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Assessing the Comparative Efficiency of Urban Mass Transit Systems in Ohio: Longitudinal Analysis

MNTRC Report 12-13

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REPORT 12-13

ASSESSING THE COMPARATIVE EFFICIENCY OF URBAN MASS TRANSIT SYSTEMS IN OHIO: LONGITUDINAL ANALYSIS

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16. Abstract

A mass transit system not only improves passenger mobility, it also affects the level of economic activities (e.g., working and shopping). Thus, changes wrought by mass transit service planning can heavily influence regional economic growth. This planning requires a careful consideration of conflicting goals (e.g., better utilization of fleets vs. transit services, improved passenger services vs. increased operating expenses, revenue increases vs. tax or fare hikes), which poses a number of problems for policy decision makers. In particular, given the public's growing concerns over government budget deficits, the continuous underutilization of a mass transit system can increase public scrutiny of additional investments in mass transit services. To find ways to better utilize mass transit systems across the state of Ohio and thus make best use of state/federal/municipal government funds and taxpayers' monies, this paper aims to evaluate the operational efficiency of the current mass transit system relative to benchmark standards and then identify the leading causes of mass transit inefficiencies. To meet these goals, window data envelopment analysis (DEA) was conducted on the past three years of time-series data for 24 (out of 27) of Ohio's urban mass transit agencies.

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EXECUTIVE SUMMARY

A mass transit system not only improves passenger mobility, it also affects the level of economic activities (e.g., working and shopping). Thus, changes wrought by mass transit service planning can heavily influence regional economic growth. This planning requires a careful consideration of conflicting goals (e.g., better utilization of fleets vs. transit services, improved passenger services vs. increased operating expenses, revenue increases vs. tax or fare hikes), which poses a number of problems for policy decision makers. In particular, given the public's growing concerns over government budget deficits, the continuous underutilization of a mass transit system can increase public scrutiny of additional investments in mass transit services. To find ways to better utilize mass transit systems across the state of Ohio and thus make best use of state/federal/municipal government funds and taxpayers' monies, this paper aims to evaluate the operational efficiency of the current mass transit system relative to benchmark standards and then identify the leading causes of mass transit inefficiencies. To meet these goals, window data envelopment analysis (DEA) was conducted on the past three years of time-series data for 24 (out of 27) of Ohio's urban mass transit agencies.

I. BACKGROUND

Generally, “urban mass transit” refers to scheduled intracity service on a fixed route in shared vehicles. This definition embraces a wide variety of vehicles, such as gasoline and diesel buses, electric streetcars and trolleys, underground and aboveground rapid transit rail, some commuter rail, cable cars, and ferries, and even horse-drawn omnibuses and streetcars. In the United States, mass transit has, for the most part, meant some kind of local bus or passenger rail service (Schrag 2000). For the last several years, ridership of the mass transit system across the United States has continued to rise. Indeed, ridership rose for seven consecutive quarters in 2011 and 2012. Mass transit use over the first three quarters of 2012 increased by 2.6%, amounting to an increase of 201 million trips in the first nine months of the year over the same period in 2011 (American Public Transit Association 2012, Hill 2012). Growing demand for mass transit often necessitates the expansion of service offerings, the improvement of transportation infrastructure, the replacement of old vehicles with new ones, and the additional hiring of mass transit employees, including drivers and maintenance crews. Such a need typically cannot be met without securing greater financial resources. In times of budget cuts and government downsizing, the mass transit authority cannot afford to spend wastefully or make risky future investments that may not recover their cost. A thorough analysis of current mass transit efficiency followed by implementation of key improvements is essential for sustaining the vitality of mass transit systems.

Generally, important benefits of mass transit services may include: (1) enhanced travel choices with public transportation alternatives; (2) improved mobility (especially in poor neighborhoods and for handicapped people); (3) enhanced living environments with less traffic congestion and reduced CO_2 emission; (4) greater opportunities for advancing transportation technologies, such as biofuel for transit buses; (5) increased traffic safety and lower number of accidents, as compared to private transportation; and (6) stimulus for local economic development. In particular, capital investment in public infrastructure, such as mass transit systems is often linked with local economic improvement. For instance, based on the review of academic literature on economic benefits of public infrastructure, Bhatta and Drennan (2003) observed that such investment tended to yield long-term economic benefits, such as higher residential property value, higher real wages for local workers, lower unemployment, and reduced travel time. Similar conclusions are drawn from the more recent studies of Africa’s transportation infrastructure (e.g., Boopen 2006) and China’s transportation infrastructure (e.g., Zhou et al. 2007). The economic impact of mass transit systems on America’s low-income families is known to be especially great because mass transit systems often represent the most cost-effective transportation alternative (Moulding 2005).

On the other hand, a mass transit system can create a financial burden for local, state, and federal governments. According to the American Public Transit Association (APTA), the U.S. mass transit system consumed $56 billion for operation, maintenance, and capital investment in 2010 (American Public Transit Association 2012). Controlling mass transit operating costs while meeting service demand remains the greatest challenge for mass transit authorities, private transit service providers, and public policy makers (Cervero, 2004; Savage 2004; Polzin and Chu 2005).

Considering the significant impact of mass transit systems on public well-being, economic development, and government finances, a growing number of local and state government officials have tried to find ways to improve mass transit services while better utilizing resources (e.g., drivers, dispatchers, maintenance crews, vehicles, equipment, depots). These attempts include an assessment of the past-three-years' performance, in terms of operating and financial efficiency, of mass transit systems across the U.S., and recommendations for improvement (e.g., new sources of revenue, greater access to services, and better utilization of assets and financial resources, including tax dollars). Since mass transit operating efficiency may hinge on the community setting (e.g., housing density, development, urban sprawl) and municipal size, a majority of the published literature has focused on discussions of appropriate municipal size and its potential impact on the efficiency of public services, such as mass transit (Kain 1967; Real Estate Research Corporation 1974; Ladd 1992 and 1994; Rosen 1992; Carruthers and Ulfarsson 2003; Moore et al. 2005; Garcia-Sanchez 2006; O'Sullivan 2007). For example, some of these earlier studies attempted to verify the theory that, although transit vehicles in densely populated urban areas travel relatively short distances, heavy traffic could cause delays and subsequently undermine transit efficiency given that the causation between urbanization and mass transit efficiency was not well established in the past. Indeed, they found a negative effect of population density (urbanization) on transit efficiency.

