ORIGINAL PAPER

Performance evaluation of Turkish disaster relief management system in 1999 earthquakes using data envelopment analysis

Abdullah Korkut Üstün · Gülay Barbarosoğlu

Abstract This study estimates the relative efficiency of disaster relief organizations that participated in the relief activities following the Marmara and Düzce earthquakes that took place in Turkey in 1999. For this purpose, the activities in the response and relief phases of the disaster management cycle following the 1999 earthquakes are classified into four groups: "search and rescue," "infrastructure rehabilitation and debris removal," "health care" and "providing basic needs to the disaster victims." Next, the unbounded data envelopment analysis (DEA) model is applied to estimate the efficiency scores and optimal input/output weights of the decision-making units (DMUs) in these groups. The efficient and inefficient units are then determined, and the target input and output values are determined for the inefficient units. However, some inputs and outputs are found to be zero or are outlier values in the unbounded model results. To eliminate this deficiency, the bounded model is applied by including additional constraints in the unbounded model. After determining a solution with this model, the optimal input/output weights, the efficiency scores of the DMUs and the efficient and inefficient units are determined. The results of the bounded version of the DEA are more accurate than those of the unbounded model. More accurate and reliable results are obtained from the unbounded model because zero and outlier values are eliminated.

Keywords Disaster management · Data envelopment analysis · Relief operations · Earthquakes

A. K. Üstün (✉)
Department of Industrial Engineering, Engineering Faculty, Aksaray University, 68100 Aksaray, Turkey
e-mail: korkut.ustun@gmail.com

G. Barbarosoğlu
Department of Industrial Engineering, Engineering Faculty, Boğaziçi University, Bebek, Istanbul, Turkey

1 Introduction

The 1999 Marmara and Düzce earthquakes had a large social and economic impact on the most developed region of Turkey. The region affected by the earthquakes included the provinces of Kocaeli, Sakarya, Yalova, Bolu, and Düzce as well as the municipalities of their sub-provinces, especially the municipality of Gölcük.

As a result of these earthquakes, more than 17,000 people lost their lives, 400,000 were injured, and 500,000 people became homeless. In the cities of Adapazarı, Gölcük, and İzmit, 70 % of the buildings were severely damaged or suffered partial or total collapse. Following these earthquakes, the performance of relief organizations and the management of the response operations were not sufficient or effective and not rapidly initiated. The following observations were made during the disaster (IMM 2002):

- The earthquakes hit the most industrialized and populated area of Turkey. The earthquakes resulted in the second highest number of human casualties in Turkey during the twentieth century.
- In the affected area, 43 schools collapsed and 377 were damaged. Foreign aid teams set up tent hospitals because local hospitals collapsed and the municipality buildings were not considered safe.
- Governmental buildings were also heavily damaged, and officers were among the disaster victims. The earthquake fault ran through the naval base at Golcuk, and as a result, the naval headquarter was directly affected, causing many flag officials to be killed.
- Initially, communication was impossible: Telephones and mobile phones were not usable, and only radio was useful during the first 48 h.
- The first few days were chaotic; rescue activities were performed only by local residents. Citizens voluntarily began rescue work on the morning of the first day following the earthquakes.
- Search and rescue activities were not organized or effective. Logistic support, such as gasoline or the provision of heavy machinery, was lacking. Rescue work during the night was difficult due to the lack of electricity and light.
- Rescue work involving collapsed buildings was difficult. Fire brigades did not have the tools required for heavy rescue activities and were not accustomed to such activities.
- The building damage assessment was not well organized. Initially, municipalities performed cursory building safety inspections within a few days to meet the demands of residents with the help of architects and professors. The results of these inspections were not used in the official assessment. In addition, the official results of the official damage assessment were not given to the municipality.
- Relief activities were not organized.
- Residents afraid of the earthquakes would still sleep in prefabricated houses. Rescue workers who worked without the knowledge of their family's safety faced psychological distress.
- Foreign rescue members were difficult to work with because there were no translators in the emergency management center. Some of the medicine donated from abroad was not used because the instructions could not be interpreted.
- Permanent housing areas were located far from the city center. The infrastructure of the tent cities was inadequate.

Therefore, to be more effectively prepared for future disasters, the existing response phase for the earthquake disaster management cycle must be evaluated and a new system must be developed and put into practice (Özerdem and Barakat 2000; Korkmaz 2010).

Table 1 Major earthquakes in Turkey over the last 20 years

Place	Date	Mag (Ms)	Number of deaths	Number of collapsed or damaged buildings
Erzincan	13.03.1992	6.8	653	21,189
Dinar	01.10.1995	6.0	95	201
Adana	27.06.1998	6.3	145	10,401
Marmara	17.08.1999	7.4	15,250	75,000
Düzce	12.11.1999	7.2	845	3,395
Van	22.10.2011	7.2	601	2,262

As shown in Table 1, there have been six urban earthquakes in Turkey over the last 20 years: Erzincan in 1992, Dinar in 1995, Adana in 1998, Marmara and Düzce in 1999 and Van in 2011. These earthquakes have resulted in the death or injury of thousands of people. The Marmara earthquake was the most serious earthquake to occur in recent years, as shown in Table 1 (Özerdem and Barakat 2000).

The high number of deaths and substantial property losses occurring from the 1999 Marmara and Düzce earthquakes were due in part to infective disaster management. Because Turkey is an earthquake-prone country, more devastating earthquakes may occur in the near future. Therefore, the causes of the poor performance and ineffectiveness of the relief activities should be determined and resolved. Data envelopment analysis (DEA) is a useful tool for this purpose because it has many advantages for evaluating the efficiency of units and determining the source of ineffectiveness (Charnes et al. 1978).

DEA estimates the relative efficiency of the decision-making units (DMUs) that perform similar tasks in any socioeconomic system that consumes multiple inputs to produce multiple outputs. It utilizes mathematical programming techniques that can control large numbers of variables and relations (Cooper et al. 2000).

The accuracy of this method has been proven through many applications. DEA can be applied to many areas, such as banking (Vijayakumar 2012; Staub et al. 2010; Khoda-bakhshi et al. 2010), education (Montoneri et al. 2012) and health care (Dash et al. 2007; Özgen and Şahin 2010); however, to our knowledge, DEA has not been applied to disaster management. If the inputs and outputs of the DMUs can be properly identified, the DEA method can be applied to analyze the disaster relief organizations; in this context, DEA could improve traditional methods and provide more objective results in evaluations of relief activities in response to natural disasters.

