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# Efficiency analysis in the management of COVID-19 pandemic in India based on data envelopment analysis

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## ABSTRACT

**Purpose:** This article measured the performance of 32 states and union territories (UTs) of India against COVID-19 disease using efficiency score which was calculated by data envelopment analysis (DEA) and compared the efficiency score with the different models which are used in many articles to evaluate the efficiency of healthcare system. Here the input parameters are taken as public health expenditure in a million, number of hospitals, number of hospital beds, percentage of health workers, population density, and number of infected, and output parameters divided into good and bad categories such as the number of recovered are taken as good output. The number of death is taken as bad outputs. The modified undesirable output model is used to calculate efficiency score and compared the efficiency score with Charnes, Cooper, and Rhodes (CCR) and Banker, Charnes, and Cooper (BCC) models. Finally, the states & UTs are completely ranked with the help of efficiency score and Maximal Balance Index, and evaluated benchmarking for each states & UTs.

**Data Source:** Secondary data were collected from Census 2011 and the Ministry of health & family welfare, Government of India on 32 states & UTs (NHAC, 2018; NHP, 2019; COVID19India, 2021).

**Results:** According to Undesirable model results, 16 (50%) of 32 Indian states & UTs were found to be efficient. Among the efficient DMUs, Chandigarh is the most efficient unit and Meghalaya is the most inefficient unit. Rajasthan was the most referenced state for inefficient states.

**Limitation:** The efficiency score is affected by changing the number of inputs and outputs. The lack of more effective parameters are used to evaluate performance and enable qualitative variable comparison.

## 1. Introduction

At the end of 2019, a highly contagious virus found in the city of Wuhan, China, which is known as Coronavirus but scientifically, it is designated as “SARS-CoV-2” by the International Committee on Taxonomy of Viruses on 11 February 2020. It spread all over the world very fast become pandemic declared by the WHO on 30 January 2020 and named as ‘COVID-19’ disease. It was initially observed that Coronavirus was transferred from one person to another due to airborne transmission via droplet nuclei due to coughing, sneezing, etc. These droplets may enter into the lungs via the mouth or nasal mucosa during inhalation causes Coronavirus disease. Most people infected with the ‘COVID-19’ virus faced mild to moderate respiratory illness and do not require any special treatment for recovery. But older people and those who already have medical problems like cardiovascular disease, diabetes, chronic respiratory disease, and cancer are more likely to develop serious illnesses. Currently, no specific treatment, medicine, or

vaccine has been proven to treat ‘SARS-CoV-2’ or ‘COVID-19’ patients effectively. Proper protective measures are the only option to break the chain of disease spread. So that, social distancing, appropriate hygienic measures, surface disinfection, good hand wash or sanitization, avoiding social gatherings, wearing masks, etc., are the essential advisories issued by the WHO and other organizations (Hu et al., 2021; Singhal, 2020; Xu et al., 2021).

In India, the first case was reported on 30 January 2020 in Kerala, having travel history to Wuhan city of China. While the ‘SARS CoV-2’ virus has become pandemic across the globe up to March 2020, the ‘COVID-19’ situation in India was under control. On 4th–5th March 2020, a group of 16 Italian tourists have been detected positive for ‘SARS-CoV-2’, and from here onwards, the number of confirmed cases increased tremendously. However, still, no deaths were reported up to 10 March 2020. On 22 March 2020, India’s government announced the Janta Curfew, followed by 21 days complete lockdown in the country from 24 March to 14 April 2020; after that extended to 19 days addi-

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tionally. The Indian Council of Medical Research (ICMR) has approved an antibody rapid test kit for screening hotspots area in the country. The “real-time reverse transcription-polymerase chain reaction (RT-PCR) -” test was taken a little time-consuming (4–5 hrs) and required skilled professionals to detect the ‘SARS-CoV-2’ virus infection. So the rapid antibody kits will enhance the traceability of hidden infections. During the COVID-19 pandemic, Indian migrant workers faced a series of problems. As a result of the lockdown imposed on the country’s factories and workplaces, millions of migrant workers lost their income sources, faced food shortages, and uncertainty about their future. Thousands of them began walking back home with no means of transport due to the lockdown. The number of cases increases continuously in all the states & UTs of India. Every state government makes their own strategy for quick decision making and dedicated teams for social distancing, capacity building, containment strategy, isolation and treatment, and awareness campaigns to break down the ‘COVID-19’ virus spread. Effective governance, assessment of the health facilities, effective monitoring, testing strategy, patient care, managing the massive influx of migrants, capacity building, financial incentives, etc., are the state government’s major decisions to break the COVID-19 virus chain. At a certain point of time in mid of September, the infection rate gradually decreased along with the number of new and active cases. The number of reported cases per day was more than 90000 in mid-September and progressively decreased to below 15000 in January 2021. The second wave beginning in March 2021, was much larger than the first wave. India is facing the worst outbreak in the global Covid-19 crisis with shortages of vaccines, hospital beds, oxygen cylinders, and other medicines in parts of the country. Last week of April, India became the first country to report over 4,00,000 new cases in 24 h. The COVID-19 crisis ultimately damages the economy, mainly through a drop in private consumption following significant declines in mobility amid rising fears of infection. All state government of India employed their strategy to overcome this pandemic. They provide proper plan to manage to return migrant people, quarantine center in every area, increase the number of the health worker, adequate tracking for COVID-19 positive patients, proper management for checking of the mask by COVID-19 frontier worker, provide food, medicine, daily needed goods, etc. properly in the lockdown and short down area, proper management of hotspot area, public awareness, etc. Even if the infection rate continuously increases all over India. Other factors also influence the rate of infection. Population density is a significant factor that increases an individual’s contact rate, thereby increasing the number of COVID-19 cases (Hu et al., 2021; Krishnakumar and Rana, 2020; Yadav and Yadav, 2020). Total sample tested 558367013, totally confirmed COVID-19 cases are 33562101 till 22 September 2021, out of total confirmed cases 294826 are active now, 32808219 are recovered, and 446081 are death which is 1.34% of confirmed cases. India began its vaccination program on 16 January 2021, with Covishield, Covaxin, Sputnik V vaccine. Every state government makes its own strategy for vaccination. The ‘COVID-19’ vaccine was offered first to healthcare workers, frontline workers, and persons above 18 years of age. Nowadays, almost 833990049 people are vaccinated, out of 16.2% fully vaccinated and 46.4% partially vaccinated (COVID19India, 2021).

