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Assessment of Efficiency and Effectiveness of Bus Transport Organizations Using DEA Incorporating Emissions and Accidents

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Abstract

Environmental pollution due to vehicular emissions and accidents reflect upon the sustainability, and social responsibility of transport organizations. However, it is also necessary to attain higher levels of performance by ensuring higher transit ridership measured in terms of passengers carried per day. The present work is focused on the analysis of performance efficiency and service effectiveness of 25 selected State Road Transport Undertakings (SRTUs) in India for the year 2004-05, 2009-10 and 2014-15. Here, it was proposed to use a hybrid output-oriented Data Envelopment Analysis (DEA) approach developed by Seiford and Zhu in 2002 to handle undesirable outputs such as annual Carbon-di-oxide (CO_2) emitted per passenger-km, and total accidents per year in addition to overall productivity. The results of the analysis provided details on targets that could be achieved for the available input resources allocated. Transport organizations can adopt similar approaches in performance evaluation and benchmarking considering sustainability, and social responsibility along with efficiency.

Keywords: performance evaluation, Vehicular emission, sustainability, bus transport, Accidents.

1. Introduction

In view of the ever-increasing travel demand in Indian cities, transport managers are required to operate the existing transport services ensuring improved mobility by focusing on improved transit ridership while maintaining overall efficiency. The passenger transportation sector is one of the high-energy-consumption sectors in the world (Chang *et al.*, 2013; Zhou, Chung and Zhang, 2013). However, issues related to increased energy-consumption need to be addressed in addition to ensuring lower Carbon-di-oxide (CO_2) emissions. As part of ensuring sustainability in urban transport, it is also necessary to focus on reducing the number of accidents. This will improve the level of safety in bus transport organizations, resulting in increase in public transit ridership.

Public transport systems in India are largely owned by state-owned passenger bus companies called as State Road Transport Undertakings (SRTUs). The present work is related to the analysis of performance efficiency and service effectiveness of 25 selected

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SRTUs in India. This study focuses on the use of a hybrid output-oriented Data Envelopment Analysis (DEA) approach developed by Seiford and Zhu (2002) that can handle negative variable in addition to measures related to overall productivity including efficiency and effectiveness. In this study, the negative variable related to vehicular emissions was represented in terms of annual CO_2 emitted per passenger-km, while the negative variable related to accidents is provided in terms of total accidents per year. The present work indicated that although some of the SRTUs were found to perform better in terms of the sustainability and social responsibility criteria, a number of such SRTUs did not satisfy the overall productivity criteria. The results of the output-oriented model also provided details on targets that can be achieved for the available input resources allocated. The DEA based approach also possesses the advantage that it can perform a benchmarking of various efficiency and effectiveness indicators for bus transport organizations. The hybrid DEA approach described in this study can provide the basic framework for transport managers in the analysis of the influence of positive and negative variables to the transit system.

2. Literature Review

2.1 Studies on Performance-Benchmarking in Indian Bus Transport Systems.

A major part of the existing studies on the determination of efficiency-levels of publicly-owned bus transport operators in India is related to the use of the non-parametric CCR-based and BCC-based DEA approaches. Also, most of the studies focused on the use of non-parametric approaches to analyse the influence of physical and financial indicators related to cost-efficiency, cost-effectiveness, and service effectiveness as suggested by Fielding, Babitsky and Brenner (1985).

In the studies performed among 35 SRTUs in India by Agarwal, Yadav and Singh (2010), the input variables considered included the fleet-size, total staff employed, fuel consumed, and accidents per 100,000 km, while the output variables included fleet utilization, passenger-km, and load factor. Similarly, in investigations conducted among 25 SRTUs in India by Saxena and Saxena (2010), a similar set of input variables were considered, while the output variables considered included seat-km, and passenger-km. Also, in studies performed by Kumar (2011), the input variables considered included fleet-size of buses, total employees, and fuel and lubricants consumed, while the output variables included revenue per bus per day and annual passenger-km performed. The study also focused on the use of Tobit analysis for identifying factors that could influence the performance of SRTUs. Studies conducted by Mulangi *et al.* (2014) focused on employing the Principal Component Analysis (PCA) approach in the selection and identification of input and output variables as part of the DEA approach.

It was also observed that a number of parametric-based approaches were used in studies related to benchmarking of SRTUs in India. Parametric approaches such as the use of Stochastic Frontier Analysis (SFA) using trans-log cost function was demonstrated by sanjay kumar singh (2000), where passenger-km, cost of labour, and total route-length was used as variables. Exploratory statistical studies were made by Badami and Haider (2007) in the analysis of quality of service and extent of coverage based on fleet-size, fleet-utilization, and capacity-utilization. The study also examined financial and operational performance of SRTUs based on traffic revenue and operating costs, profit and loss, bus and labour productivity, and fuel economy. The ratio-analysis approach, and the applications of DEA were analysed by Hanumappa *et al.* (2016) as part of benchmarking performance of BMTC, Bangalore.

An overview of the above studies indicates that although a few studies have considered the need to include accident-rate as a variable in the evaluation of operational effectiveness, the influence of vehicular emission was not considered at all. However, in the present days, the need to ensure sustainability and social responsibility indicate that the influence of such negative variables too need to be considered in performance evaluation. One of the main reasons for the poor representation of such negative variables in the analyses is attributed to the lack of maintaining historical data related to such variables. In this study, it was proposed to incorporate the use of such negative variables in performance evaluation.

2.2 Studies on DEA Considering Vehicular Emissions and Accidents as Variables

Several studies have adopted the application of DEA approaches in performance evaluation of bus/transit management organizations. However, the influence of negative variables such as vehicle emission and accident rate on the performance of transit organizations are very limited.

Pina and Torres (2001), and Yu and Fan (2009), considered the influence of accident rates in the formulation of the DEA approach for performance evaluation of transit industries in Spain and Taiwan respectively. Similarly, Starr McMullen and Noh (2007), performed investigations on vehicular emissions in the analysis of efficiency of transit agencies. On the other hand, the influence of variables such as accident-reduction and accident rate were investigated by Lin and Lan (2009), and Chen *et al.* (2012) in the evaluation of operational efficiency and safety in studies performed in Taiwan. Shen *et al.* (2011) adopted the use of indices related to fatal accidents in the European Union in analyses using the DEA model.