Few studies have applied DEA in the context of disaster management. Wei et al. (2004) proposed a DEA-related method to evaluate the relative severity of the impacts of natural disasters on different regions. Regional vulnerabilities in China's mainland were established based on statistics from 1989 to 2000. In addition, Saein and Saen used DEA to determine the vulnerability of different parts of Tehran, Iran, against earthquakes.

To the best of our knowledge, this study is the first to use DEA to assess disaster relief operations. In addition, the current study demonstrates how to improve the performance of disaster management in Turkey using DEA to analyze the activities of the DMUs and highlight the sources of inadequacies. In this manner, these DMUs can take measures to eliminate their inefficiencies and thus be better prepared for future disasters.

This study focuses on the application of DEA to disaster management and specifically analyzes the response phase during the 1999 Marmara and Düzce earthquakes. In this application, relief activities are classified into the following four categories: "search and rescue," "infrastructure rehabilitation and debris removal activities," "providing basic needs" and "health care efforts." For each of these categories, the DMUs are determined and then evaluated by the unbounded DEA model. However, a bounded model has also been developed to overcome the limitations of the unbounded DEA models.

The main purposes of this research are the following:

- To apply the DEA concepts and principles and develop a DEA modeling strategy that produces more accurate models based on the structure of disaster response management realized for the Marmara and Düzce earthquakes.
- To evaluate the relative efficiency of organizations and units that comprises the disaster response management system for the activities undertaken following the Marmara and Düzce earthquakes.
- To determine the target values of inputs and outputs for the inefficient units in the system.
- To overcome the limitations of the original unbounded DEA model using the bounded model and explore the differences between the bounded and unbounded DEA models.

The remainder of this paper is organized as follows. Section 2 provides general information about DEA, defines the relevant DEA terms and presents the classical DEA model formulations. In addition, the weight restriction approach in the DEA literature is presented, and the role of the weight restriction is discussed. The limitations and advantages of DEA are then given. Section 3 includes the results of both the unbounded and bounded DEA models for the "search and rescue efforts," "infrastructure rehabilitation and debris removal activities," "health care activities" and "providing basic needs" groups. Finally, the concluding remarks are provided in Sect. 4.

2 Data envelopment analysis

DEA is a useful and important tool for evaluating and improving the performance of manufacturing and service operations. This technique has been extensively employed in the performance evaluation and benchmarking of organizations, such as hospitals, schools, production plants and bank branches (Charnes et al. 1994).

DEA is a productivity analysis model for measuring the relative efficiencies of a homogenous set of DMUs. If there are n DMUs, each having m inputs and s outputs, the efficiency score of DMU p is obtained by solving the following model proposed by Charnes et al. (1978). The CCR model (unbounded model) is as follows:

$$\text{Max } \theta_o(v, u) = \frac{\sum_{r=1}^{s} u_r y_{ro}}{\sum_{i=1}^{m} v_i x_{io}} \tag{1}$$

$$\text{s.t.} \quad \frac{\sum_{r=1}^{n} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1, \quad j = 1, \ldots, n \tag{2}$$

$$u_1, u_2, \ldots, u_s \geq 0 \tag{3}$$

$$v_1, v_2, ..v_m \geq 0. \tag{4}$$

After linearization, the fractional model can be converted to a decision model known as the CCR model as follows (Cooper et al. 2000):

$$\text{Max } \theta_o(v, u) = \sum_{r=1}^{s} u_r y_{ro} \tag{5}$$

$$\text{s.t.} \quad \sum_{i=1}^{m} v_i x_{io} = 1 \tag{6}$$

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \geq 0, \quad j = 1, 2, \ldots, n \tag{7}$$

$$u_r, v_i \geq 0, \tag{8}$$

where θ_o efficiency score of DMU "o," n number of DMUs, s number of outputs, m number of inputs, o 1, 2,…, n, $j = 1, 2,…, n$, $i = 1, 2,…, m$, $r = 1, 2,…, s$, x_{ij} amount of input i utilized by DMU j, y_{rj} amount of output r produced by DMU j, y_{ro} amount of output r produced by DMU o, which we use to determine the efficiency scores, u_r weight given to output r and v_i weight given to input i.

The model given above is run n times, and the relative efficiency scores of all DMUs are calculated. In the model, each DMU takes input and output weights that maximize its efficiency score. A DMU is considered efficient if its efficiency score is 1; otherwise, it is inefficient.

The models above allow for unrestricted weight flexibility in determining the efficiency scores of the DMUs. However, some input and output weights can be zero or take on outlier values. The weight restriction approach can be used to address this issue. This approach also allows for the integration of managerial preferences in terms of the relative importance levels of various inputs and outputs. For example, if input 1 is at least four times as important as input 2, then this information can be incorporated into the DEA model using the linear constraint $u_1 > 4u_2$. In addition, lower and upper bounds for inputs and outputs can be added to the model (Cooper et al. 2000).

Several weight restriction methods have been suggested in the DEA literature (Charnes et al. 1990; Dyson and Thanassoulis 1988; Wong and Beasley 1990).

In this study, the following bounded model is used:

$$\text{Max } \theta_o(v, u) = \sum_{r=1}^{s} u_r y_{ro} \tag{9}$$

$$\text{s.t.} \quad \sum_{i=1}^{m} v_i x_{io} = 1 \tag{10}$$

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \geq 0, \quad j = 1, 2, \ldots, n \tag{11}$$

$$\alpha_i \leq v_i \leq \beta_i \text{ for } \forall \text{ input } i, \tag{12}$$

$$\alpha_r \leq u_r \leq \beta_r \text{ for } \forall \text{ output } r, \tag{13}$$

$$u_r, v_i \geq 0. \tag{14}$$

DEA offers a detailed picture of organizational performance. DEA is considered a particularly suitable instrument for financial services, educational institutions, heath care facilities and manufacturing firms, partially because a multitude of subjective factors affect the service quality and productivity of a service business (Thanassoulis 2001).

DEA has three important and useful features. First, DEA determines each DMU using a single efficiency score. Second, it highlights areas of improvements for each DMU by projecting inefficient units on the efficient frontier. Third, it facilitates making inferences from the DMUs' general profiles (Cooper et al. 2000).

