Available online at www.sciencedirect.com

SciVerse ScienceDirect

Procedia Engineering 26 (2011) 2270 – 2277

Procedia Engineering

www.elsevier.com/locate/procedia

First International Symposium on Mine Safety Science and Engineering

Evaluation of Safety Input-output Efficiency of Coal mine based on DEA Model

WANG Shu-ming[a] a*

[a]*Jinling Institute of Technology, Nanjing 211169, China*

Abstract

The fundamental improvement of the safety situation in mining of coalmine depends on the scientific decision making of safety input of the mining enterprise. For its objectivity, the data envelopment analysis (DEA) model is applied to evaluate the coalmine safety input-output efficiency comprehensively, and analyze the influence of the safety input factors on the safety output efficiency, such as the quantity, the structure, the time point, etc. The evaluation of DEA model can help the enterprise managers make a scientific decision and avoid the effect of subjective factors.

Selection and/or peer-review under responsibility of China Academy of Safety Science and Technology, China University of Mining and Technology(Beijing), McGill University and University of Wollongong.

Keywords: coalmine; safety input-output; data envelopment analysis model; efficiency; evaluation

1. Introduction

With the development of the social economy and the safety science, people began to realize that a certain input is necessary to reach the real safety in production, but the production can't be safety with a certain safety input. In fact, some coalmines have the ability and the desire of ensuring the safety input, and do this, but the safety output is not satisfied. The reason for this phenomenon is that the safety input awareness is not strong, the safety input quantity is not enough, the safety input decision making is not scientific and reasonable, etc. The unscientific safety input decision making will cause that the enterprise manager can't grasp the relationship between the safety input and the safety output, the safety input quantity is random, and the safety input direction is not accurate. The safety input decision making at the

* Corresponding author. Tel.: 18913806913; fax: 8625-86188975.
E-mail address: *xz_wsm@163.com*

doi:10.1016/j.proeng.2011.11.2434

low level not only can't achieve the expected effect of safety output and waste a large number of safety resources, but also make people disbelieve the effectiveness of the safety input. Studying the law of the safety input-output and finding the best radio of the safety input-output, will be good for improving the decision making level and the effect of the coalmine safety input, and make the coalmine safety improved remarkably.

2. DEA evaluation model

All figures should be numbered with Arabic numerals (1,2,...n). All photographs, schemas, graphs and diagrams are to be referred to as figures. Line drawings should be good quality scans or true electronic output. Low-quality scans are not acceptable. Figures must be embedded into the text and not supplied separately. Lettering and symbols should be clearly defined either in the caption or in a legend provided as part of the figure. Figures should be placed at the top or bottom of a page wherever possible, as close as possible to the first reference to them in the paper. In the productive and social activities, people often face this problem that after a period of operation, the departments or units (called decision making units, DMUs for short) of same type are need to evaluate according to the input data and the output data of the decision making units. The input data is the consumption quantity of decision making units in an activity, such as the total sum of input fund, the total sum of labor, etc. The output data is the information content produced by the input of decision making units and can reflect the effect of the activity, such as the quantity and the quality of the products of different types, the economic benefit, etc. Evaluation of relative effectiveness between the similar units (or departments), namely is to evaluate the advantages and disadvantages of the decision making units based on the input data and output data.

Data Envelopment Analysis (DEA for short) is a method for evaluating the relative effectiveness between the similar units (or departments) to do the decision making, also is a effective technique used for measuring the relative performance of organizational units where the presence of multiple inputs and outputs makes comparisons difficult. DEA method in use is that a group of organizational DMUs is selected, a group of evaluating indexes also is chosen, then the mathematical programming model is applied to calculate, the measure of efficiency is expressed in the form of score, the relative efficiency of DMUs is compared, finally the effective DMUs are chosen, the reasons and the degrees of the ineffective DMUs are also ensured.

