Assessing the performance of public transport services in a developing country: a case study using data envelopment analysis

Abstract

The accurate evaluation of public transport (PT) services in developing countries is a challenging task due to a lack of reliable data and formal guidelines. The aim of this study was to develop a framework addressing these data limitations and quantify PT performance using output-oriented Data Envelopment Analysis (DEA). The local bus service operation of Chattogram City Corporation (CCC) area of Bangladesh was used as a case study. A performance assessment inventory was developed identifying the major stakeholders related to local bus service operations. The relative efficiencies of different bus routes (from users' and operators' perspectives) were estimated using the DEA model, which incorporated data from a semi-structured questionnaire survey linked with the inventory. The PT authority also ranked all bus routes according to their degree of efficiency. Results indicated that relative efficiency scores in various routes varied according to the stakeholders' perspectives. A range of different parameters were considered when evaluating the performance of the service. The proposed inventory and framework would be useful for policymakers and urban planners in sequencing and prioritizing different routes. This optimization process would provide improved transport services to the general public.

Keywords: Public transport; data envelopment analysis; local bus routes; transportation modeling; Bangladesh

1. Introduction

Due to rapid rates of urbanization, cities in both developed and developing countries are facing diverse challenges in managing Public Transport (PT) services[1] (Badami & Haider, 2007; Morris, Ison, & Enoch, 2005). Increasing traffic congestion, and the high maintenance costs of PT services, restrict the transport authorities' ability to ensure the efficient operation of an affordable, quality PT service. These issues also makes this form of transport less attractive to users (Bertini & El-Geneidy, 2003; Boujelbene & Derbel, 2015; Hassan, Hawas, & Ahmed, 2013). Ensuring an efficient PT service is far more challenging in a developing country than in a developed country due to a lack of financial resources, political pressures, imbalance of supply and demand for PT services and a lack of demand-driven PT service management policies (Boujelbene & Derbel, 2015; Iles, 2005; Sohail, Maunder, & Miles, 2004). It appears that the demands for PT services are decreasing in many developed countries, with an associated deterioration in the quality of the service provided. Much of this is due to an increasing dependence on private vehicles. In developing countries, issues related to service quality are primarily

[1] Public transport service is a shared transport service available for people to commute from one place to another which consists of structural (e.g., road, transport modes) and non-structural elements (e.g., policies and rules).

associated with a rapid increase in transportation demand (Iles, 2005). Though most of the problems associated with PT service management are similar in both the developed and developing worlds, their causation, magnitude, and impacts on mobility behavior are different. In developing countries PT management issues are exacerbated by rapid urbanization, a growing population, lack of safety and security, and poor enforcement of rules and regulations (Verma & Ramanayya, 2019). Regular assessment schedules and improved PT services are deemed essential to meet an increasing transportation demand with the limited resources available.

Systematic transportation planning not only refers to the provision of transport facilities (the structural measures) but also encompasses the regular improvement in the performance of the service (the nonstructural measures). To improve PT services, cities in many developing countries have adopted various structural and nonstructural measures to reduce the gap between demand and supply. Nonstructural measures include the provision of subsidies, a performance assessment of PT service through regular monitoring, and the evaluation of service efficiency (measured by cost efficiency, labor, and vehicle utilization) and effectiveness (transit ridership, service quality, service satisfaction) (Iles, 2005; Verma & Ramanayya, 2019; C. Zhang, Juan, Luo, & Xiao, 2016). Monitoring and evaluation of PT systems are useful in identifying deficiencies in the existing transportation service. Measuring PT performance is useful in identifying issues in the existing system, possible root causes, and the sectors requiring special attention. The identification of these issues and development of rigorous management programs is a prerequisite for transit improvement (Dhingra, 2011; Litman, 2008).

Usually, the performance assessment of the PT service is carried out by the state in order to determine suitable areas for funding and incentives. This focuses primarily on the operational efficiency and effectiveness of the transit system (Dhingra, 2011; C. Zhang, Juan, & Xiao, 2015). Other organizations such as local government, municipalities, and transport operators are also involved in these assessments. Different stakeholders have their own focus areas. For instance, privately-owned transit operators usually focus on economic return in order to maximize profits while minimizing costs (Huque, 2020). Monitoring the PT service is essential for private transit operators so that they can become competitive service providers. This is especially the case where multiple transit operators are responsible for managing the PT sector of a city (Kathuria, Parida, & Sekhar, 2017; Khasnabis, Alsaidi, Liu, & Ellis, 2002; Swami & Parida, 2015). In contrast, public transit operators primarily focus on providing public service to meet social demands (Phillips, 2004). The purpose and scope of the performance assessment are also generally context-specific. Regular PT performance assessments are critical for both public and private operators in the developing countries. For a public transit operator in a developing country, major challenges in regards performing regular service assessments are related to the limited public funds available, increased demand for PT services, and expanding social needs (Yao, Xu, & Li, 2019). The influence of politics in developing cities also often result in poor service from private operators (Sohail et al., 2004). PT performance assessment in developing countries is also a challenging task due to a lack of data, data which is both labor-intensive, as well as costly, to obtain (Zannat & Choudhury, 2019).

Stakeholders such as users and communities have different expectations compared to transit operators or PT authorities. PT users are mainly concerned with reducing travel time and costs, with an expectation of good service quality at a low price. Due to differing stakeholder attitudes and expectations, it becomes necessary to consider the opinions of all stakeholders in order to gain a comprehensive understanding of PT performance. Conflicting interests among different actors, however, can lead to difficulties in performance evaluation, so it is essential to have good communication between the various stakeholders (Seker & Aydin, 2020; Susniene & Jurkauskas, 2008). Only a small number of studies have highlighted the importance of incorporating perceptions of the different stakeholders in the PT service quality evaluation process (Güner & Coşkun, 2016; Hassan et al., 2013; Chintan Sheth, Triantis, & Teodorović, 2007; C. Zhang et al., 2016; Zhao, Triantis, Murray-Tuite, & Edara, 2011). This is a challenging task, however, particularly in these developing countries due to: (i) a lack of panel data for monitoring and evaluating PT services (Zannat & Choudhury, 2019); (ii) a lack of a comprehensive framework of PT performance assessment inventory that addresses data limitations, along with the views and interests of different stakeholders (Hassan et al., 2013; Hawas, Khan, & Basu, 2012); (iii) the existence of multiple organizations and public transport authorities that have overlapping activities and a lack of an overall coordinating authority (e.g., single bus route operated by multiple public and private companies); and (iv) a lack of accountability and transparency among responsible public transport authorities.

Most of the existing studies related to PT performance assessment have been conducted on cities located in the USA, Europe, and China. Unfortunately, the PT performance assessment frameworks and inventory developed for those cities are not really transferrable to developing countries, due to a lack of commitment in addressing data limitation issues and the conflicting interests of multiple stakeholders. For example, fine-scale data (e.g., time, location, and service status of PT) can be collected using GPS technology installed in vehicles, which enables regular monitoring and evaluation of PT operation (Zannat & Choudhury, 2019). In many large and medium-sized developed cities, smart cards (e.g., Oyster card in London, Smart Link in New York) are used for automatic fare collection in the PT system. Smart card data can also be used for extracting information such as arrival time (Zhou, Yao, Chen, Gong, & Lai, 2017), passenger waiting time (Tavassoli, Mesbah, & Shobeirinejad, 2018), the number of left-behind passengers (Zhu, Koutsopoulos, & Wilson, 2017), and the spatial variation in PT ridership (Tu et al., 2018). All these data sources provide an opportunity to monitor PT performances. In developing countries, this lack of structured networks and use of manually-operated fare collection systems limit the ability for comprehensive data collection. For example, in Bangladesh, paratransit[2]

[2] Paratransit is also known as community transport that provides individualized rides without fixed routes.

service, as well as, traditional PT service (e.g., local bus service) operates beyond permitted road networks (Enam & Choudhury, 2011).

This study looked to address the challenges noted above by (i) developing a performance assessment inventory which considered the data limitations; (ii) identifying and classifying different actors and their roles in PT service operation in order to incorporate their interests in the framework of PT performance assessment; (iii) deriving an efficiency score for the PT service incorporating both qualitative and quantitative parameters; and (iv) highlighting the importance of efficiency scores and their implications in regards providing a better PT service. This study utilizes data envelopment analysis (DEA) to evaluate PT performance in a developing country and looks at developing approaches to account for the major challenges related to PT performance assessment. It highlights the importance of incorporating different stakeholders in evaluating the performance of PT service by applying a combined qualitative and quantitative approach. The study is carried out in Chattogram City Corporation (CCC) area of Bangladesh (Figure 1) and is focused on the local bus service. To the best of our knowledge, this study is the first of its kind to focus on a PT performance assessment in a city of a developing country.

2. Theoretical background

The requirement to conduct comprehensive PT performance assessments have emerged as a necessity in ensuring rigorous quality management and increased operational efficiency in regards this form of transport (Boujelbene & Derbel, 2015; Güner & Coşkun, 2016; Kathuria et al., 2017; Khasnabis et al., 2002; Taboada & Han, 2020). According to Wei et al. (2017), a performance assessment process is the first step required in making a PT management system efficient. A well-structured PT evaluation system is a prerequisite for sustainable transportation (Jasti & Ram, 2018; Zannat, Adnan, & Dewan, 2020). Continuous evaluation of the performance and effectiveness of a service is required to improve its quality (Kathuria et al., 2017; Swami & Parida, 2015). Carter and LoMAx (1992) noted that in transportation systems, the management of planning and assessment of performance have become an integral part of ensuring accountability and transparency by providing baseline data with which to assess the system as whole. Their argument has been supported by analyzing the emerging use of the PT assessment process for funding allocation, administrative planning, and to allow a comparative analysis of the various transit agencies. Performance-related information is necessary for decision-makers to evaluate public investment alternatives (Chintan Sheth et al., 2007). The increasing use of such assessment processes allows a better gauge of performance measures and indicators — integral parts of the performance assessment (Benjamin & Obeng, 1990). According to Fielding, Glauthier, and Lave (1978), the efficiency and effectiveness of PT performance measures are useful for multi-level governance. Phillips (2004) added ‘impact’ to efficiency and effectiveness. Carter and LoMAx (1992) suggested PT performance assessment should be based on effectiveness, efficiency, impact, productivity, and quality of service. The complex interaction of multiple factors, stakeholders, and organizations results in a PT performance assessment being potentially a very challenging task (Hirschhorn, Veeneman, & van de Velde, 2018; Chintan Sheth et al., 2007). Complexities in performance assessment may also vary according to (i) the system under consideration (e.g., bus, train, and airways); (ii) the routes; (iii) functions; (iv) policy changes; and (v) the specific goals and objectives (Ryus et al., 2003).