In addition, DEA is capable of handling multiple inputs and outputs given in different measurement units. Furthermore, it focuses on a best-practice frontier rather than the central tendencies of a population. Every unit is compared to an efficient unit or a combination of efficient units. Thus, the comparison reveals the sources of the inefficiency of units that do not belong to the frontier. Moreover, no restrictions are imposed on the functional form relating inputs to outputs (Cooper et al. 2000).
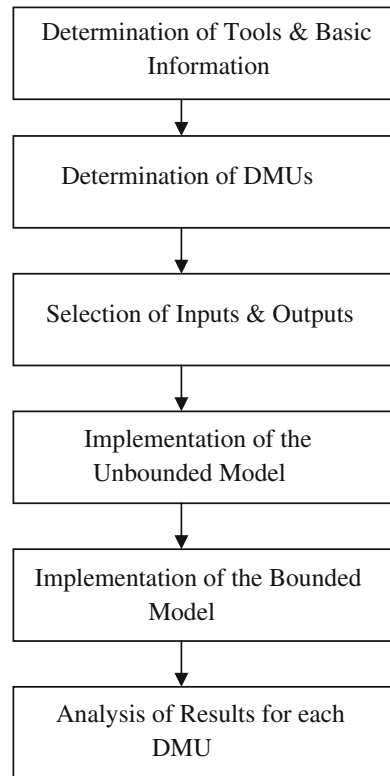
However, DEA models do have limitations that should be considered when deciding whether to use DEA. Because DEA is an extreme point technique, noise from sources such as measurement error can cause significant problems. Additionally, because DEA is a nonparametric technique, statistical hypothesis tests are difficult to perform and are thus the focus of ongoing research. Moreover, large problems can be computationally intensive because DEA generates a separate linear program for each DMU. However, there are software packages that facilitate the processing of large amounts of data (Cooper et al. 2000).

Furthermore, DEA has limitations in terms of aggregating different aspects of efficiency, especially when the DMUs perform multiple activities. Another problem is the insensitivity of DEA to intangible and categorical components.

Mixing different dimensions of the analysis is another limitation of DEA. For example, assume that a DMU is performing two different functions, where it may be efficient in the first function but inefficient in the second function. This problem can be resolved by two separate DEA models because the relevant inputs and outputs for each dimension are not directly comparable (Ramanathan 2003).

DEA does not specifically address absolute efficiency; instead, it provides information on how well the DMU performs compared with the efficient units but not compared with a theoretical maximum. This feature leads to two major issues. First, efficient units cannot be enumerated, and all of the efficient units have an efficiency score of 100 %. Second, from a managerial perspective, it may be more useful to compare branches to a frontier of absolute best performance. Efficient units may not be sufficiently efficient, and the created frontier may not reflect the real potential of the branch network. DEA is most useful in situations where it is not possible to loosely generate industry standards and thus an absolute frontier is not possible (Ramanathan 2003).

Recent trend topics in DEA are stochastic DEA (Jin et al. 2014; Tsionas and Papadakis 2010), multi-criteria DEA(Al-Shammari 1999; Köksalan and Tuncer 2009), super-efficiency models (Li et al. 2007), new application areas of classical DEA models (Jin et al. 2014), slack-based models (Chang and Yu 2014), fuzzy DEA (Azadeh et al. 2014) and multi-level DEA models (Wang et al. 2014).

Fig. 1 Stages of the study

```
┌─────────────────────────────┐
│ Determination of Tools & Basic │
│         Information          │
└─────────────────────────────┘
              │
              ▼
┌─────────────────────────────┐
│    Determination of DMUs     │
└─────────────────────────────┘
              │
              ▼
┌─────────────────────────────┐
│  Selection of Inputs & Outputs │
└─────────────────────────────┘
              │
              ▼
┌─────────────────────────────┐
│     Implementation of the    │
│       Unbounded Model        │
└─────────────────────────────┘
              │
              ▼
┌─────────────────────────────┐
│  Implementation of the Bounded │
│            Model             │
└─────────────────────────────┘
              │
              ▼
┌─────────────────────────────┐
│    Analysis of Results for each │
│             DMU              │
└─────────────────────────────┘
```

3 Data and analysis of results

This section describes a DEA model for the response and relief phases of the disaster management cycle following the Marmara and Düzce earthquakes. In this section, the efficiency of the organizations that took part in the established rescue effort categories is estimated and the results of the DEA implementation are analyzed. For each category, the DMUs and their relative efficiencies are determined. Target multipliers are determined to eliminate inefficiencies in the inefficient units using the unbounded model. Then, the bounded model is employed to remove some of the deficiencies of the unbounded DEA model.

As shown in Fig. 1, the study consists of six stages. The first stage is the determination of tools (software) and basic information about the application area. The second stage is the determination of evaluation categories and the designation of DMUs. The most important stage is the stage, inputs outputs selection. Then, DEA model implementation (stages 4 and 5). Finally, detailed efficiency analysis of each DMUs is obtained.

3.1 Data and determination of tools used in the study

The data used in the current study were obtained from official reports of the Turkish Prime Ministry Crisis Management Center (Başbakanlık Kriz Yönetim Merkezi, Depremler 2000). Figure 2 shows data structure of the study, and it consists of four columns. The first
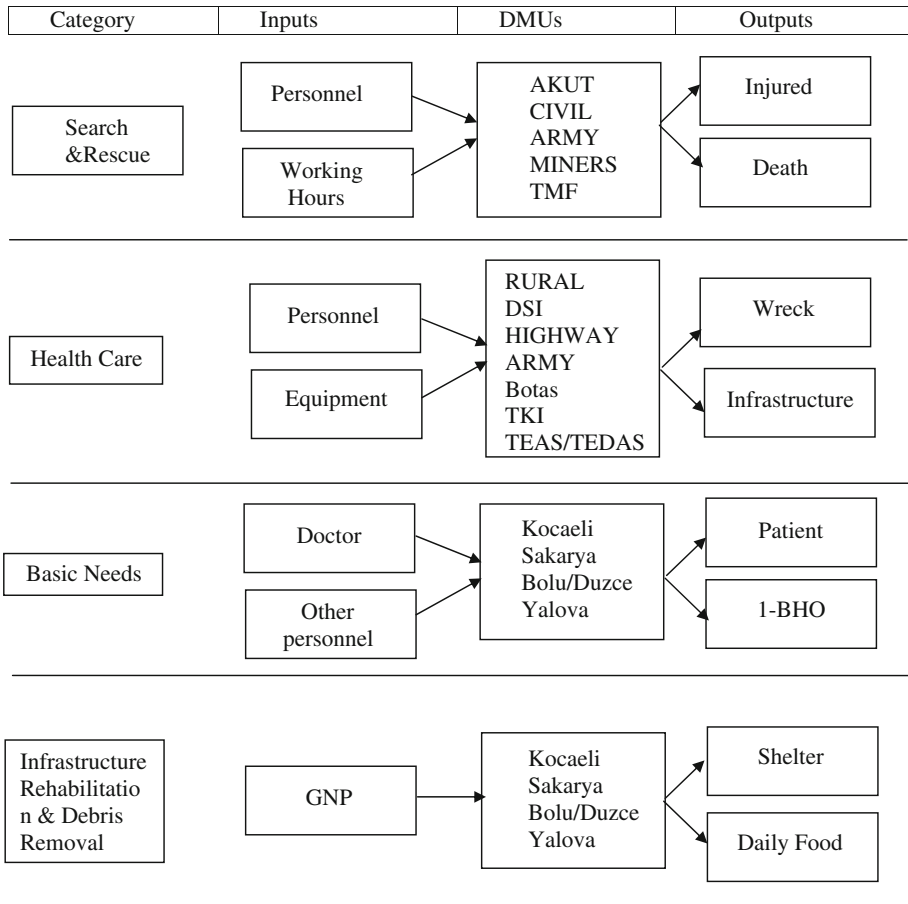
Category	Inputs	DMUs	Outputs