Without analyzing the association between input and output relations, without assumption of any weights, having obvious objectivity, and avoiding the effect of subjective factors, for these advantages, researchers in a number of fields have quickly recognized that DEA is an excellent and easily used methodology for performance evaluations. DEA has been applied are: US Air Force wings, defense bases, cities, business firms, banks, and others. At present, DEA method can be applied in the new field gradually and successfully. DEA also is used to evaluate the relative performance of multiple plans or cases, such as evaluation of investing plans, and used to forecast the relative performance of the decision before making.

Data envelopment analysis (DEA) model, occasionally called CCR model, was first put forward by A.Charnes, W. W. Cooper and E. Rhodes in 1978. The basic steps of DEA are as follows.

There are n decision making units (DMU_j, $1 \leqslant j \leqslant n$), and the corresponding input and output vectors of DMU_j are:

$$x_j = (x_{ij}, x_{2j}, \cdots, x_{mj})^T > 0, j=1,2,\cdots,n \tag{1}$$

$$y_j = (y_{1j}, y_{2j}, \cdots, y_{sj})^T > 0, j=1,2,\cdots,n \tag{2}$$

And $x_{ij}>0$, $y_{rj}>0$ (where i=1,2,⋯,m, and r=1,2,⋯,s)

$$\max \mu^T y_0 = h_0$$
$$\text{s.t.}\ \omega^T x_j - \mu^T y_j \geq 0,\ j = 1,2,\cdots,\ n$$
$$\omega^T x_0 = 1$$
$$\omega \geq 0, \mu \geq 0$$

Normally the information structure between input and output is poorly understood, the alternative substitutability between input and output is complex, and avoiding the effect of subjective willing, so the weight of input (v) and the weight output (u) are not given in advance, the input and output is taken as the variable vectors, and the value of which is calculated according to a principle. It is shown in Fig.1. And $v = (v_1, v_2, \cdots., v_m)^T$, $u = (u_1, u_2, \cdots, u_m)^T$.

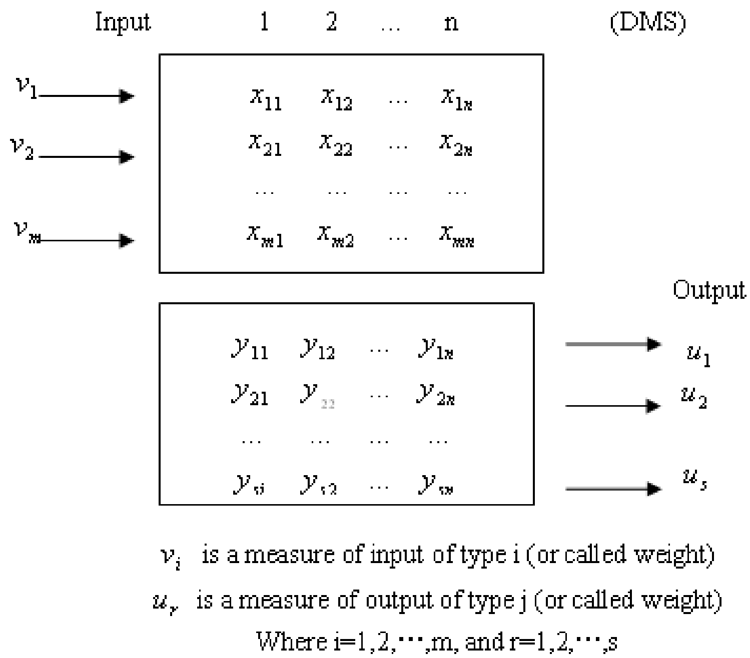

Fig.1. Schematic diagram of Input and Output of DMU

The relative efficiency index of DMU_j is h_j.

$$h_j = \frac{\sum_{r=1}^{s} u_r y_{ri}}{\sum_{i=1}^{m} v_i x_{ij}},\ j=1,2,\cdots\cdots,n \tag{3}$$

$$max\ \mu^T y_0 = h_0$$

$$s.t.\ \omega^T x_j - \mu^T y_j \geq 0,\ j = 1,2,\cdots,\ n$$

$$\omega^T x_0 = 1$$
$$\omega \geq 0, \mu \geq 0$$

For evaluating the effect of DMU_{jo}（$1 \leqslant j_o \leqslant n$）, the best model is established in (4) as follows.

