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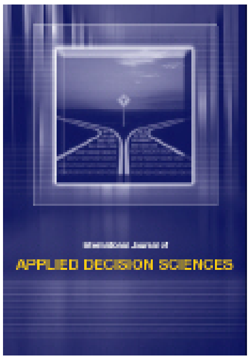

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A DEA-based decision framework for performance evaluation and ranking of workers in a real case from food industries

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Abstract: In this study, a performance evaluation problem of operational employees in a real case study is considered. The case study is a firm from the food industries where different tomato pastes are produced. In addition, after performance evaluation of the employees, they are ranked based on their performances. As the main contribution of this study, a real-world problem from food industries is focused on and solved by optimisation-based approaches. For this aim, the most important criteria from the literature such as salary, work conditions, responsiveness, motivation, and productivity are selected. A decision framework based on data envelopment analysis (DEA) is used. For this aim, the Russel DEA model is used as the first stage to evaluate the performance of each operational worker (DMU) by determining efficient and inefficient DMUs. As the second stage, an Anderson-Peterson approach based on a modification of the Russel model is proposed to rank the DMUs based on their performances. Finally, based on the obtained results, some comparisons with the other DEA models of the literature is performed and the managerial insights are presented.

Keywords: food industry; performance evaluation; performance ranking; data envelopment analysis; DEA; Russel model.

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Biographical notes: Sadegh Niroomand is an Associate Professor of Industrial Engineering in Firouzabad Institute of Higher Education in Iran. He received his PhD in Industrial Engineering from Eastern Mediterranean University, in Turkey in 2013. His research interests are operations research, fuzzy theory, exact and meta-heuristic solution approaches.

1 Introduction

In recent competitive production market, the organisations need to be more updated and productive. Producing more amount of products from the available raw material and other resources will help a manufacturing organisation to remain in the market and

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continue its business successfully. This issue can not be reached without productive operational workers in any organisation. Therefore, performance of the employees of a manufacturing organisation especially the operational workers can be very important for the managers in order to maintain and improve overall performance of the organisation. As a very important, complex, and difficult issue, the managers need to evaluate performance of the employees. Such evaluation may help them for further decisions on the issues such as operational plans, laying off the existing employees, hiring new employees, etc. Such evaluation usually is done considering various criteria and factors. For an employee, the criteria such as salary, working hours per working shift, overtime working hours, job satisfaction, motivation, work conditions, productivity, etc. can be of the important factors that affect his/her performance. Therefore, these factors can be used to evaluate the performance of an employee in any organisation.

Further than the considered criteria for performance evaluation of the employees, the decision making method for obtaining such performance is very important. As there are many mathematical and experimental methods available for this aim, use of tow optimisation based approaches such as multi-criteria decision making (MCDM) approaches, and data envelopment analysis (DEA) models can be very effective. In both methods, the employees are considered as decision making units (DMUs) and are evaluated based on the existing criteria.