Fig. 2 Data structure

column shows category names of DMUs, whereas the columns 2 and 4 illustrate inputs and outputs, respectively. The third column presents DMU names in each category.

Determining the DMUs is an important stage in constructing a DEA model. The homogeneity rule should be applied during this stage. This rule states that the DMUs examined should be homogeneous; in other words, they should use the same types of resources and should produce the same types of outputs. Thus, in this study, the four-category structure of the response and relief for a disaster is constructed. The units in every group should obey the homogeneity rule. The DEA models are applied in accordance with this structure.

The main purpose of the organizations in the "search and rescue efforts" category is to search for and rescue people from collapsed and damaged buildings in the disaster area. In this category, the DMUs of the following five organizations were evaluated:

- Non-governmental search and rescue organization (AKUT)
- Civil Defense General Directorate (CIVIL)
- Turkish Army (ARMY)
- General Directorate of Turkish Coal Corporation (MINERS)
- Turkish Mountaineering Federation (TMF)

AKUT is an association of expert volunteers that was founded in 1996 with the mission to search for and rescue victims of disasters. Beginning in the early hours of the earthquake in the Marmara region, AKUT teams went to the site of the disaster and began work in Değirmendere, Gölcük, Adapazarı, Yalova and Izmit, where they expended considerable effort to save lives. The second organization in the search and rescue efforts group is the Civil Defense General Directorate, which was founded in 1959 and works under the Interior Ministry of Turkey. After the Marmara earthquake, all subdivisions of the Civil Defense General Directorate came to the earthquake area and began their search and rescue efforts. The Turkish Army joined in all relief activities for the 1999 earthquakes, including search and rescue, infrastructure rehabilitation, health care activities and providing for the basic needs of the people living in the disaster region. The two remaining organizations are the General Directorate of the Turkish Coal Corporation and the Mountaineering Federation. Although their primary aims are not related to "search and rescue" efforts, these organizations participated in the "search and rescue" activities in an organized manner following the 1999 earthquakes.

The main responsibility of the organizations in the "infrastructure rehabilitation and debris removal" category is to create a suitable infrastructure for the prefabricated and tented accommodations for residents who had lost their homes. These organizations were also responsible for removing debris and demolishing unsafe buildings. Seven governmental institutions were examined in this category:

- Ministry of Agriculture and Rural Affairs (RURAL)
- The General Directorate of State Hydraulic Works (DSI)
- The General Directorate of the State Highway Administration (HIGHWAY)
- Turkish Army (ARMY)
- State Natural Gas Company (BOTAS)
- State Coal Company (TKI)
- Turkish Electricity Company (TEAS/TEDAS)

The basic responsibilities of the DMUs in the "health care efforts" category are to provide medical assistance to the disaster victims and prevent epidemics among the population. In this group, the cities in the disaster region were considered to be DMUs. All of the hospitals, health care provisions and medical facilities constitute the health care efforts of the cities under the following local governments:

- Kocaeli Governorship
- Bolu/Duzce Governorship
- Sakarya Governorship
- Yalova Governorship

The responsibility of the DMUs in the "basic needs" group is to determine and provide for the basic needs of disaster victims. All of the cities in the disaster area were considered DMUs, and all of the efforts to provide, for example, food, water and shelter, were included in this group.

3.2 Selection of the inputs and outputs

Because DEA has not been implemented for disaster and risk management thus far, we determined the inputs and outputs for every group with respect to the missions of the organizations within each category (Table 2).

Table 2 Input and outputs

Category	Inputs	Outputs
Search and rescue	Personnel Working hours	Injured Death
Infrastructure rehabilitation and debris removal	Personnel Equipment	Wreck Infrastructure
Health care	Doctor Other personnel	Patient 1-BHO
Basic needs	GNP	Shelter Daily food

Two inputs and two outputs were employed for the "search and rescue efforts" group. Because the duty of the organizations in this group is to rescue people from damaged or collapsed buildings, our outputs are the number of people rescued and the number of fatalities. The first input is the number of personnel that participated in the search and rescue efforts. The second input is the working hours of the participants. The term "working hours" represents the time (in hours) spent on search and rescue efforts during the first 3 days of the disaster. A duration of 3 days was selected because the probability of people being rescued after an earthquake decreases over time.

The second group consists of those engaged in infrastructure rehabilitation and debris removal efforts. Because these organizations prepare suitable areas for tented and pre-fabricated accommodation, demolish damaged and collapsed buildings, and remove debris, the first output of this group is the number of buildings in the disaster area that are no longer habitable. The second output is the size of the area to be prepared for infrastructure (in acres). These two outputs are represented under the terms "wreck" and "infrastructure," respectively, in Table 2.

The inputs of this category are specified as the amount of equipment that was utilized and the number of personnel engaged in infrastructure rehabilitation, demolition and debris removal activities. Personnel and equipment are frequently used as inputs for other DEA applications in the literature.