$$(C^2R)\begin{cases} \max hjo = \dfrac{\sum_{r=1}^{s} u_r y_{rjo}}{\sum_{i=1}^{m} v_i x_{ijo}} \\ s.t.\dfrac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1, j = 1,2,\ldots\ldots,n \\ V \geq 0, U \geq 0 \end{cases} \quad (4)$$

The matrix form of the model is shown in (5) as follows.

$$C^2R\begin{cases} \max \dfrac{U^T Y_{j_o}}{V^T X_{j_o}} \\ s.t.\dfrac{U^T Y_j}{V^T X_j} \leq 1, j = 1,2,\ldots\ldots,n \\ V \geq 0,\ U \geq 0 \end{cases} \quad (5)$$

If $t = \dfrac{1}{v^T x_0}$ $,\omega = tV,\ \mu = tU$, the equivalent Linear programming model of the model (5) is given in (6) by Charnes-Cooper conversion.(For convenience, and j_0 is 0, the same below)

$$(P)\begin{cases} \max \mu^T y_0 = h_0 \\ \text{s.t.}\ \omega^T x_j - \mu^T y_j \geq 0,\ j = 1,2,\cdots,\ n \\ \omega^T x_0 = 1 \\ \omega \geq 0, \mu \geq 0 \end{cases} \quad (6)$$

In order to facilitate the discussion and application, the slack variable S^+ and the remaining variable S^-, According to linear programming duality theory, (P) dual programming model is:

$$(D)\quad \begin{cases} \min\theta \\ \text{s.t.} \sum_{j=1} \lambda_j + s^- = \theta x_0 \\ \sum_{j=1}^{n} \lambda_j y_j - s^+ = y_0 \\ \lambda_j \geq 0, j = 1,2,\cdots,n \\ s^+ \geq 0, s^- \geq 0 \end{cases} \tag{7}$$

(D) is a linear programming, and is the dual programming of (P). The linear programming and the dual programming, all can be used to test the effectiveness of DEA, but the calculation amount for testing are more, so we can calculate by means of the professional software such as LINGO, LINDO, DEAP, etc.

3. Empirical Analysis

1996 ~ 2005 annual safety input and output results of is Jiahe coalmine in Xuzhou, is selected as a decision making unit of DEA. And select the total annual safety input (safety technology measures costs before 2005, the safety production costs in 2005), safety input of tons of coal, safety engineering input, safety equipment input, safety technology input, safety management input and other six indexes as input variables. Select the accident rate, raw coal yield in Jiahe mine as output variables [4] (see Table 1).

Table 1. Input and Output Indexes Value of Different Making Decision Units

Years	Safety input per year(*10,000 Yuan*)	Safety input of a ton coal (*Yuan/T*)	Safety engineering input(*10,000 Yuan*)	Safety equipment input(*10,000 Yuan*)	Safety technology input(*10,000 Yuan*)	Safety management input(*10,000 Yuan*)	Accident rate(*injured persons per million ton*)	Coal output(*10,000 ton*)
1996	81.80	0.75	44.00	25.00	5.00	7.80	1.08	112.20
1997	92.30	0.82	50.50	13.30	13.50	15.00	1.98	108.50
1998	99.70	0.92	65.00	16.60	8.00	10.10	3.29	107.80
1999	89.10	0.83	40.00	35.05	8.00	6.05	5.52	133.60
2000	79.56	0.60	47.00	19.56	8.00	5.00	2.70	138.90
2001	112.82	0.81	53.00	28.82	25.00	6.00	5.92	164.40
2002	164.00	0.94	62.20	54.80	25.00	22.00	5.58	174.40
2003	183.55	1.15	124.00	20.95	28.00	10.60	2.04	159.50
2004	178.75	1.09	105.50	23.25	30.00	20.00	0.15	164.10
2005	517.10	3.52	361.00	77.00	58.70	20.40	4.24	146.80