Existing studies have applied differing techniques when undertaking the task of assessing transit service performance. Examples include the SERVQUAL model (Barabino, Deiana, & Tilocca, 2012; Sam, Hamidu, & Daniels, 2018), impact score technique (Alçura, Kuşakcı, Şimşek, Gürsoy, & Tanrıverdi, 2016), importance-performance analysis (Z. M. Ali, Ismail, Suradi, & Ismail, 2009; Cao & Cao, 2017; Wu, Shieh, & Pan, 2008), customer satisfaction index (Z. M. Ali et al., 2009; Eboli & Mazzulla, 2009), ordered logit model (Echaniz, Ho, Rodriguez, & dell'Olio, 2019; Tyrinopoulos & Antoniou, 2008), structural equation modeling (Eboli & Mazzulla, 2007; Shen, Xiao, & Wang, 2016; Wan, Kamga, Hao, Sugiura, & Beaton, 2016), and multicriteria evaluation (Hassan et al., 2013; Pedroso, Bermann, & Sanches-Pereira, 2018; Yeh, Deng, & Chang, 2000). More recently, some studies have used the Structural Entropy-TROPSIS model to evaluate the PT system (Huang, Shuai, Sun, Wang, & Antwi, 2018; X. Zhang, Zhang, Sun, Zou, & Chen, 2018).

Over the last two to three decades, substantial work using data envelopment analysis (DEA) has been undertaken (Alizadeh & Safi, 2020; Lao & Liu, 2009; Chintan Sheth et al., 2007; Singh, Singh, Singh, Kumari, & Sangaiah, 2019; Wei et al., 2017). The DEA is a non-parametric approach, introduced by Charnes, Cooper, and Rhodes (1978), and based on the work of Farrel (1957). This approach uses a linear programming method to measure the relative efficiencies of multiple organizations using decision-making units (DMUs) (Lao & Liu, 2009). The DEA evaluates DMUs against best practice, so this approach is popular (Alizadeh & Safi, 2020; Lao & Liu, 2009; C. Zhang et al., 2016). It is widely used in situations where a system has a great variety of inputs and outputs (A. I. Ali & Lerme, 1997); factors common to PT systems (Lao & Liu, 2009; Wei et al., 2017). Different approaches can be taken when assessing PT performance (Eboli & Mazzulla, 2007; Hassan et al., 2013; Huang et al., 2018; Pedroso et al., 2018; Tyrinopoulos & Antoniou, 2008; Yeh et al., 2000; X. Zhang et al., 2018), however DEA offers a number of advantages. Firstly, it allows the simultaneous analysis of inputs and outputs in order to derive an efficient rating within a set of units. Secondly, inputs and outputs can have diversified units. Thirdly, the DEA does not require the generation of standards against efficiency measures. Fourthly, the method does not require predetermined production functions to relate the inputs and outputs. Finally, it is a data-driven approach (A. I. Ali & Lerme, 1997; Alizadeh & Safi, 2020; Lao & Liu, 2009; Malano, Burton, & Makin, 2004; Chintan Sheth et al., 2007; Wei et al., 2017), thereby allowing an effective assessment to be conducted.

To measure the PT performance, many studies use the original Charnes-Cooper-Rhodes (CCR) and Banker-Charnes-Cooper (BCC), which assumes a constant and variable return to scale (Karlaftis & Tsamboulas, 2012; C. Zhang et al., 2015). Other studies have attempted to improve the measurement approach by modifying the DEA or combining the DEA approach with other models. Wei et al. (2017) applied a combination of DEA, geographic information system (GIS), and multi-objective spatial optimization techniques to assess the operational efficiency of PT services. Chintan Sheth et al. (2007) used DEA and goal programming functionality in DEA to analyze the relationship among the PT service providers and users, along with exogenous factors related to the transportation investment (e.g., emissions, noise pollution, etc.). Alizadeh and Safi (2020) proposed a hybrid framework (combining DEA and data mining techniques) to measure the performance of a bus fleet. While many of the other studies have concentrated on improving the measurement approach of the DEA, the focus of the current work has been on addressing data limitation issues and incorporating the perceptions of multiple stakeholders including users, operators, and service providers.

3. Materials and methods

This study employed three interrelated steps in the development process. Firstly, any conflicting interests between the different stakeholders were identified, and their roles in the decision-making process related to PT operation were clarified, particularly those related to the local bus service in CCC. Secondly, a performance assessment inventory was developed to account for the different stakeholder groups. This was based on knowledge obtained from the literature and feedback from the various stakeholders. Finally, policy recommendations aimed at improving the performance of local bus service were developed and documented.

3.1. Study area

The study area is within the Chattogram City Corporation (CCC) located in the southeastern part of Bangladesh (Figure 1). Chattogram is the second-largest city in Bangladesh, a prime seaport, and a large commercial hub and business center (Zannat, Raja, & Adnan, 2019). The city has a total population of 3.3 million with a mean density of approximately 19,000 people per km^2 (Bondarenko, 2018). The population growth rate is 2.3%, which is higher than the national growth rate of Bangladesh (Mia, Nasrin, Zhang, & Rasiah, 2015). For administrative purposes, the CCC area is divided into 41 wards (the smallest administrative unit). The average household size is 4.8 person with 1.6 earning members per household (WB, 2018). The average daily household income is approximately BDT 1,700 (BBS, 2016). The literacy rate of the population living within the study area has increased from 44.6% in 1981 to 68.8% in 2011 (BBS, 2011). It is a polycentric city with four distinctive commercial centers: Kotwali, Chawkbazar, Agrabad, and GEC circle. The major industrial zones are located in the peripheral areas (WB, 2018). Among the EPZs found within Bangladesh, the Chattogram Export Processing Zone (EPZ) is the biggest contributor to exports. This constituted 11% of the national GDP in 2011 (Mia et al., 2015).

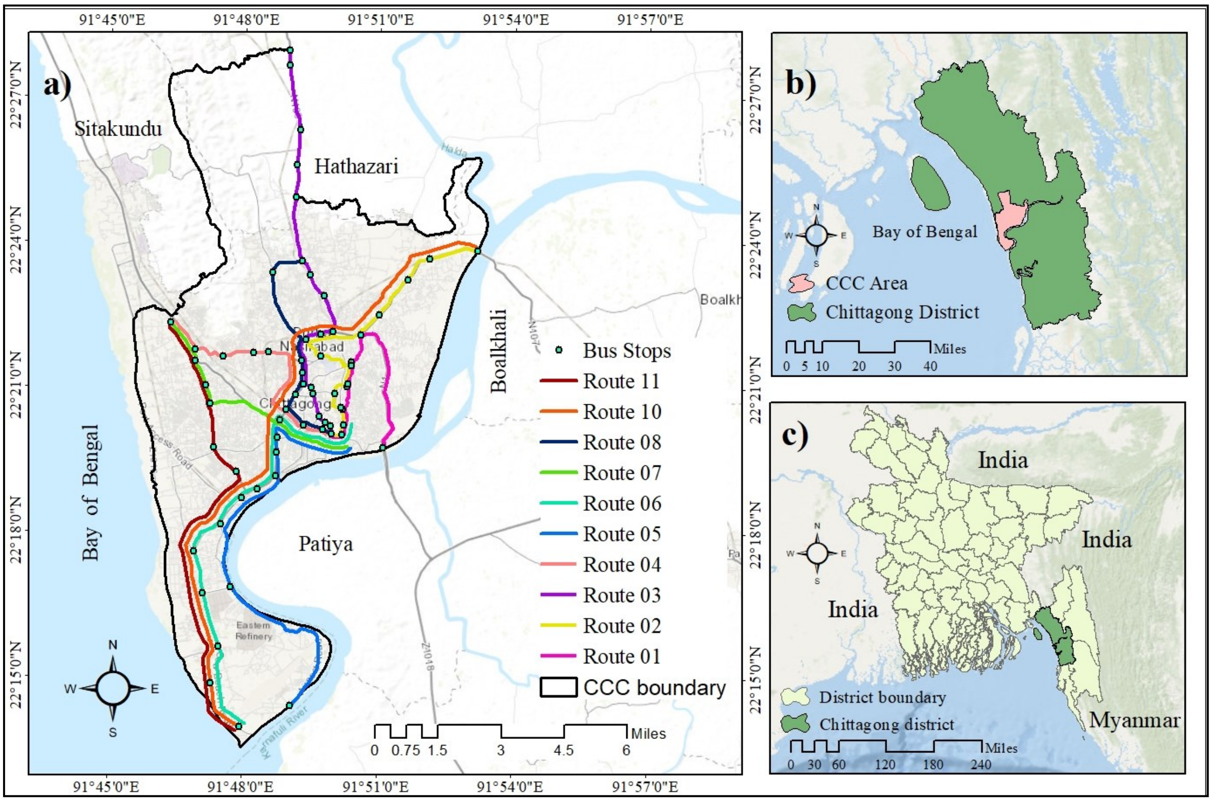

Figure 1 Location of Chattogram city corporation (CCC) area

As is the case with other major Bangladesh cities, the CCC is experiencing an increased demand for transportation caused by rapid population growth and urbanization. A local bus service is the primary mode of transport for most city dwellers. About 50% of commuters use local bus services to travel within the area (CDA, 2009). Many industries, factories, offices, garments, and shopping centers are located in the CCC, so the local bus service plays a very important role in the movement of people within the zone (Zannat, Showkat, & Islam, 2014). Other types of motorized and non-motorized vehicles (e.g., rickshaw, autorickshaw which is driven by compressed natural gas (CNG), human hauler, private car) operate within the area (Zannat et al., 2021). There are currently 10 routes traversed by the public bus service, 17 routes for human haulers, and 16 routes for CNG powered auto-rickshaws. There are, however, no dedicated bus lanes in the existing transport network. The average seating capacity of local buses ranges from 24 to 36 person and air conditioning systems are not available. Around 1,300 buses operate within the city area. There are more than 70 designated bus stops along the 10 routes, however local buses tend to pick up and drop off passengers at any point along the road (WB, 2018). This study addresses all 10 bus routes within the city (01, 02, 03, 04, 05, 06, 07, 08, 10, and 11) (Figure 1). The length of these routes are between 8 (route 08) and 25 kms (route 10) (CDA, 2009).