The third category is health care efforts. DEA has been widely applied to health care field, and the number of doctors and number of other health care personnel are often taken as input values. Thus, it was appropriate to use these two measures as inputs in the current study.

Most studies applying DEA to the health care field have used the number of patients as an output measure; therefore, this measure was also used as an output in the current study in the third category. In addition, following disasters, disease can affect the population in the disaster region, which can lead to additional loss of life. Therefore, as a second output, 1-BHO (1 % of people contracting an epidemic disease) was used in the DEA model.

The last category is "providing for basic needs." The relative efficiencies of cities located in the disaster area are evaluated for their ability to provide for the basic needs of the population affected by the disaster. Based on the aim of the category, the city GNP is considered as an input because it is a good indicator of the level of development of the city, which is directly related to efficient disaster response management in regard to providing the victims of disasters with basic needs. The percentage of city population that have been provided with shelter and percentage of city population that have been provided with food on a daily basis daily are used as outputs.

Table 3 Results of the search and rescue efforts for unbounded model

DMU no.	DMU name	Efficiency	Sum of lambdas	Optimal lambdas with peers			
1	AKUT	0.53677	0.544	0.542	CIVIL	0.002	ARMY
2	CIVIL	1.00000	1.000	1.000	CIVIL		
3	ARMY	1.00000	1.000	1.000	ARMY		
4	MINERS	0.41251	0.385	0.353	CIVIL	0.032	ARMY
5	TMF	0.26216	0.153	0.153	CIVIL		

3.3 Unbounded model analysis

As explained in Sect. 2, the unbounded model (CCR model) was applied to assess the efficiency of the DMUs. The results of the unbounded model are presented in this section. The GAMS software package (www.gams.com) is used to solve the mathematical problem.

Table 3 is obtained from the solution of the unbounded model problem for the search and rescue efforts category. The third column presents the efficiency scores of the DMUs. The results indicate that there are two efficient and three inefficient units. The DEA efficiency scores can be interpreted as the amount of input that must be used. For example, AKUT has an efficiency score of 0.53677, which implies that this unit must reduce its inputs by 46.323 % to achieve an efficiency of 100 %.

Table 3 illustrates that the AKUT, MINERS and TMF units are inefficient. The aggregate efficiency of AKUT is 53.6 % in the CCR model. The efficiency score of TMF is 26.216 % and that of MINERS is 41.251 %. In contrast, ARMY and CIVIL have efficiencies of 100 % and are thus considered efficient units.

Table 3 also illustrates the reference groups of inefficient DMUs. CIVIL and ARMY are in the same group as AKUT and MINER. However, the reference set of TMF consists of only CIVIL. The DMUs in this reference set form the reference model for the inefficient units.

The fourth column presents the summation of the lambdas, which are the parameters in the dual model. For example, for AKUT, the sum of the lambdas is 0.544 (0.542 + 0.002). The dual parameters of the DMUs determine its peer set and indicate the contribution rate for achieving the efficient input and output measures for the inefficient DMUs. For instance, AKUT has a reference set consisting of two DMUs: CIVIL and ARMY. Because the dual parameters of CIVIL are greater than those of ARMY, the inputs and outputs of AKUT are similar to the multipliers of CIVIL. The last four columns provide the optimal lambda values, which are the reference models for the inefficient units.

The target inputs can be determined from Table 3 using their dual parameters:

$$I_{AKUT} = (0.542 * I_{CIVIL}) + (0.002 * I_{ARMY}) \tag{15}$$

$$I_{MINERS} = (0.353 * I_{CIVIL}) + (0.032 * I_{ARMY}) \tag{16}$$

$$I_{TMF} = (0.153 * I_{CIVIL}). \tag{17}$$

The target values can be generated from the dual model solution. Table 4 presents the target values of the DMUs. Because this model is input oriented, the input values should be lower for the inefficient DMUs, whereas the output values should be greater than or equal to the original value. For example, the original number of personnel for AKUT is 400; therefore, this value should be 215 for the unit to be considered efficient. In other words, 215 personnel were sufficient to rescue 218 people from the debris.

Table 4 Search and rescue efforts for unbounded model targets

DMU name	Efficient input targets		Efficient output targets	
	Personnel	Working hours	Injured	Deaths
AKUT	214.70930	37.84251	218	350.89548
CIVIL	218	69.50000	275	589
ARMY	39,000	71	27,852	12,794
MINERS	1,323.74024	26.81306	987.48906	617
TMF	33.29455	10.61455	42	89.95636

Table 5 Search and rescue efforts for unbounded model input/output weights

DMU name	Efficiency	Optimal weights			
		Personnel	Working hours	Injured	Death
AKUT	0.53677	0.00175	0.00425	0.00246	0
CIVIL	1.00000	0.00053	0.01271	0	0.00170
ARMY	1.00000	0.00003	0.00006	0.00004	0
MINERS	0.41251	0.00021	0.00501	0	0.00067
TMF	0.26216	0.00787	0	0.00624	0

The results of the primal unbounded model are presented in Table 5, where the second column indicates the efficiency score and the remaining columns provide the resulting input and output multipliers. As explained above, CIVIL and ARMY are determined to be efficient organizations. In contrast, AKUT, MINERS and TMF are considered to be inefficient because their efficiency values are <1.

The results did not determine the most efficient DMU, and some input and output weights were "zero" in the model (Table 5). The zeroes in the multipliers imply that some input/output measures are not utilized in the primal DEA model. However, these multipliers may be crucial to the evaluation of the efficiency scores of DMUs because a high efficiency score may arise from only one input, ignoring the other inputs. Therefore, bounded models should be used to overcome these deficiencies.

Search and rescue operations save people's lives in the consequences of large earthquakes. Fast, efficient and well-organized deployment and operations by search and rescue teams with expert skills and technology, especially within the initial 72 h, are crucial. As shown in the results, ARMY and CIVIL are efficient DMUs in our study. Having business discipline or military discipline in the organization, having adequately trained personnel, utilizing effective usage of resources and having dedicated efforts of the staff in the first 72 h of disaster are the common points of these DMUs. In other words, managements of efficient units complete their tasks in the least amount of time possible with the least amount of resources possible by utilizing their resources. We can say that these DMUs are more effective in search and rescue operations than the others. ARMY and CIVIL are reference set of the inefficient units.

The results of the "infrastructure rehabilitation and debris removal activities," "providing basic needs" and "health care efforts" unbounded models are presented in the tables in Appendix 1 (Tables 8, 9, 10, 11, 12, 13, 14, 15, 16).

