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Essays in Production, Project Planning and Scheduling

A Festschrift in Honor of Salah Elmaghraby

Springer

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Preface

This festschrift is devoted to recognize the career of a man who not only witnessed the growth of operations research from its inception, but also contributed significantly to this growth. Dr. Salah E. Elmaghraby received his doctorate degree from Cornell University in 1958, and since then, his scholarly contributions have enriched the fields of production planning and scheduling and project scheduling. This collection of papers is contributed in his honor by his students, colleagues, and acquaintances. It offers a tribute to the inspiration received from his work, and from his guidance and advice over the years, and recognizes the legacy of his many contributions.

Dr. Elmaghraby is a pioneer in the area of project scheduling (in particular, project planning and control through network models, for which he coined the term 'activity networks'). In his initial work in this area, he developed an algebra based on signal flow graphs and semi-Markov processes for analyzing generalized activity networks involving activities with probabilistic durations. This work led to the development of what was later known as the Graphical Evaluation and Review Technique (GERT), and GERT simulation models. He has made fundamental contributions in determining criticality indices for activities, in developing methodologies for project compression and time/cost analysis, and in the use of stochastic and chance-constrained programming and Petri Nets for the analysis of activity networks. These contributions have been brought together in a seminal book in this area entitled, "Activity Networks: Project Planning and Control by Network Models" published by John Wiley, and a monograph on "Some Network Models in Management Science" published by Springer-Verlag. Dr. Elmaghraby also wrote one of the first books on production planning entitled, "The Design of Production Systems."

His fundamental contributions to the economic lot scheduling problem (ELSP) and economic manufacturing quantity (EMQ) analysis are also widely cited. This work presented a novel methodology using a combination of a dynamic programming-based model, integer programming, and a method to circumvent infeasibility. He later extended this work to include learning and forgetting effects, and to the computation of power-of-two policies. Dr. Elmaghraby's extensive work on a wide range of deterministic and stochastic sequencing and scheduling problems, arising in different machine environments, has resulted in many landmark contributions which have advanced this field of study and have strengthened its knowledge

base. It has offered novel ideas and effective methodologies relying on mathematical rigor for the solution of these problems.

Dr. Elmaghraby is one of the rare individuals who have excelled both as a researcher and an administrator. He was appointed as University Professor and Director of the Graduate Program of Operations Research at North Carolina State University in his early 40's, and over the years, he directed that program with aplomb without losing any of his scholarly productivity. That program flourished for all these years under his leadership, providing a world-class education to its students. His superb guidance and leadership by example in bringing quality in everything that he does has been a defining force that has shaped the careers of his students. It is, therefore, not surprising that, among his numerous awards, Dr. Elmaghraby has been recognized with the Frank and Lillian Gilbreth Award, the highest and most esteemed honor bestowed by The Institute of Industrial Engineers on individuals who have distinguished themselves through contributions to the welfare of mankind in the field of industrial engineering.

This volume brings together 14 contributions, which can be viewed under the following three main themes: operations research and its application in production planning, project scheduling, and production scheduling, inspired by, and in many cases based on, Dr. Elmaghraby's work in these areas. The first five chapters are devoted to the first theme, followed by four chapters each devoted to the other two, respectively. An additional chapter is devoted to the vulnerability of multimodal freight systems.

In the first chapter, "Ubiquitous OR in Production Systems", Leon McGinnis puts forth an argument for a paradigm shift in OR education, from the traditional emphasis on teaching of standalone 'artisan' type tools (where each model is developed to address a specific problem), to a reusable platform that enables their broader and deeper penetration in a domain. This argument is made in view of the advent of new computer technologies, and for applications to production systems that are well understood.

In the second chapter entitled "Integrated Production Planning and Pricing Decisions in Congestion-Prone Capacitated Production Systems," Upasani and Uzsoy address a production planning problem when the customer demand is sensitive to delivery lead times. Since the lead times are known to increase nonlinearly with the utilization of capacitated resources, a large reduction in price may increase demand to the extent that it can no longer be satisfied in a timely manner by available capacity, thereby negatively impacting customer satisfaction and future sales. They present an integrated model for dynamic pricing and production planning for a single product under workload-dependent lead times, and study interactions among pricing, sales, and lead times. Their investigation reveals a different behavior of the integrated model from a conventional model that ignores the congestive effect on resources because of price variations.

A "Refined EM Method for Solving Linearly Constrained Optimization Problems" is presented by Yu and Fang in the third chapter. They extend the original Electromagnetism-like Mechanism (EM) that has been widely used for solving global

optimization problems with box-constrained variables to solving optimization problems with linear constraints, and call it a 'Refined EM Method.' The EM method is a stochastic search method that uses a functional evaluation at each step, and does not require any special information or structure about the objective function. The proposed method explicitly considers linear constraints in an efficient manner to direct sample points to attractive regions of the feasible domain. Results of a computational investigation are also presented that show the proposed method to outperform known methods and to converge rapidly to global optimal solutions.