Zhou, Chung and Zhang (2013) considered the use of CO_2 emissions in output-oriented DEA analyses related to 30 transport regions of China. Similar studies were performed by Song and Wang (2014) to evaluate compliance of transport organizations towards ensuring environmental efficiency in China. Hahn *et al.* (2013) performed studies on the use of input-oriented DEA in evaluating the environmental efficiency of bus rapid transit (BRT) routes in Seoul. Kang *et al.* (2020) performed studies on 12 companies of Taipei bus transit system using air pollution emissions as a negative variable in the development of a two-stage network DEA model with DDF where it was observed that CO_2 emissions played a significant role in performance evaluations.

The review of literature provided above indicates that some of the studies incorporated the use of vehicle emissions, while another set of studies considered the influence of accident rates of transport managements. However, it can be seen that not many investigations were performed on the use of both vehicle emissions, and accident rates together in the performance evaluation of public transport organizations. The present study proposed to incorporate the use of negative variables such as vehicular emissions represented in terms of annual Carbon-di-oxide emission per passenger kilometre (CO_2-PKM), and the total accidents per year in performance evaluation of transport organizations in India for different time periods. The study also provides a comparison of efficiency of transport organizations without considering the influence of negative variables as well.

3. Methodology

The following sections provide details on description of the data used in the present study, along with a methodology for the estimation of one of the undesirable/negative variables related to vehicle emissions measured in terms of CO_2 Emissions. The details on the formulation of the DEA incorporating undesirable/negative output variables as proposed by Seiford and Zhu (2002) is also provided along with the type of DEA models to be analyzed in the present study.

3.1 Description of Data Used in the Analysis

The data pertaining to physical and financial performance of SRTUs obtained from both Central Institute of Road Transport (CIRT), Pune and Transport Research wing of the Ministry of Road Transport & Highways (MoRTH) were used in this study. Data pertaining to different time periods such as, 2004-05, and 2009-10, in addition to the latest published data for 2014-15 for 25 selected SRTUs were analyzed so as to incorporate changes that have taken place in bus transport organizations over the years. The selection of SRTUs for analysis was performed considering the need to maintain consistency in data available, and the diversity in services offered to urban, rural, and hilly terrains of the country. Among the SRTUs selected for analysis in this study, 7 SRTUs provide services to urban areas, while 15 and 3 SRTUs respectively, cater to the needs of rural and hilly areas. Table 1 provides details on the same.

Table 1: Description of SRTUs Considered in The Present Study

Sl no.	*SRTUs*	*Service Category*	*Service Category*
1	AMTS	Urban Services	Ahmedabad Municipal Transport Service
2	BEST	Urban Services	Brihan Mumbai Electric Supply & Transport Undertaking
3	BMTC	Urban Services	Bengaluru Metropolitan Transport Corporation
4	CSTC	Urban Services	Chandigarh Transport Undertaking
5	CHNTU	Urban Services	Calcutta State Transport Corporation
6	DTC	Urban Services	Delhi Transport Corporation
7	STHAR	Rural & regional services	Meghalaya Transport Corporation
8	MSRTC	Rural & regional services	Maharashtra State Road Transport Corporation
9	MEGTC	Hilly region	Metropolitan Transport Corporation Limited (Chennai)
10	MTC (CNI)	Urban Services	Mizoram State Transport
11	MZST	Hilly region	Nagaland State Transport
12	NGST	Hilly region	North Bengal State Transport Corporation
13	NBSTC	Rural & regional services	State Transport Haryana
14	NEKnRTC	Rural & regional services	North Eastern Karnataka Road Transport Corporation
15	NWKnRTC	Rural & regional services	North Western Karnataka Road Transport Corporation
16	OSRTC	Rural & regional services	Odisha State Road Transport Corporation
17	STPJB	Rural & regional services	State Transport Punjab Roadways
18	RSRTC	Rural & regional services	Rajasthan State Road Transport Corporation
19	SETC (TN)	Rural & regional services	State Express Transport Corporation Limited (Tamil Nadu)
20	TNSTC (CBE)	Rural & regional services	Tamil Nadu State Transport Corporation Limited (Coimbatore)
21	TNSTC (KUM)	Rural & regional services	Tamil Nadu State Transport Corporation Limited (Kumbakonam)
22	TNSTC (MDU)	Rural & regional services	Tamil Nadu State Transport Corporation Limited (Madurai)
23	TNSTC (SLM)	Rural & regional services	Tamil Nadu State Transport Corporation Limited (Salem)
24	TNSTC (VPM)	Rural & regional services	Tamil Nadu State Transport Corporation Limited (Villupuram)
25	UPSRTC	Rural & regional services	Uttar Pradesh State Road Transport Corporation

Table 2 provides a statistical summary of the input and output variables considered in the present study, while Appendix A provides a glimpse of the details on the actual data compiled for various SRTUs for the year 2004-05, 2009-10, and 2014-15.

Table 2: A Statistical Summary of Input and Output Variables Considered in this Study

year	*Statistical measure*	*Total Cost ($TC \cdot 10^5$)*	*On-road fleet-size ($FS_{on\text{-}road}$)*	*Number of Employees (EMP)*	*Total Revenue ($TR \cdot 10^5$)*	*Passenger Kilometre Performed ($PKM \cdot 10^5$)*	*Effective Kilometre Performed ($EKM \cdot 10^5$)*
	Minimum:	860.1	28	379	127.6	14.3	12.93
	Median:	47441.9	2291	15910	41832.3	108193.7	2517.24
2004-05	Mean:	55153.6	2539	17522	49668.5	117820.1	3081.52
	Maximum:	339663.0	15229	102231	326345.0	514125.7	17976.31
	Std. dev.:	67727.36	3083.76	20549.11	64698.03	115712.81	3692.81
	Minimum:	970	32	344	197.1	156.3	9.22
	Median:	86741	2958	18038	72276.0	131253.4	3329.29
2009-10	Mean:	87966	2902	18401	71742.2	146499.4	3649.93
	Maximum:	420642	15039	101138	434164.0	533655.0	18473.15
	Std. dev.:	93986.92	3217.92	20289.97	88433.34	114173.8	4093.53
	Minimum:	1361	18	286	231.4	229.2	6.5
	Median:	146414	3061	18259	111321.1	154800.5	3514.7
2014-15	Mean:	157084	3110	18634	124168.0	139158.6	3833.9
	Maximum:	764967	16702	107500	725866.0	523753.8	20848.6
	Std. dev.:	174571.4	3601.29	21823.47	151623.8	129556.3	4535.31

CIRT, pune and MoRTH, India

Accidents and Emissions play an important role in ensuring safety and sustainability of transport services. However, since information on vehicle emissions and the amount of pollution caused is not directly available from SRTUs in India, it was planned to compute the same in this study in terms of CO_2-PKM carried based on studies performed by Ramachandra, Aithal and Sreejith (2015). Information regarding accident rates available from CIRT, Pune were also used in this study.