The data in Table 1 explanation:

Considering the safety output benefit of lag, the delay period is one year. That each decision unit. The accident rate, the output of raw coal and other indexes are presented the following year data. Decision-making unit in 1996, the input variables(the total annual safety input, safety input of tons of coal, safety engineering input, safety equipment input, safety technology input, safety management input) are presented the data this year, the output variables (the accident rate, the output of raw coal) for the 1997 data. Considering the caliber of data consistency, comparability, the number of deaths, the number of serious injuries, minor injuries converted into the number of minor injuries by the number of 1:29:300[5]. Jiahe mine from 1996 to 2005, the toll conversion results as shown in table 2.

Table 2. Statistics of Industrial Injuries of Jiahe Coalmine in 1996～2007(Unit: *Person*)

Years	Deaths	Serious injuries	Minor injuries	Classification of accidents								Subtotal	Conversion value
				Roof accident	Gas accident	Mechanical and Electrical accident	Transport accident	Blasting accident	Water accident	Fire accident	Other accident		
1996	1	7	27	10		1	14				10	35	399.41
1997	0	9	28	9		0	13				15	37	121.10
1998	0	17	39	13		0	10	2			31	56	214.86
1999	1	4	13	3		9	4	1			1	10	354.38
2000	2	9	44	12		2	11				30	55	737.10
2001	1	4	34	6		3	5	1			24	39	375.38
2002	3	5	21	6		3	12				8	29	972.72
2003	1	1	15	4			4	2			7	17	325.34
2004	1	1	9	1			4				6	11	319.34
2005	0	2	4	2		1	1				2	6	24.69
2006	2	2	2	1			2				3	6	622.69

The data in table 1 is using by LINGO9.0 software for the corresponding operation, the results shown in table 3.

Table 3. Comparative Evaluation Results of Safety Input-Output Effect of Jiahe Coalmine

Years	θ（Relative efficiency）	Conclusion
1996	1.0000	DEA effective, returns to scale constant
1997	1.0000	DEA effective, returns to scale constant
1998	0.8984	Non-DEA effective, returns to scale diminishing
1999	1.0000	DEA effective, returns to scale constant
2000	1.0000	DEA effective, returns to scale constant
2001	1.0000	DEA effective, returns to scale constant
2002	0.9093	Non-DEA effective, returns to scale diminishing
2003	1.0000	DEA effective, returns to scale constant
2004	0.9999	Non-DEA effective, returns to scale diminishing
2005	0.2678	Non-DEA effective, returns to scale diminishing

Table 3 shows that in 1998, the mine safety input and output effect of the evaluation results relative to non-DEA efficient, decreasing returns to scale. Because of its coal production has declined over the previous year, while the accident rate increases over the previous year. Through the analysis of the efficiency of each input index (shown in table 4), the years of each input indicators only safety management investment efficiency over a year earlier, was 0.7220, while the other input index of efficiency are relatively on year rise or flat. Therefore, to improve the mine safety input output effect, must be thoroughly analyzed the years safety management investment efficiency decline reason, and makes the corresponding adjustment.

In 2002, the mine safety input and output effect of the relative evaluation result is relatively non-DEA efficient, decreasing returns to scale. The coal production over the last year has increased, and the accident rate decreased, but the output of raw coal increased the amplitude and the decrease in accident rates relative to the rate of increase of safety input is not the relative said. In 2005, the mine safety input and output effect of the relative evaluation results not only non-DEA efficient, decreasing returns to scale, but the overall relative efficiency is only 0.2678.The reason is obvious: although the safety input increases substantially, but the accident rate has increased dramatically, and the output of raw coal has declined over the previous year. From the beginning of 2005, the national coal mine performed "the cost of coal extraction and use of production safety management approach", the mine is also in accordance with the provisions of the safe extraction cost, so the safety input gross increases substantially, but the safety input did not play its due role.

