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Assessing the Efficiency of Mass Transit Systems in the United States

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Assessing the Efficiency of Mass Transit Systems in the United States

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ASSESSING THE EFFICIENCY OF MASS TRANSIT SYSTEMS IN THE UNITED STATES

Hokey Min, Ph.D.

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16. Abstract

Frustrated with increased parking problems, unstable gasoline prices, and stifling traffic congestion, a growing number of metropolitan city dwellers consider utilizing the mass transit system. Reflecting this sentiment, a ridership of the mass transit system across the United States has been on the rise for the past several years. A growing demand for the mass transit system, however, necessitates the expansion of service offerings, the improvement of basic infrastructure/routes, and the additional employment of mass transit workers, including drivers and maintenance crews. Such a need requires the optimal allocation of financial and human resources to the mass transit system in times of shrinking budgets and government downsizing. Thus, the public transit authority is faced with the dilemma of "doing more with less." That is to say, the public transit authority needs to develop a "lean" strategy which can maximize transit services with the minimum expenses. To help the public transit authority develop such a lean strategy, this report identifies the best-in-class practices in the U.S. transit service sector and proposes transit policy guidelines that can best exploit lean principles built upon best-in-class practices.

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EXECUTIVE SUMMARY

Frustrated with increased parking problems, unstable gasoline prices, and stifling traffic congestion, a growing number of metropolitan city dwellers consider using mass transit. Reflecting this sentiment, transit ridership across the United States has been on the rise for the past several years. Growing transit demand, however, necessitates the expansion of service offerings, the improvement of basic infrastructure/routes, and the additional employment of mass transit workers, including drivers and maintenance crews. Such needs require the optimal allocation of financial and human resources in times of shrinking budgets and government downsizing as public transit agencies are faced with the dilemma of “doing more with less.” Transit agencies need to develop a “lean” strategy which can maximize transit services with the minimum expenses. To help agencies develop such a lean strategy, this report identifies the best-in-class practices in the U.S. transit service sector and proposes transit policy guidelines that can best exploit lean principles built upon best-in-class practices.

I. BACKGROUND

In 2014, Americans took 10.8 billion trips on public transportation, which is the highest annual public transit ridership number in 58 years. This record ridership did not just happen in large cities. It also happened in small- and medium-size communities across the United States (U.S.).[1] The increase in the transit ridership may be attributed to several factors: (1) rising maintenance/repair costs and increased parking fees associated with private vehicle use; (2) worsening traffic congestion in major transportation arteries; (3) aging demographics; and (4) changing government rules such as the Americans with Disabilities Act (ADA) of 1990 which mandate door-to-door public transportation services with a reasonable fare scheme. This surge in transit ridership, however, puts a severe strain on local governments with limited budgets that need to respond to the increased demand for transit services. Such responses include: vehicle capacity expansion, the need to hire more employees, enhancement of Information and Communication Technology (ICT) needed for real-time transit scheduling, and improvement in public road and highway infrastructure. All of these responses require substantial investment. To cover the substantial outlay associated with these responses, many local governments chose to increase property taxes, sales taxes or fares incrementally; these increases were often met by strong resistance from the general public. Considering this public backlash, transit authorities need to develop better strategic options. Examples of such options may include: private outsourcing of transit services, the formation of public-private partnership (PPP) between the transit authority and the private sector, utilization of new generations of transportation vehicles, and the development of lean management principles predicated on proven best-in-class practices. This report aims to identify best-in-class practices performed by “best-of-breed” (benchmark) mass transit systems in the U.S. and to formulate a lean public transportation strategy that helps the transit authority optimize the use of given resources while enhancing transit service quality. With this mind, the investigator intends to achieve the following study objectives:

- Develop key performance metrics for evaluating the performance of transit systems;
- Compare and contrast transit system performance with respect to those key performance metrics;
- Identify what make some transit systems more efficient than others;
- Identify best-in-class practices based on common success factors;
- Recommend practical guidelines which can help transit systems improve their services with limited expenditures.

II. LITERATURE REVIEW

Over the last several decades, mass transit authorities (such as the Federal Transit Administration and local transit agencies) have sought ways to increase transit ridership while also improving transit service quality and operational efficiency. Reflecting this mindset, much of the existing literature focuses on the development of analytical tools/ methods intended to improve utilization of transit vehicles, drivers, and/or other resources (including maintenance crews and funding). For example, Ball et al. proposed a match-based heuristics to schedule vehicles and drivers simultaneously in an effort to improve the cost efficiency of the Baltimore Metropolitan Transit authority.[2] Extending the work of Ball et al., Haase et al. developed a mathematical model to solve the problem of scheduling mass transit vehicles and their crews simultaneously.[3]

Narrowing down the scope of the mass transit system to a paratransit system, Bower assessed the impact of an automated paratransit routing and scheduling system called COMSIS on operating cost and service quality of paratransit services.[4] As expected, COMSIS turned out to be useful for reducing scheduling errors, reducing the cost of generating schedules, and identifying traffic patterns. Thus, Bower concluded that COMSIS improved the overall efficiency of paratransit service quality.[5] Similarly, Chira-Chavala and Venter analyzed the impact of automated vehicle- and passenger-scheduling methods on the operating costs of paratransit systems.[6] They found that such methods reduced unit paratransit transportation cost by 13%. Further extending the earlier work of Chira-Chavala and Venter, Pagano et al. assessed the impact of the computer-assisted scheduling and dispatching (CASD) systems on the service quality of paratransit services in central Illinois.[7] They found that CASD systems allowed passengers to enjoy less riding time and more on-time services at both pickups and drop-offs and subsequently enhanced their 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 was positively affected by the implementation of the CASD system.