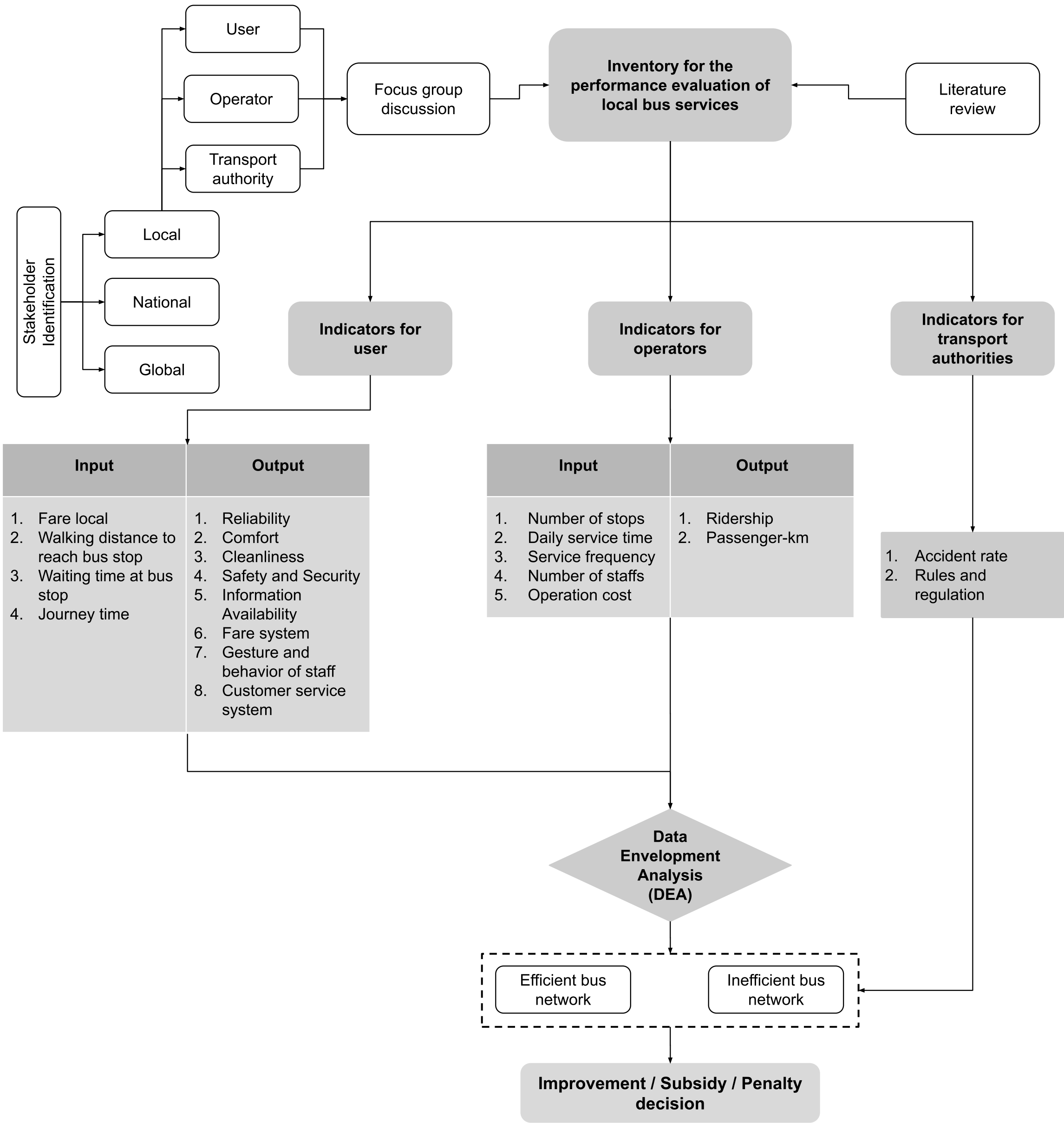

Figure 2 Flowchart, showing methodology of this work

3.2. Identifying stakeholders of local bus service

Understanding the role of the differing stakeholders responsible for PT operations is important when evaluating the performance of this mode of transport (Susniene & Jurkauskas, 2008). In a developing country like Bangladesh, a stakeholder's role and the extent of their involvement in the demand and supply management of the PT services, is not well defined. In this study all stakeholders were carefully identified and classified in regards their roles, the type of relationships with others, and their involvement in the formulation of policies. The most obvious stakeholder is the actual user of the bus service. There are no PT user-oriented organizations (formal or informal) in the study area so focus group discussions and questionnaire surveys were carried out with representatives of the various user groups. Local and national acts, rules, policies, and ordinances, institutional memorandum and organogram were reviewed to understand the involvement of other stakeholders (e.g., municipality, PT company, road maintenance service) in the provision of the service. Relevant documents were collected from the respective organizations, including from their websites. A short interview was also conducted with representatives of the major organizations within the CCC to understand their activities and ability to provide improved bus services.

Table 1 provides a summary of all the various stakeholders (apart from the actual service users) and their respective roles in the operation of the local services. These stakeholders were primarily involved in decision-making, service operation, and the overall management processes. Different stakeholders were involved in formulating policies at local (city), national, and global scales. For instance, the Road Transport and Highway Division (RTHD) formulated policies for land transport at the national and city level using information from national and international transport experts/consultants. This included existing policies, rules and laws, cross-cutting issues among other departments and resource availability. A stakeholder's involvement at the implementation level, however, is more complex. For instance, local bus services in CCC are primarily operated by a privatized organization called the Chattogram Metropolitan Paribahan Malik Group (CMPMG). The Bangladesh Road Transport Authority (BRTA) is a regulatory body that controls, manages, and ensures discipline in the sector and controls road safety at national and city levels within Bangladesh. The BRTA is also responsible for vehicle registration, providing driving licenses and the designation of specific bus routes within and outside the metropolitan area. The number of buses in a prescribed route (called the ceiling) is usually determined at an official meeting, with people present normally include an administrator of Chattogram Metropolitan Police (CMP), a Deputy Director from BRTA (Engineering), the General Secretary of CMPMG, representatives from the CCC (Traffic Engineering section), Bangladesh Road Transport Corporation (BRTC), reporters and representatives of civil society and other organizations. Stakeholders meet only once during the implementation phase with the scope of the meeting constrained by the official route ceiling. Local and state authorities do not monitor or inspect service quality. Representatives working for the service operation and management at the local level were contacted for input (Table 1). Discussions with these local officials provided details on the current inventory and the approaches used to collect data. The stakeholders (with the exception of the final users) were then divided into two groups: i) "transport operators" (e.g., BRTC, CMPMG, bus owners, and local partners) and ii) "transport authorities" (RTHD, BRTA, BRTC, CCC, CDA, and CMP). Officials who work at the national and global levels play an important role in the later phase of performance assessment such as providing subsidies or incentives to the operators to improve service quality.

Table 1 Stakeholders and their role in local bus operation in CCC

Level of involvement	**Nature of involvement**	**Scale**			**Stakeholders**
		Local	**National**	**Global**	
Decision making Level	Policy formulation and decision making	√	√		RTHD, ministers, members of Parliament, bureaucrats
	Provision of field information to the policy makers		√	√	Transport experts
Implementation level	Provision of route permit, license and registration	√	√		BRTA
	Provision of limited bus service	√			BRTC
	Maintenance and construction of roadway	√			CCC
	Construction and improvement of roadway	√			CDA
	Traffic and accident control	√			CMP
	Local bus service operation	√			CMPMG, bus owners, local partners

3.3. Developing performance assessment inventory

Following the identification of the major stakeholders (transit users, transport operators, municipality, and state authorities), a number of performance indicators that could be used to evaluate the local bus service were selected (Figure 2). This selection of input-output variables for the DEA is an important step. Performance evaluations are generally carried out by expert intervention, using a heuristic decision-making process, a review of the available literature, and exploratory analytical methods (Taboada & Han, 2020). Due to a lack of fine-scale data such as bus route level data from passengers and operators, and the lack of performance assessment standards in Bangladesh, the research team developed an input-output inventory based on an extensive review of other studies which had been done on the PT performance assessment process, with a focus on both developed and developing countries. To adjust the inventory in the context of local bus service operation in CCC area, selected indicators identified from the literature were then verified by the focus groups. During the focus group discussion, different stakeholders (local bus service users, bus operators and transport authorities) ascertained the importance, availability (i.e., source of information) and association of identified indicators with local bus service operation and management in the context of CCC. The final inventory included definitions of each indicator and the methods to be followed, or questions to be asked, to extract indicator-related information. The performance assessment indicators from the perspective of users (Table 2), and operators (Table 3), were included in the DEA analysis. The indicators from transport authorities (municipal and other local organizations) were selected based on their roles and interest.

Table 2 Inventory of performance assessment from the users' perspective

	Indicator	Definition	Sources
Input	1. Fare	Ticket price (per person per km)	(Eboli & Mazzulla, 2008)
	2. Walking distance to reach the bus stops	Time needed to reach the nearest stop from an origin on foot	(Eboli & Mazzulla, 2007; Joewono & Kubota, 2007; CH Sheth, 2003; Tyrinopoulos & Antoniou, 2008)
	3. Waiting time at stops for buses	Average time spent waiting for a bus at a stop	(Nathanail, 2008)
	4. Journey time	Time spent on the bus	(CH Sheth, 2003)
Output	1. Reliability	The ability of a transit system to adhere to schedule, as well as the ability of the transit vehicles to depart or arrive on time	(Eboli & Mazzulla, 2007; CH Sheth, 2003; Tyrinopoulos & Antoniou, 2008)
	2. Comfort	User perception about comfort within the bus in terms of crowding, air condition, noise level, and amenities	(Eboli & Mazzulla, 2007; Joewono & Kubota, 2007; Nathanail, 2008; Tyrinopoulos & Antoniou, 2008)
	3. Cleanliness	Cleanliness of the interior and exterior of buses	(Eboli & Mazzulla, 2007; Joewono & Kubota, 2007; Lai & Chen, 2011; Nathanail, 2008; Tyrinopoulos & Antoniou, 2008)
	4. Safety & security	Possibility of being involved in a road accident,	(Eboli & Mazzulla, 2007; Joewono & Kubota, 2007; Lai & Chen, 2011;

	Possibility of becoming a victim of a crime	Nathanail, 2008; Tyrinopoulos & Antoniou, 2008)
5. Information availability	Availability of information to the user provided by the service operator	(Eboli & Mazzulla, 2007; Joewono & Kubota, 2007; Lai & Chen, 2011; Nathanail, 2008; Tyrinopoulos & Antoniou, 2008)
6. Fare system	The rate of the ticket and the ticket category	(Eboli & Mazzulla, 2007; Joewono & Kubota, 2007; Lai & Chen, 2011; Tyrinopoulos & Antoniou, 2008)
7. Gesture and behavior	Personal appearance and behavior of the various types of personnel employed by the transport operator	(Eboli & Mazzulla, 2007; Joewono & Kubota, 2007; Lai & Chen, 2011; Nathanail, 2008; CH Sheth, 2003; Tyrinopoulos & Antoniou, 2008)
8. Customer service system	Ease of purchasing tickets and how well user opinions or complaints to the service operator were handled	(Eboli & Mazzulla, 2007; Lai & Chen, 2011; Tyrinopoulos & Antoniou, 2008)

Table 3 Indicators of performance assessment from the operators' perspective

	Indicator	**Definition**	**Sources**
Input	1. Number of Stops	Total number of stops in a route	(Adler & Berechman, 2001; Eboli & Mazzulla, 2007)
	2. Daily service time	Total duration of operational time in a day	(Eboli & Mazzulla, 2007; Tyrinopoulos & Antoniou, 2008)
	3. Service frequency	Number of trips made by a bus in a day	(Eboli & Mazzulla, 2007; Lai & Chen, 2011; Lao & Liu, 2009; Tyrinopoulos & Antoniou, 2008)
	5. Number of staffs	Number of staff used to operate the buses on a route	(Husain, Abdullah, & Kuman, 2000; Kerstens, 1996)
	6. Operating cost	The cost of running a bus from origin to destination, including staff wages	(Husain et al., 2000)

Output	1. Ridership	Number of passengers accommodated per day	(Adler & Berechman, 2001; Lao & Liu, 2009)
	2. Passenger-km	Multiplication of the total passengers, daily trip number, and length (km) of a route	(Kerstens, 1996; Lao & Liu, 2009)

3.4. Conducting a survey

A field survey was carried out in April 2018 to collect the necessary data from the users, operators, and transport authorities to assess performance. To obtain information from the PT users, a semi-structured questionnaire was used. The interview questionnaire was developed based on the inventory discussed in the previous section. The sample size was determined using equation 1 below (Israel, 1992). The equation determined the minimum number of the respondents within a large population size required at a 95% confidence level with a normal distribution.

$$n = z^2pq/e^2 \quad (1)$$

where, n is the sample size; z is the z-value of given confidence level (for 95% confidence level it is 1.96); p is the estimated proportion of an attribute that is present in the population, and q is the (1-p) and e is the tolerance level (assumed 5% tolerance level).