In contrast with large urban metropolitan settings, sparsely populated suburban areas pose unique challenges in providing adequate mass transit service. Serving dispersed populations requires a higher number of vehicle service hours than serving densely populated urban areas due to greater distances between stops and longer/more frequent empty trips. Also, limited financial resources, communication gaps, and a lack of skilled drivers in suburban or satellite city areas may compound the problem of delivering mass transit services to residents (Lambert and Meyer 2008; Min and Lambert 2010). Thus, the small satellite city setting can adversely influence the efficiency of mass transit services.

II. RELEVANT LITERATURE

Despite a growing interest in mass transit systems among the public, the published literature evaluating the efficiency of mass transit systems has been scant. Some attempts have been made to assess or improve the efficiency of mass transit services from operational and financial perspectives. Examples include Ball et al. (1983), who, in an effort to improve the cost efficiency of the Baltimore Metropolitan Transit authority, proposed an approximate algorithm based on match-based heuristic to schedule vehicles and drivers simultaneously. Extending the work of Ball et al. (1983), Haase et al. (2001) developed both the exact algorithm, built upon the branch-and-bound method, and the heuristic version of a set-partitioning algorithm to solve the complex problem of scheduling mass transit vehicles and their crews simultaneously. Their solution yields greater accuracy than the Ball et al. study (1983). Likewise, a vast majority of the existing literature focused on the development of analytical tools/methods for better utilization of transit vehicles, drivers, and/or other resources (including maintenance crews and capital resources).

Narrowing the scope of the mass transit system to a paratransit system, Bower (1991) investigated the impact of an automated paratransit routing and scheduling system called COMSIS on the operating cost and service quality of paratransit services. As expected, COMSIS turned out to be useful for reducing scheduling errors, reducing the cost of generating schedules, and identifying traffic patterns. Thus, Bower (1991) concluded that COMSIS improved the overall efficiency of paratransit service quality. Similarly, Chira-Chavala and Venter (1997) analyzed the impact of automated vehicles and passenger scheduling methods on the operating costs of paratransit systems. They found that such methods saved unit paratransit transportation cost by 13%. Further extending the earlier works of Chira-Chavala and Venter (1997), Pagano et al. (2002) assessed the impact of the computer-assisted scheduling and dispatching (CASD) systems on the service quality of paratransit systems in central Illinois. They found that CASD systems reduced riding time and increased on-time service at both pickups and drop-offs, enhancing riders' overall satisfaction with paratransit services. On the other hand, the use of CASD to promote higher vehicle productivity resulted in slightly longer ride times. In addition, callers to the system experienced being put on hold more often. Overall, they concluded that the quality of service, which was one of the transit efficiency indicators (e.g., Vuchic 2005), was positively affected by the implementation of the CASD system.

Rather than dealing with mass transit routing and scheduling issues, other earlier studies focused on the assessment of the efficiency and effectiveness of mass transit services from a financial or administrative perspective. For instance, Jackson (1982) compared the real costs of service provided by subsidized mass transit operations (especially paratransit) to those of private-sector operations in the New England region. Comparing nonprofit and publicly owned mass transit services, he discovered that costs-per-passenger-trip were seriously underestimated and did not reflect the actual costs or the cost efficiency of mass transit services provided. The study by Nolan et al. (2001) was one of the first to propose a data envelopment analysis (DEA) to measure the comparative operational efficiency of 25 selected mass transit systems in the U.S. The Dolan study also identified various factors influencing mass transit efficiency using the Tobit regression analysis. It found that higher-than-average fleet age and federal subsidies adversely affected transit efficiency, whereas locally based subsidies had a positive impact.

More recently, Fu et al. (2007) used data envelopment analysis (DEA) to evaluate efficiency levels of individual paratransit systems in Canada with the specific objective of identifying the most efficient paratransit systems and the sources of their efficiency. Through identification of the most efficient systems and their key influencing factors, Fu et al. suggested guidelines for new paratransit service policies and operational strategies for improved resource utilization and quality of service. Their study is one of the few that attempted to measure the comparative efficiency of municipalities relative to other comparable communities with respect to paratransit services. To help improve the efficiency of paratransit schedules, Shioda et al. (2008) proposed a computerized tool, including a data mining technique, to develop paratransit performance metrics that reflect the interests of paratransit stakeholders, such as passengers, drivers, and municipal governments. These metrics include number of passengers per vehicle per hour, dead-heading time, passenger wait time, passenger ride time, and degree of zigzagging. The computerized tool proved useful for improving overall paratransit service quality. Min and Lambert (2010) evaluated the comparative operational efficiency of 75 paratransit systems in the U.S. and identified exogenous variables (e.g., population size, rider profiles, housing density, weather) affecting the paratransit efficiency using the DEA and Tobit regression analysis. As expected, they discovered that the transit system in densely populated areas tended to be more efficient, while the presence of multiple transit systems within the same metropolitan area negatively affected transit efficiency.

Paquette et al. (2009) conceptualized and defined quality of service in dial-a-ride operation intended for people with limited mobility. In particular, they identified various service dimensions and attributes to measure quality of services. Built upon the conceptual model proposed by Paquette et al. (2009), Min (2011) used rider surveys to identify a host of factors that might significantly influence the overall service quality of paratransit in the Toledo metropolitan area. Examples include on-time, door-to-door or curb-to-curb services, flexible pickup/drop-off windows, handling of late-cancellations and no-shows, shared rides, short-notice services, peak-hour feeder services, and overnight service. He discovered that while a private contractor hired for managing the paratransit system was effective in controlling costs, service quality deteriorated under its management. Thus, he warned of the potential risk of outsourcing paratransit services.

Unlike prior studies, Tang and Lo (2010) were among the first to propose an influence diagram to determine which stakeholders (public sector, private railway company, property developers) of the public-private partnership should have primary responsibility for building, funding, or owning mass rail transit systems in Hong Kong. From a different angle, Nelson et al. (2011) introduced a life cycle analysis (LCA) model to enhance the efficiency of public transport, including mass transit systems, over its life span.

As discussed above, most of these prior studies focused on the efficiency of mass transit systems (e.g., most efficient utilization of vehicles, crews, fuel, and allocated budgets) in terms of their cost-saving opportunities and service deliveries. None of these studies conducted cost-benefit analyses of mass transit systems and evaluated the comparative operational and financial efficiencies of mass transit systems over multiple periods. Such evaluation would allow the mass transit authority to detect the patterns and main causes of transit inefficiencies and develop a better allocation of resources (e.g., tax dollars, subsidies, vehicles, and drivers) to a variety of transit services including call-in or paratransit services. Indeed, studies measuring mass transit efficiencies are still lacking, although there are a significant number of studies that developed benchmarks for other public services (e.g., Nolan et al. 2001; Magd and Curry 2003; Northcott and Llewellyn 2005; Wynn-Williams 2005; Braadbaart 2007; Vagnoni and Maran 2008). Noting the paucity of studies evaluating mass transit efficiencies, this paper intends to measure the relative efficiencies of 24 urban mass transit systems in the state of Ohio over a three-year period in their utilization of human, capital, and physical resources, given budgetary constraints. In addition, this paper identifies which exogenous variables, such as population size, city profiles, residential density, and local economic conditions, impact the relative efficiencies of mass transit systems.

