Invited Review

Contributions of Professor William W. Cooper in Operations Research and Management Science

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ABSTRACT

Over a long and remarkably productive career, Professor William W. (Bill) Cooper has made many pioneering contributions to Operations Research and Management Science (OR/MS), with notable forays into the areas of (a) linear and non-linear programming, (b) goal programming, (c) chance-constrained programming, (d) data envelopment analysis, and (e) manpower planning, among others. His legendary partnership with Abraham Charnes has provided results whose connections go back to the 18th century, bearing on problems conceived but left unsolved by Laplace and Gauss. We document cross-fertilizing links among Bill Cooper's multiple research focuses, and their impacts on other researchers. A trace of his work discloses a web of influence that has produced a wide range of advances in OR/MS by those who follow in his footsteps, representing a productive *tour de force* that shows no sign of abating.

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1. Introduction

We undertake a review of the contributions of Professor William W. Cooper (University of Texas at Austin) in celebration of his 95th birthday. Professor Cooper has dedicated his life to the development of various methodologies and concepts in business education and research. He had made major contributions that were formative in launching the fields of linear programming, non-linear programming, goal programming, chance-constrained programming, manpower planning and multi-objective optimization. Later, he extended the technique of linear programming and non-linear programming into the development of Data Envelopment Analysis (DEA) which has been widely applied to performance analysis in public and private sectors. Professor Cooper has also developed important business-related concepts and research in areas such as management science, managerial accounting, economics, management, marketing, and auditing, all of which serve currently as pedagogical and research bases in modern business and business education along with public policy.

Professor Cooper's first published article was an economic analysis entitled "The Yardstick of Public Utility Regulation" that appeared in *the Journal of Political Economy*, June 1943 LI, no. 3, pp. 258–262. In fact, still earlier in 1938 he published a proceedings paper for the Committee on Capital Gains Taxation of the National Tax Association, which later became an article entitled "Costs, Prices and Profits – Accounting in the War Program," and published in *The Accounting Review*, July, l945, val. 20, no. 3, pp. 267–308 along with E.L. Kohler. On August 31, 1945, the American Institute of Accountants (currently the American Institute of CPAs where CPAs stand for Certified Public Accountants) chose his article as the most significant contribution to accounting in the year. Since then, over a period spanning seven decades, Professor Cooper has now published 27 books and more than 520 articles in leading international journals. His research includes significant contributions to accounting, economics, management, public policy and other research areas[1] as well as to Operations Research and Management Science (OR/MS), though we focus here only on his contributions in OR/MS.

The structure of this review paper is organized as follows: Section 2, immediately following, classifies Professor Cooper's contributions into six groups and discusses relationships among them. This section corresponds to publications listed in the references of this article. Section 3 discusses the historical path of his contributions from the development of L1 regression to DEA. The article on L1 regression was also the first research effort that identified the formulation, subsequently referred to as goal programming (GP). It is widely known

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[1] The special issue of *Production and Operations Management* (2008) 17 pp. i–ii provides short curriculum vitae of Professor Cooper. The contributions of Professor Cooper in accounting, economics and public policy will be prepared by Y. Ijiri and T. Sueyoshi. Their review article on his contributions in the areas will be published in *Journal of Accounting and Public Policy*.

that GP serves an important methodological basis for multi-objective optimization. This section describes how the development of GP influences the research of Professor Cooper. Section 4 reviews Cooper's contributions in the area of DEA, to which he has devoted a major part of his research during the past three decades. Section 5 concludes the review and summarizes some of the key elements of Professor Cooper's work.

2. Research classification

Professor Cooper has a long list of publications. This review eliminates most of his contributions related to accounting, management, economics, public policy and other research areas. Furthermore, he was a recipient of many awards. For example, Professor Cooper has been a fellow of the econometric society since 1956. He was the first president of The Institute of Management Science (TIMS) in 1954 and was appointed as the Accounting Hall of Fame (the most prestigious award in Accounting) in 1995. This review does not describe a long list of his awards and professional contributions. Rather, this review focuses upon his research contributions in OR/MS and these influences to other researchers.

Table 1 classifies the OR/MS publications of Professor Cooper into six categories: linear/non-linear programming, manpower planning, GP, chance-constrained programming, DEA and others. Each research area is further classified by modeling, theory, algorithms and applications. The number in each cell corresponds to the reference number of this article. A reference number may be listed in several cells when an article with the reference number belongs to multiple features. For example, [66] is the first book on linear programming in the OR/MS community that covers both its modeling and theoretical aspects. The book also describes algorithmic aspects of the simplex method and various types of applications. Hence, [66] belongs to all categories from modeling to application, as listed in the first row of Table 1. In a similar manner, [123] has used GP as a method for manpower planning, but Table 1 classifies it as his contribution in manpower planning. The separation is based upon the purpose of each study.