## 2. Literature review

The data envelopment analysis (DEA) is used to assess the efficiency of decision-making units (DMUs) using a collection of different performance indicators categorised as “inputs” and “outputs” (Banker et al., 1984; Charnes et al., 1978). Many articles found on the DEA technique, which are widely used to calculate and compare performance in the health care sector within and between countries. They used CCR, BBC, Super efficiency, and Malmquist techniques to calculate the efficiency of the DMUs. Although the number of studies based on DEA methods is gradually increasing and DEA is the most frequently used tool in the efficiency evaluation (Zakowska and Godycki-Cwirko, 2020). The efficiency of several hospitals and medical facilities in Greece

was estimated using DEA and, as input parameters, human and medical facilities, and patients and health services as output parameters (Kontodimopoulos et al., 2006). The best performance of the DMUs is evaluated by using an extended DEA model, which includes a new benchmark filtering technique. They proposed a method using window analysis and the Malmquist technique to evaluate benchmarks that compatible perform well over multiple periods (Weng et al., 2009). The hospital’s operational efficiency is calculated for more appropriate resource allocation and cost-effectiveness. Several DEA-based techniques were first compared, and The best performing hospital could be recognized by the “DEA-artificial neural network (ANN) model”, which is more efficient than the traditional DEA models. The classification and regression tree (CART) efficiency model is used for improve resource allocation of medical institutions (Chuang et al., 2011). The DEA technique is used to evaluate the efficiency of public healthcare systems in Europe by taking input parameters as “the number of doctors, the number of hospital beds, and public health expenditures as a percentage of GDP,” and the output parameter are “life expectancy at birth, health adjusted life expectancy, and infant mortality rate.” They found some developed and developing countries lie on the efficiency frontier, while a number of the countries are not on the efficiency frontier (Asandului et al., 2014). At Peking University People’s Hospital, the output-based DEA technique is used for calculating the research performance and came up with the applicable development measures of medical subjects and analyzed the referred data from the management department of the hospital and provided references for the policy-making of medical subjects (Liang et al., 2017). The technical efficiency of select Indian private hospitals is studied by using three related methodologies: “DEA, Malmquist Productivity Index (MPI) and Tobit regression”, and taken as two output variables (i.e. “total income and profit after tax”) and four input variables (i.e. “cost of labour, net fixed assets, current assets and other operating expenses”) (Gandhi and Sharma, 2018). The Input-Oriented DEA method and the Malmquist Index Model is used to estimate the efficiency of PH-CIs in 86 counties in Hunan Province from 2009 to 2017 (Zhong et al., 2020). Then, the Tobit model was used to estimate the factors that influence the efficiency of PH-CIs. The improved slacks-based measure non-oriented DEA models is used to calculate dynamic efficiency score and Malmquist Index. The input parameter is taken as “doctors, nurses, other stapes, total beds, structure area”, and output parameter is taken as “the outpatient, emergency bed, Annual average of admissions and discharges emergency” (Zhang et al., 2018) and studied the use of DEA in healthcare focusing on hospitals (Kohl et al., 2019). The efficiency of the healthcare system in Lebanon is calculated by using a Modified DEA. The DEA technique is used to evaluate the efficiency of the healthcare system of 36 African countries and compare the efficiency score between countries (Top et al., 2020) and selected “the proportion of total health expenditures of GDP(HE), nurses (NUR), the number of physicians (PHY), hospital beds (BN) per 1000 people, the unemployment rate (UN) and the Gini coefficient (Gini)” as the input variables, and “expectancy at birth and inverse of infant mortality rate” as the output variables. DEA is used to evaluate the efficiency of intensive care units in Iran (Bahrami et al., 2018). DEA is used to calculated the healthcare efficiency assessment in the Slovak Republic (Stefko et al., 2018). The extended DEA model is used for evaluating hospital performance and their further improvement (Weng et al., 2009). The DEA model and the Malmquist Index technique is used to measure the efficiency and productivity of country-level public hospitals of china (Liang et al., 2017). The efficiency of Malaysia’s health system was calculated in the context of COVID-19 prevention and treatment response (Hamzah et al., 2021). DEA technique is used to evaluate global response to novel 2019 Coronavirus-SARS-COV-2 (Adabavazeh et al., 2020). Network DEA technique is used to evaluate the performance of the Brazilian states in the context of COVID-19 pandemic (Mariano et al., 2021). Integrated DEA, CART, and logistic regression approach is used to measured the response performance of the states of U.S. against COVID-19 (Xu et al., 2021). Two-step DEA is used to evaluate the efficiency of the countries affected

by COVID-19. In the first step, they used the number of confirmed cases for evaluating technical efficiency. In the second step, they calculated the efficiency of the countries with the help of the total number of confirmed cases, the death rates, and recovered cases (Shirouyehzad et al., 2020). The efficiency for the selected country is evaluated at each stage by using DEA tools and selected “newly confirmed cases, population density, and urbanisation degree” as the inputs parameters, and “recovered, death” as outputs parameters (Su et al., 2021).