To fill the void left by the existing literature, this paper first attempts to address the following research questions:

1. How can we assess the performance of mass transit systems over time? (Which performance metrics are relevant to the assessment of mass transit efficiency for the future investment and improvement of the mass transit system?)

2. What are the most important determinants of mass transit efficiency?

3. How do we develop a transit policy that can boost transit efficiency?

III. THE DEVELOPMENT OF THE DATA ENVELOPMENT ANALYSIS MODEL

As a way of comparatively assessing and benchmarking the efficiencies of mass transit systems, this paper proposes a data envelopment analysis (DEA) model with an input-oriented ratio form under both constant returns to scale (CRS) and varying returns to scale (VRS). In general, DEA is referred to as a linear programming (nonparametric) technique that converts multiple incommensurable inputs and outputs of each decision-making unit (DMU) into a scalar measure of operational efficiency, relative to its competing DMUs. Herein, DMUs refer to the collection of private firms, nonprofit organizations, departments, administrative units, and groups with the same (or similar) goals, functions, standards and market segments. DEA can be employed for measuring the comparative efficiency of any entity, including a mass transit system (or a transit agency), that has inputs and outputs and is homogeneous with peer entities in an analysis. Therefore, DEA can be applied to a wide variety of DMUs, such as mass transit systems in a certain municipality, without much restriction, as long as the DMUs satisfy the basic requirements of inputs and outputs. DEA is designed to identify the best-practice DMU without *a priori* knowledge of which inputs and outputs are most important in determining an efficiency measure (i.e., score) and assess the extent of inefficiency for all other DMUs not using the best practice (e.g., Charnes et al. 1978). Since DEA provides a relative measure, the efficiency rating of each DMU is relative to the ratings of the other DMUs. Since it can distinguish efficient DMUs from inefficient ones, DEA can be useful for developing benchmark standards (e.g., Min et al. 2008). The DEA model can take a variety of forms depending on its assumptions and orientations. In the following subsections, two of the most popular DEA models are described.

CCR Model

The CCR model developed by Charnes, Cooper, and Rhodes (1978) assumes Constant Returns to Scale (CRS). Its objective is to maximize multiple outputs given a set of multiple inputs. The CCR model can be mathematically expressed thusly (Charnes, et al. 1978; Fare et al. 1994; Nolan et al. 2001):

Maximize Efficiency score (*jp*) = $$\frac{\sum_{r=1}^{t} u_r y_{rjp}}{\sum_{i=1}^{m} v_i x_{ijp}} \qquad (1)$$

Subject to $$\frac{\sum_{r=1}^{t} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1, \qquad j = 1, \ldots, n, \qquad (2)$$

$$u_r, v_i \geq \varepsilon, \qquad \forall r \text{ and } i, \qquad (3)$$

where

y_{rj} = amount of output *r* produced by DMU *j*,

x_{ij} = amount of input *i* used by DMU *j*,

u_r = the weight given to output *r*,

v_i = the weight given to input *i*,

n = the number of DMUs,

t = the number of outputs,

m = the number of inputs,

ε = a small positive number.

Solving the above equations, the efficiency of a DMU (*jp*) is maximized subject to the efficiencies of all DMUs in the set with an upper bound of 1.0 (Min and Lambert 2006). DEA solves a linear program for each DMU in order to calculate a relative efficiency score that measures how well each DMU uses its inputs to produce its output when compared to the “best” DMU—the DMU that produces the greatest output using the least amount of input. Often the best DMU is a composite and may not necessarily exist; yet all DMUs are compared against the performance of this best DMU. A score of 1.0 indicates a DMU is efficient (or matches the composite producer/DMU). A score less than 1.0 indicates inefficiency (Anderson et al. 1999). A DMU with a score of 1.0 is on the frontier of a plane that relates inputs and outputs, whereas those with a score of less than 1.0 are on the interior of the frontier. Herein, the frontier represents the best-practice units— those units making the best use of resources.

The BCC model

The BCC model assumes the Variable Returns to Scale (VRS) and represents Pure Technical Efficiency (PTE) without including the Scale Efficiency (SE).

Maximize Efficiency score (θp) = $\sum_{r=1}^{t} u_r y_{\theta p} + w$ (4)

Subject to $\sum_{i=1}^{m} v_i x_{ij} = 1,$ j = 1, …, *n*, (5)

$$\sum_{i=1}^{m} u_r y_{\theta p} - \sum_{i=1}^{m} v_i x_{ij} + w \leq 0 \quad (6)$$

$$u_r, v_i \geq \varepsilon, \quad \forall r \text{ and } i, \quad (7)$$

ω = free (unconstrained in sign) (8)

In the prior equation, if $\omega > 0$, then the model becomes DEA with an Increasing Returns to Scale (IRS), and if $\omega < 0$, it becomes DEA with a Decreasing Returns to Scale (DRS).

From the mass transit system perspective, an efficiency score represents a system's ability to transform a set of inputs (given resources) into a set of outputs. Herein, the mass transit systems that were evaluated represent mostly city-owned public/nonprofit systems. For our baseline analysis, we make the conservative assumption that the mass transit system is provided with constant returns to scale because efficiency scores based on variable returns to scale tend to raise or inflate the scores, whereas constant returns to scale scores are based on more restrictive efficiency assumptions (Garcia-Sanchez 2006). The DEA analysis is conducted by applying the above equations to actual data of regional mass transit systems serving 24 urban areas in Ohio.

IV. SPECIFICATIONS OF DEA INPUT-OUTPUT MEASURES

The DEA experiment begins with the selection of appropriate input and output measures that can be aggregated into a composite index of overall performance standards. Although any resources used by DMU should be included as input, we initially selected four categories of inputs. The raw data for these inputs were obtained from the National Transit Database available from the Federal Transit Administration's website (http://www.ntdprogram.gov/ntdprogram/):

- **Total Operating Expenses:** These expenses incur in carrying out the mass transit authority's day-to-day operations. They include driver payroll, employee benefits, pension contributions, utilities, general administration expenditures, and vehicle repair and maintenance costs, while excluding reconciling items such as depreciation, interest expenses, equipment leases, and rentals. Since these expenses can affect the mass transit authority's revenues and their subsequent service offerings, they will be regarded as one of the inputs.

