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Using data envelopment analysis to evaluate the performance of post-hurricane electric power restoration activities

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ABSTRACT

Post-hurricane restoration of electric power is attracting increasing scrutiny as customers' tolerance for even short power interruptions decreases. At the peak, 8.5 million customers were without power after Hurricane Sandy and over 1 million customers were without power more than a week after the storm made landfall. Currently, restoration processes are typically evaluated on a case-by-case basis by a regional public service commission or similar body and lack systematic comparisons to other restoration experiences. This paper introduces a framework using data envelopment analysis to help evaluate post-hurricane restorations through comparison with the experiences of other companies in similar storms. The method accounts for the variable severity of the hurricanes themselves, so that companies are not penalized for outages that are long only because the hurricane that caused them was particularly severe. The analysis is illustrated through an application comparing 27 recent post-hurricane restoration experiences across 13 different electric power companies in the United States. The results of the study show some consistency in performance among individual utilities after the hurricanes they experience. The method could be applied to other types of infrastructure systems and other extreme events as well.

1. Introduction

Hurricanes can cause widespread outages that last for days. In Hurricane Sandy in 2012, for example, 439,000 Public Service Electric and Gas (PSE&G) customers in New Jersey were still without power a week after the storm made landfall [14]. While these are extreme, relatively infrequent events, their recent trends are disconcerting; the number of outage events that affect more than 50,000 customers has steadily increased since 2003 along with the incidents of extreme weather [13]. Power outages force many businesses to close, disrupt other infrastructure sectors that rely on power, such as cellular communication, and may alter law enforcement strategy to protect public safety (e.g., traffic safety). As society's dependence on and expectation of uninterrupted electric power increases, regulators have increased their focus on power companies' natural disaster responses and post-disaster investigations by public utility commissions have become increasingly common (e.g., [11]).

In practice, public utility commissions review power system performance during and after a hurricane, earthquake, and other extreme events on a case-by-case basis following the event, and the public makes its own assessment. It would be helpful to have a more consistent and transparent method for evaluating and comparing performance after an event and with this evaluation, to be able to identify where improvements in the restoration process are warranted. It is difficult, however, to set standards regarding what is considered an acceptably fast restoration (such as $X\%$ of customers should be restored in Y days). Storm intensity and size vary along with characteristics of the service area itself. A standard should depend both on the societal impacts associated with different outage durations, and on what outage durations are possible to achieve in practice given that it takes some time for crews to move around and undertake the repairs and other activities necessary to restore power. Both of these dimensions are difficult

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Abbreviations: BBC, Banker, Charnes and Cooper Model. Also referred to as the Technical Efficiency Model; CCR, Charnes, Cooper, and Rhodes Model. Also referred to as the Scale and Technical Efficiency Model; DEA, Data Envelopment Analysis; DMU(s), Decision Making Unit(s)

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to estimate. An alternative approach is to base restoration performance evaluations on a comparison to other companies' experiences in similar events. Data envelopment analysis (DEA) is well-suited to this problem.

Developed by Charnes et al. [3], DEA is a nonparametric method to measure the relative efficiency of an organization (called decision making unit, DMU), given the performance of other organizations that perform similar functions. In a DEA, the efficiency of a DMU can be measured by considering any number of inputs and outputs. The inputs and outputs can be non-commensurate (i.e., they do not need to be in the same units), and there is no need to specify the relative importance of each input and output. DEA produces a single scalar measure of efficiency for each DMU so the results of the analysis are easy to understand and communicate. With this efficiency measure, efficient levels of input or outputs can be computed, so DMUs know by how much they must reduce or augment particular inputs or outputs to become efficient. Finally, DEA provides for the inclusion of non-discretionary inputs. These are factors that are not under the control of the DMU but that influence its ability to create output.

Since the evaluation of the performance of each DMU is maximized given the performance of other DMUs, the focus of the analysis is on each DMU rather than on the estimation of the parameters of a single model. This means the DEA does not require the specification of the functional form of the relationship between the independent and dependent variables. Rather, the DEA analysis produces an estimate of the functional form of the efficient frontier [3]. Unlike statistical regression methods that measure performance based on deviations from average or "best fit" behavior, DEA uses the best-observed performance as the frame of reference.