In this paper, the outputs parameter divided into two categories as good outputs and bad outputs. So, the modified undesirable output model is used to calculate the efficiency of the DMUs and the benchmarking for inefficient DMUs. The Maximal Balance index and their efficiency score is used for ranking the DMUs, which provide a better result than other techniques discussed.

### 3. Methodology

#### 3.1. Model of evaluating the efficiency

Data Envelopment Analysis (DEA) is a non-parametric method of measuring the efficiency of a DMU. Efficiency can be calculated by the ratio between the linear combination of outputs and the linear combination of inputs with its weight. It was found that the optimised set of weights for each DMU, which optimises the DMU’s efficiency score under favorable constraints, such that the efficiency scores of all DMUs lie between 0 and 1. The technical efficiency of DMUs and benchmarking for inefficient DMUs were calculated using data envelopment analysis (Zhu, 2009). The main advantage of data envelopment analysis are

1. “The ability to assume a deterministic relationship between inputs and outputs and its ease in estimating the efficiency scale” (Grosskopf and Valdmanis, 1993).
2. “The ability to handle multiple inputs and multiple outputs simultaneously without requiring an assumption of a functional form relating inputs to outputs (as regression methods do).”

Various DEA models have been developed to calculate efficiency, which is widely used in the healthcare sector. The CCR model (Charnes et al., 1978) with the Constant Return to Scale (CRS) and Variable Return to Scale (VRS) (Banker et al., 1984) has been well studied and is recommended to calculate the performance of the hospital (Ozcan and McCue, 1996). The CCR model calculates the efficiency score for each DMUs by assuming a constant return to scale. Suppose that there are  $n$  DMUs each having  $m$  inputs and  $r$  outputs as defined by the vectors  $x_i = (x_{i1}, x_{i2}, \dots, x_{im})^T \in R^m$  and  $y_i = (y_{i1}, y_{i2}, \dots, y_{ir})^T \in R^r$  respectively. The input matrix  $X$  and the output matrix  $Y$  is defined as  $X = (x_1, \dots, x_m) \in R^{m \times n}$ , and  $Y = (y_1, \dots, y_r) \in R^{r \times n}$  respectively and assumed that  $X > 0$  and  $Y > 0$ .

The output-oriented CCR model can be defined as following linear programming. For  $DMU_p$ , we have

$$[CCR - O] \quad \rho_p^* = \max \rho_p \tag{1}$$

$$\text{subject to } \sum_{i=1}^n \alpha_i x_{ji} \leq x_{jp}, \quad (j = 1, 2, 3, \dots, m)$$

$$\sum_{i=1}^n \alpha_i y_{ki} \geq \rho_p y_{kp}, \quad (k = 1, 2, 3, \dots, r)$$

$$\alpha_i \geq 0.$$

The given DEA model is an output-oriented model, is called the output-oriented BCC model (Banker et al., 1984), which can be defined as follows. Suppose that there are  $n$  DMUs each having  $m$  inputs and  $r$  outputs as defined by the vectors  $x_j = (x_{j1}, x_{j2}, \dots, x_{jm})^T \in R^m$  and  $y_i = (y_{i1}, y_{i2}, \dots, y_{ir})^T \in R^r$  respectively. The input matrix  $X$  and the output matrix  $Y$  is defined as  $X = (x_1, \dots, x_m) \in R^{m \times n}$ , and  $Y = (y_1, \dots, y_r) \in R^{r \times n}$  respectively and assumed that  $X > 0$  and  $Y > 0$ .

$$[BCC - O] \quad \rho_p^* = \max \rho_p \tag{2}$$

$$\text{subject to } \sum_{i=1}^n \alpha_i x_{ji} \leq x_{jp}, \quad (j = 1, 2, 3, \dots, m)$$

$$\sum_{i=1}^n \alpha_i y_{ki} \geq \rho_p y_{kp}, \quad (k = 1, 2, 3, \dots, r)$$

$$\sum_{i=1}^n \alpha_i = 1, \quad \alpha_i \geq 0.$$

Since, the output of this model can be partitioned into two category such as good output and bad output that is the number of people recovered are desirable(good) outputs and the number of people death are undesirable(bad) outputs. So, the mathematical modeling for ‘Covid19’ disease are given below.

Suppose that there are  $n$  DMUs, each of having  $m$  inputs,  $r$  good outputs and  $s$  bad outputs. For each  $DMU_i$ ,  $i = 1, 2, \dots, n$ ,  $x_i = (x_{i1}, x_{i2}, \dots, x_{im})^T \in R^m$ ,  $y_i = (y_{i1}, y_{i2}, \dots, y_{ri})^T \in R^r$  and  $z_i = (z_{i1}, z_{i2}, \dots, z_{si})^T \in R^s$  are defined as the input vector, desirable output vector and undesirable output vector respectively. The input matrix  $X$ , the desirable output matrix  $Y$  and the undesirable output matrix  $Z$  are defined as  $X = (x_1, \dots, x_n) \in R^{m \times n}$ ,  $Y = (y_1, \dots, y_n) \in R^{r \times n}$  and  $Z = (z_1, \dots, z_n) \in R^{s \times n}$  respectively and assumed that  $X > 0, Y > 0$  and  $Z > 0$ .