Table 6 Search and rescue efforts for bounded model input/output weights

DMU name	Efficiency	Optimal multipliers			
		Personnel	Working hours	Injured	Death
AKUT	0.4641	0.002	0.001	0.001	0.00001
CIVIL	1	0.0055	0.001	0.00001	0.002
ARMY	1	0.00003	0.00001	0.00004	0.00001
MINERS	0.1579	0.0003	0.001	0.00001	0.0003
TMF	0.2616	0.008	0.0001	0.006	0.00001

3.4 Implementation of the bounded model

The weights of the inputs and outputs can take any non-negative value because the DEA has a weight flexibility property. However, this property results in issues in some cases. For example, important inputs or outputs may take on a zero weight or relatively less important variable weights may take on higher values. For the DEA analysis to be more realistic, there should be boundaries, called constraints, that limit the relative weight or importance of various inputs and outputs.

Wong and Beasley (1990), Dyson and Thanassoulis (1988), and Thompson et al. (1990) applied various schemes to restrict the relative size of the possible weights. The direct weight restriction method is used in this paper, as explained in Sect. 2. The bounded model was constructed by eliminating the zero values and unrealistic outliers. This approach will effectively limit the movement of the weights to a more realistic range and potentially improve the validity of the DEA analysis. The introduction of the constraints on the weights is expected to decrease the number of efficient DMUs.

The unbounded DEA model exhibits some deficiencies because of the zero values and outliers in the model. However, these deficiencies can be eliminated by adding new constraints. For the search and rescue efforts, the constraints given below are added to the original unbounded model. The bounded DEA model is then constructed, and solutions are obtained. Table 6 provides the results of this bounded model.

The new constraints are given as follows:

$$v(\text{``Personnel''}) \geq 0.00001 \tag{18}$$

$$v(\text{``Working Hours''}) \leq 0.0013 \tag{19}$$

$$v(\text{``Working Hours''}) \geq 0.0001 \tag{20}$$

$$u(\text{``Injured''}) \geq 0.00001 \tag{21}$$

$$u(\text{death}) \leq 0.0018 \tag{22}$$

$$u(\text{death}) \geq 0.00001. \tag{23}$$

As shown in Table 6, ARMY and CIVIL have an efficiency score of one and are thus considered efficient units; however, the remaining three units are inefficient. All of the zero values were eliminated using the bounded model approach. More realistic results can be obtained because all of the input and output values are considered in estimating the relative efficiencies of the DMUs.

Table 7 Search and rescue efforts for bounded model targets

DMU name	Efficient input target		Efficient output target	
	Personnel	Working hours	Injured	Death
AKUT	185.64	32.71905	218	350
CIVIL	218	69.5	275	589
ARMY	39,000	71	27,852	12,794
MINERS	506.7011	10.2635	103	617
TMF	33.2232	10.5918	42	86

A comparison of the results in Tables 5 and 6 illustrates the differences between the results of the unbounded and bounded DEA models. The scores of the efficient units are the same in both the unbounded and bounded model. However, the efficiency scores of the inefficient DMUs in the bounded model are lower than those in the unbounded version.

Adding new constraints also changed the results of the unbounded dual model. Table 7 presents the new targets of the input and output measures. The target values of the efficient units of CIVIL and ARMY did not change because these DMUs obtained an efficiency score of 1 with their input and output values. However, the target values of the three inefficient DMUs changed considerably. The outputs of MINERS produced by the original inputs in the unbounded model were obtained using the inputs of 507 personnel and 10.26 working hours in the bounded model. Moreover, the target value of personnel for AKUT decreased from 215 to 186, and the target values of the working hours decreased from 37.8 to 32.7. Furthermore, the TMF target values for the personnel and working hours are 33.22 and 10.59, respectively, in the bounded model; however, these values are 33.29 and 10.61, respectively, in the unbounded model.

The results of the "infrastructure rehabilitation and debris removal activities," "providing for basic needs" and "health care efforts" in the bounded models are presented in the tables in Appendix 2 (Tables 17, 18, 19, 20, 21, 22).

4 Conclusions and future research

This paper considered the analysis of efficiency in the response phases of the disaster management cycle following the 1999 The Marmara and Düzce earthquakes in Turkey using the DEA method. The unbounded and bounded models were used to evaluate organizations in the response and relief phases of the disaster management cycle following the 1999 Marmara and Düzce earthquakes. In this implementation, the activities during the relief and response phases were first divided into four groups: "search and rescue activities", "infrastructure rehabilitation and debris removal," "providing for basic needs" and "health care." Second, the DMUs were determined for every group and used in the unbounded DEA model. The efficient and inefficient DMUs were determined based on this model. Furthermore, improvements in the inefficient DMUs were discussed, and the relations required to achieve effective improvements were determined.

In the unbounded model implementation, some input and output weights take on zero values or are outliers. Such values are not realistic; therefore, the bounded model was considered to remove these unrealistic values.

Several weight restriction methods have been presented in the literature. This study used the direct restriction method as a weight restriction method. This method eliminates the zeroes and outliers in the weights. Therefore, the target weight multipliers of the inputs and outputs are determined, and the inefficiencies are eliminated in the inefficient DMUs.

As expected, one of the main results of this study is that the bounded model efficiency scores of the DMUs are lower than the efficiency scores in the unbounded model. Additionally, the number of efficient units in the bounded model is equal to or less than that in the unbounded DEA model. However, all of the input and output weights in the bounded model are considered; therefore, fairer and more accurate results are obtained in terms of the determination of the DMU efficiencies.

The high number of deaths and substantial property losses occurring from the 1999 Marmara and Düzce earthquakes were due in part to infective disaster management. Because Turkey is an earthquake-prone country, more devastating earthquakes may occur in the near future. We show that data envelopment analysis (DEA) is a useful tool for evaluating relief activities such as "search and rescue," "infrastructure rehabilitation and debris removal activities," "providing basic needs" and "health care efforts" after disasters.

To our knowledge, this study is the first to apply DEA to relief and disaster management. One of the contributions of this study to the enhancement of disaster management in Turkey is that it provides a way to determine the inefficient DMUs and the causes of their inefficiencies; therefore, these DMUs can take actions to address their inefficiencies and be better prepared for future disasters.