Rather than dealing with the mass transit routing and scheduling issues, some attempts were made to assess the efficiency and effectiveness of mass transit services from financial or administrative perspectives. For instance, Jackson compared the real costs of service provided by subsidized mass transit (especially paratransit) operations to those of private-sector-run operations in the New England region.[8] He discovered that cost figures per passenger trip by nonprofit and publicly-owned mass transit services were seriously underestimated and did not truly reflect the actual costs or the cost-efficiency of the mass transit services provided. Nolan et al. were among 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.[9] They also identified various factors influencing mass transit efficiency using Tobit regression analysis. Their study found that average fleet age adversely affected transit efficiency and federal subsidies undermined transit efficiency, whereas locally based subsidies had a positive impact on transit efficiency.

More recently, Fu et al. evaluated 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 using DEA.[10] Through identification of the most efficient systems along with the key influencing factors, they developed new paratransit service policies and operational strategies for improved resource utilization and quality of services. Focusing on the improvement of efficiency of paratransit vehicle schedules, Shioda et al. proposed a computerized tool including a data mining technique that developed paratransit performance metrics reflecting the interests of paratransit stakeholders such as passengers, drivers, and municipal governments.[11] These performance metrics include number of passengers per vehicle per hour, deadheading time, passenger wait time, passenger ride time, and degree of zigzagging. This computerized tool turned out to be useful for improving overall paratransit service quality. Min and Lambert 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 paratransit efficiency using DEA and Tobit regression analysis.[12] As expected, they discovered that transit systems 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.

In an attempt to enhance the quality of mass transit services, Paquette et al. conceptualized and defined quality of services in dial-a-ride operations intended for people with limited mobility.[13] In particular, they identified various service dimensions and attributes used to measure quality of services in dial-a-ride operations. Building upon the conceptual model proposed by Paquette et al., Min identified (using rider surveys) a host of factors such as 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 that might significantly influence the overall service quality of paratransit in the metropolitan Toledo area.[14] He discovered that a private contractor hired to manage the paratransit system was effective in controlling cost, but deteriorated service quality. Thus, he warned of the potential risk of outsourcing paratransit services. Unlike these prior investigators, Tang and Lo proposed an influence diagram to determine which stakeholders (public sector, private railway company, property developers) of the public-private partnership should be primarily responsible for building, funding, or owning mass rail transit systems in Hong Kong.[15] From a different angle, Nelson et al. introduced a life cycle analysis (LCA) model to enhance the efficiency of public transport (including the mass transit system) over its life span.[16]

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. Few of these prior studies evaluated the comparative operational and financial efficiencies of mass transit systems. Such evaluation would allow the mass transit authority to detect 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.[17] Min et al. conducted one of the pioneering studies that developed key performance metrics and measured the comparative efficiencies of mass transit systems.[18] Their study, however, is confined to the evaluation of urban mass transit systems in Ohio whose best-in-class practices may not be applicable to other states due to differences in public transportation policy, geographical coverage, transit service demands, and public finances.

Considering the lack of studies evaluating mass transit efficiencies, this report aims to measure the comparative efficiencies of 515 mass transit systems across the U.S. in 2011 in terms of their capability to utilize human, capital, and physical resources (given budgetary constraints). In addition, this report identifies which exogenous variables, such as demographic profiles (e.g., service area and population density) and local economic conditions (e.g., poverty rate) impact the comparative efficiencies of mass transit systems.

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

1. How can the performance of mass transit systems be assessed in comparison to their peers? (Which performance metrics are relevant to the assessment of mass transit efficiency for future investment and system improvement?)

2. What is the typical profile of best-performing transit systems, and what may be the secret behind their success? (What are the reasons for lagging performances of some transit systems?)

3. What are the most important determinants of mass transit efficiency? (What are the key success factors for mass transit services?)

4. How can a lean transit policy be developed that can boost transit efficiency with limited expenditures?

III. RESEARCH METHODOLOGY

To address the aforementioned research questions, secondary data regarding transit services were first collected from the National Transit Database compiled by the Federal Transit Administration's website (http://www.ntdprogram.gov/ntdprogram/). These data were analyzed by using DEA.