About 3.3 million people live in CCC, of whom about half rely on PT (CDA, 2009). As the population size was large, and the variability (the proportion of middle-income people using non-motorized transport) was not known, it was assumed p = 0.5 (maximum variability), so q would be 0.5. The minimum size of the sample was estimated to be 384. A total of 10 routes were selected so the minimum number of required respondents was 38-40 for each route. After conducting 40 interviews, however, the number of respondents surveyed per route was increased to give a 'data saturation' point. The data saturation was achieved after completing 80 to 100 interviews per route. No new insights were gained after this due to repetition of information. A total of 1000 PT users were selected with approximately 100 users being interviewed in each of the 10 bus routes (Figure 1). A total of 10 survey groups (each group comprising 3-4 persons) carried out the survey, with each group assigned a specific bus route during the survey. Data was collected between 9:00 am and 6:00 pm on both weekdays and on weekends. The survey was conducted in Bengali, and each question was explained to the respondent in a non-technical manner, with each questionnaire being completed in approximately 15 minutes. Respondents also provided socio-demographic information such as age, gender, education, occupation and household income. Table 4 provides a summary of the sample population in relation to the overall population distribution within the CCC. Information obtained from the local bus service evaluation is expected to be slightly biased towards the low and lower middle-income segment of the population. Such income groups tend to use local bus services due to the lower cost when compared to other modes (car, autorickshaw, ride-hailing service, rickshaw). It should be noted that the sample population is also skewed in regards gender distribution, with a higher ratio of the male population sample. This is due to the patriarchal nature of Bangladesh society and the low number of females in the labor force (36.4%) in Chattogram (ADB, 2016). A summary of the user and operator input-output indicators is presented in Table 5.

Table 4 Characteristics of the sample population (n = 1000)

Variable	Category	Sample distribution (%)	Distribution[*] of population in CCC (%)
Age	<15	49.1	58
	30-45	39.7	22
	45-60	9.4	13.4
	≥60	1.8	6.6
Gender	Male	74.1	49.5
	Female	25.9	50.5
Education level	Elementary	15.8	N/A
	Secondary	17.9	
	Higher secondary	31.3	
	Graduate or higher	35	
Occupation	Business	26.5	N/A
	Service	35.3	
	Housewife	11.9	
	Student	19.8	
	Retired	3.8	
	Others	2.7	
Income (BDT) [***]	≤20K	21.8	50
	20-40K	59.0	40
	40-60K	18.9	
	≥60K	0.3	10

[*] WorldPop (www.worldpop.org) (Bondarenko, 2018), Census Data Bangladesh, 2011(BBS, 2011) [***] 1 BDT = 0.012 USD

Table 5 Summary of the input-output, extracted from the sample users (n=1000) and operators

Variable name	Unit	Mean	Std. Dev.	Relevant questions / source
Users' perspective (inputs)				
Fare	Taka/km	22.9	7.37	Field survey
Required time to reach the bus stops	Minute	11.26	5.83	Field survey
Waiting time at stops for buses	"	9.5	4.11	Field survey
Journey time	"	70.66	15.55	Field survey
Users' perspective (outputs)				
Reliability	Scaling by 1 to 5	2.04	0.566	▪ Punctuality of an operation ▪ Frequency ▪ Reliability to reach to a destination on time during peak hours ▪ Possibility of sudden breakdown of a bus
Comfort	"	1.83	0.533	▪ Adequacy of space inside a bus ▪ Comfort level in holding/keeping bags, luggage etc. in the bus ▪ Comfort level in accessing/egressing into bus with belongings ▪ Comfort level inside the bus during the summer ▪ Convenience level to read any book/newspaper in the bus at night
Cleanliness	"	1.93	0.607	▪ Cleanliness of the seats ▪ General cleanliness inside the bus ▪ Interior condition of the bus ▪ Exterior condition of the bus
Fare system	"	2.70	0.99	▪ Flexibility of existing ticket system ▪ Existing fare in compared to affordability

Safety and security	"	1.68	0.544	▪ Availability of necessary information (e.g., map of bus line, timetable, bus fare etc.) in the bus stops ▪ Availability of necessary information (e.g., map of bus line, timetable, bus fare etc.) inside the bus ▪ Availability and adequacy of transport information within the city
Information availability	"	2.65	0.83	▪ Safety level while on the bus ▪ Safety level while waiting for a bus ▪ Safety level while accessing/egressing a bus ▪ Security level against crime (e.g., stealing, hijacking etc.) while on the bus ▪ Security level against crime (stealing, hijacking etc.) at the stoppage
Gesture and behavior of staffs	"	2.01	0.63	▪ Behavior and attitude of the bus driver ▪ Behavior and attitude of the staffs ▪ Assistance level of the bus staffs ▪ Satisfaction level with bus staffs' uniform
Customer service system	"	1.55	0.417	▪ Availability of ticket counter at the stoppage ▪ Satisfaction level with existing ticket purchasing system ▪ Response level of bus authority to complains filed by users
Operators' perspective (input)				
No. of Stops	In number	15		CMP (TD)
Daily service time	Hour	17.8		CMPMG
Service frequency (per hour)	In number	6		CMPMG
Number of staff	In number	131		CMPMG

Operating cost	Taka/One-way Trip	750	Provided by the bus driver and staffs
Operators' perspective (output)			
Ridership	In number/per day	3430	Provided by the bus driver and staffs appointed by the owner
Passenger-km	Kilometer	55700	Estimated by multiplying ridership per trip, daily trip number, and route length of the corresponding route

3.1.1. Input and output related information from the users' perspectives

Due to a lack of availability of any official data, the following adjustment was made when gathering input and output related information from the user:

i) Fare: Local bus operators tend to use a fare scale that is different from the government-defined fare. The bus staff manually collect the fare from individuals. Passengers were asked about the amount that they pay for each trip. They were also asked about their origin and destination. This was used to estimate the fare paid per kilometer.

ii) Time to reach the bus stops: To protect the privacy of the users, information of their exact origin and destination was not collected. Users also have different modes to reach the bus stop. To avoid the complexity associated with these multiple access modes, the time required to reach the bus stop is determined from the stated travel time instead of the geographically measured travel time. Users only provided information about the trips that they were making during the interview (every interview was done onboard). The collected information had less error for recall bias using this method.

iii) Bus stop waiting time and journey time: Since local bus services were manually operated, the frequency of the service does not follow a similar pattern during the day. Information on the waiting time of a trip was therefore collected at the bus stops from the users when they were making. Bus drivers allow passengers to get in or out of the bus at locations other than designated bus stops, and can wait for longer than the designated time to accumulate more passengers onboard. Buses tend to be old and have no provision for GPS facilities. Due to this factor, accurate calculation of travel time between the different bus stops was not possible. To overcome this issue, the onboard survey team recorded the travel time using a stopwatch, while the users reported their access and egress bus stop information.

iv) Qualitative information: For each question related to the quality of local bus services, the respondents provided a score on a 1 to 5 Likert-like scale. Multiple questions were asked to define each parameter such as reliability, comfort, cleanliness, fare system, safety and security, information availability, gesture and behavior of staff, and customer service system. A single response can be unreliable and misleading, or placing a check in the wrong place may result in an incorrect response. On the contrary, many items may have little impact on the overall score of discrete indicators (Ajzen, 2005). To evaluate how closely related the questions were as a group, a reliability check was performed using Cronbach's alpha score (Field, 2013).

3.1.2. Input and output related information from operators' perspectives

A telephone survey was used to obtain information from the operators with the bus drivers being interviewed at night after the end of their shift. The bus drivers answered questions related to the operation of the services. Information was also collected from the bus owners and staff. The different methods to collect the input and output variables are documented below:

i) Daily service time (hour): To calculate daily service time in each route, information was collected from the bus owners (e.g., CMPMG) and crosschecked against information provided by the transport authority (e.g., BRTA). This approach was followed because the service time of each driver/staff member could vary depending on their working hours.

ii) Service frequency (per hour): The service frequency was calculated using information from the staff responsible for monitoring the number of passengers traveling on the bus and from the number of buses passing each checkpoint. The bus owners appointed staff to record the operations for each day.

iii) Operating cost (per trip in BDT): Data related to operating cost (per trip) were also collected from the driver during the telephone interview. As the wages of the drivers and staff (those working with the drivers) is determined by the number of trips made within a day, drivers could provide information per trip regarding both wage and fuel costs. People not directly involved in operating the bus service were not considered as their salary does not vary depending on the number of trips made within a day. The following equation was used to calculate operating costs. This does not include fixed costs (insurance, road tax, registration fee, permit charge, etc.) as they do not vary within these short time periods.

Operating cost = Fuel cost (in BDT) per trip + wage of driver and staff (in BDT) per trip + maintenance cost (in BDT) per trip (2)

iv) Daily ridership (number of passengers in a day): Drivers were asked about the total number of passengers traveling on each trip, both during peak and off-peak times. Information about the total number of trips made on the day of the survey was collected from the staff involved in cross-checking the number of passengers travelling on each bus.

Daily ridership = Average number of trips made in a day * Average number of passengers traveled with each bus (3)

v) Secondary data: The number of bus stops and staff working on each bus route was collected from the Chattogram Metropolitan Police (traffic department) and bus owner organization (CMPMG). Since different bus routes were operated by different companies, one staff/driver work on multiple routes was not possible in this case.

3.1.3. Information from transport authorities

Transport authorities involved in operation and management of local bus service were asked to evaluate the routes in respect to accident rates and maintaining traffic rules and regulations.