The production possibility set ( $P$ ) is defined by

$$P = \{(x, y, z) \mid x_j \geq \sum_{i=1}^n \alpha_i x_{ji}, y_k \leq \sum_{i=1}^n \alpha_i y_{ki}, z_l \geq \sum_{i=1}^n \alpha_i z_{li}, \alpha \geq 0\} \tag{3}$$

where  $\alpha = (\alpha_1, \alpha_2, \dots, \alpha_n)^T \in R^n$  is the intensity vector. This is the constant return scale (CRS) technology which can be converted into variable return to scale (VRS) by the addition of convexity condition to Production possibilities set. The Undesirable Output model is defined as the following linear program. For  $DMU_p$

$$[\text{Undesirable}] \quad \rho_p^* = \min \rho_p \tag{4}$$

$$\text{subject to } \sum_{i=1}^n \alpha_i x_{ji} \leq \rho_p x_{kp}, \quad (j = 1, 2, 3, \dots, m)$$

$$\sum_{i=1}^n \alpha_i y_{ki} \geq y_{jp}, \quad (k = 1, 2, 3, \dots, r)$$

$$\sum_{i=1}^n \alpha_i z_{li} \leq \rho_p z_{lp}, \quad (l = 1, 2, 3, \dots, s)$$

This Model implicated here because a DMU has the ability to expand desirable outputs and to decrease undesirable outputs simultaneously.

$$[\text{Undesirable}] \quad \rho_p^* = \min \rho_p$$

$$\text{subject to } \sum_{i=1}^n \alpha_i x_{ji} + s_j^- = \rho_p x_{kp}, \quad (j = 1, 2, 3, \dots, m)$$

$$\sum_{i=1}^n \alpha_i y_{ki} - s_k^{g+} = y_{jp}, \quad (k = 1, 2, 3, \dots, r)$$

$$\sum_{i=1}^n \alpha_i z_{li} + s_l^{b-} = \rho_p z_{lp}, \quad (l = 1, 2, 3, \dots, s)$$

where  $(s_1^-, s_2^-, \dots, s_m^-)^T \in R^m$  called input slacks and  $(s_1^{g+}, s_2^{g+}, \dots, s_r^{g+})^T \in R^r$  and  $(s_1^{b-}, s_2^{b-}, \dots, s_s^{b-})^T \in R^s$  are called good and bad output slacks respectively. The slacks vector for  $DMU_p$  can be calculated by

$$s_j^{-*} = \rho_p^* x_{kp} - \sum_{i=1}^n \alpha_i x_{ji}, \quad j = 1, 2, \dots, m,$$

$$s_k^{g+*} = \sum_{i=1}^n \alpha_i y_{ki} - y_{jp}, \quad k = 1, 2, \dots, r$$

$$s_l^{b-*} = \rho_p^* z_{lp} - \sum_{i=1}^n \alpha_i z_{li}, \quad l = 1, 2, \dots, s. \tag{5}$$

Thus the DMUs are divide into three categories. These are

**Table 1**  
Variable used in the study.

Variable	Role	Details
Health expenditure	Input	Includes revenue and capital expenditure on medical, public health and family welfare of the states & UTs (NHAC, 2018)
Hospital	Input	Includes both private and government hospitals of the states & UTs (NHP, 2019)
Hospital bed	Input	Total number of hospital beds available in the states and UTs (Kapoor et al., 2020)
Health worker	Input	Percentage of the total number of doctors and nurses available in the states & UTs (NHP, 2019)
Population density	Input	Population density of states & UTs (Census, 2011)
Number of Infection	Input	Number of people infected in COVID19 disease (COVID19India, 2021)
Number of recovered	Good output	Number of people recovered in COVID19 disease (COVID19India, 2021)
Number of death	Bad output	Number of people death in COVID19 disease (COVID19India, 2021)

1. A  $DMU_p$  is said to be Fully Efficient if  $\rho_p^* = 1$  and  $s^{-*} = 0, s^{g+*} = 0$  and  $s^{b-*} = 0$  for all optimal solutions to the Undesirable Model.
2. A  $DMU_p$  is said to be Weakly Efficient if  $\rho_p^* = 1$  and at least one slack  $s^{-*}, s^{g+*}$  and  $s^{b-*}$  are not equal to zero for all optimal solutions to the Undesirable Model.
3. A  $DMU_p$  is said to be Inefficient if  $\rho_p^* \neq 1$  for all optimal solutions to the Undesirable Model.

### 3.2. Model of complete ranking

The concept of ranking DMUs through ‘Balance Index’ was introduced and given the idea of complete ranking of DMUs (Alirezaee and Afsharian, 2007). The concept of ‘Balance index’ is modified and given the concept of ‘Maximal Balance Index’ for complete ranking of the DMUs in CCR model (Wu et al., 2010). The ‘Maximal Balance Index’ model is defined for complete ranking of the DMUs in undesirable model (Guo and Wu, 2013) as shown in below.

$$\max \left( \sum_{j=1}^m u_j x_j - \sum_{k=1}^r v_k y_k + \sum_{l=1}^s w_l z_l \right) \quad (6)$$

subject to

$$\begin{aligned} \sum_{k=1}^r v_k y_{ki} - \sum_{j=1}^m u_j x_{ji} - \sum_{l=1}^s w_l z_{li} &\leq 0, \quad i = 1, 2, \dots, n. \\ \sum_{j=1}^m u_j x_{ip} + \sum_{l=1}^s w_l z_{lp} &= 1 \\ \sum_{k=1}^s u_k y_{kp} &= \rho_p. \end{aligned}$$

where  $x_j, y_k$  and  $z_l$  are the  $j$ th input,  $k$ th desirable output and  $l$ th undesirable output. The ‘maximal balance index’ for each DMUs can be calculated by the given equation.

$$\text{Maximal Balance Index} = \sum_{k=1}^r Y_k v_k - \sum_{j=1}^m X_j u_j - \sum_{l=1}^s Z_l w_l \quad (7)$$

where  $Y_k = \sum_{i=1}^n y_{ik}, X_j = \sum_{i=1}^n x_{ij}$  and  $Z_l = \sum_{i=1}^n z_{il}$  and  $v_k, u_j$  and  $w_l$  are the optimal solution for each DMU, obtain from Eq. (6).