In general, DEA is referred to as a linear programming (non-parametric) 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. Here, DMUs refer to the collection of private firms, non-profit 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), which 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 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 assessing the extent of inefficiency for all other DMUs that are not regarded as the best practice DMUs.[19] Since DEA provides a relative measure, it differentiates between inefficient and efficient DMUs relative to each other. Due to its capability to discern inefficient DMUs from efficient DMUs, DEA can be useful for developing benchmark standards.[20] The DEA model can take a variety of forms depending on its assumptions and orientations.[21] In the following subsections, two of the most popular DEA models are described.

3.1 CCR Model

The Charnes, Cooper and Rhodes (CCR) model assumes Constant Returns to Scale (CRS).[22] Its objective is to maximize multiple outputs given a set of multiple inputs. The CCR model can be mathematically expressed as:

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

$u_r, v_i \ge \varepsilon, \forall r$ and *i*, (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.[23]

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.[24] 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, which produces the greatest output using the least amount of input. A score of 1.0 indicates that a DMU is efficient (or matches the composite producer/DMU), whereas a score less than 1.0 indicates inefficiency.[25]

3.2 The BCC model

The Banker, Charnes and Cooper (BCC) model assumes Variable Returns to Scale (VRS) and can be mathematically expressed as:

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)

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

$u_r, v_i \geq \varepsilon, \forall r$ and *i*, (7)

w = free (unconstrained in sign) (8)

In the above equation, *θp* represents the designation DMU that was singled out for evaluation and thus $y_{\theta p}$ is an output of the designation DMU. If w > 0, then the model becomes DEA with an Increasing Returns to Scale (IRS), and if w < 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. In this report, mass transit systems that were evaluated represent mostly city-owned public/non-profit ones. Although efficiency scores based on variable returns to scale tend to raise or inflate the scores, as observed by Garcia-Sanchez, the investigator experimented with both CCR and BCC models based on actual data of 515 mass transit systems in the U.S.[26]

IV. KEY PERFORMANCE INDICATORS

In general, a key performance indicator (KPI) is a measure of how well an organization is making progress toward its strategic goals and can be used to understand what it will take to succeed.[27] The KPI can be broken down into two categories: (1) input and (2) output KPIs. Input KPIs typically measure assets and resources invested in or used to generate performance outcomes, whereas output KPIs measures the financial and nonfinancial results of organizational activities.[28] These two kinds of KPIs will be aggregated into a composite index of overall performance standards of mass transit systems by using the proposed DEA models. Based on the performance indicators suggested by the Florida Department of Transportation and the availability of data sources from the National Transit Database (NTD), the author identified a total of eight measures as KPIs.[29] In a broad sense, these selected KPIs represent ridership economic efficiency, vehicle load/utilization, service availability, and coverage. For other potential KPI measures, interested readers may refer to the TCRP Report.[30] To elaborate, four input KPIs were developed as below.

- *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 in the mass transit system and thus helps us gauge how well these funds are utilized for mass transit operations, 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).

- *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 tallies how often (how many times) transit vehicles are used by the passenger. The more frequently passengers use the vehicle, the less likely the vehicle will fail to fill its capacity and subsequently make empty trips. This frequency can be a surrogate measure of the vehicle utilization ratio. Thus, unlinked passenger trips are viewed as an input regardless of whether an individual fare is collected for each leg of trip.

- *Passenger Miles*. This measure represents the cumulative sum of the miles (distance) traversed by all the passengers using the transit service. Route miles or a related measure have been frequently used as a way to evaluate the efficiency of mass transit systems.[31] Since this measure reflects the revenue contribution of passenger traffic and indicates how much traffic volume transit vehicles are producing, this measure was regarded as an input.

Output KPIs represent primarily transit revenues, which include fare revenue earned, vehicle revenue miles, and vehicle revenue hours that significantly influence the operating (and financial) efficiency of mass transit systems. In this report, operating efficiency refers to the capability of a mass transit system to deliver public transportation service to its riders in the most cost-efficient manner possible given its investment in transit infrastructure and assets, while ensuring high quality transit services and generating high revenues. If all of the input and output KPIs are expressed in monetary measures, this efficiency can be regarded as the financial efficiency. Details of these output KPIs are described as follows:

- *Fare Revenue Earned*. Since fees paid by the passenger for 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 donations from those passengers who donate money on the vehicle as well as the reduced fares paid by passengers in a user-side subsidy arrangement.

- *Vehicle Revenue Miles*. Vehicle miles or a related measure have been frequently used as a way to evaluate the efficiency of transit systems.[32] Indeed, vehicle revenue miles (excluding deadhead miles) driven by the transit vehicle can reflect the revenue-generating services supplied by the vehicle. As such, vehicle revenue miles are considered output KPI.

- *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 exclude 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 reflects the overall passenger load factor as a means to maximize revenue-generating services, it was regarded as an output.

Descriptive statistics of these input/output KPIs are summarized in Table 1.