3.5. Performance assessment of local bus service

This study employed the Data Envelopment Analysis (DEA) to evaluate the performance of local bus service in CCC using both qualitative and quantitative parameters. The DEA model includes linear programming to create an empirical production function to maximize outputs or minimize inputs. The efficiency score of each decision-making unit (DMU) is calculated by comparing its production function with the estimated production function. Thus, the performance of a DMU is assessed by directly comparing inputs and outputs with the "best practice" of a peer or a combination of peers (Cooper, Seiford, & Zhu, 2011).

In this study, we classified the stakeholders into three groups — local bus operator (CMPMG, bus owner and local partner), customers (local bus users and community people), and transport authority (CMP, CDA, CCC, and BRTA). The DEA method was employed to evaluate the performance of the local bus service from the point of view of the customer and the bus operators. In general transport users tend to maximize the outputs (service quality) related to comfort, cleanliness, safety, and security. The operators were generally satisfied with the initial investment and costs. Their aim was to maximize the outputs (essentially rides).

The following assumptions were used during model development:

1) Bus-lines are isolated individual entities that have a similar type of inputs and outputs and have the same type of activities;

2) All types of service vehicles use the same amount of fuel per unit distance;

Performance was assessed from the perspective of the transport authority, using a general scoring method for each route.

This study considered each bus route as a DMU. There are two types of DEA models possible: input-oriented and output-oriented. This study applied a radial output-oriented approach. The DEA scores were calculated using the following equations (Lao & Liu, 2009):

$$
\begin{aligned}
& Max\ \mu \\
\text{Subject to} \quad & x_{i0} \geq \sum_{j=1}^{n} x_{ij}\,\lambda_j \qquad i = 1,2,\ldots,m \\
& y_{r0}\,\mu \leq \sum_{j=1}^{n} y_{rj}\,\lambda_j \qquad r = 1,2,\ldots,s \\
& \sum_{j=1}^{n} \lambda_j = 1 \\
& \lambda_j \geq 0 \qquad j = 1,2,\ldots,n
\end{aligned}
\tag{4}
$$

where, j is the index of decision-making units, i is the index of input, r is the index of output, x_{ij} is the i^{th} input for DMU$_j$, y_{rj} is the r^{th} output for DMU$_j$, λ_j is the nonnegative scalars (weight) for DMUj, and μ is the optimal output level.

For model 3, there might be both input and output slacks[3]. After calculating model (3) we have:

$$
\begin{aligned}
S_i^- &= \theta^* x_{i0} - \sum\nolimits_{j=1}^{n} \lambda_j x_{ij} \qquad i = 1,2,3\ldots,m \\
S_r^+ &= \sum\nolimits_{j=1}^{n} \lambda_j\, y_{rj} - y_{r0} \qquad r = 1,2,3\ldots,s
\end{aligned}
\tag{5}
$$

[3] Slacks represent potential reduction in the input (for input-oriented DEA) or increase in the output (for output-oriented DEA) variables for the weakly efficient or inefficient DMU units in the data set when compared with the ultimate benchmark targets.

where, S_i^- and S_r^+ represents input and output slacks, respectively. Therefore, we use following linear programming model to determine possible non-zero slacks after solving model 3.

$$max \sum_{i=1}^{m} S_i^- + \sum_{r=1}^{s} S_r^+$$

$$\sum_{j=1}^{n} \lambda_j x_{ij} + S_i^- = \theta^* x_{i0} \qquad i = 1,2,3 \ldots, m$$

$$\sum_{j=1}^{n} \lambda_j y_{ij} + S_r^+ = \theta^* y_{i0} \qquad r = 1,2,3 \ldots, s \qquad (6)$$

$$\sum_{j=1}^{n} \lambda_j = 1$$

$$\lambda_j \geq 0 \qquad j = 1,2,3 \ldots, n$$

4. Results

4.1. Performance of local bus service

4.1.1. Performance assessment by users

Table 6 provides a summary of the results. It presents the relative efficiency scores and the ranks of different bus routes from the perspective of the user and the operator, as well as a rank of each route from the perspective of the transport authority. The relative efficiency score lies between 0 and 1, where 0 and 1 indicate the respective inefficient and efficient DMU (bus routes) among all the DMUs considered. Of the ten bus routes used in this study, four (routes 02, 03, 06, 08) were relatively efficient ($1/\mu$=1.0) from the users' perspective and were ranked as 1.

Figure 3 provides further insights into the performance of the local bus service according to the user, and presents the relative efficiency scores of single input and output for the different bus routes. Most of the routes were found to be efficient in regards fares (as the input). Route 02 was efficient in all four input areas: fare, access time, journey time, and waiting time. The users provided relatively higher scores for most of the outputs for this route such as cleanliness, customer service, information, reliability, comfort, personal appearance. Route 08 was efficient for fare, journey time, and waiting time, while route 03 yielded a higher efficiency score for fare and access time. The relative efficiency scores of routes 04 and 07 were the lowest. Although four of the ten routes obtained higher efficiency scores according to the user, their performance was not equivalent for all input-output pairs.

Table 6 DEA scores ($1/\mu$) of routes from different perspectives

Route	Users' perspective	Ranking from users' perspective	Operators' perspective	Ranking from the operators' perspective	Ranking of routes by TA
Route 01	0.858	3rd	0.956	2nd	7
Route 02	1	1st	1	1st	8

Route 03	1	1st	0.567	3rd	4
Route 04	0.847	3rd	0.8	3rd	1
Route 05	0.919	2nd	0.744	3rd	9
Route 06	1	1st	1	1st	2
Route 07	0.847	3rd	1	1st	5
Route 08	1	1st	0.976	2nd	10
Route 10	0.849	3rd	1	1st	3
Route 11	0.931	2nd	0.879	3rd	6

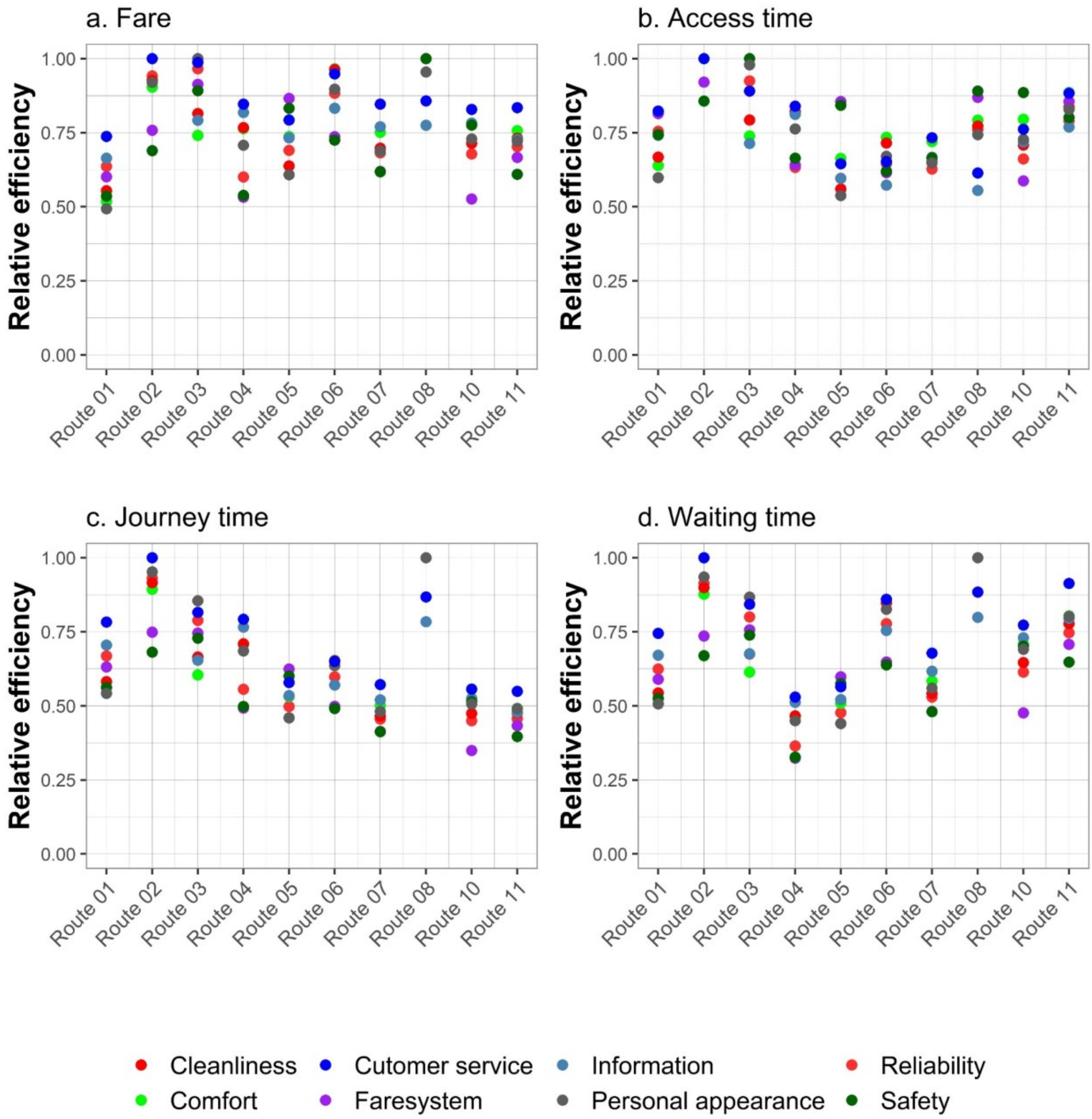

Figure 3 Individual input and output wise efficiency score of the routes (users' perspective)

4.1.2. Performance assessment by operators

Bus routes 02, 06, 07, and 10 were the most efficient (ranked as 1) according to the operator, while route 03 was the least efficient (Table 6). Route 03 is approximately 11 km in length and has a relatively low operating cost. However, the number of staff working during the service time was high compared to the number of daily ridership and the passenger-km of other routes. Due to this, the route was least efficient in all five aspects of inputs (Figure 4). On the other hand, routes 02, 06, 07, and 10 were characterized by a larger number of bus stops, leading to longer service times of buses that provide service to a larger group (i.e., higher ridership and passenger-km). Hence, these routes received higher efficiency scores from the operators.