In "The Price of Anarchy for a Network of Queues in Heavy Traffic," Shaler Stidham investigates the price of anarchy in a congestive network of facilities in which the cost functions at the facilities follow the characteristics of the waiting-time function for a queue with infinite waiting room. Similar to a network of parallel *M/M/1* queues, Stidham develops an analytical expression for the price of anarchy for the *GI/GI/1* network.

In the fifth chapter entitled, "A Comparative Study of Procedures for the Multinomial Selection Problem," Tollefson, Goldsman, Kleywegt, and Tovey address the multinomial selection problem originally formulated by Bechhofer, Elmaghraby, and Morse (1959), that of determining the number of trials needed to select the best among a given number of alternatives. The aim is to minimize the expected number of trials required while exceeding a lower bound on the probability of making the correct selection. The authors present a comparative study on the performances of various methods that have been proposed for this problem over the years.

The sixth chapter is entitled, "Vulnerability of Multimodal Freight Systems." In this chapter, Aydin and Pulat explore the vulnerability of multimodal freight transportation infrastructure in the face of extreme disruptive events. The freight transportation system constitutes a backbone of global economy. This study, motivated by recent hurricane-related events encountered in the USA, examines the concepts of vulnerability, reliability, resilience, and risk, and the relationship among them, for the freight transportation infrastructure, and provides valuable insights on how vulnerable and resilient the transportation infrastructure is to extreme disruptive events.

The following two chapters address stochastic project scheduling problems. In, "Scheduling and Financial Planning in Stochastic Activity Networks," Dodin and Elimam analyze the impact of stochastic variations in the renewable and nonrenewable resources required by each activity of the project, on project cost and duration. An analytical approach is used to determine the probability density functions of the project cost and duration. A linear programming model is used to distribute the resulting project budget over its activities and to minimize the project duration. Willy Herroelen presents "A Risk Integrated Methodology for Project Planning Under Uncertainty" in the eight chapter. A two-phase methodology is presented in the face of the risk of resource breakdown and variability of activity durations. In the first phase, the number of regular renewable resources to be allocated to the project is determined, and in phase two, first a resource-feasible proactive schedule is constructed, after which resource and time buffers are inserted to protect it against disruptions.

The schedule is then tested by simulating stochastic disruptions and by appropriately repairing it if it becomes infeasible. This approach provides an implementable schedule along with a workable reactive schedule procedure that can be invoked in case it becomes infeasible despite the protection built in it.

In the ninth chapter, entitled, "Dynamic Resource Constrained Multi-Project Scheduling Problem with Earliness/Tardiness Costs," Pamay, Bulbul, and Ulusoy address the problem of scheduling a new arriving project against a set of known renewable resources when a number of projects are already in process. The due dates and earliness/tardiness penalties of the activities of the existing project are known while the due date of the new project is to be determined, which is accounted for by assigning a penalty cost per unit time the new project spends in the system. A heuristic method is proposed to solve large-sized problems, and its efficacy is demonstrated.

"A Multi-Mode Resource-Constrained Project Scheduling Problem Including Multi-Skill Labor" is discussed by Santos and Tereso in the tenth chapter. Each activity of the project may require only one unit of a resource type, which can be utilized at any of its specified levels (called modes) that dictates its operating cost and duration. The processing time of an activity is given by the maximum of the durations that result from the different resources allocated to that activity. The objective is to determine the operating mode of a resource for each activity so as to minimize the total cost incurred, given a due date as well as a bonus for earliness and penalty cost for tardiness. A filtered beam method is proposed for the solution of this problem, and results of its performance are presented.

The last four chapters address production scheduling problems. Allaoui and Artiba consider "Hybrid Flow Shop Scheduling with Availability Constraints" in the eleventh chapter. They assume that a machine is not continuously available, and instead, is subjected to at most one preventive maintenance in a specified time window. The jobs are non-resumable, and the objective is to minimize the makespan. For a special case of this problem, with one machine at each stage (the traditional two-machine flow shop problem), a dynamic programming-based method is presented to determine an optimal schedule, while for the hybrid flow shop with one machine at the first stage and m machines at the second stage, a branch-and-bound procedure is proposed that exploits an effective lower bound.

In the twelfth chapter entitled, "A Probabilistic Characterization of Allocation Performance in a Worker-Constrained Job Shop," Lobo, Thoney, Hodgson, King, and Wilson address a job shop scheduling problem in the presence of dual resource constraints pertaining to limited availabilities of both machines and workers. The objective is to minimize maximum lateness. For a given allocation of workers to the machines, they estimate a distribution of the difference between the maximum lateness achievable and a lower bound on maximum lateness. Both heuristic methods for worker allocation and schedule generation as well as a lower bound on maximum lateness that are used for this investigation are presented in an earlier paper.