### 4. Data collection

The data used in this study have been selected from the Indian government’s authentic website (Census, 2011; COVID19India, 2021; NHP, 2019). The input parameters are taken as health expenditure (HE) in a million, number of hospitals (H), number of hospital beds (HB), number of health workers (HW) in percentage, population density (PD), and number of people infected (NI) in COVID-19 disease of different states & UTs of India (Census, 2011; Kapoor et al., 2020; NHAC, 2018; NHP, 2019). The output parameters are taken as the number of people recovered (NR) and number of people death (ND) (COVID19India, 2021). All the inputs and outputs parameters are defined in Table 1. The abbreviation of the states & UTs of India are denoted as ‘‘Andhra Pradesh (AP), Arunachal Pradesh (AR), Assam (AS), Bihar (BR), Chandigarh (CH),

Chhattisgarh (CG), Delhi (DL), Goa (GA), Gujarat (GJ), Haryana (HR), Himachal Pradesh (HP), Jammu & Kashmir (JK), Jharkhand (JH), Karnataka (KA), Kerala (KL), Madhya Pradesh (MP), Maharashtra (MH), Manipur (MN), Meghalaya (ML), Mizoram (MZ), Nagaland (NL), Odisha (OD), Punjab (PB), Puducherry (PY), Rajasthan (RJ), Sikkim (SK), Tamil Nadu (TN), Tripura (TR), Uttarakhand (UK), Uttar Pradesh (UP), West Bengal (WB)’’. The input and output data are shown in Table 2.

### 5. Results and discussion

The efficiency value of the DMUs measured by the DEA technique ranges from [0, 1]. A DMU is said to be efficient if its efficiency value is 1; otherwise, it is inefficient. Table 3 shows the efficiency score of the different DEA models and also shows both the efficient (fully & weakly) and inefficient states & UTs. According to table Table 3, it was found that 59.375% efficient and 40.625% inefficient states & UTs in CCR model and 78.125% efficient and 21.875% inefficient states & UTs in BCC model. In the Undesirable model, it was found that 50% of the Indian states & UTs are efficient, and 50% of the Indian states & UTs are inefficient. The efficiency scores of states & UTs of India found to be efficient and inefficient generally varied between zero to one. The efficiency score in different models are compared in Fig. 1 and Undesirable model provides better results as compared to other models. The rate of infection and recovered are shown in Fig. 2 and Table 3. Out of 32 states & UTs, 16 are efficient, and their efficiency scores are 1. The efficient States & UTs divided into two categories, that is, fully efficient and weakly efficient. Out of 16 efficient DMUs, 14 states & UTs are fully efficient, and 2 states & UTs are weakly efficient, as shown in Table 4. Andhra Pradesh, Arunachal Pradesh, Chandigarh, Chhattisgarh, Delhi, Gujarat, Karnataka, Maharashtra, Manipur, Mizoram, Odisha, Puducherry, and Telangana are fully efficient. Gujarat and Rajasthan are weakly efficient. The ‘maximal balance index’ is calculated for each DMUs using Eq. (6), as shown in Table 5. ‘Maximal balance index’ is used for ranking the efficient states & UTs because the efficiency score of fully efficient and weakly efficient states & UTs are one and other inefficient states & UT ranked based on their efficiency score as shown in Table 3. Table 5 shows the complete ranking of the states & UTs. According to Table 5, Chandigarh is the most efficient unit, and Meghalaya is the most inefficient state with an efficiency score of 0.9718. Benchmarking the states & UTs can be calculated with the help of production possibilities set and optimized  $\alpha$ ’s value for each State & UT. The benchmarking of the states & UTs are shown in Table 5. The following findings was addressed based on the research findings:

- Kerala, Goa, Puducherry, Delhi, Mizoram, Chandigarh, Maharashtra, Sikkim are the most infected states and UTs that is more the 5%, respectively. Bihar, Uttar Pradesh, Jharkhand, Madhya Pradesh, Gujarat, Rajasthan, Nagaland, Assam, West Bengal have low rate of infection that is less than 2%, respectively. These states have taken extra stringent steps to stop the spread of COVID-19, such as shutting borders, proscribing travel, and implementing large emergency measures. On the other side, the low infection rate may additionally be attributable to the state’s minimal tourist visitation. Health behaviors are closely influenced by means of social and cultural factors.

