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STOCHASTIC NETWORK MODELS IN INNOVATIVE PROJECTING

VOLUME 1

NETWORK PROJECTS WITH DETERMINISTIC STRUCTURE

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The book presents a unification of the most essential models to monitor stochastic network projects of innovative nature. The book comprises various on-line control models for different kinds of projects with fixed structure and constrained project scheduling models with various resource delivery schedules. The book is widely illustrated with examples.

The monograph is intended for researchers in innovation-oriented design offices and companies, academic institutions as well as for graduate scholars specializing in "Project Management", "Industrial Engineering" and "Operations Research".

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CONTENTS

In the middle of the 20th century a group of gifted scientists including D. Malcolm, L. Roseboom, C. Clark and W. Fazar, suggested a new method of project management based on network analyzing [117]. This method which acquired world-wide popularity under the name PERT provided excellent application results in managing complex space- and defense-related projects "Apollo" and "Pollarius". In the 60-s and 70-s, many scientists from all over the world did their best to further develop theoretical and application aspects of the PERT methodology.

Yet, as soon as in the early 80-s the promising PERT legacy began transmitting distress signals. The main problem boiled down to the growing gap between the latest theoretical PERT achievements, on one hand, and the rather poor level of practical field implementations based on insufficient and improper assumptions, on the other. The latter almost reduced the universal PERT method to merely managing models of deterministic type only. All other models of managing complex R&D projects not only including random stochastic elements and restrictions but also displaying stochastic structure being subject to random influences and disturbances, either disappeared from the scientists' working table or became subject to fierce and often justified practitioners' criticism. As a matter of fact, from the very first days of PERT implementations a number of vigilant and emphatic scientists warned [13,101,128,143,152] the broad international PERT community about difficulties and even principal failures originating from infertile attempts to implement complicated probabilistic models on the basis of primitive assumptions reducing their profound stochastic nature to a cheap determinate palliative. When the latter scenario was chosen, any kind of monitoring the project's model became virtually impossible; as a result, the pregiven due date was most commonly unmet.

Following the regarded misfortunate developments, the PERT method through recent years ceased to meet its primary objective, namely, providing a powerful on-line control method for complex stochastic network projects; instead, it downgraded to a kind of advisory information system with control actions linked to managerial decisions only. The Russian delegation to the 22nd World Symposium of the International Project Management Association (Rome, 2008) mentioned that every complex system being denied its scientific basement ceases to be creational and vibrant. Nowadays, the Russian Federation decided to create within its borders a science-oriented future-city Skolkovo aimed at developing pioneering high-tech projects of immense complexity and importance. That is why we may be nothing but proud to issue the new scientific monograph by Golenko-Ginzburg Dimitri on monitoring complex and often unique stochastic network projects. The author made an ambitious and at the same time successful attempt to demonstrate that it is his theory and that of his scientific school developed and cherished through the last 50 years first in the USSR and later on in Israel with fruitful links to colleagues and followers in the nowadays Russian Federation, that suits mostly the novel innovative projects developed at Skolkovo, which require modern probabilistic models of multi-choice and stochastically-driven nature.

Referring to the monograph's contents, it can be well-recognized that practically all top questions related to:

- planning stage modeling;
- on-line control models;
- stochastic network project scheduling under chance constraints;
- hierarchical control models for several stochastic network projects;
- have been explicitly and thoroughly outlined.

The author took a justified decision to publish the monograph in two volumes. The first volume, which is the present one, covers all types of models for planning, scheduling and controlling innovative projects with fixed structure and random activity durations. The second volume presents innovative projects with alternative structure and stochastic multi-variant outcomes.

Thus, a conclusion can be drawn that the monograph represents a useful research which is published in due time and within the right scientific community which is by all means mature to make the utmost benefits from its legacy.

The monograph can be used as tutorial for graduate scholars specializing at "Project Management", "Industrial Engineering", "Operations Research", as well as in Academic Institutions and Design Offices.