3.2 Estimation of CO_2 Emissions for SRTUs in India

The estimation of CO_2 emissions can be performed using a top-down approach where emissions are computed for each transport unit based on total pollutants emitted by the transport sector, whereas, in a bottom-up approach, the emission of pollutants by an organization or activity sector is computed based on emission-rate per bus. In the present study, the bottom-up approach is adopted in computing the total CO_2 emitted by the transport organization under study. This is performed using the following expression:

$$E_i = \sum\left(Veh_j \cdot D_j\right) \cdot \left(E_{i,j,km}\right) \tag{1a}$$

where, E_i = emission of the pollutant 'i'; Veh_j = number of vehicles of type 'j'; D_j = distance travelled in a year by a single vehicle of type 'j'; and Eijkm = emission factor for pollutant 'i' for vehicle-type 'j' per 'km' driven.

Information on emission factor (E_{ijkm}) for CO_2 emitted for buses per 'km' driven is assumed as 567.03gm per km as suggested by Ramachandra, Aithal and Sreejith (2015). However, in the present work, it was proposed to use the emission per passenger-km performed so as to ensure a balanced computation of vehicular emissions by various types of transport organizations in a region. The expression for estimation of CO_2-PKM is given as:

$$E_{CO_2} = \frac{(Veh_j)\cdot(D_j)\cdot(E_{CO_2,j,km})}{passengers\ kilometers\ performed} \quad (1b)$$

where, E_{CO_2} = emission of the pollutant 'CO_2'; Veh_j = number of vehicles of type 'j'; D_j = distance travelled in a year by a single vehicle of type 'j'; and $E_{CO2,j,km}$ = emission factor for pollutant 'CO_2' for vehicle-type 'j' per 'km' driven.

However, in the present study CO_2 emission of the only buses were analysed. Table A.1, Table A.2, and Table A.3 in Appendix A provide details on the data compiled for selected SRTUs in India with information on number of accidents, and CO_2-PKM for 2004-05, 2009-10, and 2014-15, respectively.

3.3 Formulation of the DEA for Undesirable Outputs (Seiford and Zhu, 2002)

The output-oriented and the input-oriented DEA models developed by Charnes, Cooper and Rhodes (1978) involved the development of the logic for computation of efficiency of organizations analysed, identification of the best performing set of frontier organizations, and the computation of relative efficiency scores of other organizations. In the output-oriented model, the objective function is formulated to maximise the output for a given set of input values. In the case of input-oriented DEA models, the objective function is formulated to minimize the input of resources required for a given set of output values. However, in the analysis of real-world systems, it is not possible to maximize all output variables, especially when output variables include negative/ undesirable variables such as accident rates, and vehicular emissions as in public transport organizations. The DEA model proposed by Seiford and Zhu (2002) developed based on the BCC model (Banker, Charnes and Cooper, 1984) is essentially a variable-returns to scale model which is capable of handling negative variables in the analysis.

The standard formulation of an output-oriented (Seiford and Zhu, 2002) model is given below:

$$Maximise\ \theta \quad (2a)$$

Subject to,

$$\sum_{q=1}^{n} \lambda_q \cdot X_{iq} + S_i^- = X_{iq} \qquad i = 1,2,..,m \quad (2b)$$

$$\sum_{q=1}^{n} \lambda_q \cdot Y_{rq} - S_r^+ = \theta \cdot Y_{rq} \qquad r = 1,2,..,s \quad (2c)$$

$$\sum_{q=1}^{n} \lambda_q \cdot \bar{Y}_{tq} - S_t^+ = \theta \cdot \bar{Y}_{tq} \qquad t = 1,2,..,k \quad (2d)$$

$$\sum_{q=1}^{n} \lambda_q = 1, \quad (2e)$$

$$\lambda q,\ S_i^-,\ S_r^+, S_t^+ \geq 0 \quad (2f)$$

where, θ = efficiency score of the DMU or the organization under consideration which varies between 1 and ∞; λ_q = weight associated with the q^{th} DMU; X_{iq}= amount of input 'i' used by the q^{th} DMU; y_{rq} = amount of desirable output 'r' produced by the q^{th} DMU; $\bar{Y}_{tq}$ = amount of undesirable/ negative output 't' produced by the q^{th} DMU; m = the number of input variables; s = the number of desirable output variables; k = the number of undesirable/ negative output variables and n = the number of DMUs. Also, S_i^-, $S_r^+$and S_t^+ are the *Slack*/*Surplus* variables used in the mathematical formulation. A higher value of θ indicates that the performance of the DMU is lower than that of the efficient DMUs that possess a score of 1.00.

Based on the results obtained using the analysis related to DEA output-oriented model, it is possible to determine the improvements that can be made for each DMU by decreasing the input variables for the inefficient DMU and/or by increasing the output variables.

The constraint equation given in Eq.2(b) can be transformed and expressed for the input variables as:

$$X_{iq-target} = X_{iq} - S_i^- = \sum_{q=1}^{n} \lambda_q \cdot X_{iq-ref} \qquad (3a)$$

where, $X_{iq-target}$ = target value of input 'i' for the qth DMU; X_{iq} = actual value of input 'i' for the inefficient q^{th} DMU; S_i^-= value of the corresponding input slack/surplus variable; X_{iq-ref} = value of the input variable 'i' for the referenced efficient qth DMU; and λ_q= corresponding weight associated with the referenced DMU.

Considering the changes to the input variables that can be performed, the value of the input variable of the inefficient DMU can be decreased by reducing the value of the slack variable (S_i^-) provided as part of the second term in Eq. 3(a). Alternatively, it is possible to decrease the value of the input variable by making changes to the third term ($\sum_{q=1}^{n} \lambda_q X_{iq-ref}$) in Eq. 3(a) where $\lambda_q$represents the weight associated with the referenced DMU which is more efficient; and X_{iq-ref}represents the input variable for the reference DMU.