In this subject, the literature is full of interesting and application based studies. Some related studies of the literature are reported here. Boles et al. (1995) focused on salesperson evaluation considering relative performance efficiency as an application of DEA. Narasimhan et al. (2001) performed an empirical study to evaluate suppliers by DEA models. Paradi et al. (2002) applied a DEA based approach to evaluate performance of the engineering design teams for the case of Bell Canada. Feng et al. (2004) combined AHP approach and DEA for measurement of the efficiency of R&D management activities in universities. Paradi and Schaffnit (2004) applied a DEA based approach for commercial branch performance evaluation and results communication in banking sector of Canada. Chen and Chen (2007) used a DEA approach based on BSC indicators for evaluating performance in semiconductor industry. Manoharan et al. (2009) applied DEA for employee performance evaluation. They applied the DEA model on a real case problem. Wu (2009) proposed an integrated method consists of DEA and fuzzy preference relations for performance evaluation purpose. Zeydan and Çolpan (2009) proposed a new decision support system by combining fuzzy TOPSIS and DEA approaches for performance measurement. Osman et al. (2011) proposed a DEA model for evaluating the appraisal and relative performance of nurses at an intensive care unit. Shirouyehzad et al. (2012) proposed a DEA approach to measure the efficiency of employees. They solved a real case for model verification and validation. Zha et al. (2012) proposed a two-stage DEA approach with feedback for evaluating team performance. Tavana et al. (2013) proposed a new network epsilon-based DEA model in order to evaluate supply chain performance. Shafiee et al. (2014) evaluated supply chain performance using a combination of DEA and balanced scorecard approaches. Azadi et al. (2015) proposed a new fuzzy DEA model in order to evaluate efficiency and effectiveness of suppliers in sustainable supply chain management. Dotoli et al. (2015) proposed a cross-efficiency fuzzy DEA technique in uncertain environment in order to evaluate performance of DMUs. Monika and Mariana (2015) applied DEA to performance evaluation and controlling human resources. Wang and Feng (2015) in their study focused on performance evaluation of the energy, environmental, and economic efficiency and productivity in China considering an application of global DEA. Jablonsky (2016) applied DEA for efficiency analysis in multi-period systems. He applied his methodology to evaluate performance in Czech higher education. Akhavan Kharazian et al. (2017) applied DEA for performance evaluation of knowledge workers at R&D department in outsourcing conditions. Zeng et al. (2019) applied DEA to evaluate performance of warehouse operators in E-commerce enterprises. Goswami and Ghadge (2020) proposed decision framework based on single and bi-objective DEA efficiency modelling approach from individual and cross-efficiency perspective for supplier performance evaluation. Shao et al. (2021) proposed a SBM-DEA based performance evaluation and optimisation approach for social organisations participating in community and home-based elderly care services. Biswas et al. (2022) proposed a multi-criteria based analytic framework for exploring the impact of COVID-19 on firm performance in emerging market. Goodarzi et al. (2022) proposed an integrated multi-criteria decision-making and multi-objective optimisation framework for green supplier evaluation and optimal order allocation under uncertainty. Heesche and Bogetoft (2022) studied incentives in regulatory DEA models with discretionary outputs for the case of Danish water regulation. İç et al. (2022) applied an integrated AHP-modified VIKOR model for financial performance modelling in retail and wholesale trade companies. Luo et al. (2022) applied a three-stage network DEA approach in order to evaluate performance of BIM application in construction projects. Deretarla et al. (2023) proposed an integrated analytic hierarchy process and complex proportional assessment for vendor selection in supply chain management. Chakrabortty et al. (2023) proposed a multi-criteria decision analysis model for selecting an optimum customer service chatbot under uncertainty. Bánhidi and Dobos (2023) applied DEA model for ranking digital development in the countries of the European Union without explicit inputs and common weights analysis. Debnath et al. (2023) introduced an integrated stepwise weight assessment ratio analysis and weighted aggregated sum product assessment framework for sustainable supplier selection in the healthcare supply chains. Önden et al. (2023) applied a spatial multi-criteria decision-making model for planning new logistic centres in metropolitan areas. Wang and Rogge (2023) introduced a two-stage data envelopment model for evaluating the exchange efficiency of the imports and exports in a railway supply chain network. Lahmiri (2023) performed a comparative study of statistical machine learning methods for condition monitoring of electric drive trains in supply chains. A novel grey multi-objective binary linear programming model for risk assessment in supply chain management was proposed by Vafadarnikjoo et al. (2023). Huiliang et al. (2022) performed an interesting research on human resource performance evaluation of furniture enterprise based on DEA. For more applications of DEA the studies such as Ren et al. (2022) and Khan et al. (2023) can be referred. For more engineering based evaluation studies, Taassori et al. (2016), Niroomand et al. (2016), Tavana et al. (2018), Niroomand et al. (2019a), Mahmoodirad et al. (2019), etc. can be referred.

In this study a performance evaluation problem of operational employees in a real case study is considered. The case study is a firm from food industries of Iran where different tomato pastes are produced there. As additional study, further than performance evaluation, in this study the operational employees need to be ranked based on their performances. As the main contribution of this study, a real-world problem from food industries is focused and solved by the optimisation-based approaches. For this aim, the most important criteria from the literature such as salary, work conditions, responsiveness, motivation, and productivity are selected. Furthermore, 19 operational workers from the production line of the firm are selected for evaluation purpose where all of them are working in similar conditions and handling manual tasks. A decision framework based on DEA is used to perform the evaluation and ranking decisions. For this aim the Russel DEA model is used as the first stage to evaluate the performance of each operational worker as a DMU by determining efficient and inefficient DMUs. As the second stage of the proposed decision framework, an Anderson-Peterson approach based on a modification of the Russel model is used to rank the DMUs (operational workers) based of their performances. Finally, based on the obtained results, some comparisons with the other DEA models of the literature is performed and the managerial insights are presented.