**Table 2**  
Input and output data.

State & UT	HE	H	HB	HW	PD	NI	NR	ND
AP	74.3	928	83230	5.22	308	2040708	2012714	14089
AR	11.2	238	2624	0.14	17	54190	53504	273
AS	53.77	1729	24178	1.91	398	598864	587970	5813
BR	66.69	3034	30857	4.42	1102	725907	716188	9659
CH	42.26	13	5631	0.3	9252	65195	64333	818
CG	44.87	396	17430	1.66	189	1005120	991260	13563
DL	59.03	176	39455	3.22	11297	1438556	1413071	25085
GA	9.6	65	4584	0.29	394	175690	171507	3297
GJ	88.16	1408	64862	4.27	308	825751	815536	10082
HR	43.85	2148	36141	2.09	573	770754	760618	9808
HP	20.54	1036	16040	0.75	123	217403	212033	3655
JK	35.45	157	7995	1.08	297	328214	322345	4419
JH	31.3	1364	26496	2	414	348139	342941	5133
KA	72.3	10684	262109	5.27	319	2969361	2917944	37648
KL	68.82	3342	99227	6.06	859	4539926	4354264	23897
MP	80.65	971	64939	4.75	236	792410	781803	10517
MH	122.25	3203	231739	13.67	365	6527629	6344744	138616
MN	6.05	38	1790	0.27	122	118870	114861	1835
ML	7.64	185	5244	0.17	132	79817	76558	1381
MZ	5.56	113	2496	0.25	52	82815	67184	268
NL	6.16	49	2561	0.26	119	30959	29832	657
OD	57.51	2501	25650	3.54	269	1021216	1008226	8146
PY	5.27	20	5172	0.25	2598	125618	122864	1832
PB	36.38	2320	60997	3.19	551	601359	584554	16501
RJ	98.14	5644	93176	3.92	201	954275	945222	8954
SK	3.64	41	1952	0.12	86	31014	30007	380
TN	99.76	2439	155375	6.72	555	2648688	2596316	35379
TG	63.91	4110	99919	2.61	307	663906	655061	3907
TR	7.36	164	4667	0.28	350	83956	82794	809
UP	189.67	17103	281402	10.81	828	1709693	1686612	22887
UT	22.47	1289	23843	0.89	189	343405	335765	7391
WB	79.21	2263	113535	9.44	1029	1562710	1536291	18678

**Table 3**  
Efficiency score in CCR, BCC, Undesirable model.

State & UT	CCR	BCC	Undesirable	State & UT	CCR	BCC	Undesirable
Andhra Pradesh	1	1	1	Maharashtra	1	1	1
Arunachal Pradesh	0.9995	1	1	Manipur	1	1	1
Assam	0.994	0.994	0.9939	Meghalaya	0.9771	1	0.9718
Bihar	1	1	0.9985	Mizoram	0.822	1	1
Chandigarh	1	1	1	Nagaland	0.9861	1	0.9758
Chhattisgarh	1	1	1	Odisha	1	1	1
Delhi	1	1	1	Puducherry	1	1	1
Goa	1	1	1	Punjab	1	1	0.984
Gujarat	1	1	1	Rajasthan	1	1	1
Haryana	0.9998	0.9999	0.9995	Sikkim	0.9801	1	0.9801
Himachal Pradesh	0.9924	0.9935	0.9859	Tamilnadu	0.996	0.9996	0.9938
Jammu & Kashmir	0.9959	0.997	0.9958	Telangana	0.9966	0.9967	1
Jharkhand	1	1	0.996	Tripura	0.9986	1	0.9986
Karnataka	1	1	1	Uttar Pradesh	1	1	0.9959
Kerala	1	1	1	Uttarakhand	1	1	0.9898
Madhya Pradesh	1	1	0.9995	West Bengal	0.9963	0.9983	0.996

Social factors include poverty, health discrimination, and education, whereas cultural factors include religious beliefs, language, and geographic origin.

- Delhi, Chandigarh, Puducherry, Bihar, West Bengal, Kerala, Uttar Pradesh have high population density, recorded more than 800, respectively. There is a possible to increase the rate of infection.
- Rajasthan, Gujara, Arunachal Pradesh, Odisha, Hariyana, Chandigarh, Telangana, Madhya Pradesh, Bihar, Uttar Pradesh, Andhra Pradesh, Chhattisgarh, Tripura and Jharkhand have the highest percentages of Recovered that is approximately 99%, respectively. In addition to the expert competence of clinical staff, successful affected person remedy is established on a range of elements such as well timed diagnosis, exceptional of care, modern and superior

equipment, medical team of workers coaching and knowledge, fitness care budget, and fitness centre self-management of the health system unit.

- Mizoram, Arunachal Pradesh, Kerala, Telengana, Andhra Pradesh, Odisha, Rajasthan, Tripura, Assam recorded lowest death percentage that is less than 1%, respectively. The death rate is a reflection of society’s socioeconomic situations, as well as people’s health and living standards. On the other hand, the death rate is affected by geographical location, environmental and climatic circumstances, underlying disease, and population age.
- The UTs were more efficient than the states because their government efficiently monitored the COVID19 patient. Even though the population density of UTs was high in comparison to states, the area

