Transportation Research Part E 47 (2011) 1160–1176

Contents lists available at ScienceDirect

Transportation Research Part E

journal homepage: www.elsevier.com/locate/tre

Improving the efficiency of metropolitan area transit by joint analysis of its multiple providers

Darold T. Barnum [a,*], Matthew G. Karlaftis [b], Sonali Tandon [c]

[a] Departments of Managerial Studies, Information & Decision Sciences, and Pharmacy Administration, University of Illinois at Chicago (MC 243), 601 South Morgan Street, Chicago, IL 60607-7123, USA

[b] Department of Transportation Planning Engineering, School of Civil Engineering, National Technical University of Athens, 5, Iroon Polytechniou Street, Zografou Campus, Athens 15773, Greece

[c] Chicago Transit Authority, 567 W. Lake Street, Chicago, IL 60661, USA

ARTICLE INFO

Article history:
Received 24 August 2009
Received in revised form 16 May 2010
Accepted 18 July 2010

Keywords:
Data Envelopment Analysis
DEA
Technical efficiency
Allocation efficiency
Urban transit
Urban public transportation
Urban transport

ABSTRACT

Public transportation in a metropolitan area often is supplied by multiple types of transit. This paper develops and illustrates a DEA-based procedure for estimating: overall efficiency of an area's public transportation; technical efficiencies of the individual transit types; effect of each type on overall efficiency; and efficiency of the allocation of resources among types and an algorithm for improving it. The paper concludes that the overall efficiency of an urban area's public transportation can be validly estimated only if the technical efficiency of each major transport type and the efficiency in allocating resources among them are taken into consideration.

1. Introduction

Efficiency has long been a critical consideration in both policy and operational decisions of urban transit systems, and transit efficiency has recently become even more important. In the US, for example, transit ridership has been increasing while tax-supported funds to cover its expenses have been declining (Fausset, 2009; Murray, 2010; Torbati, 2010). Of course, fares can be increased and service decreased in response to these lost resources. But, such actions especially hurt those who are unemployed and those who are transit-dependent. And, cuts in service and ridership negatively impact efforts to decrease the use of oil and reverse undesirable climate trends. The effects of declining revenues can be lessened if efficiency is improved. Indeed, the desirable effects on energy and climate would be multiplied many times over if cities across the world could improve the efficiency of their transit systems.

Because of efficiency's long-standing importance to government, there have been many US federal, state and local studies that compare the efficiency of transit systems, with a few recent publications including (Perk and Kamp, 2004; Stanley and Hendren, 2004). Further, more than 60 transit Data Envelopment Analysis (DEA) papers have been published or are in press as of mid-2009, involving cities in Asia, Europe, and North and South America. Perhaps as a sign of the growing importance of transit efficiency, over half of these DEA studies have come in the last six years (Barnum, 2009), including six in *Transportation Research Part E* (Boame, 2004; Sheth et al., 2007; Graham, 2008; Lin et al., 2008; Yu and Fan, 2009; von Hirschhausen and Cullmann, 2010).

* Corresponding author. Tel.: +1 312 996 3073; fax: +1 312 996 3559.
E-mail addresses: dbarnum@uic.edu (D.T. Barnum), mgk@central.ntua.gr (M.G. Karlaftis), standon@transitchicago.com (S. Tandon).

1366-5545/$ - see front matter
doi:10.1016/j.tre.2011.04.006

2. Joint analysis of multiple transportation modes

Multiple types of public transportation, overseen by metropolitan transit agencies, serve most urban areas. Therefore, to best improve the efficiency of an urban area's transit service, it is necessary to individually and jointly analyze the various methods by which that service is supplied. That is, it is necessary to analyze the individual efficiencies of the main methods of delivering public transportation in urban areas, and synthesize the individual results to show their effects on the efficiency of an urban area's public transportation as an integrated whole. Specifically, in order to provide government policy makers and transit managements with sufficient information, it is necessary to:

- Estimate technical efficiency of each type of transit service provided by a transit agency.
- Estimate efficiency of the agency as a whole in supplying service to its urban area.
- Estimate effect of changes in each of service type's efficiency on its parent agency's efficiency.
- Estimate efficiency of the parent agency's allocation of resources among service types.
- Estimate reallocation of resources among the service types that minimizes the parent agency's total costs while maintaining its total output.