The paper is organised in some other sections. Section 2 describes the performance evaluation problem, considered criteria, and the data of the case study. Section 3 describes the proposed decision framework as a solution methodology. Section 4 represents the obtained results. Section 5 includes concluding remarks.

2 Problem description and case study

As mentioned earlier performance evaluation in manufacturing environments can be considered as a useful managerial tool for progressing and developing the organisational goals. In this study, performance evaluation and ranking of the operational operators of a real case from food industries are considered. For this aim, the Arman Gasempoor firm (known as Mehran Javid Sivand) located in Sivand, Marvdasht, Fars province, Iran. This firm is of food industries which produces different tomato pastes. As, performance of the operational workforces of this firm should be assessed and ranked according to some indexes, in the rest of this section the operational workforces and the considered indexes are explained.

2.1 Operational workforces

According to idea of the managers of the firm, the operational workforces in the production line of the firm are considered for performance evaluation and ranking purposes. It is notable to mention that, there workers are all homological, meaning that they are working in a common place of the firm, and all are performing manual tasks. The number of workers is 19, where all of them are in normal and healthy physical conditions.

2.2 Indexes considered for performance evaluation

In order to evaluate and rank the operational workforces of the mentioned firm, according to the literature, the below indexes are considered.

- salary
- work conditions
- responsiveness

- motivation
- productivity.

These indexes are explained by the rest of this section.

- Salary is the net monthly wage paid by the firm to each of the operational workforce. It is measured by the unit of Rials. The salary of last month before performing the study is considered in this study. This indexes earlier has been considered by Shirouyehzad et al. (2012), Monika and Mariana (2015), etc. for performance evaluation.
- Work condition shows how difficult is the work performed by each of the operational workforce. This index is depended on difficulty of the performed task, physical conditions of the workplace, temperature, humidity, etc. this index earlier has been determined for each employee by the firm. According to data of the firm, the value of this index varies from 1 to 9 where the value of 9 shows the most difficult condition.
- Responsiveness is of the main criteria which affect the performance of manual workers in production environments (see Shirouyehzad et al. (2012)). It can be mentioned that the people with higher responsiveness have better performance comparing to others. In production environment, responsiveness of the workers can be realised and measured from the way that performing their tasks and their carefulness in getting results by performing the tasks. In this study the responsiveness of each operational worker is determined by the managers of the firm where its scale is from 0 to 100%.
- Motivation is another index which widely has been used for performance evaluation purposes. Motivation of the employees is of the necessary factors for a successful organisation. Earlier the motivation of the operational workforces of the firm has been determined by the method of Hackman and Oldham (1976) and Kim (2006) by the managers. Therefore, the available data for motivation of the operational workers are used in this study to evaluate their performance.
- Productivity is a factor that widely has been used for performance evaluation in the literature (Monika and Mariana, 2015). It can be represented as the amount of work performed by each operator in a considered period of time, or even the amount of work a worker performs comparing to standard performance (as a percentage). In this study productivity of each operational workforce of the firm that has been determined by the managers are used to analyse their performance.

2.3 Data

According to the operational workforces of Section 2.1 and the factors considered by Section 2.2 the data of the operational workforce performance evaluation of the case study is represented by Table 1. In this study the workers are shown by numbers instead of their names.

Table 1 The data used for performance evaluation.

Operational personnel	Factors				
	Salary (Rials)	*Work conditions (out of 10)*	*Responsiveness (out of 1)*	*Motivation (out of 1)*	*Productivity (out of 1)*
OP1	72000000	6	0.90	0.50	0.82
OP2	63200000	6	0.80	0.54	0.81
OP3	78800000	9	0.70	0.71	0.66
OP4	60400000	6	0.80	0.64	0.80
OP5	78200000	8	0.70	0.79	0.74
OP6	62400000	6	0.70	0.70	0.73
OP7	71000000	9	0.70	0.70	0.83
OP8	64400000	7	0.70	0.66	0.84
OP9	69200000	7	0.90	0.55	0.74
OP10	76600000	6	0.80	0.62	0.76
OP11	60200000	6	0.70	0.53	0.77
OP12	65200000	7	0.90	0.63	0.72
OP13	72600000	6	0.90	0.68	0.83
OP14	61400000	9	0.70	0.74	0.83
Op15	65600000	6	0.80	0.51	0.79
OP16	66600000	6	0.90	0.54	0.80
OP17	78400000	7	0.80	0.54	0.68
OP18	62200000	7	0.70	0.74	0.69
OP19	66000000	6	0.80	0.52	0.84

3 DEA-based decision framework

In this section, the performance evaluation and ranking problem described in previous section is formulated and solved. In order to decide about formulation of the problem, first of all nature of the considered factors should be discussed. The considered factors of Section 2.2 can be divided to two types. Among these factors, the factors such as

- salary
- work conditions
- responsiveness

can be considered as input factors that can affect performance, but the factors such as

- motivation
- productivity.

can be considered as output factors that influenced by the input factors and also affect performance. Therefore, the schematic relations of Figure 1 can be obtained for each operational workforce.