**Table 4**  
Slacks in undesirable model.

State & UT	s1	s2	s3	s4	s5	s6	s7	s8	Type
AP	0	0	0	0	0	0	0	0	Fully Efficient
AR	0	0	0	0	0	0	0	0	Fully Efficient
AS	15.0365	63.2953	0	0	256.7874	0	0	57.6045	Inefficient
BR	17.6854	652.0411	0	1.7894	918.6309	0	0	3618.522	Inefficient
CH	0	0	0	0	0	0	0	0	Fully Efficient
CG	0	0	0	0	0	0	0	0	Fully Efficient
DL	0	0	0	0	0	0	0	0	Fully Efficient
GA	0	0	0	0	0	0	0	0	Fully Efficient
GJ	0	0	0.0009	0	0	0	0	0	Weak Efficient
HR	0	664.8883	0	0	431.0642	0	0	2347.99	Inefficient
HP	1.8552	90.4496	0	0	76.8425	0	0	1380.478	Inefficient
JK	18.8726	0	0.0001	0.4243	0.0001	0	0	297.3969	Inefficient
JH	0	0.0004	0.0004	0.6977	331.7007	0.0001	0.0001	1393.845	Inefficient
KA	0	0	0	0	0	0	0	0	Fully Efficient
KL	0	0	0	0	0	0	0	0	Fully Efficient
MP	17.3956	0	14167.2129	1.446	0	0	0	2453.495	Inefficient
MH	0	0	0	0	0	0	0	0	Fully Efficient
MN	0	0	0	0	0	0	0	0	Fully Efficient
ML	3.0826	65.8341	2537.992	0	113.3457	0	0	357.4628	Inefficient
MZ	0	0	0	0	0	0	0	0	Fully Efficient
NL	2.5277	0	198.0685	0.1033	0	0	0	282.9301	Inefficient
OD	0	0	0	0	0	0	0	0	Fully Efficient
PY	0	0	0	0	0	0.0001	0	0	Fully Efficient
PB	0	842.4449	23689.7179	1.2929	440.0847	0	0	11620.28	Inefficient
RJ	0	0.0028	0.0304	0	0	0	0	0.0007	Weak Efficient
SK	0.7536	0	157.1336	0	0.0001	0	0	0	Inefficient
TN	0	1043.9272	47889.3401	0	147.741	0	0	16108.97	Inefficient
TG	0	0	0	0	0	0	0	0	Fully Efficient
TR	0.6757	0	0	0.02	0	0	0	0	Inefficient
UP	13.7849	6962.8011	114002.7317	3.7715	465.9897	0	0	6817.149	Inefficient
UT	0	457.3354	7364.1512	0	120.9963	0	0	3350.167	Inefficient
WB	0	0	31968.4106	4.8422	760.1546	0	0	6862.261	Inefficient

**Table 5**  
Benchmarking and ranking of the states and UTs.

State & UT	Benchmarking	Max. Bal Index	Ranking
AP	AP (1)	-56.49000736	10
AR	AR (1)	-923.7029084	4
AS	CG (0.203005) OD (0.307985) RJ (0.14699)	-0.604722356	25
BR	OD (0.539581) RJ (0.182146)	-0.513506273	20
CH	CH (1)	-1822.532391	1
CG	CG (1)	-105.9263022	8
DL	DL (1)	-314.9785362	7
GA	GA(1)	-391.8592243	6
GJ	GJ (1)	-0.424008785	16
HR	AP (0.142044) CG (0.242886) OD(0.040648) RJ (0.204162)	-0.415676874	18
HP	CG (0.054589) OD (0.009563) RJ (0.156873)	-1.663300498	28
JK	AP (0.020888) CH (0.025141) CG (0.261917) GJ (0.023369)	-1.068196826	24
JH	AP (0.00241) CG (0.075053) GJ (0.071625) RJ (0.217174)	-0.95312749	21
KA	KA (1)	-44.09661881	11
KL	KL (1)	-15.27470261	12
MP	AP (0.14887) CH (0.00086) GJ (0.591153)	-0.442501719	17
MH	MH (1)	-65.32672502	9
MN	MN (1)	-868.6278999	5
ML	CG (0.06214) RJ (0.015828)	-4.613762761	32
MZ	MZ (1)	-944.7040163	3
NL	AP (0.00101) CH (0.011412) GJ (0.033187)	-11.32140409	31
OD	OD (1)	-5.378881513	14
PY	PY (1)	-1052.175808	2
PB	AP (0.184839) RJ (0.224842)	-0.526965291	29
RJ	RJ (1)	-2.017968352	15
SK	AP (0.000802) CH (0.008155) CG(0.009615) GJ (0.02137) RJ (0.000964)	-10.8564555	30
TN	AP (1.213971) CG (0.119469) RJ (0.036516)	-0.120853298	26
TG	TG (1)	-6.455237659	13
TR	AP (0.016531) CH (0.036027) CG (0.017485) GJ (0.010781) RJ (0.022301)	-4.040713521	19
UP	RJ (1.784355)	-0.253655247	23
UT	AP (0.008326) CG (0.198079) RJ (0.129768)	-0.930778123	27
WB	AP (0.60055) GJ (0.074902) RJ (0.281913)	-0.212580455	22