This study has focused on the response and relief phases of the disaster management cycle. However, the complete disaster management cycle, including the mitigation and preparedness phases, can be evaluated in future research. The loss of life and property can be reduced in future earthquakes by performing efficiency analyses for the mitigation and preparedness phases. Moreover, DEA can be applied to relief activities following other disasters, such as floods or hurricanes. Furthermore, the efficiency of the disaster management systems in countries, such as Japan and the USA, can be compared with the system in Turkey to highlight areas of potential improvement.

Appendix 1

See Tables 8, 9, 10, 11, 12, 13, 14, 15 and 16.

Table 8 Infrastructure rehabilitation activities dual model for unbounded model

DMU name	Efficiency	Sum of lambdas	Optimal lambdas with peers					
RURAL	0.93415	2.487	2.487	HIGHWAY				
DSI	0.30742	4.870	0.192	HIGHWAY	4.672	Botas	0.007	TKI
HIGHWAY	1.00000	1.000	1.000	HIGHWAY				
ARMY	0.81421	3.996	0.379	HIGHWAY	3.617	Botas		
Botas	1.00000	1.000	1.000	Botas				
TKI	1.00000	1.000	1.000	TKI				
TEAS/TEDAS	0.12303	0.129	0.059	HIGHWAY	0.069	TKI		

Table 9 Infrastructure rehabilitation activities for unbounded model targets

DMU name	Efficient input targets		Efficient output targets	
	Personnel	Equipment	Wreck	Infrastructure
RURAL	2,611.59574	2,027.09574	11,690	7,337.34043
DSI	529.07005	297.27527	1,183	3,000.00000
HIGHWAY	1,050	815	4,700	2,950.00000
ARMY	651.52184	417.68858	2,000	3,000.00000
Botas	70	30	60	520.00000
TKI	95	119	168	725.00000
TEAS/TEDAS	68.77382	56.52143	290	225.00000

Table 10 Infrastructure rehabilitation activities for unbounded model weights

DMU name	Efficiency	Optimal weights			
		Personnel	Equipment	Wreck	Infrastructure
RURAL	0.93415	0	0.00046	0.00008	0
DSI	0.30742	0.00051	0.00012	0.00009	0.00007
HIGHWAY	1.00000	0.00095	0	0.00016	0.00009
ARMY	0.81421	0	0.00195	0.00029	0.00008
Botas	1.00000	0.01298	0.00305	0.00240	0.00165
TKI	1.00000	0.01053	0	0.00174	0.00098
TEAS/TEDAS	0.12303	0.00179	0	0.00030	0.00017

Table 11 Providing basic needs dual model for unbounded model

DMU name	Efficiency	Sum of lambdas	Optimal lambdas with peers	
Kocaeli	0.42553	0.998	0.998	Sakarya
Sakarya	1.00000	1.000	1.000	Sakarya
Bolu/Düzce	0.75488	0.887	0.887	Sakarya
Yalova	0.66111	0.986	0.986	Sakarya

Table 12 Providing basic needs for unbounded model targets

DMU name	Efficient input targets	Efficient output targets	
	GNP	Shelter	Daily food
Kocaeli	3,191.89900	89.90000	63.82820
Sakarya	3,199.00000	90.10000	63.97020
Bolu/Düzce	2,836.84906	79.90000	56.72829
Yalova	3,152.84351	88.80000	63.04721

Table 13 Providing basic needs for unbounded model weights

DMU name	Efficiency	Optimal weights		
		GNP	Shelter	Daily food
Kocaeli	0.42553	0.00013	0.0047	0
Sakarya	1.00000	0.00031	0.011	0
Bolu/Düzce	0.75488	0.00027	0.00945	0
Yalova	0.66111	0.00021	0.00744	0

Table 14 Health care efforts dual results for unbounded model

DMU name	Efficiency	Sum of lambdas	Optimal lambdas with peers					
Kocaeli	1.00000	1.000	1.000	Kocaeli				
Sakarya	0.63985	0.999	0.107	Kocaeli	0.115	Bolu/Duzce	0.777	Yalova
Bolu/Duzce	1.00000	1.000	1.000	Bolu/Duzce				
Yalova	1.00000	1.000	1.000	Yalova				

Table 15 Health care efforts for unbounded model targets

DMU name	Efficient input targets		Efficient output targets	
	Doctor	Other health personnel	Patient	1-BHO
Kocaeli	617.00000	2,725.00000	19,508.00000	0.92068
Sakarya	254.65952	950.81419	7,452.00000	0.97275
Bolu/Duzce	188.00000	1,208.00000	5,670.00000	0.95209
Yalova	215.00000	670.00000	6,067.00000	0.98384

Table 16 Health care efforts weights for unbounded input-oriented model

DMU name	Efficiency	Optimal weights			
		Doctor	Other health personnel	Patient	1-BHO
Kocaeli	1.00000	0.002	0	0.00005	0
Sakarya	0.63985	0.002	0.00005	0.00008	0.063
Bolu/Duzce	1.00000	0.005	0.0001	0.00015	0.125
Yalova	1.00000	0.004	0.0001	0.00014	0.117

Appendix 2

See Tables 17, 18, 19, 20, 21 and 22.

Table 17 Infrastructure rehabilitation activities for the bounded model weights

DMU name	Efficiency	Optimal weights			
		Personnel	Equipment	Wreck	Infrastructure
RURAL	0.9306	0.00001	0.0000446	0.0000796	0.00001
DSI	0.3074	0.00051	0.00012	0.00009	0.00007
HIGHWAY	1.00000	0.00080527	0.00019	0.000149	0.000102
ARMY	0.8038	0.00001	0.002	0.00028	0.00008
Botas	0.1570	0.011	0.009	0.002	0.0001
TKI	0.3665	0.004	0.005	0.002	0.0001
TEAS/TEDAS	0.1183	0.002	0.00012	0.00033	0.0001

Table 18 Infrastructure rehabilitation activities for bounded model targets

DMU name	Efficient input targets		Efficient output targets	
	Personnel	Equipment	Wreck	Infrastructure
RURAL	2,601.671033	2,019.476	11,690	3,350
DSI	529.03563	297.3195	1,183	3,000
HIGHWAY	1,050	815	4,700	2,950
ARMY	643.1918731	412.345	2,000	3,000
Botas	10.99	4.707399	60	520
TKI	34.8175	43.47212	168	725
TEAS/TEDAS	66.12974808	54.348	290	225