Figure 1 The input and output factors affecting performance of the workers (see online version for colours)

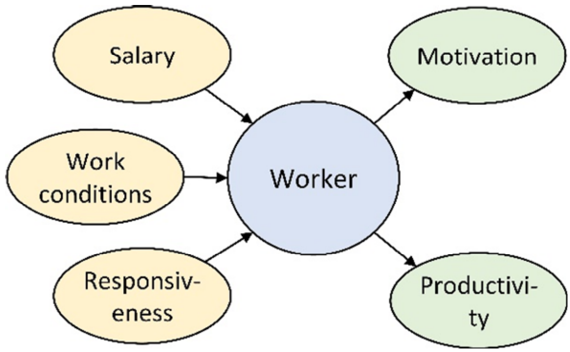
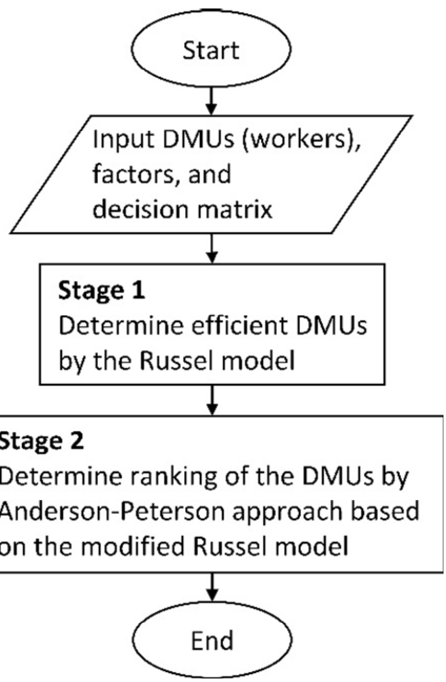


Figure 2 Flowchart of the proposed solution approach



Based on the explanations of Section 2 and categories of the factors represented by Figure 1, the DEA models can be useful tool to formulate and solve the performance evaluation problem of Section 2. According to the input based and output based factors of Figure 1, for evaluating the operational workers of the case study firm, the following issues should be considered

- Each operational worker is considered as a DMU. Therefore, there are 19 DMUs in this problem.
- There are three input factors, and there are two output factors.

As mentioned, the DEA models are very useful tools for performance evaluation. As there are different DEA models such as CCR (Kuah et al., 2010), BCC (Kuah et al., 2010), Russel (Kuah et al., 2010), etc. In this study the Russel model is used to evaluate performance of the considered workers. The Russel model (also most of the DEA models) can only decide about efficiency or inefficiency of the DMUs (workers) and these models cannot rank the DMUs directly. It means that the Russel model also just determines the efficiency or inefficiency of a DMU and cannot rank them. As the aim of this study is to evaluate and rank the operational workers, a two stage approach should be used for this aim. The stages are:

1 evaluating the DMUs

2 ranking the DMUs.

For the first stage, as a useful model, the Russel DEA model is used. But, in order to perform the second stage, the Anderson-Peterson approach (Andersen and Petersen, 1993) based on a modified version of the Russel model is applied (Pastor et al., 1999). The summary of these stages is represented by the flowchart of Figure 2 and the stages are explained by the rest of this section.

3.1 Stage 1: The Russel model for performance evaluation

In this stage the Russel model is considered for evaluating performance of the DMUs (operational workers). The following notations are considered in advance

n he number of DMUs

m the number of input-based factors

s the number of output-based factors

x_{ip} the value of input-based factor i in DMU p

y_{rp} the value of output-based factor r in DMU p.

ρ_p efficiency value of DMU p.