- **Total Funds:** Since the amount of total funds used for mass transit services represents financial resources invested and utilized in the mass transit system, this measure should be regarded as an input. These funds include directly generated funds, federal funds, state funds, and local funds (e.g., tax levies and donations).

- **Vehicle Revenue Miles:** Vehicle miles or a related measure have frequently been used to evaluate the efficiency of mass transit systems (Viton 1997; Nolan et al. 2001). Indeed, vehicle revenue miles (excluding dead-head miles) driven by a mass transit vehicle can reflect the revenue-generating services supplied by the vehicle and the subsequent utilization rate of that vehicle. As such, we viewed vehicle revenue miles as the input.

- **Vehicle Revenue Hours:** Vehicle revenue hours are the total number of hours traveled when the vehicle is in revenue service (i.e., the time during which a vehicle is available to the general public for fare-paying passenger services). Generally, vehicle revenue hours excludes hours spent for school bus and special charter services. For conventionally scheduled services, vehicle revenue hours include running time and layover/recovery time. Since this measure considers the overall passenger load factor to assess vehicle utilization, it was regarded as an input.

On the output side, the overall performance of mass transit systems can be measured by revenues and services provided. These can be derived from three data types: fare revenue earned, unlinked passenger trips, and passenger miles that significantly influence the operating (and financial) efficiency of mass transit systems. These outputs are described as follows:

- **Fare Revenue Earned:** Since fees paid by the passenger for mass transit services are an important part of revenue streams, fare revenue earned is considered the output. This revenue includes all income received directly from passengers, paid either in cash or through prepaid tickets, passes, and so forth. It also includes revenue from passengers who donate money, as well as reduced fares paid by passengers in a user-side subsidy arrangement.

- **Unlinked Passenger Trips:** An unlinked passenger trip refers to the number of times passengers board public transportation vehicles. Passengers are counted each time they board vehicles no matter how many vehicles they use to travel from their origin to destination and regardless of whether they pay a fare, use a pass or transfer, ride for free, or pay in some other way. That is to say, this measure represents a frequency of boarding by the passenger, which reflects the level of passenger services. Thus, unlinked passenger trips are viewed as an output regardless of whether an individual fare is collected for each leg of trip.

- **Passenger Miles:** This measure represents the cumulative sum of the miles (distances) traversed by all passengers using the transit services. Since this measure reflects the level of transit services and volume of traffic produced by transit vehicles, it was regarded as the output.

Descriptive statistics of these input/output measures are summarized in Tables 1 through 3.

Table 1. Descriptive Statistics of Input and Output Measures in 2009

	Total Operating Expenses (in dollars)	Total Funds (in dollars)	Unlinked Passenger Trips	Passenger Miles	Annual Vehicle Revenue Miles	Annual Vehicle Revenue Hours	Fare Revenues Earned (in dollars)
Max	2.29E+08	2.38E+08	45,612,053	1.82E+08	23,557,154	1,805,109	50,332,127
Min	370,762	370,762	24,664	181,717	119,744	7,038	9,417
Average	35,548,456	36,257,576	7,212,881	30,275,229	4,843,330	346,239.7	7,517,952
SD	57,455,314	59,356,604	11,942,932	48,498,314	6,138,799	468,679.4	13,351,557

Table 2. Descriptive Statistics of Input and Output Measures in 2010

	Total Operating Expenses (in dollars)	Total Funds (in dollars)	Unlinked Passenger Trips	Passenger Miles	Annual Vehicle Revenue Miles	Annual Vehicle Revenue Hours	Fare Revenues Earned (in dollars)
Max	2.03E+08	2.11E+08	42,419,301	1.8E+08	19,789,927	1,490,126	47,152,334
Min	316,026	394,343	31,415	194,739	114,351	7,496	9,615
Average	33,567,674	34,239,012	6,379,064	27,897,722	4,431,051	321,050.4	7,556,553
SD	51,829,218	53,509,658	10,989,083	46,514,169	5,317,480	401,807.7	12,948,798

Table 3. Descriptive Statistics of Input and Output Measures in 2011

	Total Operating Expenses (in dollars)	Total Funds (in dollars)	Unlinked Passenger Trips	Passenger Miles	Annual Vehicle Revenue Miles	Annual Vehicle Revenue Hours	Fare Revenues Earned (in dollars)
Max	2.06E+08	2.14E+08	46,210,832	2E+08	19,658,780	1,471,552	49,928,892
Min	267,333	330,856	36,993	196,802	109,978	7,575	10,342
Average	34,651,348	35,281,352	6,808,894	30,236,694	4,548,717	330,382	7,916,737
SD	52,691,569	54,231,922	11,866,185	51,702,760	5,316,309	401,851.8	13,470,313

V. RESULTS AND DISCUSSIONS

To see if there is room for the improvement of mass transit efficiency and which factors significantly affect the operating efficiency of Ohio's urban mass transit systems, we ran both CCR and BCC versions of the DEA models proposed earlier. Columns 3, 4, 5 and 6 in Tables 4, 5, and 6 show the DEA efficiency scores of the 24 Ohio mass transit systems all of which are considered the urban transit systems in terms of their total amount of fare revenues earned, annual unlinked trips, and passenger miles given the four inputs specified earlier. As a mass transit efficiency measure, we considered both CRS and VRS efficiency scores along with scale and super efficiency scores.

To elaborate, scale efficiency (SE) was calculated as:

$$SE = \frac{\theta^*_{CCR}}{\theta^*_{BCC}} \qquad (9)$$

Where the CCR score, θ^*_{CCR} , which represents Technical Efficiency (TE), is a combination of Pure Technical Efficiency (PTE) and Scale Efficiency (SE). That is to say, TE = PTE × SE. Since Tables 4, 5, and 6 show that multiple DMUs (Ohio transit agencies) have the "efficient status" with an efficiency score of 1, we need to differentiate those DMUs with a full efficient status. Thus, we calculated each DMU's full super-efficiency score so that we could discriminate among the efficient DMUs and then rank them by assigning the efficiency score greater than 1 (Tone 2001, Tone 2002).

The DEA results show that both the Southwest Ohio Regional Transit Authority (SORTA) and the Greene County Transit Board (Greene CATS) turned out to be the best performers for three years in a row (2009, 2010, and 2011). On the other hand, several transit agencies such as the Brunswick Transit Alternative (BTA), the Butler County Regional Transit Authority (BCRTA), and the Miami County Public Transit (MCPT) struggled throughout the entire review period (Table 3, Figure 1). Although both SORTA and Greene CATS are based in Southwest Ohio, the poor performers such as BCTRA and MCPT are located in the Southwest Ohio region as well. That is to say, the geography or local climate or regional economy may have little to do with the performance of Ohio mass transit systems. However, one intriguing pattern that can be observed by the DEA results is that most laggards such as BTA, BCRTA, and MCPT are covering areas right next to those areas served by better performing agencies. For instance, BCRTA is right next to SORTA, MCPT is right next to Greene CATS, while BTA is a neighbor to The Greater Cleveland Regional Transit Authority (GCRTA) which consistently performed well. Perhaps, mass transit systems which played supporting roles for the top performers and were primarily concentrated in the suburban area tended to perform relatively poorly due to less population density and some services duplicated and overlapped by the neighboring top performers which were preferred by the passengers.