Scientific Editor

Vladimir Voropaev - Professor, Honorary SOVNET President,
Academician of the Russian Academy of Natural Sciences

Preface

It is important for me to share with my readership the reasons which brought me to the decision to write this book. Circa five decades ago a scientific group in the former USSR under my supervision started undertaking research in the area of managing stochastic network projects. In the 60's and 70's I was responsible for R&D stochastic network projecting linked to the Ministry of Aviation. After my immigration to Israel in 1985 the group proceeded with the research, being ultimately joined by gifted Israeli scholars. Today, thanks to my ongoing participation in the major world conferences held by the International Project Management Association (IPMA), I am well-informed about the current state of things in my research area. The resulting picture is neither one-sided nor simple.

It can be well-recognized that the initial period of excitement caused by the effectiveness of the primary network models applied to world-renowned R&D projects "Pollarius" and "Apollo" (1960-1970), gave way to a phase of sobering not to say disappointment. At that period it became clear enough to anybody involved that the variety of existing projects can be subdivided into three different types. The first one is characterized by a very low level of indeterminacy, more-or-less simple graph structure with a well-known, standard project's goal. This type of projects comprises, e.g., construction enterprises aimed at providing standardized living houses in populated areas, where all activities entering the network projects, have practically deterministic durations. In order to monitor such projects one has merely to substitute the duration of a certain activity (when necessary) by its mean value. Thus, the network project becomes in fact deterministic, and can be easily managed. There is no need in on-line control, and the project manager is fully satisfied by receiving periodically advisory information.

The second type of projects may be found in the majority of modern design offices and is usually carried out under non-essential random disturbances. The projects are inspected by means of periodical control (especially in milestone events), and appropriate decisions have to be developed by the project's manager. The latter may introduce corrective control actions, e.g., the project plan's updating, resource reallocation, etc., which can be determined by solving non-sophisticated optimization problem. However, the latter do not form a multilevel on-line control model.

The third type of projects is characterized by high indeterminacy and is usually aimed at creating new unique high-technology products, which have no prototypes in the past. The project's activities' durations are random values with a large variance range. Projects may comprise branching nodes of random or deterministic types and milestones of deterministic type (decision nodes). Monitoring such projects cannot be facilitated by means other than on-line control models. Representative examples of this type can be found among highly complicated R&D projects, especially those linked to innovative technologies.

Over the years run, the fate of the outlined above projects' types was different. Non-complicated projects nowadays are lucky to benefit from the world-wide support of above 350 software packages available on market, with the annual sales revenue of over 25 billion dollars [158]. On the contrary, complicated R&D projects have very much of a feel of being left behind.

From the beginning, in the early 80's, an attempt was made to manage unique complicated projects by merely the same techniques as those which did so well for the case of simple deterministic projects. This attempt, however, proved very soon to become a major failure. Within more than a decade this shortcoming has been the subject of a prolonged professional debate involving also sharp and sometimes emotional criticism [101,128,143,158, etc.].

In our opinion, the main reason for the nowadays situation when complicated projects are all usually completed late and remain, in practice, uncontrolled, boils down to the very fact that they are carried out under random disturbances (new estimates of random nature without any prior experience, random activities' durations, periodical revisions of networks over time due to random emergency situations, etc.). However, project managers usually [128] avoid probabilistic terms since they are not sufficiently trained. They are trying to control highly complicated projects with uncertainty by using simplified techniques. This leads to biased estimates that underestimate the actual time required to accomplish the project. Therefore the targeted project's due date can rarely be met.

Since I am undertaking research mainly for the last type of projects, I was often asked about the reasons of such inconsistencies. The question becomes even more challenging in view of the well-known fact that many of our Japanese colleagues demonstrate over years convincing success of numerous realized innovative projects with a high level of indeterminacy [141,148]. That is why I carefully examined the situation to compare results accumulated by our scientific group with those stemming from Japanese conceptions.