McFadden and Yano address a problem on "A Mine Planning Above and Below Ground: Generating a Set of Pareto-Optimal Schedules Considering Risk and Return" in chapter thirteen. They assume the availability of different methods for

mining minerals with each method leading to a different profit and risk. They employ a methodology based on a longest-path network framework to determine mining plans that give the k best values of expected profit, and integrate it with various measures of risk to construct a set of Pareto-optimal solutions. The various measures of risk considered include variance, probability of achieving a specified profit target, and conditional value-at-risk. The methodology is illustrated using a simple example with conditional value-at-risk as the risk measure.

In chapter fourteen entitled, "Multiple-Lot Lot Streaming in a Two- stage Assembly System," Yao and Sarin apply lot streaming to a two-stage assembly shop in which the first stage consists of m parallel machines and the second stage consists of one assembly machine. Each lot consists of items of a unique product type. A lot-attached set up time is incurred at the machines at both the stages. For a given number of sublots of each lot, the problem is to determine sublot sizes and the sequence in which to process the lots at both the stages so as to minimize the makespan. Although the problem of scheduling in such a machine environment has been addressed in the literature, the application of lot streaming to this problem is new. Some structural properties for the problem are presented, and a branch-and-bound-based method is applied for its solution. The efficacy of this method is also demonstrated through computational investigation.

We hope that the contributions in this volume serve to extend the body of knowledge in the wide range of research areas to which Professor Elmaghraby has contributed, which we believe is the most appropriate recognition for an outstanding scholar and administrator. The fields of Industrial Engineering and Operations Research will remain deeply in his debt for many years to come.

Contents

Biography

Salah E. Elmaghraby earned a Bachelor's degree in Mechanical Engineering from Cairo University in 1948, a Master of Science degree in Industrial Engineering from Ohio State University in 1955 and a PhD from Cornell University in 1958. He is University Professor Emeritus at the Edward P. Fitts Department of Industrial and Systems Engineering at North Carolina State University, where he has been a professor of Operations Research and Industrial Engineering since 1967. He established the interdisciplinary Graduate Program in Operations Research and was its Director from 1970 to 1989. Previously, he was Associate Professor at Yale University; Research Leader at the Western Electric Engineering Research Center in Princeton, NJ; and Visiting Professor at Cornell University, the Katholieke Universiteit Leuven (Belgium) and the FUCAM (Belgium), the Claude Bernard Université Lyon I (France), and the Nagoya Institute of Technology (Japan). He has 12 years of industrial experience, including eight abroad in Egypt, Kuwait (where he was Principal Scientist and Project Leader for 2 years) and Europe (the U.K., Belgium and Hungary where he was Inspecting Engineer for the Egyptian Railways for 5 years). He has served as reviewer for many US and European journals; was Regional Editor (the Americas) for the International Journal of Production Economics and was the founder and editor-in-chief of the Journal of Operations and Logistics, 2004–2011.

Professor Elmaghraby is a recipient of numerous awards and honors, including the Frank and Lillian Gilbreth Industrial Engineering Award (IIE, 2003), the Alexander Quarles Holladay Medal for Excellence (NCSU, 2000), the Kuwait Foundation for the Advancement of Science Distinguished Award (1990), the R. J. Reynolds

Distinguished Award in Research and Education (College of Engineering, NCSU, 1987), the Operations Research Division Award (IIE, 1980), and the David F. Baker Distinguished Research Award (IIE, 1970). He obtained an Honorary Doctorate from the Université Claude Bernard Lyon I (France, 1998). He was elected Fellow of the Institute of Industrial Engineers in 1986 and Fellow of the Institute for Operations Research and Management Sciences (INFORMS) in 2004.

Professor Elmaghraby has written four books, among them the seminal production management text "The design of production systems" (Reinhold 1966) and the pioneering activity networks textbook "Activity networks" (Wiley 1977). He edited/co-edited three books, contributed chapters in nine books, and authored/co-authored over 118 scientific papers.

He initiated the research in generalized activity networks by developing an algebra for the analysis of networks in which activities may be undertaken probabilistically. By providing the theoretical foundations, he paved the way for what later became the GERT model (Graphical Evaluation and Review Technique) and the special purpose GERTS simulation models.

Professor Elmaghraby developed numerous deterministic and stochastic algorithms for scheduling and sequencing problems involving single and parallel machines, flow jobs, and job shops. Most noteworthy and of fundamental impact, however, is his work in the domain of activity networks. He pioneered in the analysis of probabilistic and generalized activity networks, the analysis of activity networks under generalized precedence relations, network representation problems and methodologies for criticality and sensitivity analysis. He made fundamental contributions in the use of stochastic and chance-constrained programming and Petri nets, and published seminal papers on project compression and time/cost trade-off analysis, project bidding, project risk management, complexity issues and test set generation.

Over the years, Professor Elmaghraby has supervised over 60 doctoral and master's students in the USA and abroad, and inspired an extensive population of researchers over the world. At the age of 84, he still continues his research in the field of project planning and control.