Another pattern that emerged from the DEA analyses is that transit authorities (i.e., SORTA, GCRTA, COTA) serving three biggest metro areas in Ohio - Cincinnati, Cleveland, and Columbus - tended to perform better than the agencies (e.g., GDRTA, METRO, TARTA) serving the mid-size cities of Dayton, Akron, and Toledo. Since there is little difference in scale efficiencies among big metro areas and mid-size cities, the size of the cities served by the transit agency is not considered a significant factor for the source of efficiencies.

However, since the three biggest metro areas in Ohio are surrounded by many suburban areas served by alternative transit agencies, the transit agencies (i.e., SORTA, GCRTA, COTA) serving those areas tend to face the greater level of competition from neighboring agencies with overlapped services and thus may have increased their efforts to become more efficient. Also, the better transportation infrastructure (greater road networks) of these biggest metro areas may have contributed to their efficiencies.

Though rarely scrutinized by the existing literature on mass transits, we also examined carefully whether the heavy use or reliance of certain transportation modes significantly influenced the efficiency of mass transit systems. As summarized in Table 4, it is intriguing to note that a ferry boat, bus rapid transit, inclined plane, van pool, and commuter rail turned out to be the five most efficient modes of transit vehicles among 15 different types of available modes. That is to say, the access to these vehicles and their utilization can affect the efficiency of mass transit systems. Finally, we stacked the state of Ohio against other states in terms of its mass transit efficiencies. As Table 5 indicates, the Ohio mass transit system performs poorly (below national average) as compared to other peer states with respect to mass transit efficiencies. Given the history of more economic woes and stagnant population growth for the past two decades, the state of Ohio needs to enhance its economic profiles and standard of living. One way of doing so is to improve mass transit efficiencies which would increase the mobility of state residents such as the poor, the elderly, and the handicapped who have no personal transportation means. The Ohio Department of Transportation (2004) reported that 2.8% of Ohio households did not own a vehicle. Especially, as of 2011, 24.3% of Cleveland households and 22% of Cincinnati households have no access to a vehicle, making both Cleveland and Cincinnati listed as one of eleven U.S. cities with most households without a car (U.S. Census Bureau 2012). In particular, this study finds that there is a wide performance gap between good performers and bad performers as displayed by Table 3 and Figure 1. Although some poor performers such as BTA, BCRTA, and SARTA are beginning to rebound and improve over time, there is a growing concern over other transit agencies such as TARTA and METRO whose efficiencies have declined over the last three years. In particular, TARTA experienced a dramatic decline in its transit efficiencies for the last three years. Indeed, TARTA recently suffers from a declining ridership and a lack of operating funds due to its relatively heavy reliance on local property taxes which were decreased as a result of its depressed real estate market. Also, the renegade Toledo suburban area such as Perrysburg which opted out of the TARTA system and wanted to hire its own transit agency may have undermined its transit efficiency.

Table 4. Efficiency Scores of Ohio Mass Transit Systems in 2009 Using DEA Systems in 2009 Using DEA

		DEA Efficiency Scores				
No.	**Mass Transit Agency (DMU)**	**CCR**	**BCC**	**SE**	**Super Efficiency**	**Rank**
1	Brunswick Transit Alternative (BTA)	0.423	1.000	0.423	0.310	22
2	Butler County Regional Transit Authority (BCRTA)	0.411	0.479	0.858	0.342	20
3	Central Ohio Transit Authority (COTA)	0.849	0.849	1.000	0.838	7
4	City of Middletown - Middletown Transit System (MTS)	0.868	1.000	0.868	0.654	12
5	City of Newark Transit Operations (Earthworks)	0.446	0.750	0.595	0.313	21
6	Clermont Transportation Connection (CTC)	0.639	0.687	0.930	0.401	18
7	Greater Dayton Regional Transit Authority (GDRTA)	0.730	0.731	0.999	0.700	10
8	Greene County Transit Board (Greene CATS)	1.000	1.000	1.000	1.418	1
9	Laketran	0.701	0.717	0.978	0.582	15
10	Lawrence County Port Authority (LCT)	1.000	1.000	1.000	1.033	3
11	Licking County Transit Board (LCTB)	0.886	1.000	0.886	0.743	9
12	Lorain County Transit (LCT)	0.768	0.812	0.946	0.591	14
13	Metro Regional Transit Authority (METRO)	0.588	0.595	0.988	0.581	16
14	Miami County Public Transit (MCPT)	0.463	0.648	0.715	0.362	19
15	Niles Trumbull Transit (NiTTS)	0.318	0.430	0.740	0.226	23
16	Portage Area Regional Transportation Authority (PARTA)	0.804	0.833	0.965	0.679	11
17	Richland County Transit (RCT)	0.737	0.904	0.815	0.605	13
18	Sandusky Transit System (STS)	0.292	0.564	0.518	0.224	24
19	Southwest Ohio Regional Transit Authority (SORTA / METRO)	1.000	1.000	1.000	1.326	2
20	Springfield City Area Transit (SCAT)	0.825	1.000	0.825	0.756	8
21	Stark Area Regional Transit Authority (SARTA)	0.675	0.688	0.981	0.551	17
22	The Greater Cleveland Regional Transit Authority (GCRTA)	1.000	1.000	1.000	1.007	5
23	Toledo Area Regional Transit Authority (TARTA)	1.000	1.000	1.000	1.017	4
24	Western Reserve Transit Authority (WRTA)	0.976	1.000	0.976	0.911	6