Table 19 Providing basic needs group for the bounded model weights

DMU name	Efficiency	Optimal weights		
		GNP	Shelter	Daily food
Kocaeli	0.4233	0.00013	0.005	0.0001
Sakarya	1	0.00031	0.011	0.0001
Bolu/Düzce	0.7521	0.00027	0.009	0.0001
Yalova	0.6574	0.000209	0.007	0.0001

Table 20 Providing basic needs group for the bounded model targets

DMU name	Efficient input targets	Efficient output targets	
	GNP	Shelter	Daily food
Kocaeli	3,175.173	89.9	41.1848
Sakarya	3,199	90.1	63.9702
Bolu/Düzce	2,826.392	79.9	28.9472
Yalova	3,135.141	88.8	25.7562

Table 21 Health care activities group for the bounded model weights

DMU name	Efficiency	Optimal weights			
		Doctor	Other health personnel	Patient	1-BHO
Kocaeli	1	0.001	0.0001	0.00005	0.0001
Sakarya	0.6365	0.002	0.00001	0.00008	0.045
Bolu/Duzce	1	0.005	0.0001	0.00015	0.125
Yalova	1	0.00418	0.00015	0.00017	0.117

Table 22 Health care activities group for bounded model targets

DMU name	Efficient input targets		Efficient output targets	
	Doctor	Other health personnel	Patient	1-BHO
Kocaeli	617	2,725	19,508	0.92068
Sakarya	253.32	945.83	7,452	0.97275
Bolu/Duzce	188	1,208	5,670	0.95209
Yalova	215	670	6,067	0.98384

References

Al-Shammari M (1999) A multi-criteria data envelopment analysis model for measuring the productive efficiency of hospitals. Int J Oper Prod Manag 19(9):879–891

Azadeh A, Armin R-G, Mohsen M (2014) Location optimization of wind power generation–transmission systems under uncertainty using hierarchical fuzzy DEA: a case study. Renew Sustain Energy Rev 30:877–885

Başbakanlık Kriz Yönetim Merkezi, Depremler (2000) 1999, 17 Ağustos ve 12 Kasım Depremlerinden Sonra Bakanlıklar ve Kamu Kuruluşlarınca Yapılan Çalışmalar

Chang YC, Yu M-M (2014) Measuring production and consumption efficiencies using the slack-based measure network data envelopment analysis approach: the case of low-cost carriers. J Adv Transp 48(1):15–31

Charnes A, Cooper WW, Rhodes E (1978) Measuring the efficiency of decision making units. Eur J Oper Res 2(6):429–444

Charnes A, Cooper WW, Huang ZM, Sun DB (1990) Polyhedral cone-ratio DEA models with an illustrative application to large commercial banks. J Econ 30:91–107

Charnes A, Cooper WW, Lewin AY, Seiford LM (eds) (1994) Data envelopment analysis: theory, methodology, and application. Kluwer Academic Publishers, Boston, MA

Cooper WW, Seiford LM, Tone K (2000) Data envelopment analysis: a comprehensive text with models, applications, references and DEA-solver software. Kluwer Academic Publisher, Dordrecht

Dash U, Vaishnavi SD, Muraleedharan VR, Acharya D (2007) Benchmarking the performance of public hospitals in Tamil Nadu: an application of data envelopment analysis. J Health Manag 9:59. doi:10.1177/097206340700900104

Dyson RG, Thanassoulis E (1988) Reducing weight flexibility in data envelopment analysis. J Oper Res Soc 39:563–576

IMM IMM (2002) The study on a disaster prevention/mitigation basic plan in İstanbul including seismic microzonation in the Republic of Turkey

GAMS optimization software. www.gams.com

Jin J, Zhou D, Zhou P (2014) Measuring environmental performance with stochastic environmental DEA: the case of APEC economies. Econ Model 38:80–86

Khodabakhshi M, Asgharian M, Gregoriou GN (2010) An input-oriented super-efficiency measure in stochastic data envelopment analysis: evaluating chief executive officers of US public banks and thrifts. Expert Syst Appl 37(3):2092–2097

Köksalan M, Tuncer C (2009) A DEA-based approach to ranking multi-criteria alternatives. Int J Inf Technol Decis Mak 8(01):29–54

Korkmaz KA (2010) Integrated seismic hazard evaluation and disaster management approach for Turkey. Environ Earth Sci 61(3):467–476

Li S, Gholam RJ, Khodabakhshi M (2007) A super-efficiency model for ranking efficient units in data envelopment analysis. Appl Math Comput 184(2):638–648

Montoneri B, Lin TT, Lee CC, Huang SL (2012) Application of data envelopment analysis on the indicators contributing to learning and teaching performance. Teach Teach Educ 28(3):382–395

Özerdem A, Barakat S (2000) After the Marmara earthquake: lessons for avoiding short cuts to disasters. Third World Q 21(3):425–439

Özgen H, Şahin İ (2010) Measurement of efficiency of the dialysis sector in Turkey using data envelopment analysis. Health Policy 95(2–3):185–193

Ramanathan R (ed) (2003) An Introduction to data envelopment analysis: a tool for performance measurement. Sage, London

Saein, AF, Saen RF (2012) Assessment of the site effect vulnerability within urban regions by data envelopment analysis: a case study in Iran. Comput Geosci 48:280–288

Staub RB, Souza G, Tabak BM (2010) Evolution of bank efficiency in Brazil: a DEA approach. Eur J Oper Res 202:204–213

Thanassoulis E (2001) Introduction to theory and application of data envelopment analysis. Kluwer Academic Publishers, Norwell

Thompson RG, Langemeier LN, Lee CT, Thrall R (1990) The role of multiplier bounds efficiency analysis with application to kansas farming. J Econ 46:93–108

Tsionas EG, Papadakis EN (2010) A bayesian approach to statistical inference in stochastic DEA. Omega 38(5):309–314

Vijayakumar A (2012) Evaluating performance of banks through camel model: a case study of State Bank of India and its associates. Online Int Interdiscip Res J 2(4):104–124

Wei YM, Fan Y, Lu C, Tsai HT (2004) The assessment of vulnerability to natural disasters in China by using the DEA method. Environ Impact Assess Rev 24(4):427–439

Wang W-K, Wen-Min L, Pei-Yi L (2014) A fuzzy multi-objective two-stage DEA model for evaluating the performance of US bank holding companies. Expert Syst Appl 41(9):4290–4297

Wong Y, Beasley JE (1990) Restricting weight flexibility in data envelopment analysis. J Oper Res Soc 41:829–835