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Original Research Paper

# Evaluating transit operator efficiency: An enhanced DEA model with constrained fuzzy-AHP cones

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ABSTRACT

This study addresses efforts to comb the Analytic Hierarchy Process (AHP) with Data Envelopment Analysis (DEA) to deliver a robust enhanced DEA model for transit operator efficiency assessment. The proposed model is designed to better capture inherent preferences information over input and output indicators by adding constraint cones to the conventional DEA model. A revised fuzzy-AHP model is employed to generate cones, where the proposed model features the integration of the fuzzy logic with a hierarchical AHP structure to: 1) normalize the scales of different evaluation indicators, 2) construct the matrix of pairwise comparisons with fuzzy set, and 3) optimize the weight of each criterion with a nonlinear programming model. With introduction of cone-based constraints, the new system offers accounting advantages in the interaction among indicators when evaluating the performance of transit operators. To illustrate the applicability of the proposed approach, a real case in Nanjing City, the capital of China's Jiangsu Province, has been selected to assess the efficiencies of seven bus companies based on 2009 and 2010 datasets. A comparison between conventional DEA and enhanced DEA was also conducted to clarify the new system's superiority. Results reveal that the proposed model is more applicable in evaluating transit operator's efficiency thus encouraging a boarder range of applications.

## 1. Introduction

### 1.1. Background

Over the past several decades, traffic congestion and air pollution has emerged as imperative issues across the world. Development of a transit-oriented urban transport system has been realized by an increasing number of countries and administrations as one of the most effective strategies for mitigating congestion and pollution problems. Despite the rapid development of public transportation system, doubts regarding the efficiency of the system and financial sustainability have arisen. A significant amount of public resources

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have been invested into public transportation. However, complaints about low service quality and unreliable transit system performance have increasingly arisen as well. Evaluating transit operational efficiency from various levels has become one of the most crucial challenges faced by responsible authorities to sustain the public transport system development and improve its performance and service.

### 1.2. *Evaluation of transit system performance*

A transit system performance evaluation is an essential task for transit service providers to capture the passenger demand trends, operational constraints, stakeholders concerns, and evolving service needs. It also allows the responsible authorities to achieve better economic performance assessments, organize their administration, and plan and finance transportation service.

In view of literature, previous studies on transit performance evaluation focus on the service level and fall into three different categories (Hassan et al., 2013), namely the user perception/satisfaction approach (Eboli and Mazzulla, 2011; Nathanail, 2008; Tyrinopoulos and Antoniou, 2008), the efficiency indicator approach (Badami and Haider, 2007; Lao and Liu, 2009), and the integrated approach based on both user opinions and efficiency indicators (Sheth et al., 2007).

To better promote public transport development, some countries and transit associates have enacted a series of national standards or codes to offer best-practice guideline for evaluating transit performance. The International Association of Public Transport (UTIP) has set up a group of indictors, including population of transit users; services coverage; number of bus routes; stations, vehicles, and vehicle mileage; patronage; average trip distance; and fare compared to the performance of public transport systems across the different cities and regions (UITP, 2010). The Transit Capacity and Quality of Service Manual (TRB, 2003) has developed guidelines for evaluating the performance of public transport systems. The manual has categorized the evaluation index system into three groups which are station, route, and system. Moreover, all three groups are required to be ranked in terms of accessibility and convenience, which are decided by indicators of frequency, occupancy, services hours, punctuality, and time gap between private car and public transport.

Some scholars have concentrated comprehensively on evaluating transit system efficiency. Horowitz and Thompson (1995) constructed a list of 70 generic objectives for evaluation of an intermodal transfer facility after extensive literature review and interviews with various stakeholders. Xu and Lian (2011) proposed an evaluation system, including convenience, adaptability, and efficiency. The evaluation system was further divided into eleven indictors to assess transit system performance.

### 1.3. *Literature review*

Regarding literature on transit efficiency evaluation, most researchers employed multi-criterion decision-making approaches. Yeh et al. (2000) employed a fuzzy multi-criteria analysis approach to evaluate the performance of urban public transport system. Hanaoka and Kunadhamraks (2009) used fuzzy logic analytical hierarchy process (fuzzy-AHP) to evaluate the logistics performance of intermodal freight transportation. Yu et al. (2011) developed a comprehensive AHP-based framework for ranking candidate location plans of multiple urban transit hubs. Zak et al. (2010) used multiple criteria analysis method with graphical facilities, called Light Beam Search to optimize the transit vehicle assignment problem. Campos et al. (2009) used a weightage based index to evaluate sustainable mobility in urban areas.

Other researchers have assumed transit system as production lines, evaluating the efficiency of such lines by comparing multiple inputs and outputs (Barnum et al., 2007; Boile, 2001; Fare and Grosskopf, 1996, 2000; Hwang and Kao, 2006; Kao and Hwang, 2008; Karlaftis, 2004; Lao and Liu, 2009; Nakanishi and Falcocchi, 2004; Nolan et al., 2002; Sanchez, 2009; Seiford and Zhu, 1999; Sexton and Lewis, 2003; Sheth et al., 2007; Tsamboulas, 2006; Yu and Fan, 2009; Zhao et al., 2011; Zhu, 2002). Most of these researchers used the Data Envelopment Analysis (DEA), a non-parametric method introduced by Farrell (1957) and popularized by Charnes et al. (1978). It is a managerial approach to assess relative performance/efficiency for evaluating decision making units (DMUs). Each DMU selects its best set of corresponding weights to consider inputs and outputs and the values of weights may thus vary from one DMU to another. The DEA models then calculate each DMU's performance score ranging between 0 and 1 that represents its relative degree of efficiency (Wei and Chang, 2011). The basic relative performance model of DMU0, as perceived by DMU0 itself, can be formulated, following the CCR model (Charnes et al., 1978)

$$\max\ p_0 = \left(\nu^T Y_{k0}\right) \tag{1}$$

$$\text{s.t.}\ \ W^T X_{ij} - \nu^T Y_{kj} \ge 0 \quad j = 1, \cdots, J; \quad i = 1, \cdots, N; \quad k = 1, \cdots, M \tag{2}$$

$$W^T X_{i0} = 1 \tag{3}$$

$$W \ge 0, \quad \nu \ge 0 \tag{4}$$

where $j$ is a decision making unit (DMU) index, $j = 1, \cdots, J$, $i$ is an input index, $i = 1, \cdots, N$, $k$ is an output index, $k = 1, \cdots, M$, $X_{ij}$ is the $i$th input for the $j$th DMU, $Y_{kj}$ is the $k$th input for the $j$th DMU, $\nu^T$ and $W^T$ are two non-negative scalars (weights) for the $k$th output and the $i$th input, $p_0$ is the efficiency/effectiveness ratio of DMU0.

Recently, Arman et al. (2014) presented a DEA-based framework to comparatively assess the operational productivity and efficiency of transit agencies. In their study, input indicators were selected for annual operating expenses, number of employees, and total fuel consumption. Outputs include the total ridership and total vehicle miles traveled during an 8-year period (2002–2009) for public transit agencies in Indiana. Both datasets were used to construct relative efficiency scores through data envelopment analysis.

As ever-increasing applications of DEA in the transit efficiency assessment, some critical issues are deserved further investigation. Halme et al. (1999) has pointed out that DEA