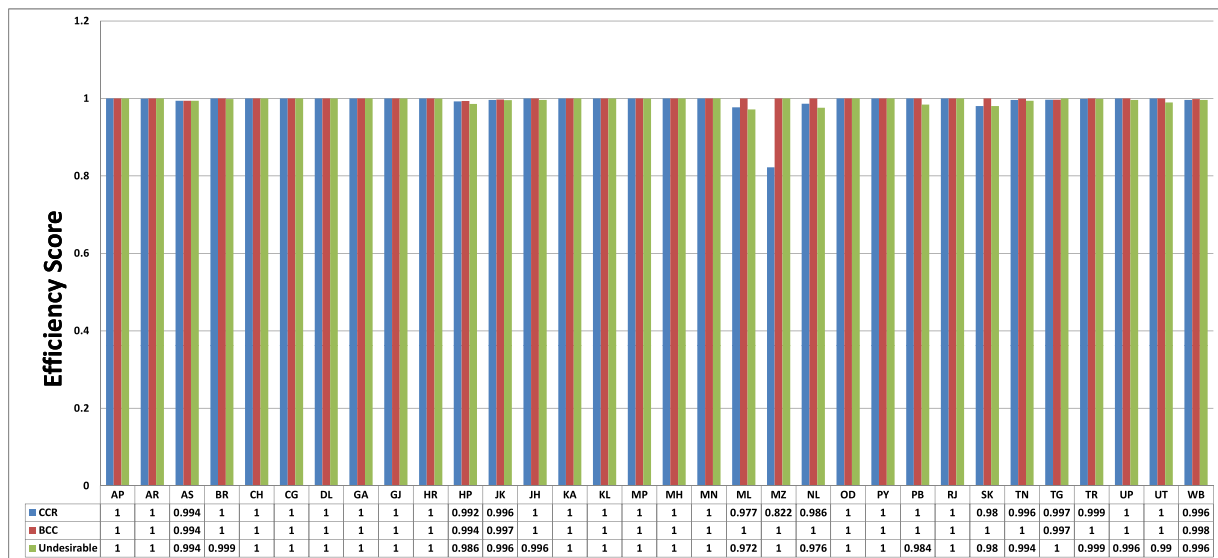


Fig. 1. Efficiency score.

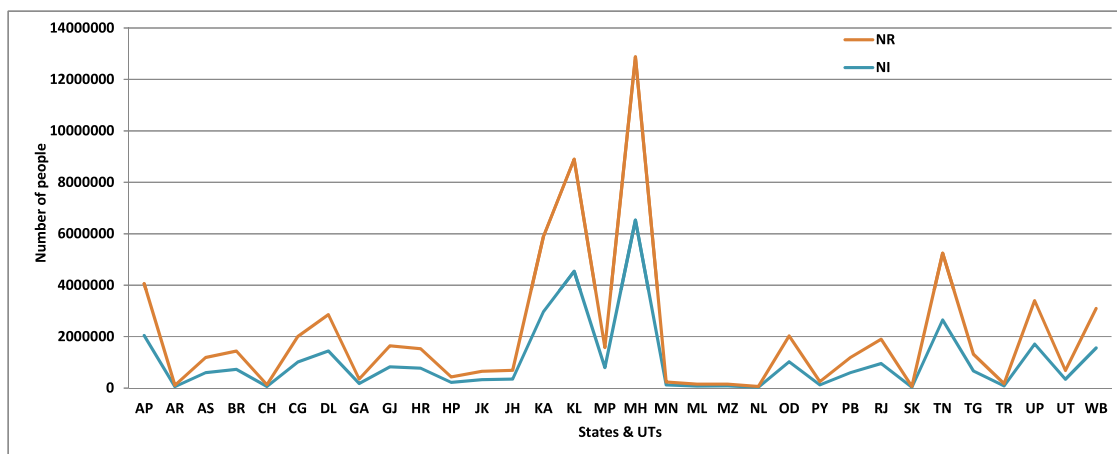


Fig. 2. Number of people infected and recovered.

of the UTs was small and the literacy rate was high, influencing performance.

6. Conclusions

The data envelopment analysis is a more generalizable non-parametric methods frontier-based linear programming optimization performance evaluation technique. This method is an alternative for regression which is parametric. If the units have multiple inputs and outputs, the econometric methodology cannot appropriately evaluate the efficiency of these units. The main purpose of data envelopment analysis is to evaluate the efficiency score of a DMU associated with multiple inputs and multiple outputs. The DEA technique is frequently used to compare national healthcare systems. The CCR and BBC models with CRS or VRS are widely used to evaluate the efficiency of healthcare systems. The main aim is to identify the units that get the highest good and lowest bad output from their respective inputs. So the undesirable output model with constant return scale (CRS) is used to evaluate the efficiency of the states & UTs, and the Undesirable output model provides better results than the CCR and BBC model. The present study aims to measure the efficiency of India's states & UTs during the 'COVID-19' crises in 2021. 16 states out of 32 states & UTs perform well to manage the 'COVID-19' pandemic as shown in Table 4. In the COVID19

pandemic management, Chandigarh is the most efficient unit, whereas Meghalaya is the most inefficient unit. A lack of crisis committee activity, a lack of a system for organising medical personnel, a lack of training courses, a lack of new technologies, a lack of human resources, and a shortage of medical equipment are some of the most serious issues confronting state and UT governments in dealing with crises. Well-planned crisis management, internal and external crisis coordination in the organisation, particularly with the use of new technologies, identification of capabilities to respond to crises through proper reinforcing and organising human resources, and provision of necessary training, will all help to achieve proper crisis management. Planning is critical in terms of resource allocation, training, pandemic prevention, cultural promotion, and reducing the expenses and resources of healthcare organisations. To maintain and improve their performance, inefficient states and UTs can recognise their faults and learn from the experiences of more efficient units. Furthermore, better resource management can transform them into a more efficient unit. Limited data (inputs and outputs) are used to assess the performance of states and UTs. Other effective indices may be a better criterion for evaluating states and UTs in the country, which is suggested for further research. The following limitation can be addressed based on the research :

- The duration of data collection restricts the scope of research findings. Increasing or decreasing the variety of units in the health sys-



tem is also one of the research's constraints because altering the research community would affect the outcomes.

- The drawback of this study is the lack of more effective indicators for evaluating performance.
- This approach is simply a mathematical approach based on linear programming and is unable to examine the qualitative characteristics of decision units.

#### Data and Code availability statement

All the used data for the study are available and has been referenced in the manuscript. The data used were gathered from official site of Government of India.

#### Declaration of Competing Interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.

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