERT analysis is very simple. A graphical presentation may be either an arrow diagram or a precedence diagram. If the number of activities and/or the number of relationships are great, the network will be unwieldy, but the steps themselves follow well-established rules and pose no problem. The problem is that usually, as soon as a network is constructed, it becomes obsolete because of the great uncertainty surrounding the implementation of projects in developing countries and the changing expectations from day to day.

The PERT technique attempts to overcome this uncertainty by requiring three-time estimates for each activity and using a formula to average these estimates into a single estimate which is then used in a similar manner as in CPM calculations. Several project planners, including those of the Bokaro Steel project, are averse to the use of three-time estimates. In the first place, a single estimate is in itself very difficult. When more than one estimate is demanded, values may be given impulsively. Furthermore, analytical studies of PERT[2,3] have shown that it gives biased estimates of project durations which tend to be lower than theoretically valid estimates. Both CPM and PERT make the following assumptions about the project and its network:

1. Activity durations are predetermined and not changeable by decisions. For many practical situations, an activity may be performed by any

[2] D. R. Fulkerson, "Expected critical path lengths in PERT networks", *Operations Research*, vol. 10, No. 6 (1962), pp. 808-817.

[3] K. R. MacCrimmon and C. A. Ryavec, "An analytical study of the PERT assumptions", *Operations Research*, vol. 12, No. 1 (1964), pp. 16-37.

one of alternative methods, each having its own unique requirements for time, costs and resources. The consideration of alternative methods allows the project manager to choose a course of action that is most consistent with the project objectives, for example through a trade-off of time and cost.

2. The project musters all the resources needed to implement each activity at its earliest time. Clearly, this is not a valid assumption in the usual case since most resources are constrained. Allowance must thus be made at the planning stage for the limitation of resources. Some analysis techniques in circumstances of constrained resources are available which may be used for this purpose; they are mostly heuristic procedures.

3. The network structure is deterministic in that the network logic requires that *all* activities shall be completed before a succeeding activity may start, and that once an activity is completed, *all* succeeding activities shall start and finish *with certainty*. Both these assumptions are challenged in projects in which alternative actions are pursued with the purpose of achieving only one, such as seeking several funding sources but using only one. Another example would be the case in which the outcome of an activity is unknown in advance, such as whether the decision will be to accept the project, to reject the product or to improve the product. The answer to this objection to these assumptions is the use of stochastic network models such as Graphical Evaluation and Review Technique (GERT).[4,5] Analytical solutions generally do not exist for project problems formulated by these models, and computer

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[4] A. A. B. Pritsker and W. W. Happ, "GERT: graphical evaluation and review technique—part I, fundamentals", *Journal of Industrial Engineering*, vol. XVII, No. 5 (May 1956), pp. 207-274.

[5] A. A. B. Pritsker and G. B. Whithouse, "GERT: graphical evaluation and review technique—part II: probabilistic and industrial en neering applications", *Journal of Industrial Engineering*, vol. XVII, No. 6 (June 1966), pp. 293-301.

simulation is required in these cases. On the other hand, the use of stochastic network models for projects performed under uncertainty tends to yield more realistic plans and provides answers to questions which CPM cannot address, such as the probability of meeting a given due date and the effect of changing implementation policies.

4. There is no choice of the paths to be followed from beginning to end of the project. All paths (i.e., sequences of activities) must be realized. This assumption is violated when the choice of a course of action (e.g., a construction technique) depends on information which becomes available only after the completion of certain preceding activities (e.g., detailed plant layout design). The choice may also be tied to future choices to be made in the course of the project, such as whether construction will be subcontracted or done internally. In these cases, a point of decision exists in the network at which a path is chosen from a set of alternative ones. A technique that addresses this problem is Decision Critical Path Method (DCPM). However, it is effective only for solving problems in small networks.

Because CPM and PERT fail to incorporate the options and possibilities outlined above, they often yield unreliable predictions and lead to erroneous estimates and decisions. However, the application of more sophisticated techniques requires the availability of personnel who are versed in their use as well as in the use of computers. Without an experienced staff, it is futile to attempt the use of the simplest network techniques, not to mention the advanced ones.