Table 1. Descriptive Statistics of Input and Output KPIs in 2011 (n = 515)

	Input KPIs				Output KPIs		
	Total Funds (in Dollars)	**Unlinked Passenger Trips**	**Passenger Miles**	**Total Operating Expenses (in Dollars)**	**Annual Vehicle Revenue Miles**	**Annual Vehicle Revenue Hours**	**Fare Revenues Earned (in Dollars)**
Maximum	$7,827,721,655	3,303,625,225	12,170,489,747	$6,366,441,275	500,439,586	19,713,110	$3,578,282,013
Minimum	149,193	23,602	104,832	149,193	40,115	34,613	2,384
Average	76,391,011.95	19,411,979.24	105,170,596.9	68,575,780.5	74,296,61.3	429,269.3	25,072,538.64
Standard Deviation	393,109,700.7	152,571,522.7	612,897,900.2	325,730,756.8	26,838,160	1,218,990	173,401,168.4

V. DATA ANALYSIS AND RESULTS

To see if there is room for improvement of mass transit efficiency and which factors significantly affect the operating efficiency of mass transit systems in the U.S., the author employed both CCR and BCC versions of the DEA models proposed earlier. Table 2 shows the DEA efficiency scores of the 515 mass transit systems in the U.S. given the four input KPIs and three output KPIs specified earlier. As a mass transit efficiency measure, the author considered CCR and BCC efficiency scores along with scale and super-efficiency scores. Although CCR and BCC efficiency scores do not necessarily match each other, they tend to correlate with each other (see Table 2). In this report, scale efficiency (SE) scores are calculated using the following equation.

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

where the CCR score, θ^*_{CCR}, represents Technical Efficiency (TE), while the BCC score, θ^*_{BCC}, represents Pure Technical Efficiency (PTE). Herein, TE (often called overall technical efficiency) refers to how productive the DMU (i.e., mass transit system) can be a given set of inputs. TE shows the mass transit system's ability to transform inputs into desired outputs (or maximum outputs). TE can be calculated by the ratio of sum of weighted outputs to sum of weighted inputs.[33] PTE (sometimes called controllable efficiency) is a measure of technical efficiency without scale efficiency (without the conditions of constant-returns-to-scale) and purely reflects the managerial performance to organize the inputs in the production process.[34] Thus, PTE measure has been used as an indicator to capture managerial performance. These scores obtained from the conventional DEA models, however, can produce too many efficient DMUs due to their dichotomous classification (either efficient or inefficient) of DMU performances. To discriminate among so many transit agencies with a perfect efficiency score of one, the author computed super-efficiency scores proposed by Andersen and Petersen.[35] Super-efficiency is intended to discern truly efficient DMUs and then rank them by assigning an efficiency score greater than one.[36] In other words, the super-efficiency score enables us to distinguish among many efficient transit agencies by allowing extremely efficient DMUs to achieve an efficient score greater than one. This score can be calculated by removing the constraint in the primal form of DEA equations that restricts the efficiency score to no larger than one.[37] Super-efficiency scores can be calculated by using the following mathematical equation.

$$\text{Maximize} \sum_{r=1}^{s} u_r y_{rj} \qquad (10)$$

Subject to:

$$\sum_{i=1}^{m} v_i x_{ij} - \sum_{r=1}^{s} u_r y_{rk} \geq 0 \text{ for all } k \in j \qquad (11)$$

$$\sum_{i=1}^{m} v_i x_{ij} = 1 \text{ for all } j = 1,\ldots,n \qquad (12)$$

$u_r \geq \varepsilon$ for all $r = 1,\ldots, s$

$v_i \geq \varepsilon$ for all $i = 1,\ldots m$

y_{rj}= the vector of output r produced by unit j

x_{ij}= the vector of input i used by unit j

u_r= the weight given to output r

v_i= the weight given to input i

ε = a very small positive number

Table 2. Efficiency Scores of Selected Mass Transit Systems

No.	Name	Tier	Super-Efficiency	CCR	BCC	SE
1	TA1)	1	2.989	1.000	1.000	1.000
2	TA2	1	1.482	1.000	1.000	1.000
3	TA3	1	1.369	1.000	1.000	1.000
4	TA4)	1	1.351	1.000	1.000	1.000
5	TA5)	1	1.345	1.000	1.000	1.000
6	TA6	1	1.309	1.000	1.000	1.000
7	TA7	1	1.278	1.000	1.000	1.000
12	TA12	1	1.110	1.000	1.000	1.000
14	TA14c.	1	1.100	1.000	1.000	1.000
16	TA1612)	1	1.072	1.000	1.000	1.000
18	TA18)	1	1.071	1.000	1.000	1.000
19	TA19	1	1.064	1.000	1.000	1.000
20	TA20	1	1.063	1.000	1.000	1.000
21	TA21	1	1.042	1.000	1.000	1.000
23	TA23	1	1.030	1.000	1.000	1.000
24	TA24)	1	1.027	1.000	1.000	1.000
26	TA26	1	1.008	1.000	1.000	1.000
27	TA27	1	1.002	1.000	1.000	1.000
28	TA28y	2	0.995	0.997	1.000	0.997
29	TA29)	2	0.978	0.999	1.000	0.999
30	TA30)	2	0.925	0.940	0.960	0.979
31	TA31)	2	0.924	0.928	0.970	0.956
37	TA37	2	0.870	0.976	1.000	0.976
38	TA38)	2	0.869	0.873	0.894	0.977
41	TA41	2	0.848	0.912	1.000	0.912
42	TA42	2	0.835	0.930	1.000	0.930
43	TA43	2	0.829	0.838	0.888	0.943
49	TA44)	2	0.786	0.833	0.861	0.967
51	TA51	2	0.780	0.838	0.852	0.984