The constraint equation given in Eq.2(c) and Eq.2(d) can be transformed and expressed for the desirable and undesirable outputs respectively as:

$$Y_{rq-target} = \theta \cdot Y_{rq} + S_r^+ = \sum_{q=1}^{n} \lambda_q \cdot Y_{rq-ref} \qquad r = 1,2,..,s \qquad (3b)$$

$$\bar{Y}_{tq-target} = \theta \cdot Y_{tq} + S_t^+ = \sum_{q=1}^{n} \lambda_q \cdot \bar{Y}_{tq-ref} \qquad t = 1,2,..,k \qquad (3c)$$

where, $Y_{rq\text{-}target}$ = target value of desirable output 'r' for the q^{th} DMU; θ = efficiency score of the DMU; Y_{rq} = actual value of output 'r' for the inefficient q^{th} DMU; S_r^+ = value of the corresponding output slack/surplus variable; Y_{rq-ref} = value of the output variable 'r' for the referenced efficient qth DMU; λ_q= corresponding weight associated with the referenced DMU;

$\bar{Y}_{tq-target}$ = target value of undesirable output 't' for the q^{th} DMU; Y_{tq} = actual value of undesirable output 't' for the inefficient q^{th} DMU; S_t^+= value of the corresponding undesirable output slack-variable; and $\bar{Y}_{tq-ref}$ = value of the undesirable output variable 't' for the referenced efficient q^{th} DMU.

Considering the changes to the output variables that can be performed, the value of the output variable of the inefficient DMU can be increased by enhancing the value of the output variable (Y_{rq}) proportionately by θ, followed by the addition of a slack variable (S_r^+) as part of the second term in Eq. 3(b). Alternatively, it is possible to increase the value of the output variable by making changes to the third term ($\sum_{q=1}^{n} \lambda_q \cdot Y_{rq-ref}$) in Eq. 3(b) where $\lambda_q$represents the weight associated with the referenced DMU which is more efficient; and Y_{rq-ref}represents the output variable for the reference DMU.

Also considering the changes to the undesirable output variables that can be performed, the value of the undesirable output variable of the inefficient DMU can be increased by enhancing the value of the undesirable output variable (Y_{tq}) proportionately by θ, followed by the addition of a slack variable (S_t^+) as part of the second term in Eq. 3(c). Alternatively, it is possible to increase the value of the undesirable output variable by making changes to the third term ($\sum_{q=1}^{n} \lambda_q \cdot \bar{Y}_{tq-ref}$) in Eq. 3(c) where $\lambda_q$represents the weight associated with the referenced DMU which is more efficient; and $\bar{Y}_{tq-ref}$ represents the undesirable output variable for the reference DMU.

3.4 Types of Seiford and Zhu (2002) Based DEA Models Analysed in the Present Study

Based on a review of literature performed in the above sections, availability of data, and need to incorporate the influence of negative variables, it was deemed appropriate to use the DEA models proposed by Seiford and Zhu (2002) in the present study. Table 3 provides details on the variables considered in the present study. Here, it can be seen that the three input variables such as, TC, EMP and $FS_{on\text{-}road}$ considered in the present study represent service inputs related to capital, labour, and energy-resource consumed as recommended in fundamental studies on performance indicators by Fielding, Babitsky and Brenner (1985). The output variables considered include EKM as part of service output in addition to PKM and TR as part of service consumption as in the framework of transit performance concept model developed by Fielding, Babitsky and Brenner (1985). It was also proposed to incorporate the influence of negative/ undesirable variables such as CO_2-PKM and ACC_{total} per annum in the present study of performance evaluation.

Table 3: Types of Seiford and Zhu (2002) Based DEA Models Analysed.

Model no	*Model details*	*Input/output*	*Variable*	*Abbreviation for Variable*
Model 1	Overall Productivity (Efficiency and Effectiveness)	Input	Total Cost	TC
			On-road fleet-size	$FS_{on\text{-}road}$
			Number of Employees	EMP
		Output	Total Revenue	TR
			Passenger kilometer Performed	PKM
			Effective kilometer Performed	EKM
Model 2	Environment & Safety (sustainability & social responsibility criteria)	Input	Total Cost	TC
			On-road fleet-size	$FS_{on\text{-}road}$
			Number of Employees	EMP
		Output - Desirable	Total Revenue	TR
			Passenger kilometer Performed	PKM
			Effective kilometer Performed	EKM
		Output - Undesirable	Carbon-di-oxide per passenger kilometer	CO_2 -PKM
			total number of Accidents	ACC_{total}
Model 3	Eco-Efficiency (sustainability criteria)	Input	Total Cost	TC
			On-road fleet-size	$FS_{on\text{-}road}$
			Number of Employees	EMP
		Output - Desirable	Total Revenue	TR
			Passenger kilometer Performed	PKM
			Effective kilometer Performed	EKM
		Output - Undesirable	Carbon-di-oxide per passenger kilometer	CO_2 -PKM
Model 4	Safety-Efficiency (social responsibility)	Input	Total Cost	TC
			On-road fleet-size	$FS_{on\text{-}road}$
			Number of Employees	EMP
		Output - Desirable	Total Revenue	TR
			Passenger kilometer Performed	PKM

		Effective kilometer Performed	EKM
	Output - Undesirable	total number of Accidents	ACC_{total}

Model 1 was formulated to evaluate the efficiency and effectiveness of transport organizations based on input variables representing the TC, EMP, and $FS_{on\text{-}road}$, and output variables such as TR, PKM and EKM as per recommendations made by various literature (Fielding, Babitsky and Brenner, 1985; Karlaftis, 2004).

Model 2 considers the influence of negative variables such as vehicular-emissions in terms of CO_2-PKM, and ACC_{total}, on the efficiency of the SRTUs considering sustainability, and social responsibility criteria.

Model 3 was formulated to evaluate the influence of the negative variable such as *vehicular-emissions* in terms of CO_2-PKM on the efficiency of SRTUs considering sustainability in addition to overall productivity. Similarly, Model 4 was formulated to evaluate the influence of the negative variable such as ACC_{total} on the efficiency of SRTUs considering social responsibility criteria.