One of the most effective classes of advanced techniques is computer simulation of stochastic networks. Two sets of software packages are available for this purpose. The first is a group of simulation programs built around GERT networks and called GERT SIMULATION or GERTS, the most basic being GERTS III[6]. and the most updated version being Q-GERT[7]. The second set is a versatile program called Generalized Network Simulator (GNS) developed at the University of Illinois.[8] Because its use is widespread a brief explanation of the GERT technique is given here.

GERT can be used to analyse projects for which the assumption of deterministic network logic is not valid. The network logic is generalized by allowing the set of activities, the completion of which is required to realize an immediately succeeding event, to be a subject of the complete s . of activities immediately preceding the event. CPM/PERT is a special case of GERT in which the two sets of activities are identical. The number of activities required to realize an immediately succeeding event is called the number of releases.

One instance in which this feature applies is when several courses of action are pursued, but the successful completion of only some of them is necessary for accomplishing the goals of the project. An example is seeking alternate sources of funds and proceeding when one is acquired; the number of activities preceding the event "funds acquired" is the number of sources of funds, and the number of releases is one.

Once an event is realized, two cases are allowed: deterministic input and probabilistic output. The case of deterministic input is equivalent to CPM/PERT; the realization of an event releases all succeeding activities. In the case of probabilistic output, the realization of an event allows only one activity out of a set of more than

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[6] A. A. B. Pritsker and R. R. Burgess, "The GERT simulation programs: GERTS III, GERTS IIIQ, GERTS IIIC, and GERTS IIIR", research sponsored by the Electronics Research Center, National Aeronautics and Space Administration, NASA Contract NAS-12-2113.

[7] A. A. B. Pritsker, *Modeling and Analysis using Q-GERT Networks* (New York, Wiley, 1977).

[8] Koichi Tonegawa, "Generalized stochastic networks and generalized network simulator", Ph.D. thesis, University of Illinois at Urbana-Champaign, Urbana, Illinois, USA, 1974.

one succeeding activity to be released. An example is when there is a chance that the event may be a success (leading to progress towards the next stage of the project) or a failure (leading to corrective action or the abandonment of the project). The probabilities of realization of all activities succeeding a node are given; their sum must always be unity. The feature of probabilistic output allows feedback or recycling to be represented in the network. An event signalling the completion of a phase of the project which is judged unsatisfactory may call for the repetition of a sequence of activities. In this case, the probabilistic activity representing unsatisfactory output will lead back to the first activity in that sequence.

An event may thus occur more than once in the life of a project. Additional versatility is achieved by permitting the number of releases for the initial realization of an event (initial releases) to differ from the number of releases for subsequent realizations.

In activity-on-arc representations of networks, events are indicated by nodes. A graphical presentation of GERT nodes is given in figure I.

As an example application of GERT networks, consider the process of procuring equipment or material. First, a local supplier is approached, and if negotiations succeed, a test is made of his ability to fulfil obligations. If negotiations fail, a foreign supplier is approached. If the local supplier passes the test, the project proceeds; if he fails, a foreign supplier is negotiated with. In case of success, foreign currency is sought; in failure, another local supplier is approached and the cycle is repeated. If foreign currency is found, the project proceeds; if not, return to a local supplier and repeat the cycle. The GERT network is portrayed in figure II. GERT can be a very useful tool for the analysis of risk and uncertainty characteristics of projects in developing countries. It is available through Pritsker and Associates, Inc., Consultants in