No.	Name	Tier	Super-Efficiency	CCR	BCC	SE
52	TA52	2	0.762	0.803	0.959	0.837
67	TA67	3	0.676	0.751	0.869	0.865
68	TA68	3	0.676	0.881	0.942	0.935
96	TA96	3	0.553	0.854	0.875	0.976
110	TA110)	3	0.516	0.572	0.811	0.705
119	TA119	4	0.499	0.654	0.667	0.981
121	TA121	4	0.495	0.538	0.541	0.994
128	TA128	4	0.474	0.514	0.516	0.996
148	TA148	4	0.450	0.536	0.707	0.758
184	TA184	4	0.402	0.422	0.450	0.939
188	TA188	4	0.397	0.466	0.610	0.763
189	TA189	4	0.397	0.444	0.549	0.809
190	TA190	4	0.396	0.468	0.471	0.994
194	TA194	4	0.394	0.487	0.497	0.980
195	TA195	4	0.393	0.402	0.493	0.816
327	TA327	4	0.310	0.375	0.375	0.998
336	TA336	4	0.302	0.359	0.433	0.830
340	TA340	4	0.299	0.362	0.416	0.869
346	TA346	4	0.296	0.368	1.000	0.368
347	TA347	4	0.296	0.345	0.350	0.988
441	TA441	4	0.255	0.266	0.269	0.990
443	TA443	4	0.254	0.301	0.405	0.745
445	TS445	4	0.253	0.308	0.389	0.792
448	TA448	4	0.251	0.267	1.000	0.267
451	TA451	4	0.250	0.306	0.782	0.391
452	TA452	5	0.248	0.341	0.357	0.954
453	TA453	5	0.247	0.278	0.383	0.725
493	TA493	5	0.215	0.248	0.624	0.398
497	TA497)	5	0.209	0.247	0.295	0.837
498	TA498	5	0.208	0.238	0.336	0.709
499	TA499	5	0.207	0.240	0.284	0.847
500	TA500	5	0.200	0.236	0.503	0.469
501	TA501)	5	0.196	0.235	0.286	0.822
504	TA504	5	0.173	0.217	0.312	0.695
506	TA506	5	0.168	0.210	0.437	0.480
508	TA508	5	0.167	0.210	0.678	0.309
509	TA509	5	0.159	0.275	0.304	0.905
510	TA510)	5	0.139	0.167	0.175	0.954
515	TA51)	5	0.019	0.022	0.022	1.001

Notes: To keep the confidentiality of mass transit agencies that were evaluated in this study, we concealed the names and specific profiles of these agencies.

The above table does not contain the exhaustive list of all the transit agencies that were evaluated in this study.

Tier 1 agencies (agencies with a super efficiency score of 1 or higher); tier 2 (a score of 0.750 to 0.990); tier 3 (a score of 0.500 to 0.749); tier 4 (a score of 0.250 to 0.499); tier 5 (a score below 0.250).

The DEA results summarized in Table 2 show a list of top-tier transit agencies which registered a super efficiency score of 1 or higher. Among these agencies, we identified five transit agencies: one in Alabama, two in Colorado, one Ohio, and one in Pennsylvania as the benchmark performers in 2011. Their super efficiency scores ranged from 1.345 to 2.989. In particular, the best performing agency's success hinges on its demand response services for low-density neighborhoods during off-peak hours (e.g., evening hours), which allows for a better cost-recovery ratio by utilizing smaller vehicles. Also, it has been exploiting hub-and-spoke systems and van pools to improve service efficiency. Another distinguishing feature of the best performing agency is the development of public-private partnerships (PPPs) in conjunction with the Ride-Share program to reduce single-occupancy vehicles.

Similar to the best performing agency, the common denominator among the aforementioned five high performers is the use of van pools, other ride-share programs, and/or demand-responsive services that better utilize vehicles and allow for higher service efficiency. This finding is not surprising since van pooling is the most efficient commuting option among various public transportation modes as shown in Table 3.

On the other hand, some agencies did not perform as well using the DEA methodology. Among these, the poor performers are located in both economically stagnant, cold-weather states and economically booming, warm southern states. That is to say, geographic location, local climate or regional economy may have little to do with performance of mass transit systems.