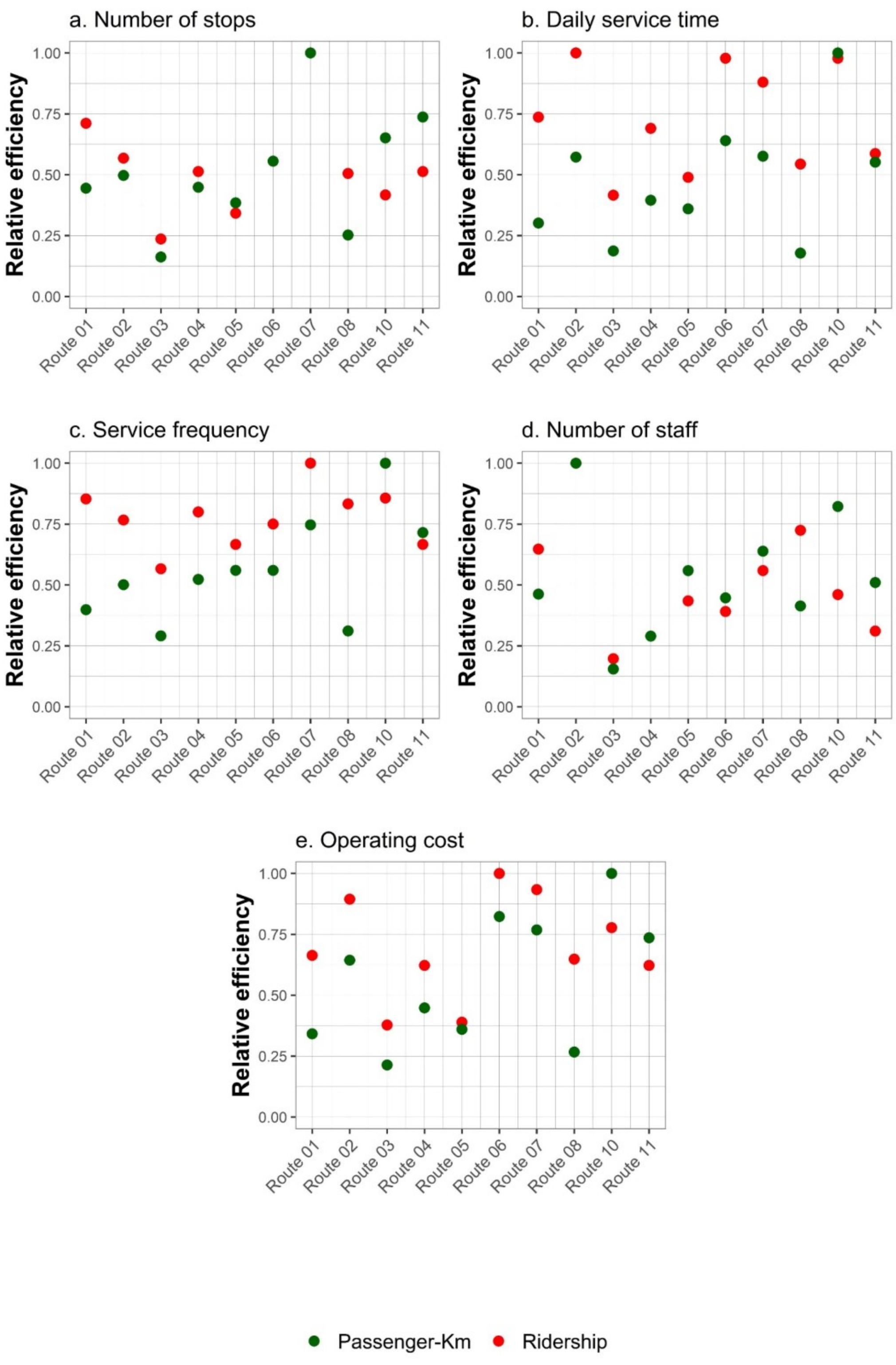

Figure 4 Individual input- and output-wise efficiency score of the routes (Operators' perspective)

4.1.3. Performance assessment by PT authority

The PT authority ranked the 0 bus routes based on the application of existing traffic rules and regulations, and accident rates. Compared to the ranking of the users and operators, the PT authority selected route 04 as the best due to its low accident rate, the regularity of license upgrades, and tax clearance. Route 08 was regarded as the least efficient in terms of traffic rules and regulations.

4.2. Performance evaluation of the DEA model

The performance of the DEA model was assessed by estimating slacks. Slacks were measured from both a user and operator perspective. Bus routes with an efficiency score (μ) 1 without slack was considered efficient, while routes having an efficiency score of 1 with slacks was weakly efficient. The routes with an efficiency score >1 (with or without slack) are inefficient.

Table 7 exhibits that route 02, route 03, route 06, and route 08 were estimated to be efficient (slack is zero) from the users' perspective (i.e., there is no weakly efficient DMU). Similarly, route 02, route 06, route 07, and route 10 were efficient from the operators' perspective (Table 8). It was noted that route 02 and route 06 were on the efficiency frontier line both from the users' and operators' perspectives. On the other hand, routes that had an efficiency score >1 and slack status "True" were inefficient. These inefficient routes had slacks in both inputs and outputs. Tables 7-8 also show non-zero optimal λ_j which is the benchmark for a specific inefficient DMU under evaluation.

The output-oriented model reveals that to improve the efficiency of route 01, route 04, route 05, route 07, route 10, and route 11, operators must improve the service quality to increase user satisfaction. For example, operators of route 01 need to improve the service quality for additional slack variables S_{y1}=0.27, S_{y2}=0.39, Sy_3=0.39, S_{y5} =0.08, S_{y6} =0.15, S_{y7} =0.84 to increase the users' satisfaction relevant to the reliability, comfort, cleanliness, information system, safety and security, and appearance of staff. Service quality of route 02 or route 03 can be considered as a benchmark. Likewise, route 01 needs to increase passenger-km for an additional slack variable $\mathbf{S_{y2}}$ =17440 from the operators' perspective. On the other hand, for route 11, the operator needs to increase ridership for an additional slack variable S_{y1}=860 passengers/day.

Table 7 Efficiency score of the routes with slack (users' perspective)

Route	μ	Slack status	Fare	Access time	Waiting time	Journey time	Reliability S_{y1}	Comfort S_{y2}	Cleanliness S_{y3}	Fare S_{y4}	Info. system S_{y5}	Safety and security S_{y6}	Personal appearance S_{y7}	Customer service S_{y8}	λ_2	λ_3	λ_6	λ_8
Route 01	1.17	TRUE	0.27	0	0.82	1.15	0.27	0.39	0.39	0	0.08	0.15	0.84	0	0.75	0.41	0	0
Route 02	1	FALSE	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Route 03	1	FALSE	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Route 04	1.18	TRUE	0	0.08	4.87	3.82	0.60	0.003	0.05	0.47	0.07	0.19	0.22	0	1	0	0	0
Route 05	1.09	TRUE	0	0	2.59	14.47	0.57	0.14	0.49	0	0	0.08	0.78	0.12	0.06	0.49	0	0.42
Route 06	1	FALSE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Route 07	1.18	TRUE	0	1.27	1.83	25.11	0.37	0	0.23	0.21	0.12	0	0.32	0	0.83	0.15	0	0.02
Route 08	1	FALSE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Route 10	1.05	TRUE	0.01	0	0	21.16	0.58	0	0.28	1.06	0.08	0	0.46	0.16	0.37	0.49	0	0.11
Route 11	1.07	TRUE	0.14	0	0	33.22	0.27	0.02	0.14	0	0.21	0.02	0.17	0	0.77	0.05	0	0.07

Table 8 Efficiency scores of routes with slack (operators' perspective)

Route	μ	Slack status	No. of Stops	Daily service time	Service frequency	No. of staffs	Operating cost	Ridership S_{y1}	Pass-km S_{y2}	λ_2	λ_6	λ_7	λ_9
Route 01	1.05	TRUE	0.33	2.83	0	0	182.5	0	17440	0.29	0	0.45	0
Route 02	1	FALSE	0	0	0	0	0	0	0	1	0	0	0
Route 03	1.76	TRUE	9.33	2.67	0	56.67	200	0	15000	0	0	0.67	0

Route 04	1.25	TRUE	4.67	0.33	0	63.33	125	0	7500	0	0	0.83	0
Route 05	1.34	TRUE	3.69	4.71	0	0	322.96	0	0	0.14	0	0.29	0.16
Route 06	1	FALSE	0	0	0	0	0	0	0	0	1	0	0
Route 07	1	FALSE	0	0	0	0	0	0	0	0	0	1	0
Route 08	1.03	TRUE	2.88	7.38	0	0	162.5	0	17625	0.31	0	0.25	0
Route 10	1	FALSE	0	0	0	0	0	0	0	0	0	0	1
Route 11	1.14s	TRUE	0	1.5	0.05	27.5	0	860.87	0	0	0	0.7	0.25

5. Discussion

5.1. Stakeholders and their roles in the PT performance assessment

One of the main objectives of this study was to identify the major stakeholders involved in providing local bus services in the CCC area and to understand their specific roles and responsibilities. This was to determine who would be involved in the process of performance assessment. Results revealed that several stakeholders are associated with the operation of local bus service in CCC (Table 1). The study identified that the complex nature of stakeholder involvement, and a general lack of coordination and accountability among the differing players, limited any possibility of improvement in the quality of service provided by the local bus service. Al-Qadery and Muhibbullah (2008) also demonstrated these issues in regards a lack of coordination and integration of the different institutions. This also resulted in a deterioration in service quality. As a result, traffic congestion in many areas increased significantly, a factor which was also observed in the CCC.

5.2. Factors influencing efficiency of different bus routes

Transport planners, local governments, and transport operators in many cities have recognized the PT performance assessment as an effective tool for planning, management, monitoring and evaluation of this form of transport (Litman, 2008). The results seen in this study indicate that even with ongoing data limitations the use of proper guidelines can allow a PT performance assessment to be successfully undertaken in developing countries with the outcomes used to improve general service quality. The DEA modeling indicated that significant differences existed among the various stakeholders. These findings are in line with the original hypotheses. For example, routes 02, 03, 06, and 08 were efficient from the users' perspective, with an average bus stop wait time of less than 10 minutes. The average travel time to reach the final destination (55 to 65 minutes) was also generally less than other routes. A similar association of efficiency score with travel time and waiting time was reported in other studies (Lee, Lee, Kho, & Kim, 2019; Sun, Chen, Zhang, & Shen, 2016). However, input parameters such as fare per kilometer and average time to reach a bus stop from home indicated a lower influence on the efficiency score. Most of the bus stops were located within 400 m or 15 minutes walking distance. However, the estimated slack values (Table 7) indicated that, from the users' point of view, poor reliability, cleanliness, safety and security and lack of comfort on some of the routes were issues which resulted in a lower efficiency score. Several studies have highlighted that improvements in these services can improve the efficiency of the PT service (Eboli & Mazzulla, 2009; Joewono & Kubota, 2007; Lai & Chen, 2011). From an operator's perspective, routes with a smaller number of stops, a low service time, staff, and higher daily ridership and passenger-km were more efficient. Routes 02, 06, 07, and 10 were found to be in this category. In contrast, routes 03 and 08 were more efficient from a user point of view than from an operator point of view. These routes received a high score from users for reliability, comfort, fare system, safety and security, gesture and behavior, access time, waiting time, time spent on buses, and egress time, while the operators provided low scores for ridership and passenger-km. Several studies have also demonstrated that bus route operating costs are associated with operation time, passenger-km, and the number of bus stops (Eboli & Mazzulla, 2007; Lao & Liu, 2009). Routes 02 and 06 were quite efficient according to both the users and operators. In contrast to users and operators, the PT authority mainly considered the existing state of applicable traffic rules and regulations when evaluating the performance of the different bus routes.