As part of performance evaluation using the DEA method, it is required to satisfy the following condition for the number of DMUs (N_{DMU}) selected for the analysis in order to ensure reliable predictions (Cooper, Seiford and Tone, 2007):

$$N_{DMU} >= 3\ (Var_{Inp} + Var_{Out}),\ \text{or}\ N_{DMU} >= Var_{Inp}\ .\ Var_{Out}$$

where, Var_{Inp} = total input variables; and Var_{Out} = total output variables;
The above-mentioned conditions were fulfilled in the present study by considering details of 25 DMUs.

4. Results of Analysis Performed and Discussions

The analysis was performed using the output-oriented DEA model that operates on variable returns to scale. The "*deaR*" package available as part of *R Studio* GPL software was used in performing the related computations. The *deaR* program was formulated by Coll-Serrano, Bolos and Benitez Suarez (2020).

In the results obtained from the analysis of *Model 1* based on data analyzed for the year 2004-05, it was observed as summarized in column 3 of Table 4 that the efficiency scores for the SRTUs varied between 1 and 2.0775 with an average value of 1.1869. Based on the analysis assuming an output-oriented model, it can be said that the SRTUs with efficiency scores higher than 1.0 need to increase the outputs by about 18.69% (computed as, 100 x [1.1869–1]) while keeping the input at the existing levels. Similar interpretations and insights can be obtained based on efficiency scores summarized in Table 4.

In the analysis related to *Model 2*, the input variables considered were TC, EMP, and $FS_{on\text{-}road}$, while the output variables considered include TR, PKM and EKM in addition to the negative/ undesirable outputs such as CO_2-PKM, and the ACC_{total} as summarized in Table 3. The results obtained for analysis of data for the year 2004-05 as summarized in column 4 of Table 4 indicate that the efficiency scores for the SRTUs varied between 1 and 1.0011 with an average value of 1.0001. This indicates that when the two negative/ undesirable outputs such as CO_2-PKM, and the ACC_{total} were considered together in addition to other variables, the difference in performance between the SRTUs did not show much difference. This is due to the reason that almost all SRTUs performed in a similar manner when considering the combined effect of the two negative/ undesirable outputs. Hence, it was proposed to analyze the influence of each of the negative/ undesirable outputs separately as in *Model 3* and in *Model 4*.

Table 4: Distribution of technical efficiency scores (θ) of SRTUs categorised based on type of service

(1) Sl. no.	*(2) SRTUs*	*2004-05*				*2009-10*				*2014-15*			
		(3) Model1	*(4) Model2*	*(5) Model3*	*(6) Model4*	*(7) Model1*	*(8) Model2*	*(9) Model3*	*(10) Model4*	*(11) Model1*	*(12) Model2*	*(13) Model3*	*(14) Model4*
1	AMTS	1.6308	1.0011	1.0011	1.0616	1.9149	1.0187	1.0187	1.2268	2.2538	1.0182	1.0182	1.1494
2	BEST	1	1	1	1	1.2125	1	1.0055	1.1056	1.1679	1.0050	1.0082	1.0555
3	BMTC	1	1	1	1	1	1	1	1	1.0137	1	1	1
4	CSTC	2.0775	1.0011	1.0021	1.0213	2.3981	1	1	1.0334	2.8287	1.0178	1.0178	1.0561
5	CHNTU	1	1	1	1	1.1308	1	1	1.0179	1.5002	1.0059	1.0059	1.0301
6	DTC	1.7629	1.0001	1.0016	1.0519	1.6960	1	1.0117	1	1.7776	1	1.0032	1
7	MTC (CNI)	1.0938	1	1	1.0938	1.0894	1	1	1.0894	1.0734	1	1	1.0734
Avg. of Urban SRTUs		1.3664	1.0003	1.0007	1.0326	1.4917	1.0027	1.0052	1.0676	1.6593	1.0067	1.0076	1.0521
1	STHAR	1.0239	1	1.0026	1	1.1216	1	1.0158	1	1.1593	1	1.0061	1
2	MSRTC	1	1	1	1	1	1	1	1	1	1	1	1
3	NBSTC	2.0566	1.0009	1.0021	1.0179	2.1583	1	1.0215	1	1.6886	1.0122	1.0162	1.0143
4	NEKnRTC	1	1	1	1	1.0504	1.0196	1.0241	1.0297	1	1	1	1
5	NWKnRTC	1.0200	1	1.0011	1	1.0561	1.0175	1.0195	1.0491	1.0024	1	1.0023	1
6	OSRTC	1	1	1	1	1	1	1	1	1	1	1	1
7	STPJB	1.5765	1	1.0033	1	2.4755	1	2.4755	1	1.4398	1	1.4398	1
8	RSRTC	1	1	1	1	1	1	1	1	1.0109	1	1.0020	1
9	SETC (TN)	1	1	1	1	1	1	1	1	1	1	1	1
10	TNSTC (CBE)	1.0242	1.0001	1.0001	1.0242	1.1124	1	1	1.0616	1.0854	1	1.0007	1.0282
11	TNSTC (KUM)	1	1	1	1	1.0153	1	1.0038	1	1.0167	1.0001	1.0016	1.0001
12	TNSTC (MDU)	1	1	1	1	1	1	1	1	1.0452	1	1.0017	1
13	TNSTC (SLM)	1.0090	1	1	1	1.0057	1	1	1	1.0646	1	1.0029	1
14	TNSTC (VPM)		1	1	1	1	1	1	1	1	1	1	1
15	UPSRTC	1	1	1	1	1	1	1	1	1	1	1	1
Avg. of Rural & reg. SRTUs		1.1140	1.0001	1.0006	1.00281	1.1997	1.0025	1.1040	1.0094	1.1009	1.0008	1.0316	1.0028
1	MEGTC	1	1	1	1	1	1	1	1	1	1	1	1
2	MZST	1	1	1	1	1	1	1	1	1	1	1	1
3	NGST	1.3963	1	1.3963	1	2.3737	1	1.0009	1	2.6982	1	1.0200	1
Avg. of Hilly region SRTUs		1.1321	1.0000	1.1321	1.0000	1.4579	1.0000	1.0003	1.0000	1.5661	1.0000	1.0067	1.0000
Avg. of ALL SRTUs		1.1869	1.0001	1.0164	1.0108	1.3124	1.0022	1.0639	1.0245	1.3131	1.0024	1.0219	1.0163

Column 5 in Table 4 provides details on results obtained for analysis of *Model 3* based on data analyzed for the year 2004-05 where the use of a negative/ undesirable output such as CO_2-PKM was considered along with other variables. Here, the efficiency scores varied significantly among SRTUs between 1 and 1.3963 with an average value of 1.0164. The results indicate that vehicular emissions measured in terms of CO_2-PKM can be reduced by improving fuel consumption, possibly by incorporating the use of bio-fuels, by upgrading the quality of existing fuel consumed, and by adopting the use of CNG and electric-powered vehicles. Additionally, an increase in passengers carried per bus can further result in an improvement in the performance of SRTUs.