According to these notations, the following Russel model is used to evaluate performance of DMU p (the operational worker p). This means that the equation (1)–(6) should be solved for each DMU separately.

$$\min \rho_p = \frac{\frac{1}{m}\sum_{i=1}^{m}\theta_i}{\frac{1}{s}\sum_{r=1}^{s}\varphi_r} b \tag{1}$$

subject to

$$\sum_{j=1}^{n}\lambda_j x_{ij} \le \theta_i x_{ip} \qquad i = 1,\ldots,m \tag{2}$$

$$\sum_{j=1}^{n} \lambda_j y_{rj} \geq \varphi_r y_{rp} \qquad r = 1, \ldots, s \tag{3}$$

$$\theta_i \leq 1 \qquad i = 1, \ldots, m \tag{4}$$

$$\varphi_r \geq 1 \qquad r = 1, \ldots, s \tag{5}$$

$$\lambda_j \geq 0 \qquad j = 1, \ldots, n \tag{6}$$

By solving the above model for DMU p, the DMU is efficient if the optimal objective function of $\rho_p = 1$. Otherwise, it is inefficient.

3.2 Stage 2: The Anderson-Peterson approach for ranking

As mentioned earlier, in order to rank the DMUs, the efficiency value obtained by the Russel model cannot be used. For this aim, super efficiency of each DMU should be obtained and compared to each other. In the study of Andersen and Petersen (1993), a model for calculating the super efficiency of each DMU is proposed (R_p) which is known as the Anderson-Peterson approach. The following Anderson-Peterson model based on the modified Russel model is proposed to calculate the super efficiency of DMU p (Pastor et al., 1999).

$$\min R_p = \frac{\frac{1}{m}\sum_{i=1}^{m} \theta_i}{\frac{1}{s}\sum_{r=1}^{s} \varphi_r} \tag{7}$$

subject to

$$\sum_{\substack{j=1 \\ j \neq p}}^{n} \lambda_j x_{ij} \leq \theta_i x_{ip} \qquad i = 1, \ldots, m \tag{8}$$

$$\sum_{\substack{j=1 \\ j \neq p}}^{n} \lambda_j y_{rj} \geq \varphi_r y_{rp} \qquad r = 1, \ldots, s \tag{9}$$

$$\theta_i - 1 \leq M\delta \qquad i = 1, \ldots, m \tag{10}$$

$$-\theta_i + 1 \leq M(1-\delta) \qquad i = 1, \ldots, m \tag{11}$$

$$-\varphi_r + 1 \leq M\delta \qquad r = 1, \ldots, s \tag{12}$$

$$\varphi_r - 1 \leq M(1-\delta) \qquad r = 1, \ldots, s \tag{13}$$

$$\delta \in \{0,1\} \tag{14}$$

$$\theta_i \geq 0 \qquad i = 1, \ldots, m \tag{15}$$

$$\lambda_j \geq 0 \qquad j = 1, \ldots, n \tag{16}$$

The above model is solved for each DMU (operational worker) separately and for each of them a supper efficiency value is obtained (such as R_p^* for DMU p). In this model based on the binary variable δ, for the DMU inside of the production possibility set the equation (10) and (11) are considered, and for the DMU outside of the production possibility set the equation (12) and (13) are considered. Therefore, the DMU can move to the efficiency frontier and the ranking can be obtained. Finally, the performances of the DMUs are ranked according to decreasing order of the supper efficiency values.

4 Computational results

In this section the methodology of Section 3 is implemented for the data of Table 1 in order to evaluate and rank the performances of the operational workers of the case study company detailed by Section 2.

For this aim, first the data of Table 1 is considered and the Russel equation (1)–(6) is solved for each DMU in order to identify the efficient operational workers among all 19 workers. As mentioned earlier, if for p-th operational worker the optimal objective function value of $\rho_p^* = 1$ is obtained, it is efficient. Otherwise, the operational worker is inefficient. The results obtained for this stage is represented by Table 2.

Table 2 Results obtained for performance evaluation stage of the case study

DMU (operational worker, p)	*Obtained results Optimal value* ρ_p^*	*Efficient/inefficient*
1	0.83	Inefficient
2	0.93	Inefficient
3	0.79	Inefficient
4	1	Efficient
5	1	Efficient
6	1	Efficient
7	0.92	Inefficient
8	1	Efficient
9	0.75	Inefficient
10	0.87	Inefficient
11	0.96	Inefficient
12	0.81	Inefficient
13	1	Efficient
14	1	Efficient
15	0.85	Inefficient
16	0.85	Inefficient
17	0.71	Inefficient
18	1	Efficient
19	1	Efficient

According to the results of Table 2, the operational workers 4, 5, 6, 8, 13, 14, 18, and 19 are efficient workers, and the operational workers 1, 2, 3, 7, 9, 10, 11, 12, 15, 16, and 17 are inefficient workers.