5.3. Measures to improve bus route efficiency

The differences in efficiency scores indicated variations in the quality of service, technical efficiency, and the level of traffic law maintenance across the bus routes examined. It is likely that reducing the relative differences in efficiency scores could help improve the performance of the local bus service. The modeling has provided details on these major deficiencies. Poor satisfaction levels felt by users in respect to current service conditions indicated a general need for other stakeholders to listen to their thoughts and incorporate these into any rectification measures. The survey has highlighted the major areas of dissatisfaction where improvements are most needed. Islam, Hasan, Das, and Rahman (2018) have also stated the necessity of incorporating the needs and expectations of service users into PT service improvement procedures. For example, the low satisfaction of users in regards comfort, information systems and customer service conditions have reinforced the need to improve conditions inside the buses, stoppage intervals and ticket counters. Previous PT policies also overlooked the minimum standards that a bus operator should follow in order to provide acceptable services within the CCC area. Efforts to reduce waiting times at bus stops, as well as reductions in the average travel time, would make this mode of transport more acceptable to users. Although cities of many developing countries heavily rely on government subsidies for PT services, it does not necessarily ensure improved management and operation of the service due to a weak association between the subsidies provided and the actual fare structure (Iles, 2005; Verma & Ramanayya, 2019).

From the operators' perspective, having higher ridership and passenger-km would not translate into higher efficiency rates. It is important to provide demand-driven route planning to ensure adequate stoppage intervals and dedicated service frequency. The poor performance score from the transport authorities indicated issues with the attitudes of the various operators towards current transport rules and regulation, and the dissatisfaction of the authorities with the current operation of these bus services.

6. Conclusion

This study aimed to develop a comprehensive framework to assess the performance of different bus routes from the perspective of users, operators, and the local authorities. It also aimed to address the data limitation issues which are common in developing countries. The DEA method was employed to calculate the relative efficiency of 10 bus routes in the CCC area of Bangladesh. The modeling results indicated perceived differences in the performance of local bus routes according to the particular viewpoint of the specific stakeholder. Data collection is resource-intensive, however the measures outlined could replicate the framework necessary to allow successful evaluation of the PT, both in the short and the long term. For instance, transport authorities could store information related to the business (such as fuel cost, the wages of staff, daily service timings, service frequency and total ridership) which individual bus owners regularly collect to enable accurate monitoring of business profitability. Such information is essential for useful PT evaluation activities. The transport authority (e.g., BRTA) will be able to utilize this compiled information for use in renewing of transit operator contracts. The most labor-intensive task in implementing the proposed inventory is the collection of user satisfaction information. Alternative methods such as the use of mobile technology would help collect data quickly and also reduce associated costs. In Bangladesh, mobile and smartphones are being used by 83% and 43% of the total population, respectively. A recent study revealed that almost 80% of slum dwellers have personal mobile phones, while 30% have internet facilities and access to social networks such as Facebook (Huq, Holvoet, & Huq, 2020). In this case it is unlikely that the collection of user opinions using mobile phone technology will be skewed to certain income groups. Consideration of the opinion of users (customer satisfaction criteria) in the performance assessment could assist in improving the service to the satisfaction of the users. The inclusion of transport operators in the performance evaluation process will also permit the suppliers to be proactive in fulfilling the demands of the customers. This will also likely reduce uncontrolled competition between the many poorly performing transit operators.

Although this study has presented a comprehensive approach to assessing the performance of local bus services, a few limitations must be noted. First, the performance of local bus services may vary within a route. This study only estimated an overall efficiency score for each route. Second, users provided only approximate data for some of the input variables. This included such things as the time needed to arrive at the bus stop from home, the time needed to reach the destination from bus stops, and the waiting time for the bus. Third, temporal variations in the performance of different bus routes were not considered. Fourth, a very basic measurement method (CCR) has been used which can be further improved by using an advanced DEA model such as super-efficiency network data envelopment analysis (SE-NDEA). Future research can utilize the proposed framework and also incorporate other urban factors such as land use mix and density of population, along with other environmental factors such as pollution figures and number of recorded accidents. This approach would enable a more detailed inspection and comparison of performance differences between differing bus routes. The inventory can also be used for assessing the performance of inter-city PT services. In those circumstances stakeholder identification and classification may differ, and focus group discussions will be needed to adjust all indicators for inter-city level assessments where necessary. The proposed inventory and framework would be useful in other developing countries where access to detailed and accurate data is limited. Policymakers and urban planners can use the results of this work when sequencing and prioritizing different routes. Use of this process will provide an improved service experience.

7. References

ADB. (2016). *ADB BRIEFS - Women at Work*. Retrieved from www.adb.org/publications/bangladesh-women-at-work

Adler, N., & Berechman, J. (2001). Measuring airport quality from the airlines' viewpoint: an application of data envelopment analysis. *Transport policy, 8*(3), 171-181.

Ajzen, I. (2005). Attitudes, personality and behavior. McGraw-Hill Education, Bershire, UK.

Al-Qadery, S. M., & Muhibbullah, M. (2008). People's perception on urban traffic congestion; a case study on Chittagong Metropolitan City, Bangladesh. *Chittagong University Journal of Biological Sciences*, 149-160.

Alçura, G. A., Kuşakcı, S. Ş., Şimşek, G. G., Gürsoy, M., & Tanrıverdi, S. C. (2016). Impact Score Technique for Analyzing the Service Quality of a High-Speed Rail System. *Transportation research record, 2541*(1), 64-72.

Ali, A. I., & Lerme, C. S. (1997). Comparative advantage and disadvantage in DEA. *Annals of Operations Research, 73*, 215-232.

Ali, Z. M., Ismail, M., Suradi, N. R. M., & Ismail, A. S. (2009). *Importance-performance analysis and customer satisfaction index for express bus services.* Paper presented at the 2009 World Congress on Nature & Biologically Inspired Computing (NaBIC).

Alizadeh, S., & Safi, M. (2020). A new model for efficiency evaluation of a bus fleet by window analysis in DEA and data mining. *Transportation Planning and Technology, 43*(1), 62-77.

Badami, M. G., & Haider, M. (2007). An analysis of public bus transit performance in Indian cities. *Transportation Research Part A: Policy and Practice, 41*(10), 961-981.

Barabino, B., Deiana, E., & Tilocca, P. (2012). Measuring service quality in urban bus transport: a modified SERVQUAL approach. *International Journal of Quality and Service Sciences*.

BBS. (2011). *Districts statistics 2011: Chittagong district*. Retrieved from

BBS. (2016). *Preliminary Report on Household Income and Expenditure Survey 2016*. Retrieved from

Benjamin, J., & Obeng, K. (1990). The effect of policy and background variables on total factor productivity for public transit. *Transportation Research Part B: Methodological, 24*(1), 1-14.

Bertini, R. L., & El-Geneidy, A. (2003). Using archived data to generate transit performance measures. *Transportation research record, 1841*, 109-119.

Bondarenko, M. (2018). Global 1km Population.

Boujelbene, Y., & Derbel, A. (2015). The performance analysis of public transport operators in Tunisia using AHP method. *Procedia Computer Science, 73*, 498-508.

Cao, J., & Cao, X. (2017). Comparing importance-performance analysis and three-factor theory in assessing rider satisfaction with transit. *Journal of Transport and Land Use, 10*(1), 837-854.

Carter, D. N., & LoMAx, T. J. (1992). Development and application of performance measures for rural public transportation operators. *Transportation research record, 1338*, 28-36.

CDA. (2009). *Preparation of Detailed Area Plan (DAP) for Chittagong Metropolitan Master Plan (CMMP)*. Retrieved from Chittagong:

Charnes, A., Cooper, W. W., & Rhodes, E. (1978). Measuring the efficiency of decision making units. *European Journal of Operational Research, 2*(6), 429-444.

Cooper, W. W., Seiford, L. M., & Zhu, J. (2011). *Handbook on data envelopment analysis* (Vol. 164): Springer Science & Business Media.

Dhingra, C. (2011). Measuring public transport performance: Lessons for developing cities. *Sustainable Urban Transport Technical Document, 9*(11).

Eboli, L., & Mazzulla, G. (2007). Service quality attributes affecting customer satisfaction for bus transit. *Journal of Public Transportation, 10*(3), 2.

Eboli, L., & Mazzulla, G. (2008). Willingness-to-pay of public transport users for improvement in service quality.

Eboli, L., & Mazzulla, G. (2009). A new customer satisfaction index for evaluating transit service quality. *Journal of Public Transportation, 12*(3), 2.

Echaniz, E., Ho, C. Q., Rodriguez, A., & dell'Olio, L. (2019). Comparing best-worst and ordered logit approaches for user satisfaction in transit services. *Transportation Research Part A: Policy and Practice, 130*, 752-769.

Enam, A., & Choudhury, C. F. (2011). Methodological issues in developing mode choice models for Dhaka, Bangladesh. *Transportation research record, 2239*(1), 84-92.

Farrel, J. (1957). The measurement of Productive efficiency. Journal of the Royal Statistical Society. Series A, General 125. *Part*(2), 252.

Field, A. (2013). *Discovering statistics using IBM SPSS statistics*: sage.

Fielding, G. J., Glauthier, R. E., & Lave, C. A. (1978). Performance indicators for transit management. *Transportation, 7*(4), 365-379.

Güner, S., & Coşkun, E. (2016). Determining the best performing benchmarks for transit routes with a multi-objective model: the implementation and a critique of the two-model approach. *Public Transport, 8*(2), 205-224.

Hassan, M. N., Hawas, Y. E., & Ahmed, K. (2013). A multi-dimensional framework for evaluating the transit service performance. *Transportation Research Part A: Policy and Practice, 50*, 47-61.

Hawas, Y. E., Khan, M., & Basu, N. (2012). Evaluating and enhancing the operational performance of public bus systems using GIS-based data envelopment analysis. *Journal of Public Transportation, 15*(2), 2.

Hirschhorn, F., Veeneman, W., & van de Velde, D. (2018). Inventory and rating of performance indicators and organisational features in metropolitan public transport: A worldwide Delphi survey. *Research in Transportation Economics, 69*, 144-156.

Huang, W., Shuai, B., Sun, Y., Wang, Y., & Antwi, E. (2018). Using entropy-TOPSIS method to evaluate urban rail transit system operation performance: The China case. *Transportation Research Part A: Policy and Practice, 111*, 292-303.

Huq, F. F., Holvoet, N., & Huq, M. (2020). Application of mobile technology in monitoring and evaluation of household water security for Dhaka city. *Technology in Society, 62*, 101308.

Huque, A. S. (2020). Infrastructure, Political Conflict, and Stakeholder Interests: The Case of a Public–Private Partnership in Bangladesh. *Public Works Management & Policy*, 1087724X19895281.