Thus the quantity of coal mine safety input increase, the efficiency of safety input and output can't increase accordingly. The structure and the time of safety input are also affecting the safety input and output efficiency of the important factors. So mine should be considering their own situation, the scientific and reasonable safety input is decision-making, in determining the total amount of safety input, but also special attention to input direction choice, input structure arrangement and input time grasp. Only in this way, can improve the efficiency of the safety input-output maximize the effectiveness of safety investment.

Table 4. Efficiency of Safety Input-Output Indexes of Jiahe Coalmine in 1996～2005

Years	Safety input per year	Safety input of a ton coal	Safety engineering input	Safety equipment input	Safety technology input	Safety management input	Accident rate	Coal output
1996	1.0000	0.8318	0.5329	0.1457	0.9994	0.2542	0.2433	0.7908
1997	0.6321	1.0000	0.8681	0.5471	1.0000	0.7945	0.4382	1.0000
1998	0.6662	1.0000	0.8984	0.5617	1.0000	0.7220	0.4430	0.8736
1999	1.0000	0.4994	0.6387	1.0000	1.0000	0.5243	0.4888	0.3723
2000	0.6321	1.0000	0.8681	0.5471	1.0000	0.7945	0.4382	1.0000
2001	0.8147	0.7729	0.5986	0.9587	1.0000	1.0000	0.8036	0.4815
2002	0.8227	0.6951	0.5454	1.0000	1.0000	1.0000	0.9093	0.4596
2003	0.7055	1.0000	0.7835	0.4383	0.9998	0.6429	0.3867	1.0000
2004	1.0000	0.8318	0.5329	0.1457	0.9994	0.2542	0.2433	0.7908
2005	0.6219	0.9181	0.8301	0.5499	1.0000	0.8144	0.4301	1.0000
Average	0.7895	0.8549	0.7097	0.5894	0.9999	0.6801	0.4825	0.7769

From table 4 can still be seen, over the years, Jiahe mine safety technology into the relatively high output efficiency, an average of 0.9999, the basic play its due role. Safety of equipment input and safety management input of output efficiency are low, average respectively 0.5894 and 0.6801, input in safety equipment, especially the worst. Therefore, the mine should analyze the reasons for this situation and take appropriate measures to improve the safety equipment and safety management of input-output efficiency.

4. Conclusions

Mine safety depends on the input-output efficiency of investment in a reasonable degree of safety. When the reasonable safety input, output would tend to secure a large, secure input and output efficiency is high. Conversely, a mine safety input-output efficiency is high, often indicates that the mine safety input is reasonable. The quantity of the safety input increased, but the performance of safety input-output not increased accordingly. The structure and the time of safety input also are affecting the safety input and output efficiency of the important factors. So mine should be considering their own situation, the scientific and reasonable safety input is decision-making, in determining the total amount of safety input, but also special attention to input direction choice, input structure arrangement and input time grasp. The efficiency of safety input-output can be improved in this way only.

Acknowledgements

These and the Reference headings are in bold but have no numbers. Text below continues as normal. Safety Technology Project of Jiangsu Province(2010-49).

References

[1]Du Dong. *Modern Comprehensive Evaluation Method and Case Selection* [M]. Beijing : Tsinghua University press, 2005.(in Chinese)

[2]Wu Wen-jiang. *Data Envelopment Analysis and Its Applications*[M]. Beijing : China Statistics Press, 2002.(in Chinese)

[3]Long Ru-yin. Mining city sustainable development theory and method research[D]. Doctoral Dissertation of China University of Mining and Technology.2005,05. (in Chinese)

[4] Wang Shu-ming, He Xue-qiu, Wang En-yuan. Screening and Determination of Comprehensive Evaluation Indexes about Safety Input in Coal Mine[J].Journal of Xuzhou Institute of T echnology(Natural Sciences Edition), 2009,24(4):5-9. (in Chinese)

[5] Wang De-ming. Calls for protection of Mine Safety Technology[EB/OL]. http://news.sina.com.cn/0/2004-10-26/06264035217s.shtml