Similarly, column 6 in Table 4 provides details on results obtained for analysis of *Model 4* based on data analyzed for the year 2004-05 where the use of a negative/ undesirable output such as the ACC_{total} was considered along with other variables. Here, the efficiency scores varied moderately among SRTUs between 1 and 1.0938 with an average value of 1.0108. However, in view of the need to reduce accidents considering the social responsibility of transport organizations, it is required to adopt strategies for reducing accidents by providing proper training to drivers, and by adopting the use of speed-governors to limit vehicle speeds. Moreover, accidents while boarding and alighting of passengers can be reduced by providing dedicated bus-lanes with merging zones near bus stops.

Considering the performance of SRTUs for analysis based on Models 1, 2, 3, and 4 together for the year 2004-05, it can be inferred from Table 4 that out of a total of 25 SRTUs, 14 SRTUs are found to be efficient ($\theta = 1$). Among these 14 efficient SRTUs, 3 SRTUs operate in urban areas, while another set of 9 SRTUs serve the rural sector. The remaining 2 efficient SRTUs cater to the transport needs of passengers belonging to hilly regions.

Also, considering the performance of SRTUs for analysis based on Models 1, 2, 3, and 4 together for the year 2009-10, it can be observed from Table 4 that 10 SRTUs are efficient with efficiency scores equal to 1.0. Out of these, 1 SRTU operates in urban areas, while another set of 7 SRTUs operates in the rural sector. The remaining 2 efficient SRTUs provide services to hilly regions.

Similarly, considering the performance of SRTUs for analysis based on Models 1, 2, 3, and 4 together for the year 2014-15, it can be observed from Table 4 that 8 SRTUs are found to be efficient ($\theta = 1$). Out of these, 6 SRTUs operate in rural sector, while another set of 2 SRTUs operates in the hilly regions. There are no efficient SRTUs that provide services to urban areas.

The efficient SRTUs with efficiency scores equal to 1.0 for Models 1, 2, 3, and 4 are highlighted in Table 4. Here, it can be seen that MSRTC, OSRTC, SETC(TN), TNSTC(VMP), and UPSRTC operating in rural areas displayed exemplary performance levels at higher efficiencies across all the study periods 2004-05, 2009-10, 2014-15. Also, MEGTC, and MZST operating in hilly regions performed consistently well across all the study periods considered.

The five worst performing SRTUs with efficiency scores higher than 1.0 for Models 1,2, 3, and 4 considered together across all the study periods 2004-05, 2009-10, 2014-15 are identified as AMTS, CSTC, DTC, NBSTC, and STPJB.

4.1 Improving the Worst Performing organization STPJB Based on the Results of the DEA Approach

This section provides a detailed explanation on identifying the strategies required to be adopted in improving the functioning of STPJB, one of the SRTUs with the worst performance ratings for the study period 2014-15. It is observed that the efficiency of STPJB is very low (at an efficiency score of 1.4398) for Model 3 when compared to the performance of 25 SRTUs selected in the present study. The analysis was performed for the output-oriented BCC model (Banker, Charnes and Cooper, 1984) that operates on variable returns to scale. This section demonstrates the manner in which the results can be interpreted considering increase in outputs or, reduction in inputs based on analysis for Model 3.

The actual values of input variables ($X_{i\text{-actual}}$), and output variables ($Y_{i\text{-actual}}$) related to STPJB were extracted from Table A.2, and recompiled as in Table 5 for the analysis period 2014-15 pertaining to Model 3.

Table 5: Actual Values of Inputs & Outputs for the Inefficient Organization STPJB and the Related Benchmarked Efficient SRTUs for the Year 2014-15 (Extracted from Table A.3)

	$X_{iq\text{-existing}}$			$Y_{rq\text{- existing}}$			$\bar{Y}_{tq-existing}$	
	TC_{ex} (10^5)	EMP_{ex}	$FS_{on\text{-}road\text{-}ex}$	TR_{ex} (10^5)	PKM_{ex} (10^5)	EKM_{ex} (10^5)	$CO_2\text{-}PKM_{ex}$	$ACC_{total\text{-}ex}$
MEGTC	1360.98	286	42	1179.95	399.09	22.58	32.08	0
STPJB	27759.11	4252	420	16540	295.73	295.73	567.03	3
SETC (TN)	78693.05	6997	1011	65749.16	77551.5	2226.15	16.28	354
TNSTC (VPM)	177126.83	22573	3352	161852.37	293359.86	6037.99	11.67	1091

The output from the DEA analysis obtained using the "*deaR*" package provides details related to coefficients of the input and output variables (or lambda values), the values of the slack (or surplus) for input and output variables, and the targets to be achieved at higher efficiencies. The details pertaining to STPJB is provided in the output tables *Table 6a* (the table of efficiency scores θ), *Table 6b* (the table of slack values S_i^-, S_r^+ and S_t^+), *Table 6c* (the table of target values $X_{i\text{-target}}$, and $Y_{i\text{-target}}$), and *Table 6d* (the table of coefficients λ).

Table 6a: Model 3 Efficiency Scores (θ) for the Year 2014-15 (partial data)

Sl no.	*SRTU*	*Eff. Score*
-	-	-
17	MEGTC	1
21	STPJB	1.4398
24	SETC (TN)	1
27	TNSTC (VPM)	1
-	-	-

Table 6a indicates that based on the analysis conducted using *Model 3*, the performance of STPJB can be improved by increasing the outputs by 43.98% (computed as, 100 · [1.4398-1.00]). However, the actual values of reduction in input variables, and the increase in output variables can be computed based on Eq.3(a), Eq.3(b), and Eq.3(c). The related computations to improve the performance of STPJB considering data for 2014-15 are explained below.

