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An analysis of operations efficiency in large-scale distribution systems

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Abstract

This research applies Data Envelopment Analysis (DEA) methodology to evaluate the efficiency of units within a large-scale network of petroleum distribution facilities in the USA. Multiple inputs and outputs are incorporated into a broad set of DEA models, yielding a comprehensive approach to evaluating supply chain efficiency. This study empirically separates three recognized, important and yet different causes of performance shortfalls which have been generally difficult for managers to identify. They are: (1) managerial effectiveness; (2) scale of operations and potential for a given market area (and efficiency of resource allocation given the scale); and (3) understanding the resource heterogeneity via programmatic differences in efficiency. Overall, the efficiency differences identified raised insightful questions regarding top management's selection of the appropriate form and type of inputs and outputs, as well as questions regarding the DEA model form selected.

Keywords: Effectiveness/performance; DEA models; Petroleum; Logistics

1. Introduction

The accurate, reliable assessment of individual system components or of the overall supply chain system remain critical prerequisites to managerial decision-making, especially in the face of higher customer expectations, shrinking profit margins and little brand loyalty. Systemic performance evaluation can meld the components of complex value-creating supply chain systems by directing strategy formulation as well as monitoring implementation at the operational level (Fawcett and Clinton, 1996). Effective systemic performance evaluation should improve managers' overall understanding of the process being evaluated (e.g. inputs/outputs), influence behaviors throughout the system, and provide useful information to system members and other stakeholders. However, the genesis of poor/superior performance is multi-faceted: operations size, workforce knowledge, direct salaries (influenced by experience), market differences, vehicle costs, discharge time/rate into customer facilities, customer densities and many other factors can influence financial and time-based performance. Thus, due to the sheer number of potential variables, performance assessment is no simple task: Nutt (2000) contends that many decisions fail because of the singularity in focus.

We use recent advances in Data Envelopment Analysis (DEA) to evaluate efficiency performance in the presence of multiple resource inputs, multiple outputs,

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unequally endowed operational units, and multiple hierarchical decision-making units. Our context is the efficiency evaluation of a petroleum distribution system in which 207 distribution centers (DCs) are organized into three regions, which report to corporate headquarters. DC managers compete internally for allocation of resources from corporate managers and externally for market share. While performance of such a system can be defined in many ways, we focus on efficiency of resource input use in relative rather than absolute terms (as in the engineering disciplines). Some resource decisions are of a strategic nature, are determined by top management and inherited by local managers, and are classified as non-discretionary; in contrast, discretionary resource decisions are tactical and determined by DC managers (e.g. workforce profiles in the form of driver experience). As in our case, decision-making units are generally within a larger organizational hierarchy where multiple inputs are used to produce multiple outputs and thus both the managerial and inherent efficiencies of units need to be addressed. Corporate logistics managers wanted to know what fundamental change in distribution strategy was required (if any), while DC managers were concerned primarily with the tactical issues reflecting only on their individual performance. Past DEA studies (Seiford, 1996) have addressed many arenas such as schools and libraries; but few have considered supply chain contexts similar to ours which focuses on the heterogeneity of resources within the firm.

This research draws on previous work to advance the construction and comprehensive testing of models of distribution efficiency, and we extend past research in a number of ways. First, Kleinsorge et al. (1989) used DEA efficiency scores in allocating transportation resources, and Ross et al. (1998) incorporated DEA targets for network redesign, thus rationalizing consolidation. The current study goes further by examining efficiency differences among units within a large operation, without focusing on the mechanics of system design. Second, Gillen and Lall (1997) and Sarkis (2000) have studied airport efficiency using several versions of DEA, but only the later study explored structural differences in efficiency. Our study also explores structural differences, but goes further by examining alternative pairings of input variables within different process views (following recent developments in Brockett and Golany (1996)). Third, Aida et al. (1998) applied DEA-RAM to Japanese water distribution systems, but did not address the impact of their 'uncontrollable' variable. Although similar in many ways to the current study, we go further by addressing (1) inherent efficiency versus efficiency attributable to effective management and (2) the impact of non-discretionary variables. Fourth, Seiford and Zhu (1998) analyzed the sensitivity of input/output levels for efficient units. However, their approach cannot completely explore differences between units or between groups of units, unlike the approach we advocate in the current research.

Interesting managerial implications emerged from this study: for example (1) several models can appropriately assess performance of all DCs simultaneously, which allows comparison of overall performance from several strategic viewpoints; (2) inherently good operations can be distinguished from operations that are managed well, which may be useful in determining managerial incentives for sub-par performers; (3) scale diseconomies identify market opportunities for expansion/downsizing; and (4) non-discretionary variables can be important to an assessment, but their use appears contextual and inclusion is a decision of stakeholders.

In summary, we first evaluate distribution performance from several strategic process views in order to understand the general nature of efficiency. Second, we identify and differentiate managerial efficiency, scale efficiency (SE), and programmatic efficiency. Third, we explore (using parametric tests) the efficiency impact of variables that may not be directly controlled. The paper is organized as follows: Section 2 summarizes the DEA methodology utilized in this paper; Section 3 discusses efficiency measurement in supply chains; Section 4 discusses our results and Section 5 concludes with interpretations of the study.

2. The DEA analysis of efficiency

DEA methodology was selected over the regression approach for estimating efficiencies for several reasons. First, no initial estimates of distribution center efficiency (performance) were available. Second, we also found that other potential input variables