Though the specific challenges of poor performers vary from one agency to another and can be region-specific, one intriguing pattern that characterizes poorly performing agencies was their heavy reliance on rapid transit systems with dedicated lanes (e.g., light rail, street car, bus rapid transit), which make transfers more difficult for riders and incur huge infrastructure maintenance costs. Also, both light rail and street cars tend to have a lower proportion of seats to standees and can make riders feel uncomfortable, not to mention the inflexibility of their routes and the reduced service frequency as compared to the bus. Indeed, as summarized in Table 3, transit modes such as light rail and streetcar may be viewed as potential sources of transit inefficiencies. On the other hand, considering the increasing popularity of bus rapid transit (BRT) as an emerging mode of public transit, it is somewhat surprising that BRT is tied to relatively inefficient transit agencies. BRT has a topological advantage over light rail or street cars in that it can operate in an open configuration without any special infrastructure such as tracks and switches. Its capital cost and maintenance cost, however, may be still higher than those of traditional buses over time, and its service reliability can be lower than that of buses due to its queue jump lanes and operation in mixed traffic or an exclusive transit-way.

Another pattern that emerged from the DEA analyses is that transit authorities serving the biggest metro areas in the US do not necessarily perform better than the agencies serving mid-size or smaller cities such as Mobile in Alabama, Newark in Ohio, and Athens, Georgia. Since there is little difference in scale efficiencies between 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.

Table 3. Efficiency Scores of Transit Systems with Respect to Transportation Mode

	DEA Efficiency Scores				
Transportation Mode	**CCR**	**BCC**	**SE[1]**	**Super-Efficiency[2]**	**Rank**
Van Pool	1.000	1.000	1.000	2.454	1
Inclined Plane	1.000	1.000	1.000	2.264	2
Demand Response - Taxi	1.000	1.000	1.000	1.200	3
Commuter Rail	1.000	1.000	1.000	1.197	4
Demand Response	1.000	1.000	1.000	1.105	5
Commuter Bus	0.864	0.887	0.974	0.826	6
Bus	0.620	1.000	0.620	0.521	7
Bus Rapid Transit	0.552	1.000	0.552	0.510	8
Heavy Rail	0.488	1.000	0.488	0.400	9
Ferryboat	0.640	0.874	0.733	0.347	10
Trolleybus	0.451	0.805	0.561	0.333	11
Street Car Rail	0.387	0.601	0.643	0.298	12
Light Rail	0.347	0.663	0.523	0.283	13
Hybrid Rail	0.295	0.375	0.787	0.231	14
Monorail/Automated Guideway	0.237	0.237	0.999	0.183	15

Note 1: Scale Efficiency (SE) was calculated as: $SE=\frac{\theta^*_{CCR}}{\theta^*_{BCC}}$, 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.

Note 2: The author calculated each DMU's full super-efficiency score in order to discriminate among the efficient DMUs and then rank them by assigning the efficiency score greater than 1.

To further identify the main sources of efficiency or inefficiency of mass transit systems, the author paired DEA scores for transit efficiency at the state level against a set of independent variables using a special form of regression analysis called Tobit regression. Tobit regression was employed as an effective post-hoc analysis which aims to examine any causal relationship between environmental factors (e.g., geographic or demographic compositions in the transit market) and transit efficiency scores. In general, Tobit regression aims to analyze continuous data that are censored, or bounded at a limiting value. The Tobit regression model is well suited to measure transformed efficiency such as DEA efficiency scores, when dependent variables have sensible partial effects over a wide range of independent variables and are interval-censored with the presence of both the threshold value and the saturation limit.[38] In the Tobit regression model, the following variables were used as independent variables to predict the DEA efficiency scores for each form of travel for each state:

1. _Geographical size (service area in square miles)_. In smaller cities, transit primarily serves transportation-disadvantaged riders (such as people who cannot use an automobile due to physical or mental limitations), typically representing 5-10% of the population. As cities grow in size, transit tends to serve more discretionary riders (people who have the option of driving), and so eases traffic congestion problems and supports more efficient land use patterns.[39] In other words, the size of a transit service area may potentially improve the transit efficiency. Thus, the author considered the size of a transit service area as a way to gauge the mass transit efficiency.

2. *Population density in square miles of the service area.* If large populations are concentrated in a relatively compact area or in the same neighborhood, the distance that a transit vehicle travels is shorter while serving more riders and thus can increase the mass transit efficiency. Also, densely populated areas may provide greater economies of scale in mass transit services, which can lead to higher DEA scores.

3. *Poverty level.* Min discovered that a vast majority (more than 80% of his surveyed respondents) of paratransit riders were people who were well below the federal poverty threshold (annual income less than $10,830 for one-person household; $14,570 for two-person household).[40] By analogy, it is assumed that the mass transit system may have become a low-cost alternative means of transportation for low-income people who cannot afford to use their own vehicles. As discussed above, since the concentration of low-income residents can influence the utilization of mass transit services, the percentage of households below the poverty line in the mass transit service area may be used as a proxy for the mass transit efficiency.