The reduction in the input variables of STPJB can be determined based on the second term $(X_{iq} - S_i^-)$ in Eq.3(a). For example, the target number of employees (Emp_{tar}) of STPJB should be existing value of employees (EMP_{ex}) of 4252 units (as shown in *Table 5*) minus the value of 1375.25 units for the slack variable Emp (as shown in Table 6b). This computes to a target value of 2876.75 units of EMP_{tar} for STPJB as shown in Table 6c. In a similar manner, the reductions in other input variables can be implemented so as to achieve the target input values for the total cost (TC_{tar}), and the on-road fleet size ($FS_{on\text{-}road\text{-}tar}$) for the inefficient organization, STPJB.

Table 6b: Model 3 Slack Values for the Year 2014-15 (Partial data)

DMU	Values of Slack Variables for Inputs (S_i^-) TC -(10^5)	EMP	$FS_{on-road}$	Values of Slack Variables for Outputs (S_r^+) TR -(10^5)	PKM -(10^5)	EKM -(10^5)	S_t^+ CO_2-PKM
-	-	-	-	-	-	-	-
MEGTC	0	0	0	0	0	0	0
STPJB	0	1375.25	0	0	31324.05	391.93	539.242
SETC (TN)	5.38E-05	7.27E-06	0	0	0.00017	1.68E-06	2.67E-06
TNSTC (VPM)	0	1.06E-08	-5.91E-10	1.16E-07	1.56E-06	1.583E-08	4.18E-09
-	-	-	-	-	-	-	-

S_t^+ = Values of Slack Variable for the undesirable/ negative output, pune and MoRTH, India

Additionally, it is required to increase the output variables of STPJB based on the third term ($\sum_{q=1}^{n} \lambda_q \cdot Y_{rq-ref}$) in Eq.3(b) where $\lambda_q$represents the weight associated with the referenced efficient SRTU (used as a benchmark), and Y_{rq-ref} is the existing value of the referenced efficient SRTUs. Table 6d provides partial data of the output obtained for values of λ_q. Here, it can be seen that for STPJB, the referenced efficient SRTUs used as benchmark are MEGTC, SETC(TN), and TNSTC(VPM) with values 0.7129, 0.2445, and 0.0426 respectively. It may be observed that the details on the existing values of output variables ($Y_{rq-existing}$) for the referenced efficient SRTUs (used as a benchmark) were already provided in Table 5. The target total revenue (TRtar) of 23814.60 units for STPJB as in Table 6c can be achieved as the sum of 0.7129 x TR_{ex} for MEGTC, 0.2445 x TR_{ex} for SETC(TN), and 0.0426 x TR_{ex} for TNSTC(VPM) in place of the existing value (TR_{ex}) of 16540 units as shown in Table 5. In a similar manner, the increase in other output variables can be implemented so as to achieve the target output values for the passenger-km performed (PKM_{tar}), and the effective-km performed (EKMtar) for the inefficient organization, STPJB.

Table 6c: Targets Generated by the DEA Model 3 for the 2014-15 (Partial data)

DMU	$X_{i-target}$ TC_{tar} -(10^5)	EMP_{tar}	$FS_{on-road-tar}$	$Y_{i-target}$ TR_{tar} -(10^5)	PKM_{tar} -(10^5)	EKM_{tar} -(10^5)	$\bar{Y}_{t-target}$ CO_2-PKM_{tar}
-	-	-	-	-	-	-	-
MEGTC	1360.98	286	42	1179.95	399.09	22.58	32.082
STPJB	27759.11	2876.75	420	23814.6	31749.85	817.724	27.348
SETC (TN)	78693.05	6997	1011	65749.16	77551.5	2226.15	16.28
TNSTC (VPM)	177126.8	22573	3352	161852.4	293359.9	6037.99	11.671
-	-	-	-	-	-	-	-

The decrease in the undesirable/ negative output variables of STPJB can be obtained based on the third term ($\sum_{q=1}^{n} \lambda_q \cdot \bar{Y}_{tq-ref}$) in Eq.3(c) where λ_q represents the weight associated with the referenced efficient SRTU (used as a benchmark), and as in Table 6d, and $\bar{Y}_{tq-ref}$ is represented by the existing value $\bar{Y}_{tq-existing}$ as in Table 5. For example, the target CO2 emission per passenger-km (CO_2-PKM_{ex}) as in Table 6c should be equal to the sum of (0.7129 · CO_2-PKM_{ex}) for MEGTC, (0.2445 · CO_2-PKM_{ex}) for SETC(TN), and (0.0426 · CO2-PKM_{ex}) for TNSTC(VPM) which in turn is equal to 27.348 units as shown in Table 6c as opposed to the actual value of 567.03 units as shown in Table 5.

Table 6d: Summary of λ Values and the Reference SRTUs for the Year 2014-15 (Partial data)

	MEGTC	*MSRTC*	*MZST*	*SETC(TN)*	*TNSTC(VPM)*	*UPSRTC*
-	-	-	-	-	-	-
MEGTC	1	0	0	0	0	0
STPJB	0.7129	0	0	0.2445	0.0426	0
SETC (TN)	0	0	0	1	0	0
TNSTC (VPM)	0	0	0	0	1	0
-	-	-	-	-	-	-

Moreover, the decrease in the undesirable/ negative output variables of STPJB can be obtained based on the third term ($\sum_{q=1}^{n} \lambda_q \cdot \bar{Y}_{tq-ref}$) in Eq.3(c) where $\lambda_q$represents the weight associated with the referenced efficient SRTU (used as a benchmark), and $\bar{Y}_{tq-ref}$ is the existing value of the referenced efficient SRTUs. Table 6d provides values of λ_q (partial data of output generated by DEA analysis) and Table 5 provides details on the existing values of output variables ($Y_{rq-existing}$) for the referenced efficient SRTUs (used as a benchmark).

The target CO_2 emission per passenger-km (CO_2-PKM_{tar}) of 27.34 units for STPJB as in Table 6c can be achieved as the sum of (0.7129 · CO2-PKM_{ex}) for MEGTC, (0.2445 · CO2-PKM_{ex}) for SETC(TN), and (0.0426 · CO_2-PKM_{ex}) for TNSTC(VPM) in place of the existing value (CO_2-PKM_{ex}) of 567.03 units as shown in Table 5.

