Developing a New Theory of Integer-Valued Data Envelopment Analysis for Supplier Selection in the Presence of Stochastic Data

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ABSTRACT

Supplier selection has a strategic importance for every company. Hybrid integer data is one of the models in data envelopment analysis (DEA). In many real world applications, data are often stochastic. A successful approach to address uncertainty in data is to replace deterministic data via random variables, leading to chance-constrained DEA. In this paper, a chance-constrained hybrid integer data envelopment analysis (CCHIDEA) model is developed and also its deterministic equivalent which is a nonlinear program is derived. Furthermore, it is shown that the deterministic equivalent of the CCHIDEA model can be converted into a quadratic program. In addition, sensitivity analysis of the CCHIDEA model is discussed with respect to changes on parameters. Finally, a case study demonstrates the application of the proposed model.

Keywords: Chance-Constrained Data Envelopment Analysis (CCDEA), Hybrid Integer Data Envelopment Analysis (HIDEA), Stochastic Data Supply Chain Management (SCM), Supplier Selection

1. INTRODUCTION

Supply chain management (SCM) can be defined as “the management of upstream and downstream relationships with suppliers and customers in order to create enhanced value in the final market place at less cost to the supply chain as a whole”. The synergies between SCM and marketing have been widely acknowledged, leading some to conclude that better coordination could define competitive superiority in new ways (Jüttner et al., 2007).

The decision maker needs to decide from which supplier to purchase parts required to complete each customer order. These decisions are based on multiple criteria such as price, qual-
ity (defect rate), and reliability (on time delivery) that may conflict each other. For example, the supplier offering the lowest price may not have the best quality or the supplier with the best quality may not deliver on time. Furthermore, to reduce the fixed ordering (transaction) costs, the number of suppliers and the total number of orders should be minimized.

Supplier selection is one of the most important components of production and logistics management in the competitive environment of the global market. As organizations become more dependent on their suppliers the direct and indirect consequences of poor decisions become more severe. Such decisions involve the selection of individual suppliers to employ and the determination of order quantities to be placed with the selected suppliers. Practitioners need to follow strategies to achieve higher quality, reduced costs and shorter lead times to be able to compete in the global market. Within new strategies for purchasing and manufacturing, suppliers play a key role in achieving corporate competition (Ebrahim et al., 2009).

Conventional data envelopment analysis (DEA) method implicitly assumes inputs and outputs to be continuous, real-valued data (Kazemi Matin & Kuosmanen, 2009). However, in many applications, some of the input and/or output data are characteristically integer-valued. For example, in efficiency evaluation of university departments, inputs such as the number of professors and outputs such as the number of published articles are restricted to the whole numbers. While the rounding of performance targets to the nearest whole number does not necessarily make a big difference for large departments, for small departments it can be a major issue. For example, suppose a department has 3 full professors, and the DEA analysis suggests the efficient level of professors is 2.4. Such result raises a dilemma: there is no evidence that 2 professors would suffice to meet the educational and scientific objectives of the department, but rounding 2.4 up to 3 does not save any resources even though the efficiency score of the department is only 0.8. As another example, in supplier selection problem, number of personnel is an integer-valued input.

Lozano and Villa (2006, 2007) were the first to emphasize the importance of introducing explicit integrality constraints to the DEA framework, developing a mixed integer linear programming (MILP) procedure for solving the DEA efficiency scores. Kuosmanen and Kazemi Matin (2009) developed the axiomatic foundation for Lozano and Villa’s integer DEA (IDEA) technology, and pointed out a corrected MILP formulation for solving the efficiency scores. Kuosmanen and Kazemi Matin’s minimum extrapolation theorem builds upon the new axioms of natural disposability and natural divisibility. Imposed together with the classic additivity postulate of Koopmans (1951), these axioms characterize an integer-valued technology. They are obtained as the subset of integer-valued input–output vectors enveloped by the classic DEA technology with constant returns to scale (CRS). While the assumptions of additivity and natural divisibility are intuitive, they are not general enough to allow for increasing or decreasing returns to scale.

Kazemi Matin and Kuosmanen (2009) extend and generalize the axiomatic foundation of Kuosmanen and Kazemi Matin (2009) for IDEA to the variable, non-decreasing and non-increasing returns to scale environments. To establish an IDEA variant of the variable returns to scale (VRS) technology, they introduce a new notion of natural convexity, which restricts the feasible convex combinations to the subset of integer-valued points. The connection to the non-increasing returns to scale (NIRS) technology is established by making use of the earlier natural divisibility postulate, but the non-decreasing returns to scale (NDRS) variant requires a new axiom of natural augmentability. Equipped with these alternative sets of axioms, they expand the theory of IDEA to cover the full set of possible returns to scale available in DEA. Conveniently, all alternative variants of the IDEA technology are obtained as the...
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