In continue the Anderson-Peterson equation (7)–(16) is used to rank the operational workers. For this aim, the equation (7)–(16) is solved for each operational worker separately using data of Table 1 and the super efficiency values of the operational workers are obtained. Then based on the decreasing order of the super efficiency values, performance ranking of the workers is obtained. The results obtained for this stage is represented by Table 2.

Table 3 Results obtained for performance ranking stage of the case study.

DMU (operational worker, p)	*Obtained results*	
	Optimal value $\left(R_p^*\right)$	*Ranking*
1	0.813	15
2	0.904	13
3	0.813	15
4	1.004	6
5	0.913	12
6	1.024	5
7	0.924	10
8	1.054	3
9	0.834	14
10	0.963	8
11	0.994	7
12	0.914	11
13	1.044	4
14	1.085	1
15	0.914	11
16	0.924	10
17	0.793	16
18	1.065	2
19	0.944	9

As can be seen from Table 3, the best performance is given by operational worker 14 and the worst performance is given by performance worker 17. It is notable to mention that the workers with equal super efficiency values are assigned similar rankings.

Based on the results of Table 2 and Table 3, some managerial insights can be proposed as below

- The managers can consider some rewarding and encouragement strategies for the efficient workers in order to maintain and increase their efficiency for future.
- On the other hand, the managers may help the inefficient workers in order to improve their performances. For this aim the levels of input factors cab be decreased or the values of output factors can be increased.

- The results of Table 3 can be used by the managers for deciding about extra payments to the workers, or even assigning penalties to them.

In order to compare the obtained results of this study to other DEA models of the literature, the classical BCC and CCR DEA models are used in the Anderson-Peterson procedure of this study. The obtained rankings are presented by Table 4.

Table 4 Results obtained for performance ranking stage of the case study by BCC and CCR based Anderson-Peterson approach

DMU (operational worker, p)	*Obtained results*	
	BCC model	*CCR model*
1	17	15
2	10	11
3	16	16
4	4	6
5	12	12
6	5	5
7	11	10
8	3	3
9	15	14
10	10	10
11	7	7
12	13	13
13	6	4
14	1	1
15	11	11
16	8	8
17	14	15
18	2	2
19	9	9

In order to compare the obtained rankings, Jaccard Similarity Index (JSI) (see Niroomand et al. (2019b)) is used. When comparing a pair of rankings, this index takes a value between 0 and 1, where, its greater values show more similar rankings. The JSI values for the rankings obtained in this section are represented by Table 5.

According to the JSI values of Table 5, the most similar rankings of the operational workers are obtained by Anderson-Peterson-BCC and Anderson-Peterson-CCR models while the least similar rankings of the operational workers are obtained by Anderson-Peterson-BCC and Anderson-Peterson-Russel models.

Table 5 JSI values for comparing the obtained rankings

	Anderson-Peterson-Russel	*Anderson-Peterson-BCC*	*Anderson-Peterson-CCR*
Anderson-Peterson-Russel	-	0.8907	0.9435
Anderson-Peterson-BCC	-	-	0.9438
Anderson-Peterson-CCR	-	-	-

5 Concluding remarks

In this study a performance evaluation problem of operational employees in a real case study was considered. The case study was a firm from food industries where different tomato pastes are produced there. In addition, further than performance evaluation, in this study the operational employees had to be ranked based on their performances. For this aim, the most important criteria from the literature such as salary, work conditions, responsiveness, motivation, and productivity were selected. Furthermore, 19 operational workers from the production line of the case study firm were selected for evaluation purpose where all of them were working in similar conditions and handling manual tasks. A decision framework based on DEA was used to perform the evaluation and ranking decisions. For this aim the Russel DEA model was used as the first stage to evaluate the performance of each operational worker as a DMU by determining efficient and inefficient DMUs. As the second stage of the proposed decision framework, an Anderson-Peterson approach based on a modification of the Russel model was proposed to rank the DMUs based of their performances. Finally, based on the obtained results, some comparisons with the other DEA models of the literature was performed and the managerial insights were presented.

As future study, some other criteria can be considered for employees efficiency evaluation purposes and also this efficiency evaluation problem can be considered in uncertain environment.

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