Table 5. Efficiency Scores of Ohio Mass Transit Systems in 2010 Using DEA

		DEA Efficiency Scores				
No.	Mass Transit Agency (DMU)	CCR	BCC	SE	Super Efficiency	Rank
1	Brunswick Transit Alternative (BTA)	0.588	1.000	0.836	0.372	20
2	Butler County Regional Transit Authority (BCRTA)	0.413	0.494	0.999	0.320	21
3	Central Ohio Transit Authority (COTA)	0.878	0.879	0.936	0.826	4
4	City of Middletown - Middletown Transit System (MTS)	0.936	1.000	0.446	0.696	7
5	City of Newark Transit Operations (Earthworks)	0.299	0.671	0.974	0.227	24
6	Clermont Transportation Connection (CTC)	0.854	0.877	0.997	0.533	17
7	Greater Dayton Regional Transit Authority (GDRTA)	0.757	0.759	1.000	0.692	8
8	Greene County Transit Board (Greene CATS)	1.000	1.000	0.977	1.449	1
9	Laketran	0.759	0.777	0.636	0.616	9
10	Lawrence County Port Authority (LCT)	0.636	1.000	0.920	0.469	18
11	Licking County Transit Board (LCTB)	0.920	1.000	0.482	0.741	5
12	Lorain County Transit (LCT)	0.338	0.701	0.983	0.298	22
13	METRO Regional Transit Authority (METRO)	0.630	0.641	0.699	0.601	12
14	Miami County Public Transit (MCPT)	0.577	0.825	0.741	0.404	19
15	Niles Trumbull Transit (NiTTS)	0.326	0.440	0.967	0.227	23
16	Portage Area Regional Transportation Authority (PARTA)	0.932	0.964	0.824	0.738	6
17	Richland County Transit (RCT)	0.754	0.915	0.735	0.585	13
18	Sandusky Transit System (STS)	0.620	0.844	1.000	0.543	15
19	Southwest Ohio Regional Transit Authority (SORTA/METRO)	1.000	1.000	0.791	1.230	2
20	Springfield City Area Transit (SCAT)	0.682	0.862	0.983	0.610	11
21	Stark Area Regional Transit Authority (SARTA)	0.763	0.776	1.000	0.611	10
22	The Greater Cleveland Regional Transit Authority (GCRTA)	1.000	1.000	0.986	1.080	3
23	Toledo Area Regional Transit Authority (TARTA)	0.628	0.637	0.956	0.534	16
24	Western Reserve Transit Authority (WRTA)	0.646	0.676	0.956	0.554	14

Table 6. Efficiency Scores of Ohio Mass Transit Systems in 2011 Using DEA

		DEA Efficiency Scores				
No.	Mass Transit Agency (DMU)	CCR	BCC	SE	Super Efficiency	Rank
1	Brunswick Transit Alternative (BTA)	0.631	1.000	0.631	0.386	17
2	Butler County Regional Transit Authority (BCRTA)	0.568	0.628	0.904	0.434	14
3	Central Ohio Transit Authority (COTA)	0.900	0.900	1.000	0.793	5
4	Clermont Transportation Connection (CTC)	0.662	0.695	0.953	0.420	15
5	Greater Dayton Regional Transit Authority (GDRTA)	0.756	0.757	0.999	0.644	7
6	Greene County Transit Board (Greene CATS)	1.000	1.000	1.000	1.209	1
7	Laketran	0.637	0.651	0.978	0.523	12
8	Licking County Transit Board (LCTB)	1.000	1.000	1.000	1.013	4
9	Lima Allen County Regional Transit Authority (LACRTA)	0.656	0.823	0.797	0.547	11
10	METRO Regional Transit Authority (METRO)	0.614	0.619	0.992	0.549	10
11	Miami County Public Transit (MCPT)	0.489	0.698	0.701	0.392	16
12	Portage Area Regional Transportation Authority (PARTA)	0.860	0.879	0.978	0.666	6
13	Southwest Ohio Regional Transit Authority (SORTA/METRO)	1.000	1.000	1.000	1.209	2
14	Stark Area Regional Transit Authority (SARTA)	0.751	0.761	0.987	0.617	8
15	The Greater Cleveland Regional Transit Authority (GCRTA)	1.000	1.000	1.000	1.146	3
16	Toledo Area Regional Transit Authority (TARTA)	0.565	0.571	0.989	0.464	13
17	Western Reserve Transit Authority (WRTA)	0.734	0.752	0.976	0.591	9

Table 7. DEA Window Analysis Results of Ohio Mass Transit Systems (2009 – 2011)

No.	Mass Transit Agency (DMU)	2009	2010	2011	Annual Average
1	Brunswick Transit Alternative (BTA)	0.423	0.528	0.631	**0.527**
2	Butler County Regional Transit Authority (BCRTA)	0.397	0.393	0.557	**0.449**
3	Central Ohio Transit Authority (COTA)	0.849	0.785	0.813	**0.816**
4	Clermont Transportation Connection (CTC)	0.637	0.767	0.662	**0.689**
5	Greater Dayton Regional Transit Authority (GDRTA)	0.730	0.682	0.678	**0.697**
6	Greene County Transit Board (Greene CATS)	1.000	1.000	0.966	**0.989**
7	Laketran	0.700	0.683	0.637	**0.673**
8	Licking County Transit Board (LCTB)	0.885	0.891	0.899	**0.892**
9	Lima Allen County Regional Transit Authority (LACRTA)	Not applicable			
10	Metro Regional Transit Authority (METRO)	0.588	0.585	0.581	**0.585**
11	Miami County Public Transit (MCPT)	0.455	0.545	0.477	**0.492**
12	Portage Area Regional Transportation Authority (PARTA)	0.804	0.806	0.750	**0.787**
13	Southwest Ohio Regional Transit Authority (SORTA/METRO)	1.000	1.000	1.000	**1.000**
14	Stark Area Regional Transit Authority (SARTA)	0.674	0.686	0.751	**0.704**
15	The Greater Cleveland Regional Transit Authority (GCRTA)	0.866	0.929	1.000	**0.932**
16	Toledo Area Regional Transit Authority (TARTA)	1.000	0.618	0.551	**0.723**
17	Western Reserve Transit Authority (WRTA)	0.976	0.559	0.640	**0.725**
	Transit Efficiency Average	**0.749**	**0.716**	**0.725**	

Note: Some transit agencies are omitted from this window analysis due to unavailability of comparable 2011 transit data.