As a result of this cross-over examination, it became evident that as far as our scientific group is concerned, our main research philosophy is not only non-contradictive but even close to the basic Japanese conceptions of planning and controlling with uncertainty. Moreover, they supplement each other.

What is the essence of the Japanese philosophy when controlling a system with uncertainty and being at the outset of something which is basically indeterminate? Many examples from high performance practice in Japan show that under such circumstances the control system should not work to a predetermined plan, but should be inherently adaptable, seeking at each decision node to assess the *best route forward*, reconfiguring if appropriate the ultimate goals.

Note that the subproblem of determining the *best route* may be very difficult and complicated, especially for systems with a high level of indeterminacy. Solving this subproblem usually results in solving the general control problem.

Further, what is our philosophy in project planning and control with indeterminacy? We are not predetermining the initial network model; moreover, in certain cases the structure of such a model may be indeterminate. At the initial stage of the project's realization, the network may be restricted to a source node and several alternative sink nodes (goals) together with some milestones (a decision-tree model). Various activities are usually of random duration. Such a stochastic alternative network is renewed permanently over time, including changes in the ultimate goals. At each decision node our techniques enable us to choose the optimal outcome. Decision making is repeatedly introduced for the renewed network at every sequentially reached decision node.

Thus, the modern project manager should not fear indeterminacy but on the contrary, has to treat the latter the way the Japanese do, i.e., as a friend and assistant, and avoid excluding indeterminacy from the international Project Management community like the devil being banished from church.

In 1996 I was appointed key speaker of the NATO workshop "Managing and Modeling Complex Projects" [68]. From the broad spectrum of various planning and control problems for complicated stochastic network projects, within several days of discussion it was decided to choose and recommend for practical usage four milestones, namely

1. Alternative network models.
2. On-line control models.
3. Stochastic network project scheduling.
4. Multilevel control models for several stochastic network projects.

Since that forum 15 years have elapsed but little was done if at all to resolve the above mentioned stochastic project management contradiction. In certain senses, the situation even became more critical [158]. As a matter of fact, former PERT creators [117] have been brilliant scientists, both in mathematics, industrial engineering and management. Nowadays, their majority are not with us any longer. New project managers have certain experience in managing industrial enterprises but nothing more than that! Most of them are not trained either in cybernetics (including the probabilistic area) or in industrial engineering. Some of them prefer undertaking voluntaristic decisions which are not based on any theoretical grounds. This leads to an extremely dangerous situation when science is emasculated *de-facto* from PM.

It can be well-recognized that in the last several years a variety of countries, especially those entering the BRIC group (Brasilia, Russia, India, and China), exercise a great effort to boost and modernize their industries. This, in turn, causes for the necessity to carry out ambitious innovative projects, the majority of them belonging to the regarded class of complicated stochastic network projects. Taking into account that since 1977, when the excellent monograph by S. Elmaghraby [40] has been published, not a single book on managing stochastic network projects has been presented to the readers, it becomes clear why I decide to write this book. The general idea is to summarize all the results developed by our scientific group within five decades in order to help the innovative projects companies to carry out their projects on the basis of scientifically grounded planning, control and scheduling techniques.

This is not a text-book but a monograph. The difference between the two causes me to refrain from rewriting anew classical theoretical grounds developed and presented so well like [40]; instead, I use to quote appropriate references.

This monograph refers not only to R&D projects but to all other complicated projects under random disturbances, which are *innovative in nature*. For example, the venture of constructing the Trans-Siberian pipe-line from the Arctic coast to China cannot be catalogued as an R&D enterprise; yet, it definitely involves a great amount of sophisticated models of alternative type with branching outcomes. Thus, to carry out such a project successfully the manager really has to be experienced in stochastic network control and participate in a great amount of “brainstorming”. Another example may be associated with developing a multi-well major oil/gas field with variable well capacities, to minimize the project’s total expenses as well as consecutive exploitation costs, etc.