DEA[2] contains the largest number of his publications in Table 1. The linear/non-linear programming[3] is the second, and the chance-constrained programming (CCP)[4] is the third in his publication record. The remaining research areas include GP, manpower planning[5] and the others.[6]

The cell in Table 1, that contains the largest number of his publications, is the theoretical work on DEA. Nevertheless, one of Professor Cooper's most seminal contributions, viewed in terms of its impact on applications and on a broad range of investigations by other researchers, has been the introduction of GP. This review examines his contributions on GP in the next section.

3. Goal programming and data envelopment analysis: origins and influences

3.1. History of L1 regression

To describe the historical context out of which GP has arisen, we go back to the science of the 18th century and then trace forward to consider how GP influences modern statistics and mathematical programming. Fig. 1 depicts the history of L1 regression, GP and DEA. The article [163] prepared by Professor Cooper describes relationships between GP and DEA,[7] but we are motivated to cover additional aspects of GP not examined there.

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[2] Professor Cooper increased his publications in OR/MS after the first DEA article [142] was published in 1978. The development of DEA gave him an opportunity to increase his publication rate. At that time, he was already recognized as an international researcher in OR/MS so that many researchers paid attention to DEA. Furthermore, the practicality of DEA also invited much research interest and activities among many researchers in OR/MS, economics, accounting, management and other business-related areas in many different countries. The contribution of DEA can be found in many places. For example, the research [142] is selected as the most influencing article in EJOR Celebrating the 30th Anniversary of Euro. See the web site of this journal (http://www.elsevier.com/authored_subject_sections/S03/Anniversary/30th_anniversary.htm). Several review articles published in *Socio-Economic Planning Sciences* report that DEA has more than 4000 contributions. Such research efforts are due to the DEA development of Professor Cooper and his associates.

[3] Professor Cooper and his associates produced many contributions in the initial stage of linear programming and non-linear programming. Professor Cooper established his reputation by his works in the research area because linear programming is the main stream of OR/MS. For example, his works include various methods to solve transportation problems [56,65], network models [67,76], reformulation of a fractional model [70], geometric programming [97,115,116] and non-linear programming [60,111–114]. All of these studies make an important foundation of modern OR/MS.

[4] The topic of chance-constrained programming (CCP) was first introduced in [151]. The research [63,68] established theoretical foundations on CCP. The approach is a transformation method that changes a stochastic problem to an equivalent linear programming problem. The reformulation of CCP needs to prescribe a tolerance (or satisficing) level of risk. As a result of the reformulation, we can solve the stochastic problem by linear programming algorithm. The reformulation process of CCP is related to the three models (an expectation model, a probability model and a variance model). Professor Cooper applied the CCP to accounting and DEA in many decisional cases. For example, Refs. [31,32] discussed the relationship among, cost, volume and profit within an accounting framework with a time horizon. See Refs. [45–48] for the CCP applications to finance and accounting. The CCP method was used as an analytical method in these studies. Furthermore, Refs. [166,167,172] discussed stochastic DEA where the CCP added a stochastic feature to the radial models (CCR and BCC).

[5] Professor Cooper was very interested in manpower planning. Maybe, his interest was influenced by his wife (Ruth Cooper, J.D., Esq.). She was the first woman lawyer in the state of Pennsylvania (USA) who fought for women's social issues and supported low income families. During World War II, Dr. Ruth Cooper worked in a Japanese concentration camp. She realized at that time that US policy was not always in justice. Then, she decided to help underprivileged people as a woman lawyer. In USA, many women work as layers and corporate executives nowadays. Dr. Ruth Cooper was the first individual who understood the importance of the woman's issue from World War II. She dedicated her life for helping women and underprivileged families. Influenced by Ruth, funding opportunities from US Navy made Professor Cooper to explore manpower planning issues as part of his concern toward public policy. For example, Refs. [126,135,136,138,140,141] discussed EEO (Equal Employment Opportunity) affirmative action planning by combining CCP with GP in a Markov process of EEO. Furthermore, the research [123–125] discussed EEO and military manpower planning by combining GP with generalized network as an assignment problem.

[6] Professor Cooper was interested in public policy. He established the School of Urban & Public Affairs and serviced as the first Dean (l969–l975) at Carnegie-Mellon University (CMU). He was also interested in the development of statistical methods such Khinchin–Kullback–Leibler estimation [146,158]. The CCP has a statistical linkage with risk [68]. The research [149] explored how to deal with multi-collinearlity in regression analysis. His interest in statistics was because he taught statistics at CMU.

[7] From Table 1, we find that GP does not have the number of publications that adequately reflect its influence on multiple criterion optimization. Thus, the number of publications produced by Professor Cooper does not reflect the level of its scientific contribution. Furthermore, Professor Cooper shifted his research effort from GP to DEA even though he clearly understood the importance of GP. However, there is a close linkage between GP and DEA. The research [163] provides an exact analytical characterization on the relationship between GP and DEA. The article was written by Professor Cooper in response to his receiving a Gold Medal Award from the International Society for Multi-Criteria Decision Making in 2004.