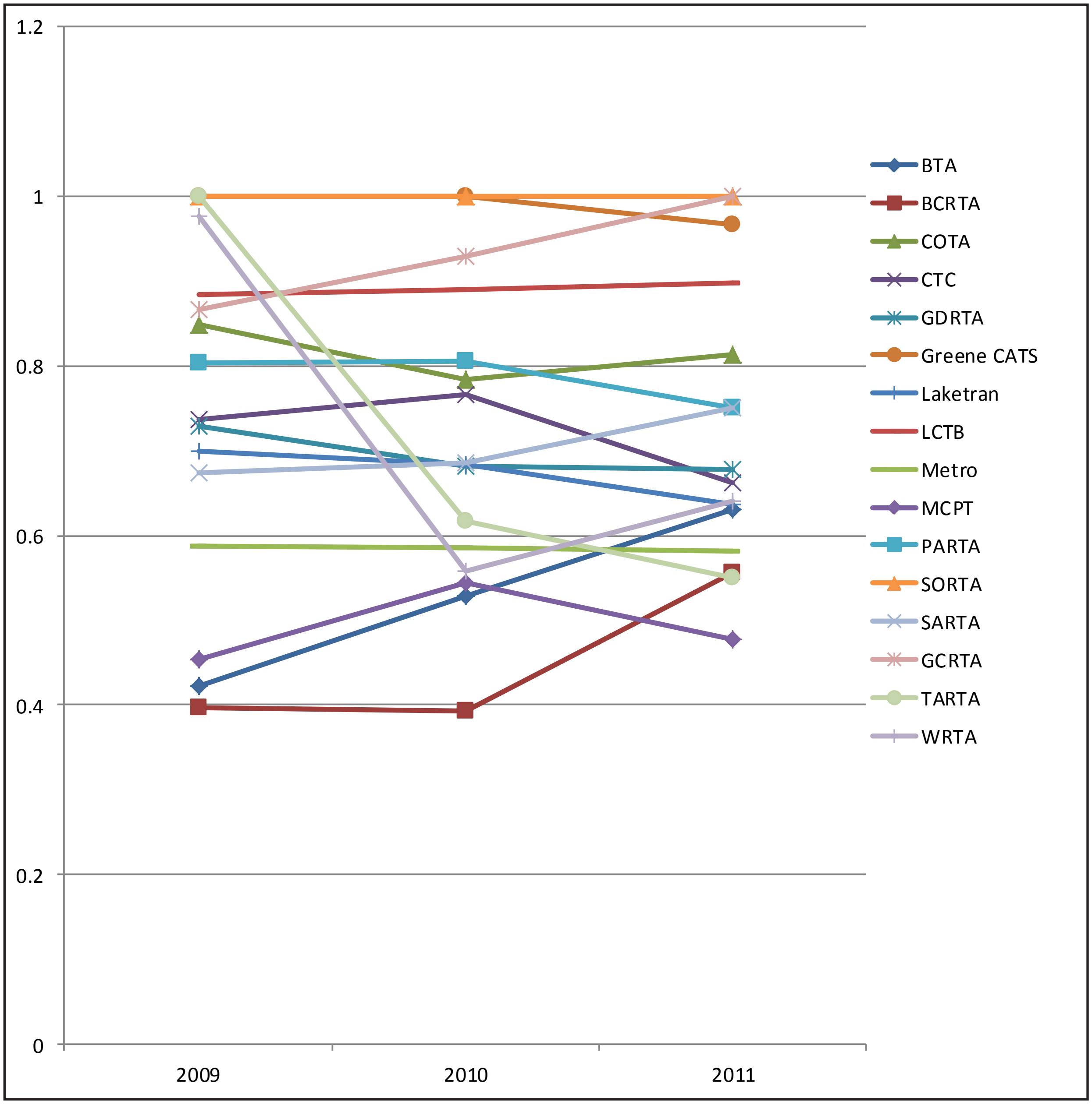

Figure 1. Performance Patterns of Ohio Mass Transit Systems (2009 – 2011)

Table 8. Efficiency Scores of U.S. Transit Systems with respect to Mode (2011)

No.	Mass Transit Agency (DMU)	DEA Efficiency Scores				
		CCR	BCC	SE	Super Efficiency	Rank
1	Commuter Bus	1.000	1.000	1.000	1.012	7
2	Commuter Rail	1.000	1.000	1.000	1.485	5
3	Demand Response - Van	0.093	0.106	0.877	0.060	15
4	Demand Response - Taxi	0.106	0.118	0.898	0.065	14
5	Ferryboat	1.000	1.000	1.000	1.998	1
6	Heavy Rail	1.000	1.000	1.000	1.240	6
7	Inclined Plane	1.000	1.000	1.000	1.629	3
8	Light Rail	0.817	0.817	1.000	0.736	9
9	Bus	0.504	1.000	0.504	0.389	13
10	Monorail/Automated Guideway	0.540	0.549	0.984	0.430	12
11	Bus Rapid Transit	1.000	1.000	1.000	1.886	2
12	Street Car Rail	0.786	0.786	1.000	0.644	10
13	Trolleybus	0.706	0.987	0.715	0.570	11
14	Vanpool	1.000	1.000	1.000	1.540	4
15	Hybrid Rail	0.779	0.882	0.883	0.758	8

Table 9. Efficiency Scores of Mass Transit Systems across the United States (2011)

No.	States (DMU)	Efficiency Scores				
		CCR	BCC	SE	Super Efficiency	Rank
1	AK	0.548	0.612	0.895	0.431	35
2	AL	0.338	0.380	0.889	0.248	53
3	AR	0.610	0.685	0.891	0.412	37
4	AZ	0.639	0.644	0.992	0.469	29
5	CA	0.754	0.812	0.929	0.674	10
6	CO	0.739	0.739	1.000	0.601	19
7	CT	0.540	0.546	0.989	0.388	41
8	DC	0.993	1.000	0.993	0.938	6
9	DE	0.373	0.404	0.923	0.320	46
10	FL	0.653	0.703	0.929	0.529	22
11	GA	0.922	0.954	0.966	0.766	8
12	HI	1.000	1.000	1.000	1.076	2
13	IA	0.893	0.915	0.976	0.602	18
14	ID	0.491	0.652	0.753	0.320	47
15	IL	0.970	1.000	0.970	0.923	7
16	IN	0.653	0.664	0.983	0.508	25
17	KS	0.502	0.541	0.928	0.327	45
18	KY	0.626	0.637	0.983	0.433	34
19	LA	0.619	0.632	0.979	0.512	24
20	MA	0.767	0.768	0.999	0.685	9
21	MD	0.631	0.637	0.991	0.570	20
22	ME	0.887	0.961	0.923	0.632	15