It can be well-recognized that a significant part of innovative R&D projects is carried out in design (project) offices. A large design office may be running, within a one- to two-year period, several hundred projects at a time, many of them characterized by large-size network models under random disturbances. However, nowadays the number of references on planning and controlling projects under random disturbances in a design office remains very scanty [3-5,48,53,85,149]. Therefore a part of the monograph is devoted to stochastic network models aimed on innovative projecting in a design office.

We have undertaken an examination of results obtained by our scientific school in the area of controlling stochastic organization systems [6,47-56], including innovative projecting. A conclusion can be drawn, that those results refer to the following different groups. The first one comprises planning, scheduling and control models in order to monitor innovative projects with a fixed, deterministic structure. The second part comprises innovative projects with a permanently changing structure, usually of alternative stochastic type with multi-variant outcomes. Thus, the core of the first group are control models based on the classical control theory for monitoring a project with a fixed structure, while the cornerstone of the second group is the model of a project with numerous and randomly changing structure. For stochastic projects with a fixed structure control actions are introduced only in emergency situations [53-56,63], while for the second class of projects control actions mostly deal with situations when an alternative milestone event is realized.

Since the two parts refer to different directions, we decided to publish the monograph entitled "Stochastic Network Models in Innovative Projecting" in two volumes. The first volume "Network Projects with Deterministic Structure" comprises various planning, scheduling and control models to monitor innovative projects with predetermined fixed network structure, while the second volume "Alternative Stochastic Network Projects" comprises stochastic innovative projects with multi-variant outcomes and different targets.

The structure of the first volume is as follows. We have subdivided the volume into four main parts. The first part "General Concepts of Stochastic Network Models" comprises the first three chapters. In Chapters 1-3 justification of determining the main parameters of a stochastic network project by means of analytical, simulative and heuristic methods is outlined.

Part II "Optimal Planning and Control Models in Modern Project (Design) Offices" comprises five chapters. A realistic methodological approach to control the progress of stochastic projects by means of inspecting the latter periodically, via confidence probability analysis, is presented in Chapter 4. Chapter 5 describes various optimization problems for projects with deterministic activity durations. The next Chapter considers optimization problems and their solutions for projects with random activity durations. Chapter 7 presents resource reallocation algorithms based on precise solutions, while Chapter 8 comprises various budget reassignment algorithms by means of statistical optimization methods.

Part III "On-Line Control Planning and Scheduling Models for Complicated Non-Hierarchical Innovative Projects" comprises five chapters. Chapter 9 "Milestone problems in monitoring innovative projects with a fixed structure" presents a survey of planning, controlling and scheduling models in R&D innovative projects under random disturbances. Chapter 10 considers in depth on-line control models under chance constraint which enable efficient solution of cost-optimization problems. Chapters 11-13 outline resource constrained scheduling problems for stochastic network projects. Three different cases are examined:

a) Random resource delivery schedule (Chapter 11).
b) Resource constrained project scheduling with deterministic resource delivery models (Chapter 12).
c) Scheduling models for determining projects planning parameters (Chapter 13).

Part IV "Hierarchical On-Line Control Model for Monitoring Several Stochastic Network Projects" comprises three chapters. Chapter 14 "Hierarchical model for PERT-COST projects (planning stage)" presents various budget reassignment problems for several projects with either different priorities or equal significance. Chapter 15 "Hierarchical model for PERT-COST projects (control stage)" presents control actions on different system's levels together with hierarchical on-line heuristic algorithms. The developed theory is based on the principle of analyzing emergency situations [53-56,63,86,92] which has been efficiently used in production management as well. In Chapter 16 novel harmonization models to estimate the stochastic network projects' utility, are outlined. Here the concept of utility signifies the quality of the project's functioning. Various cost-optimization models of human behavior based on unified principles of projects' utility in conjunction with the theory of active systems [17], are outlined as well.

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Scientific publication

Dimitri Golenko-Ginzburg

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