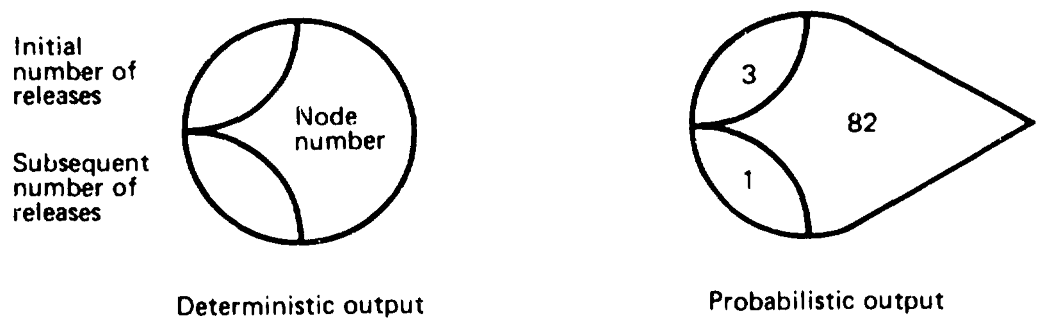

Figure 1. Node symbolism for GERTS

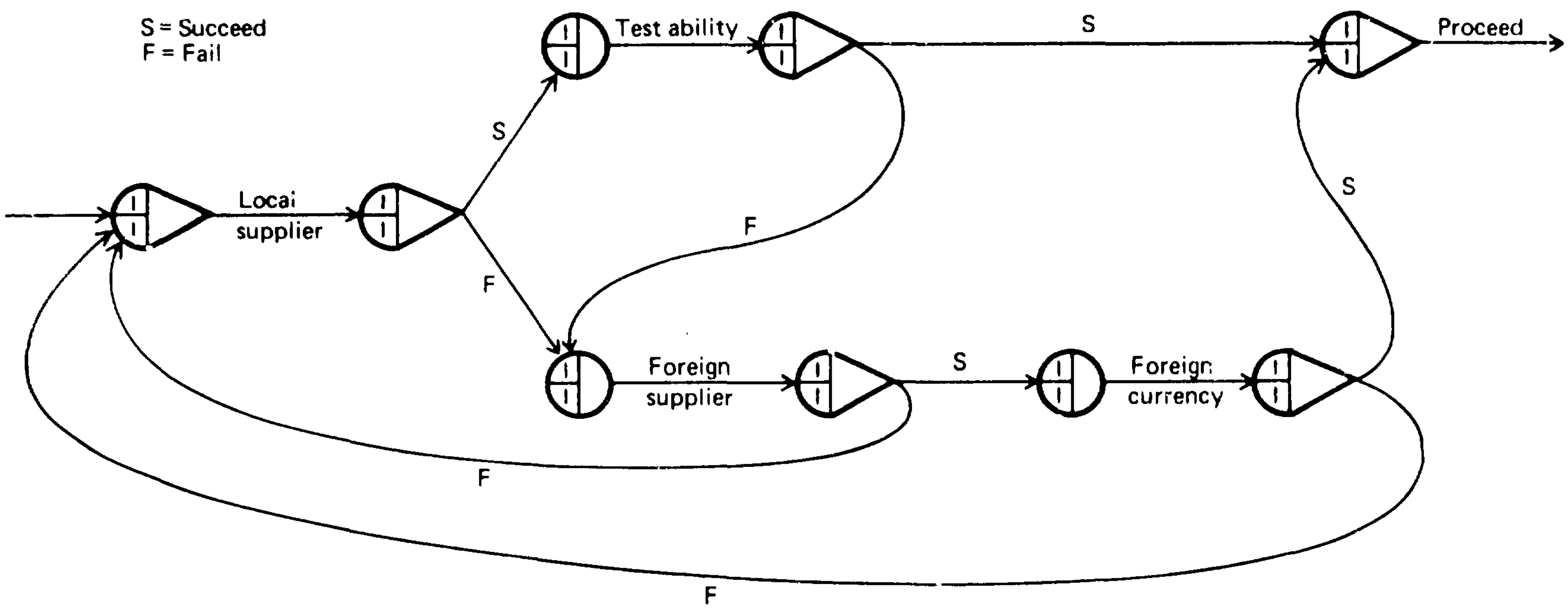

Figure II. Example of application of the GERT network

Systems Engineering, Post Office Box 2413, West Lafayette, IN 47906, United States of America.

Generalized Network Simulator (GNS) is a fledgling program which contains additional features that contribute to greater versatility. An example of these features is the capability to incorporate queues, resources and costs simultaneously. Queues (which are also modeled in Q-GERT) are useful in representing units waiting for processing, resource allocation, and cost modeling is needed for financial planning and cost accounting. Furthermore, GNS allows pre-emption of activities to accommodate ones with higher priorities and the existence of lag relationships among the activities. It also permits greater interaction with the user in the form of accepting user-provided optimization subroutines, preconceived decision rules, and optional procedures, and allowing user intervention during simulation to select options for progress through the network or to modify the network structure of parameters. GNS has been applied to applications in manufacturing and construction. It is available through Mohamed I. Dessouky, Ph.D., Industrial Engineer, 1106 Mitchem Drive, Urbana, IL 61801, United States of America.