No.	States (DMU)	Efficiency Scores: CCR	BCC	SE	Super Efficiency	Rank
23	MI	0.590	0.598	0.987	0.424	36
24	MN	0.641	0.645	0.994	0.434	33
25	MO	0.570	0.574	0.993	0.478	28
26	MS	0.634	0.855	0.742	0.481	27
27	MT	0.562	0.708	0.794	0.380	42
28	NC	0.670	0.673	0.996	0.469	30
29	ND	0.602	0.759	0.793	0.392	40
30	NE	0.476	0.523	0.910	0.320	48
31	NH	1.000	1.000	1.000	1.035	3
32	NJ	1.000	1.000	1.000	1.033	4
33	NM	0.663	0.702	0.944	0.603	17
34	NV	0.933	0.938	0.995	0.644	13
35	NY	1.000	1.000	1.000	1.424	1
36	OH	0.562	0.563	0.998	0.407	38
37	OK	0.432	0.469	0.921	0.299	51
38	OR	0.737	0.738	0.999	0.604	16
39	PA	0.795	0.796	0.999	0.637	14
40	Puerto Rico	0.767	0.772	0.994	0.486	26
41	RI	0.533	0.547	0.974	0.404	39
42	SC	0.526	0.574	0.916	0.317	49
43	SD	0.467	0.699	0.668	0.303	50
44	TN	0.500	0.508	0.984	0.370	43
45	TX	0.561	0.602	0.932	0.461	31
46	UT	0.787	0.791	0.995	0.660	12
47	VA	0.833	0.833	1.000	0.672	11
48	Virgin Islands	1.000	1.000	1.000	1.000	5
49	VT	0.650	0.828	0.785	0.458	32
50	WA	0.587	0.601	0.977	0.533	21
51	WI	0.726	0.728	0.997	0.523	23
52	WV	0.531	0.591	0.898	0.350	44
53	WY	0.427	1.000	0.427	0.250	52

VI. CONCLUDING REMARKS

Ohio's economy in 2012 grew for the third consecutive year, registering a 2.2% in growth of the gross domestic product (GDP). However, this level of Ohio's growth lagged the national average of 2.5%. In fact, Ohio's economic growth has been lagging behind the national average for thirteen out of the last fifteen years (Frolic 2013). To reverse this undesirable trend, the state of Ohio actively seeks ways to improve its economic status and grow its job opportunities. One way to do this is to improve the mobility of Ohio residents by increasing their access to public transportation, which can boost economic activities such as job commuting and shopping. Sanchez (1999) discovered that access to public transit was a significant factor in the extent of labor participation in the cities of Portland and Atlanta. Recently, Drennan and Brecher (2012) further theorized that public investments in mass transit could make urban economies more efficient by enhancing employers' access to a larger labor pool at lower transport costs. In other words, all else being equal, public transit could, in theory, make urban areas more efficient by promoting the economic benefits of agglomeration, such as increased access to skilled labor pools, through reductions in transportation costs and increases in mobility. Since mobility is affected by the affordability and quality of mass transit services, this paper attempts to comprehensively measure and assess the operating efficiencies of selected mass transit systems in Ohio using DEA, while identifying the potential sources of either efficiencies or inefficiencies.

DEA is a technique that helps public policy makers identify lagging mass transit systems with respect to various performance standards (e.g., vehicle utilization, service hours/miles, return-on-investment of financial resources) and then highlight the specific aspects of mass transit performance that should be strengthened to further improve their efficiencies. In our DEA analysis, we discovered that urban mass transit systems in the high-density, large metropolitan areas, such as Cincinnati, Cleveland, and Columbus, tended to perform better, whereas urban mass transit systems in the suburbs of those areas tended to perform poorly. However, we found that the overall size of a city has no bearing on the mass transit efficiency, which is congruent with the findings of O'Sullivan (2007) and Min and Lambert (2010). In other words, the economies of scale alone did not seem to dictate the mass transit efficiency. For example, despite being relatively small, the Greene CTS became one of the benchmark performers. Also, somewhat interestingly, GCTRA serving the Cleveland metro area performed well for the three-year span, despite Cleveland's economic woes that led to a series of more severe budget cuts. Ironically, GCTRA's lack of resources may have created a sense of urgency to improve planning, and subsequently may have helped lead to better utilization of resources and more creative planning, such as the introduction of public-private partnerships (PPPs) dubbed Build Up Greater Cleveland (BUGC) for generating additional funds. BUGC was created in 1983 as one of the earliest PPPs in the city of Cleveland, which helped attract more than $6 billion in funds to improve public infrastructure, including GCTRA's transit infrastructure.

Another finding worth noting is the lack of correlation between geographical location and the transit efficiency. This pattern indicates that local climate and economic conditions themselves are not necessarily tied to transit efficiency. In other words, economic prosperity is not necessarily an indicator of transit efficiency, although transit efficiency (especially accessibility to high-quality transit) may affect the local economy. Some studies (e.g., Vessali, 1996; So et al. 1997) reported that accessibility to transit tended to affect average residential property value by six to seven percent. For instance, public bus stops or subway stations may raise the value of nearby properties by reducing commuting costs or by attracting more retail activities to the neighborhood. Other social impacts of efficient and effective mass transit systems include reduced carbon footprints resulting from the reduced use of private automobiles. Indeed, increasing concerns over air pollution, traffic congestion, and high fuel costs accompanying the use of the private auto in urban settings have led to various initiatives to upgrade scheduled bus and rapid rail transit service in U.S. cities including those in Ohio.

Finally, we found that the use of particular transportation modes (transit vehicles) could influence mass transit efficiency, based on the DEA analysis of 515 transit agencies across the U.S. (see Table 4). For instance, ferry boats and bus rapid transit tended to create greater efficiencies than other traditional modes of public transportation, such as regular bus and light rail. While access to ferry boats can be limited due to the absence of waterways surrounding the city, greater use of bus rapid transit should be a viable option for enhancing mass transit efficiency. Since bus rapid transit operates on exclusive bus highways in high-occupancy-vehicle (HOV) lanes, it increases the speed of transit services, reduces traffic congestion, and utilizes high-capacity vehicles. Thus, bus rapid transit can significantly improves mass transit efficiency, as evidenced by this study's finding. Also, the required infrastructure investment for bus rapid transit is less than for light rail systems, which can be costly to develop and sustain. In fact, recognizing the benefit potential of bus rapid transit, the Central Ohio Transit Agency (COTA) recently received approval from the Federal Transit Administration to launch the Northeast Corridor Bus Raid Transit (NCBRT) project in the downtown area of Columbus, Ohio. The NCBRT intends to increase the speed and convenience of transit services through prioritized traffic signals, fewer stops than conventional bus routes, and real-time passenger information.

For public policy and resource allocation purposes, state and municipal governments in Ohio should reward and prioritize the development of mass transit systems that serve densely settled urban areas (a population per square mile of at least 7,000, on average), while increasing the use of bus rapid transit as the more reliable, effective, and cleaner transit alternative. As for lagging mass transit systems whose financial and human resources are not fully utilized, public policy makers need to consider either outsourcing their operation to private enterprises or building a long-term partnership with those private enterprises to leverage their expertise and financial resources. Also, considering the impact of high performers on the efficiency of their contiguous transit services, public policy makers should eliminate duplications and/or have high-performing transit agencies manage services for low-performing adjacent areas.

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