Similar computations for other models can be made using the output generated by the *deaR* package. As part of analysis using Model 4, it may be observed that the organization AMTS was found to be inefficient with regard to total number of accidents as in Table 4. The computations for reduction in accidents can be performed in a similar manner as explained above.

5. Conclusions

The main focus of the present work was on demonstrating the capability of a hybrid output-oriented DEA approach developed by Seiford and Zhu (2002) approach in performance evaluation considering the additional influence of negative variables such as annual CO_2-PKM, and the total accidents per year. These two variables related to environment and safety were considered due to the reason that apart from assessment of productivity of various input variables, it is also required to examine the sustainability of the operation of transport services. The study was performed based on data made available for the year 2004-05, 2009-10 and 2014-15 in order to evaluate performance of 25 SRTUs in India.

In the above study, analysis related to model 1 assisted in identifying the SRTUs that did not perform well with regard to overall productivity. The results shown in column 3, column 7, and column 11 of Table 4 indicate that the efficiency scores for the SRTUs varied significantly between 1 and 2.0775 with an average value of 1.1869 for the year 2004-05. Similar variations in performance efficiency were observed for analysis based on data for year 2009-10 and 2014-15, where the average efficiency score was found to be 1.3124 and 1.3131, respectively. This indicated that the overall performance of SRTUs decreased over the years. It can be observed that while 14 SRTUs were found to be efficient for the year 2004-05, the numbers reduced to 10 and 8 for the years 2009-10 and 2014-15 respectively. It was also observed that a majority of the efficient SRTUs provided services to the rural areas and hilly regions based on analyses performed using model 1.

Analysis based on model 3, provided insights on the performance of SRTUs based on the sustainability perspective. The results shown in column 5, column 9, and column 13 of Table 4 indicate that the efficiency scores for the SRTUs varied moderately between 1 and 1.3963 with an average value of 1.0164 for the year 2004-05. Similar variations in performance efficiency were observed for analysis based on data for year 2009-10 and 2014-15, where the average efficiency score was found to be 1.0639 and 1.0219, respectively. This indicated that the overall performance of SRTUs remained almost stable. However, in the year 2009-10, the performance of SRTUs based on sustainability criteria was not impressive. It can also be seen that while 16 SRTUs were found to be efficient for the year 2004-05, the numbers reduced to 15 and 10 for the years 2009-10 and 2014-15 respectively. It was also observed that a majority of the sustainably efficient SRTUs provided services to the rural areas and hilly regions based on analyses performed using model 3. The results indicate that CO_2-PKM can be used to represent the environmental sustainability of operations provided by the SRTUs.

It may be observed that no significant conclusion can be arrived at based on model 2, where the influence of both undesirable outputs such as vehicular emissions and accidents were considered. In the case of analysis using model 4 where undesirable effects due to accidents were considered, it was observed that most SRTUs performed at par. This implies that the accident rate in most of the SRTUs are almost same with minor variations. In view of the above, it was considered ideal to study the performance of organizations with respect to model 1 and model 3.

The study provides details on analysis using the DEA approach for performance evaluation based on efficiency and effectiveness measures in addition to analyses where factors related to sustainability (in terms of vehicular emissions), and social responsibility (in terms of accident rates) are also included as part of the DEA approach. It is suggested that organizations adopt a two-pronged approach in DEA-based performance evaluation and benchmarking.

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Conflict of Interest

The authors confirm that there is no conflict of interest to declare for this publication.

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Appendix A

Table A.1 Details on the Actual Data Compiled Based on CIRT and MoRTH for Various SRTUs in India for the year 2004-05: (Partial List)

S.No.	*Name of SRTU*	*TC -(10^5) (Rs.)*	*$FS_{On-road}$*	*EMP*	*TR -(10^5) (Rs.)*	*PKM -(10^5)*	*EKM -(10^5)*	*CO_2-PKM (in g)*	*ACC_{total}*
-	-	-	-	-	-	-	-	-	-
9	MEGTC	860.09	379	41	611.31	433.6	17.2	22.51	1
17	STPJB	27643.58	9500	1444	18379.81	40253.9	1290.2	18.17	94
19	SETC (TN)	26439.07	6971	820	22489.88	61931.7	1859.5	17.03	570
24	TNSTC (VPM)	61066.87	18690	2520	62534.07	222367.0	4206.9	10.73	1225
-	-	-	-	-	-	-	-	-	-

CIRT, pune and MoRTH, India

Table A.2 Details on the Actual Data Compiled Based on CIRT and MoRTH for Various SRTUs in India for the year 2009-10: (Partial List)

S.No.	*Name of SRTU*	*TC -(10^5) (Rs.)*	*$FS_{On-road}$*	*EMP*	*TR -(10^5) (Rs.)*	*PKM -(10^5)*	*EKM -(10^5)*	*CO_2-PKM (in g)*	*ACC_{total}*
-	-	-	-	-	-	-	-	-	-
9	MEGTC	970.01	344	36	789.86	542.9	26.1	27.25	1
17	STPJB	13048.46	6795	646	5785.65	586.4	253.5	245.09	7
19	SETC (TN)	42199.80	6978	921	34317.06	66959.7	2053.7	17.39	637
24	TNSTC (VPM)	99711.88	21118	3108	93277.27	306637.8	5730.5	10.60	1651
-	-	-	-	-	-	-	-	-	-

CIRT, pune and MoRTH, India

Table A.3 Details on the Actual Data Compiled Based on CIRT and MoRTH for Various SRTUs in India for the year 2014-15: (Partial List)

S.No.	*Name of SRTU*	*TC -(10^5) (Rs.)*	*$FS_{On-road}$*	*EMP*	*TR -(10^5) (Rs.)*	*PKM -(10^5)*	*EKM -(10^5)*	*CO_2-PKM (in g)*	*ACC_{total}*
-	-	-	-	-	-	-	-	-	-
9	MEGTC	1360.98	286	42	1179.95	399.09	22.58	32.08	0
17	STPJB	27759.11	4252	420	16540	295.73	295.73	567.03	3
19	SETC (TN)	78693.05	6997	1011	65749.16	77551.5	2226.15	16.28	354
24	TNSTC (VPM)	177126.83	22573	3352	161852.37	293359.86	6037.99	11.67	1091
-	-	-	-	-	-	-	-	-	-

CIRT, pune and MoRTH, India