Table 4 shows the results of the Tobit regression analysis used to assess the DEA scores for mass transit systems at the state level. The results of the two different sets of Tobit models show that only one explanatory variable is statistically significant at $\alpha = 0.05$ in the CCR-based model and all three variables at $\alpha = 0.05$ in the BCC-based model, respectively. The Tobit regression models explain only small amounts of variation in the dependent variable due to the low log-likelihood scores. In Table 4, the population density in square miles of the service area is the strongest predictor of both CCR- and BCC-based transit efficiencies. In other words, the greater the population density of the service area, the greater number of riders can be served in a short amount of distance and time. Additionally, the investigator checked to see whether state characteristics (e.g., weather, population size, income level, and transit policy) influenced mass transit efficiency. As shown in Table 5, no consistent patterns are found indicating the influence of state characteristics (e.g., different transit policy, budget, potential rider bases) on mass transit efficiency. Furthermore, the current study examined whether public ownership or private operation of transit systems could make any differences in transit efficiency. As Table 6 indicates, no evidence was found that either public or private operations are conducive to mass transit efficiency.

Table 4. The Results of Tobit Regression

Response Variable: CCR Efficiency Scores for Transit Efficiency				
Predictor	**Coefficient**	**Std. Error**	**t-score**	**P-value**
Intercept	0.59104	0.07106	8.33	0.000
Service area in square miles	0.00005	0.00003	1.65	0.107
Population density in square miles of the service area	0.00001	0.00000	2.16	0.036**
Poverty level	0.00001	0.00489	1.37	0.178
Log-Likelihood = 7.68884533				
Pseudo R^2 = -1.0464				

Response Variable: BCC Efficiency Scores for Transit Efficiency				
Predictor	**Coefficient**	**Std. Error**	**t-score**	**P-value**
Intercept	0.51917	0.09715	5.34	0.00000
Service area in square miles	0.00008	0.00003	2.19	0.033**
Population density in square miles of the service area	0.00002	0.00001	2.96	0.005**
Poverty level	0.01590	0.00742	2.14	0.037**
Log-Likelihood = -5.7497949				
Pseudo R^2 = 0.6317				

Note: **Statistically significant at α = 0.05.

Table 5. Efficiency Scores of Mass Transit Systems at the State Level

	Efficiency Scores				
States (DMU)	**CCR**	**BCC**	**SE**[1]	**Super-Efficiency**[2]	**Rank**
NH	1.000	1.000	1.000	1.875	1
WY	1.000	1.000	1.000	1.225	2
MS	1.000	1.000	1.000	1.040	3
NY	1.000	1.000	1.000	1.009	4
PR	1.000	1.000	1.000	1.003	5
SC	1.000	1.000	1.000	1.002	6
NJ	0.997	1.000	0.997	0.750	7
ME	0.926	1.000	0.926	0.709	8
AL	0.945	1.000	0.945	0.664	9
DC	0.922	1.000	0.922	0.652	10
NV	0.866	0.973	0.891	0.586	11
WV	0.819	0.907	0.904	0.579	12
ID	0.833	0.934	0.891	0.578	13
SD	0.784	0.917	0.855	0.565	14
ND	0.830	0.950	0.874	0.558	15
KS	0.740	0.862	0.858	0.547	16
VA	0.739	0.984	0.751	0.528	17
AK	0.653	0.685	0.954	0.517	18
PA	0.723	1.000	0.723	0.516	19
NE	0.689	0.854	0.807	0.515	20

	Efficiency Scores				
States (DMU)	**CCR**	**BCC**	**SE[1]**	**Super-Efficiency[2]**	**Rank**
MT	0.710	0.770	0.921	0.515	21
IN	0.692	0.864	0.801	0.505	22
IA	0.799	0.859	0.930	0.503	23
WI	0.705	1.000	0.705	0.498	24
AR	0.731	0.837	0.873	0.497	25
IL	0.731	0.990	0.738	0.491	26
TN	0.662	0.986	0.671	0.488	27
CO	0.715	0.896	0.798	0.486	28
CA	0.656	1.000	0.656	0.485	29
VT	0.683	0.688	0.994	0.484	30
NC	0.724	0.986	0.734	0.481	31
OH	0.634	1.000	0.634	0.480	32
FL	0.711	1.000	0.711	0.477	33
KY	0.696	0.880	0.791	0.476	34
OK	0.636	0.715	0.890	0.473	35
UT	0.706	0.886	0.797	0.472	36
CT	0.614	0.988	0.621	0.464	37
MA	0.690	0.856	0.807	0.454	38
MI	0.639	1.000	0.639	0.445	39
GA	0.712	0.904	0.788	0.435	40
DE	0.659	0.905	0.728	0.434	41
MO	0.610	0.852	0.716	0.430	42
RI	0.555	0.752	0.738	0.429	43
OR	0.607	0.728	0.835	0.418	44
AZ	0.642	0.839	0.765	0.418	45
HI	0.653	0.757	0.863	0.417	46
TX	0.613	1.000	0.613	0.411	47
MD	0.542	0.755	0.717	0.407	48
WA	0.544	0.909	0.598	0.404	49
MN	0.680	0.834	0.815	0.394	50
LA	0.469	0.670	0.700	0.344	51
NM	0.484	0.524	0.924	0.340	52
VI	0.578	1.000	0.578	0.246	53

Table 6. Differences in Efficiency Scores of Public and Private Transit Systems

	Mean		Standard Deviation			
	Public (n=237)	**Private (n=278)**	**Public (n=237)**	**Private (n=278)**	**t-value**	**P-value***
CCR	.490	.460	.220	.204	1.615	.107
BCC	.551	.575	.230	.221	-1.196	.232
Super-Efficiency	.453	.298	.298	.223	1.904	.057

Note: *Statistically significant, if p<0.05.