The goal of this paper is to develop a wholly new, transparent, and consistent evaluation process for the restoration of electric power after a hurricane. This paper provides an illustrative case study using real data to compare 27 recent post-hurricane restoration experiences of U.S. electric power companies. While the data in the case study are real and collected from utility websites and news articles, they are ultimately masked; the purpose of this paper is not to say how specific utilities responded to recent storms but rather to develop a framework for consistent, unbiased evaluation of these responses. The evaluation metrics we choose may not suffice for a true evaluation. Those that are chosen reflect a combination of the authors' perception of what are valuable metrics for evaluating response and limited amounts of publically available data. Ultimately, it is for utilities, public service commissions, and other stakeholders to decide the metrics that are appropriate for comparison.

Under this paper's framework, each DMU is a post-hurricane electric power restoration performed by a specific utility, such as Dominion Virginia Power's restoration after Hurricane Isabel. The most efficient restorations are those for which there is no other restoration or linear combination of restorations that was faster given the money spent or the storm severity. The most efficient DMUs serve as an efficient frontier to which all other DMUs are compared. Hurricane severity is considered a non-discretionary input, so that the analysis acknowledges that a utility does not have control over the hurricane severity, and therefore should not be penalized for restorations that take longer because they were associated with very severe hurricanes.

Many other studies have modeled the post-disaster restoration processes of various infrastructure systems in an effort to estimate expected restoration times, and several have tried to optimize post-disaster restoration strategies. Previous work in these areas is summarized in Liu et al. [8,20], and Nateghi et al. [10]. No published work could be found, however, related to the *evaluation* of restoration processes, or using DEA to evaluate system performance in extreme events more generally.

DEA has been used in the electric power industry more broadly to evaluate the relative efficiency of, for example, electricity distribution utilities in the U.S. Pahwa et al. [12], power plants in Israel [6], service centers in Taiwan [4], and the impact of the clean air act on coal-fired generators [18]. Chien et al. [4] and Yang and Lu [21] offer reviews of this literature. DEA has not been used to develop infrastructure system, including electric power systems, performance comparisons for extreme events.

The paper is organized as follows. In Section 2, DEA models are reviewed, and the type of formulation used in this study is developed. The post-hurricane electric power restoration case study is described in Section 3, and the paper concludes with a summary of the strengths and limitations of this approach in Section 4.

2. DEA models and example

The original DEA model was developed by Charnes et al. [3], and is often referred to as the CCR model for Charnes, Cooper and Rhodes. It assumes decision-making units (DMUs) operating with constant returns-to-scale are efficient. Banker et al. [2] developed a modification of the CCR model (often referred to as the BCC model for Banker, Charnes, and Cooper) that relaxes the constant returns-to-scale requirement in favor of variable returns-to-scale. In this paper, we use the BCC model because it is less restrictive and allows for a richer exploration of the data. Before developing the DEA models to be used in evaluating the performance of post-hurricane electric power restoration activities, the simple case of one discretionary input and one output (Fig. 1) is used to illustrate four key concepts: (1) the character of CCR and BCC efficiency

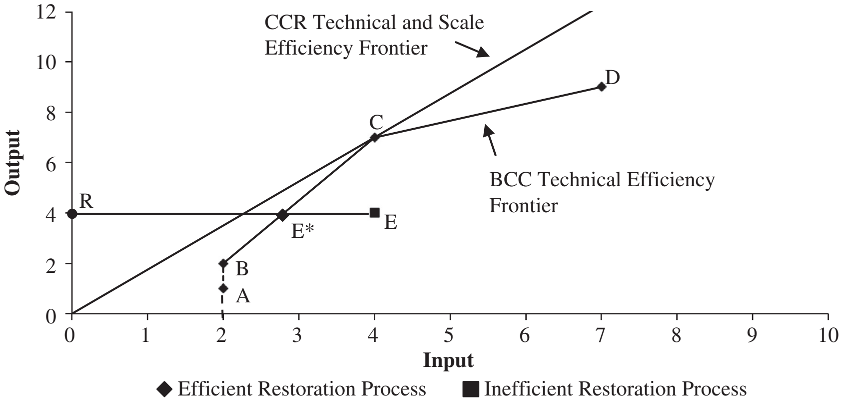

Fig. 1. Example DEA model.