Without *all* of this information, decision makers cannot comprehensively evaluate and improve the transit service in a metropolitan area.

3. Review of the literature

Unfortunately, 56 of the 63 transit DEA articles published through mid-2009 deal only with one mode, almost always motorbuses (Barnum, 2009). The remaining publications are discussed next.

The earliest transit DEA articles to consider multiple modes were published in 1997 and 1998, involving fixed-route, fixed-schedule motorbuses and demand-responsive (paratransit) operations (Viton, 1997; Viton, 1998). Outputs and most inputs were entered as separate variables for each of the modes. So, for example, an agency's four outputs were bus vehicle-miles, paratransit vehicle-miles, bus passenger-trips, and paratransit passenger-trips. For the most part, the inputs were also separated by mode. One DEA score was reported for each agency, and the two modes were not analyzed separately.

The next set of transit DEA articles that considered multiple modes were published in 2006 and 2008, and involved organizations that operated both highway and urban bus lines (Yu and Fan, 2006; Yu, 2008). Again, the values of most input and output variables were entered separately for each mode. There were also a shared input and a shared output in the earlier paper, and a shared input in the later. The values of the shared variables were artificially allocated to the two modes in a way that maximized the efficiency score for the organization as a whole. There were analyses of the organizations as a whole using all inputs and all outputs, and analyses of each mode separately using only variables attributed to that mode (including the amount of the shared variable that had been previously artificially allocated to it).

In Yu and Fan's, 2009 paper in *Transportation Research Part E*, again the non-shared input and output values were entered separately for highway and urban bus lines, and again shared inputs were artificially allocated among the modes in order to maximize the organizations' overall efficiency scores (Yu and Fan, 2009). In addition, they presented a network model in which the outputs from the first stage were used as the inputs into the second stage. They presented a DEA score for each organization, as well as DEA scores for each mode at each stage, using input and output variables applicable to each mode and stage including the artificially allocated amounts.

In 2008 Sampaio, Neto and Sampaio published a paper using DEA to analyze the aggregated inputs and outputs from the major public transportation modes in large urban areas from around the world. Because they used data aggregated across multiple modes, they identified the overall efficiency of public transportation in each urban area, but not the efficiency of individual components (Sampaio et al., 2008).

Barnum, Gleason, Hemily and others published a set of papers involving demand-responsive transit, using separate input and output values for publicly owned service and for service outsourced to private operators (Barnum et al., 2008, 2009, 2010b). These papers did not address the multiple mode issue, however, with their topic of concern being the use of statistical panel data analysis to estimate valid confidence intervals and trends of individual DMU efficiencies.

As a whole, these papers leave a number of issues unresolved, and, in some cases, contain errors that invalidate their methodologies. All but one of the papers compute DEA scores measuring technical efficiency only, because they utilize separate input and output values for each mode (Barnum and Gleason, 2006a,b). Only Sampaio, Neto and Sampaio's DEA aggregates the inputs and outputs across modes, and therefore is the only one to measure overall total efficiency because it encompasses both allocation and technical efficiency in its DEA scores. Although technical efficiency is important, it does not tell the whole story because allocation efficiency is ignored.

Further, with the exception of the papers by Yu and his colleagues, these past papers only report each organization's technical efficiency, thereby not identifying each separate subunit's contribution. Clearly, in attempts to improve an organization's overall technical efficiency as well as the efficiency of each subunit, it is necessary to identify the technical efficiency of each subunit. So, while Yu et al. do not provide a method for reporting total (technical and allocational)