VI. CONCLUDING REMARKS

Since people's mobility and their subsequent economic activities are affected by the accessibility and affordability of mass transit services, this paper conducted a comprehensive benchmarking study of mass transit systems in the U.S. using DEA, while identifying potential sources of either efficiencies or inefficiencies. DEA is a technique that helps public policy makers such as mass transit authorities identify lagging mass transit systems with respect to various performance standards (e.g., vehicle utilization, revenue hours/miles, return-on-investment of financial resources) and then highlight the specific aspects of mass transit performances that should be strengthened to further improve their efficiencies. In this study's DEA analysis, it was found that the overall (population) size of a city has no bearing on its mass transit efficiency, as congruent with the findings of O'Sullivan and of Min and Lambert.[41] In other words, economies of scale alone did not seem to dictate mass transit efficiency. For example, all top-five performers serve relatively small cities, whereas some agencies serving big metro areas performed comparatively poorly. Also, the author discovered that mass transit systems that made use of van-pooling services or Ride-Share programs tended to perform better, whereas mass transit systems that used light-rail heavily tended to perform poorly. Another noticeable pattern of the top performers is their willingness to partner with external stakeholders (e.g., public-private partnership with local enterprises). This pattern may be a reflection of growing economic trends encouraging a collaborative economy that aims to fully utilize expensive assets such as mass transit vehicles and infrastructure by promoting shared consumption and investment. Furthermore, the transportation mode of mass transit services really matters to mass transit efficiency. For example, commuter rail and demand response taxis tended to create greater efficiencies than other modes of public transportation such as trolley bus and light rail.

Another finding worth noting is a lack of correlation between geographical location and 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 have affected the local economy. For example, some studies reported that accessibility to transit tended to affect an average residential property value by six to seven percent.[42] Some researchers made it a premise that public bus stops or subway stations might raise the value of nearby properties by reducing commuting costs or by attracting more retail activities to the neighborhood.[43] Another social impact of efficient and effective mass transit systems is reduced carbon footprint resulting from less 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.

Finally, the author found that, defying common perception, private operations of mass transit systems did not necessarily enhance transit efficiency. Thus, outsourcing transit services to private companies does not always lead to cost savings and improved services as previously observed by this author.[44] For public policy purposes, transit authorities need to consider leveraging car or van pooling services rather than simply investing more into transit infrastructure and broadening service areas and offerings. Also, they need to consider building a long-term partnership with local private enterprises for exploiting their expertise and financial resources. In light of this discussion, future studies may examine the influence of public-private partnership on mass transit services and their efficiencies, while assessing the impact of a particular mode of transportation on mass transit performance over an extended period of time. In addition, DEA model experiments with different combinations of input and output KPIs including a measure gauging the level of passenger satisfaction with transit services (e.g., rider satisfaction index) will be intriguing. Although the level of rider satisfaction with mass transit services is difficult to quantify, it better reflects the true success of mass transit services. For potential inputs, workforce size (e.g., transit vehicle drivers, maintenance crews) can be a meaningful input in gauging how human resources are utilized for offering mass transit services. Furthermore, future studies need to assess the impact of the following variables on mass transit efficiency: (1) residential density which measures the number of dwelling units and household size in a given land area serviced by a particular mass transit agency; (2) cost of living that may influence the affordability of transit services; (3) vehicle ownership rates; (4) percentage of the disabled population unable to drive; (5) the availability and/or diversity of alternative means of transportation including on-demand taxi services such as Uber and Lyft. Furthermore, considering potential changes in rider demographics and transit service offerings, future studies can overcome the key shortcoming of the current study which was confined to a single period benchmarking by analyzing the multiple years of transit data using either the DEA Windows analysis or the Malmquist Productivity Index.

ACRONYMS AND ABBREVIATIONS

ADA	Americans with Disabilities Act
BCC Model	Banker, Charnes and Cooper model of DEA
BRT	Bus Rapid Transit
CASD	Computer-Assisted Scheduling and Dispatching
CCR Model	Charnes, Cooper and Rhodes model of DEA
CRS	Constant Returns to Scale
DEA	Data Envelopment Analysis
DMU	Decision-Making Unit
DOT	Department of Transportation
DRS	Decreasing Returns to Scale
IRS	Increasing Returns to Scale
ICT	Information and Communication Technology
KPI	Key Performance Indicator
LCA	Life Cycle Analysis
MNTRC	Mineta National Transit Research Consortium
MTI	Mineta Transportation Institute
NTD	National Transit Database
PPP	Public-Private Partnership
PTE	Pure Technical Efficiency
SE	Scale Efficiency
TE	Technical Efficiency
U.S.	United States
VRS	Variable Returns to Scale

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