Testing and application

Two types of tests can be applied to a model. The first is an examination of the validity of its structure (that is, its logical relationships) and the second is the "adequacy" of the estimates of its parameters. To the extent that the assumptions underlying a project network model approximate reality, the basic model structure will be valid unless precedence relationships are not described correctly. If the assumptions depart from reality, for example if CPM is used while great uncertainties prevail regarding the outcome of events, the validity of the model becomes questionable and other models should be explored.

The measures of the adequacy of data are their validity, or absence of bias, and their reliability, or the degree to which estimated values approximate actual values. As the number of parameters in any project is generally very large, a thorough estimate of each one will be costly and a selective distribution of effort in estimation becomes a necessity. The most commonly used tool for determining the crucial parameters is sensitivity analysis. Typically, parameters of critical path activities are among the crucial ones.

Selection of the model depends on the nature of the project and its environment and the questions for which answers are sought. The application of the model, on the other hand, depends on how the answers are used in making decisions and on how the decisions are carried out. One important reason for the scarcity of applications of network analysis to projects in developing countries is the absence of effective communication links between project analysts and project managers and between project analysts and the people who furnish them with information. This situation hinders the analysts from obtaining reliable data and makes it difficult for them to communicate their results and recommendations to management. This communication gap has to be bridged if effective use is to be made of network models.

Another aspect of the problem of application is the need to update the model as the project progresses. Because of the difficulty of updating the data on a regular basis, many analysts tend to follow one of two courses. Either they are content with working with outdated information or they disregard the model entirely. As one of the basic purposes of network modelling is to assure that the implementation of the project shall proceed according to a well-prepared plan, either action will be defeating the purpose of the analysis.

The application of a network model covers the following aspects of project management: planning, direction and control. In order to plan a project with the use of the model, it is necessary to install a mechanism for translating the results of the model computations into resource utilization profiles so that needed resources are acquired and financial plans are set up. Project direction requires translation of the plans into work orders, material requisitions, equipment dispatches and other instructions. Finally, project control involves a close monitoring of progress and modification of plans when deemed necessary. In a project containing a large number of activities, executing these tasks manually is cumbersome and time consuming; at this point computer programming becomes most useful. In the Bokaro Steel project, a monthly report based on a network plan compared with actual progress was printed out by the computer.

Several software packages are available for project planning with the use of a deterministic network model; examples are: RAMPS (Resource Allocation and Multiproject Scheduling), IBM's PMS/360 (Project Management System/360), PROJACS, Honeywell's CPM (Critical Path Method) and several others. These programs accept inputs in the form of a list of activities, their precedence relationships, their resource requirements and costs, in addition to resource availability information, and they print out job instructions and resource profiles. Software packages that depend on stochastic networks are not as yet commercially available.

Three aspects of control are worth emphasizing. The first is the need for an effective data-gathering mechanism. In the Bokaro project, a number of men were assigned specifically to collect information about progress. The cost of maintaining this group was far less than the value of the information collected. The second aspect is devising observable measures of progress. Two methods, employing milestone events and quantitative measures, may be used. Without an observable measure, comparison between plans and progress is meaningless. The third aspect is communication and error correction. Although it is obvious that control is not exercised unless observed deviations are corrected, systems do not always have the mechanism for error correction.

Evaluation

The contribution of network modeling to evaluation is straightforward. With a clear definition of the project objectives and its scope, an explicit statement of the measures used to assess the attainment of objectives and a well-conceived plan, it is easy to evaluate accomplishment against expectations. Furthermore, the use of a model makes it possible to attribute deviations from goals to their real cause so that mistakes are not repeated.

Conclusions and recommendations

While network techniques, especially those based on deterministic models, are imperfect tools for project planning, they can still contribute immensely to the success of a project. In order to assure the effective use of these techniques, project planners or analysts must be trained and must be provided with computational capabilities which are appropriate to the size and complexity of the project. Furthermore, they should have access to the people who provide the data and to the decision makers who define the policies and use the analysts' recommendations to make decisions. Without a correct reading of policy, a planner may recommend unacceptable courses of action.

Regardless of the model, tools or techniques used, project planners in a developing country must strive to rely on local resources as much as possible and seek implementation processes that allow self-reliance in carrying out the project and that enhance the opportunity of self-reliance in future projects.

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