Husain, N., Abdullah, M., & Kuman, S. (2000). Evaluating public sector efficiency with data envelopment analysis (DEA): a case study in Road Transport Department, Selangor, Malaysia. *Total Quality Management, 11*(4-6), 830-836.

Iles, R. (2005). *Public transport in developing countries* (Vol. 478): Elsevier Amsterdam.

Islam, M. A., Hasan, M. M., Das, P., & Rahman, F. (2018). *ASSESSING BUS SERVICE QUALITY BASED ON PUBLIC PERCEPTION: A CASE STUDY IN CHITTAGONG CITY.* Paper presented at the Proceedings of the 4th International Conference on Civil Engineering for Sustainable Development
(ICCESD 2018), Khulna University of Engineering and Technology, Khulna, Bangladesh.

Israel, G. (1992). Determining Sample Size (PEOD6). Agricultural Education and Communication Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. *Gainesville, FL: University of Florida*.

Jasti, P. C., & Ram, V. V. (2018). Integrated performance assessment and service level benchmarking of urban bus system using fuzzy logic. *European Transport\Trasporti Europei*(69).

Joewono, T. B., & Kubota, H. (2007). User satisfaction with paratransit in competition with motorization in indonesia: anticipation of future implications. *Transportation, 34*(3), 337-354.

Karlaftis, M. G., & Tsamboulas, D. (2012). Efficiency measurement in public transport: are findings specification sensitive? *Transportation Research Part A: Policy and Practice, 46*(2), 392-402.

Kathuria, A., Parida, M., & Sekhar, C. R. (2017). Comparative evaluation of bus rapid transit routes using super efficiency data envelopment analysis. *Current Science, 113*(7), 1408.

Kerstens, K. (1996). Technical efficiency measurement and explanation of French urban transit companies. *Transportation Research Part A: Policy and Practice, 30*(6), 431-452.

Khasnabis, S., Alsaidi, E., Liu, L., & Ellis, R. D. (2002). Comparative study of two techniques of transit performance assessment: AHP and GAT. *Journal of Transportation Engineering, 128*(6), 499-508.

Lai, W.-T., & Chen, C.-F. (2011). Behavioral intentions of public transit passengers—The roles of service quality, perceived value, satisfaction and involvement. *Transport policy, 18*(2), 318-325.

Lao, Y., & Liu, L. (2009). Performance evaluation of bus lines with data envelopment analysis and geographic information systems. *Computers, environment and urban systems, 33*(4), 247-255.

Lee, E. H., Lee, H., Kho, S.-Y., & Kim, D.-K. (2019). Evaluation of transfer efficiency between bus and subway based on data envelopment analysis using smart card data. *KSCE Journal of Civil Engineering, 23*(2), 788-799.

Litman, T. (2008). Valuing transit service quality improvements. *Journal of Public Transportation, 11*(2), 3.

Malano, H., Burton, M., & Makin, I. (2004). Benchmarking performance in the irrigation and drainage sector: a tool for change. *Irrigation and Drainage: The journal of the International Commission on Irrigation and Drainage, 53*(2), 119-133.

Mia, M. A., Nasrin, S., Zhang, M., & Rasiah, R. (2015). Chittagong, Bangladesh. *Cities, 48*, 31-41.

Morris, M., Ison, S., & Enoch, M. (2005). The role of UK local authorities in promoting the bus. *Journal of Public Transportation, 8*(5), 2.

Nathanail, E. (2008). Measuring the quality of service for passengers on the Hellenic railways. *Transportation Research Part A: Policy and Practice, 42*(1), 48-66.

Pedroso, G., Bermann, C., & Sanches-Pereira, A. (2018). Combining the functional unit concept and the analytic hierarchy process method for performance assessment of public transport options. *Case Studies on Transport Policy, 6*(4), 722-736.

Phillips, J. K. (2004). An application of the balanced scorecard to public transit system performance assessment. *Transportation Journal*, 26-55.

Ryus, P., Connor, M., Corbett, S., Rodenstein, A., Wargelin, L., Ferreira, L., . . . Blume, K. (2003). A guidebook for developing a transit performance-measurement system (TCRP Report 88). *Transportation Research Board: Washington, DC, USA*.

Sam, E. F., Hamidu, O., & Daniels, S. (2018). SERVQUAL analysis of public bus transport services in Kumasi metropolis, Ghana: Core user perspectives. *Case Studies on Transport Policy, 6*(1), 25-31.

Seker, S., & Aydin, N. (2020). Sustainable Public Transportation System Evaluation: A Novel Two-Stage Hybrid Method Based on IVIF-AHP and CODAS. *International Journal of Fuzzy Systems, 22*(1), 257-272.

Shen, W., Xiao, W., & Wang, X. (2016). Passenger satisfaction evaluation model for Urban rail transit: A structural equation modeling based on partial least squares. *Transport Policy, 46*, 20-31.

Sheth, C. (2003). The Measurement and Evaluation of Performance of Urban Transit Systems: The Case of Bus Routes. *Blacksburg: Virginia Polytechnic Institute and State University*.

Sheth, C., Triantis, K., & Teodorović, D. (2007). Performance evaluation of bus routes: A provider and passenger perspective. *Transportation research part E: logistics and transportation review, 43*(4), 453-478.

Singh, P., Singh, A. K., Singh, P., Kumari, S., & Sangaiah, A. K. (2019). Multimodal data modeling for efficiency assessment of social priority based urban bus route transportation system using GIS and data envelopment analysis. *Multimedia Tools and Applications, 78*(17), 23897-23915.

Sohail, M., Maunder, D., & Miles, D. (2004). Managing public transport in developing countries: Stakeholder perspectives in Dar es Salaam and Faisalabad. *International Journal of Transport Management, 2*(3-4), 149-160.

Sun, D., Chen, S., Zhang, C., & Shen, S. (2016). A bus route evaluation model based on GIS and super-efficient data envelopment analysis. *Transportation Planning and Technology, 39*(4), 407-423.

Susniene, D., & Jurkauskas, A. (2008). Stakeholder approach in the management of public transport companies. *Transport, 23*(3), 214-220.

Swami, M., & Parida, M. (2015). Comparative appraisal of metro stations in Delhi using data envelopment analysis in a multimodal context. *Journal of Public Transportation, 18*(3), 3.

Taboada, G. L., & Han, L. (2020). Exploratory Data Analysis and Data Envelopment Analysis of Urban Rail Transit. *Electronics, 9*(8), 1270.

Tavassoli, A., Mesbah, M., & Shobeirinejad, A. (2018). Modelling passenger waiting time using large-scale automatic fare collection data: an Australian case study. *Transportation research part F: traffic psychology and behaviour, 58*, 500-510.

Tu, W., Cao, R., Yue, Y., Zhou, B., Li, Q., & Li, Q. (2018). Spatial variations in urban public ridership derived from GPS trajectories and smart card data. *Journal of transport geography, 69*, 45-57.

Tyrinopoulos, Y., & Antoniou, C. (2008). Public transit user satisfaction: Variability and policy implications. *Transport policy, 15*(4), 260-272.

Verma, A., & Ramanayya, T. (2019). *Public transport planning and management in developing countries*: CRC Press.

Wan, D., Kamga, C., Hao, W., Sugiura, A., & Beaton, E. B. (2016). Customer satisfaction with bus rapid transit: a study of New York City select bus service applying structural equation modeling. *Public Transport, 8*(3), 497-520.

WB. (2018). *Chittagong Strategic Urban Transport Master Plan*. Retrieved from

Wei, R., Liu, X., Mu, Y., Wang, L., Golub, A., & Farber, S. (2017). Evaluating public transit services for operational efficiency and access equity. *Journal of transport geography, 65*, 70-79.

Wu, H.-H., Shieh, J.-I., & Pan, W.-R. (2008). Applying importance-performance analysis to analyze service quality: a case of two coach companies. *Journal of Information and Optimization Sciences, 29*(6), 1203-1214.

Yao, D., Xu, L., & Li, J. (2019). Evaluating the performance of public transit systems: A case study of eleven cities in China. *Sustainability, 11*(13), 3555.

Yeh, C.-H., Deng, H., & Chang, Y.-H. (2000). Fuzzy multicriteria analysis for performance evaluation of bus companies. *European Journal of Operational Research, 126*(3), 459-473.

Zannat, K. E., Adnan, M. S. G., & Dewan, A. (2020). A GIS-based approach to evaluating environmental influences on active and public transport accessibility of university students. *Journal of Urban Management, 9*(3), 331-346.

Zannat, K. E., Ashraful Islam, K., Sunny, D. S., Moury, T., Tuli, R. D., Dewan, A., & Adnan, M. S. G. (2021). Nonmotorized Commuting Behavior of Middle-Income Working Adults in a Developing Country. *Journal of Urban Planning and Development, 147*(2), 05021011.

Zannat, K. E., & Choudhury, C. F. (2019). Emerging big data sources for public transport planning: A systematic review on current state of art and future research directions. *Journal of the Indian Institute of Science*, 1-19.

Zannat, K. E., Raja, D. R., & Adnan, M. S. G. (2019). Pedestrian facilities and perceived Pedestrian Level of Service (PLOS): A case study of Chittagong Metropolitan area, Bangladesh. *Transportation in developing economies, 5*(2), 9.

Zannat, K. E., Showkat, S., & Islam, M. R. (2014). A Methodology for Assessing the Performance of Structural Measures to Mitigate Traffic Congestion: A Case Study of Chittagong Port Flyover. *Journal of Bangladesh Institute of Planners ISSN, 7*, 1-10.

Zhang, C., Juan, Z., Luo, Q., & Xiao, G. (2016). Performance evaluation of public transit systems using a combined evaluation method. *Transport policy, 45*, 156-167.

Zhang, C., Juan, Z., & Xiao, G. (2015). Do contractual practices affect technical efficiency? Evidence from public transport operators in China. *Transportation Research Part E: Logistics and Transportation Review, 80*, 39-55.

Zhang, X., Zhang, Q., Sun, T., Zou, Y., & Chen, H. (2018). Evaluation of urban public transport priority performance based on the improved TOPSIS method: A case study of Wuhan. *Sustainable Cities and Society, 43*, 357-365.

Zhao, Y., Triantis, K., Murray-Tuite, P., & Edara, P. (2011). Performance measurement of a transportation network with a downtown space reservation system: A network-DEA approach. *Transportation Research Part E: Logistics and Transportation Review, 47*(6), 1140-1159.

Zhou, Y., Yao, L., Chen, Y., Gong, Y., & Lai, J. (2017). Bus arrival time calculation model based on smart card data. *Transportation Research Part C: Emerging Technologies, 74*, 81-96.

Zhu, Y., Koutsopoulos, H. N., & Wilson, N. H. (2017). Inferring left behind passengers in congested metro systems from automated data. *Transportation research procedia, 23*, 362-379.