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Application of Data Envelopment for Technical Efficiency Analysis of the Electrohydraulic Forming Process Using the Aluminum Alloy Sheets for Automotive Panels

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ABSTRACT

Presently, there exists a dearth of useful practical guidance on the operational efficiency of electrohydraulic forming setups for industrial applications. Despite the increasing demand for efficient operations by managers, the deployment of technical efficiency methods has not been contemplated to distinguish elements of the process that should be given more attention than others distinguished by performance. Consequently, this article proposes an application of data envelopment analysis to practical experimental data obtained from the literature for improved performance. As a platform for analysis, the DEAP 2 application software is deployed to examine the major parameters of the process, namely the stand-off distance (SOD), electrode, voltage and medium while the peak strain is considered as the output. Based on the structure of the problem, the technical efficiency of the process was broken into nine firms. Results indicate that the technical efficiency of forms 1 to 9 is 0.817, 1-000, 1.000, 1.000, 1.000, 0.692, 1.000, 0.613, and 0.532, respectively. The mean efficiency is then 0.850. Furthermore, the mean input slacks for the SOD, electrode, voltage and medium parameters are 1.531, 3.620, 3.027 and 0.049, respectively. Besides, the peers for firms 1 to 9 are (5, 2), 2, 3, 4, 5, (7,5), 7, (5,4), and (7,5), respectively. In addition, the peer weights were attained for firms 1 to 9 as (0.272, 0.272), 1.000, 1.000, 1.000, 1.000, (0.369, 0.138), 1.000, (0.369, 0.138), 1.000 (0.002, 0517), and (0.0099, 0363), respectively. The work is useful in developing operational policies, which contribute to the sustainability of the process.

1. Introduction

For several decades, forming [13, 14], machining [12, 18, 24], casting [5] and joining [37] have remained the principal operations in product manufacture. Nowadays, however, modern technology has expanded product manufacture to technologically advanced stages, generating products of high quality with value for money to the customer. Of these various processes, the forming process has remained one of the most interesting aspects with an increasing appeal to manufacturers using the electrohydraulic process. Electro-hydraulic forming is a manufacturing process that uses a combination of electric current and hydraulic pressure to shape and form metals with high-

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quality, high precision and minimal surface defects. The electrohydraulic process includes cleaner machining since hydraulic fluids leaks are avoided. Besides, the potential to contaminate the factory environment, factory building or the manufactured product is either substantially minimize or avoided since hazardous hydraulics fluid is not used.

Despite these advantages, while processing automotive panels using AA1100 sheets, there is a limitation in efficiently running the process. But, efficiency is important to best utilize the resources of a system. Mohammed demonstrated this fact in the oil production industry. Additional studies to promote process improvement could be found in Asif [4] and El-Abagy et al. [6]. Unfortunately, many production processes appear to have ineffective control of the optimal operation of the plan. According to the efficiency literature, efficiency is commonly classified into the following groups: dynamic efficiency [26], productive efficiency [16], social efficiency [9], allocative efficiency [23] and technical efficiency [7]. But the objective of technical efficiency is the minimization of inputs, which is the prime goal of the present study. Notice that the minimization concepts belong to the optimization domain [2, 3, 6, 22, 24, 27, 29]. Therefore, it is worthwhile to adopt the technical efficiency approach, which is delivered by the data envelopment analysis using the idea of the decision on making the unit as presented in the current work. In this work, a method called data envelopment analysis has been used. Data from the literature on the electrohydraulic process has been obtained and analyzed. This article discusses the experimental data of Shrivastava et al. [29], which showcases a control situation where the stand-off distance, medium, voltage and electrode gap were established by the authors as the principal and the controlling parameters to best attain the goal of the electrohydraulic process such as the selection of the most technically efficient entity in the present situation. The entities are considered on the assumption of a constant return to scale as well as utilized in the input-oriented data envelopment analysis to attain the desired results. With the complexity of the present objective of evaluating the technical efficiency of entities by the various choices of parameters, the multiple barriers faced by employing other mathematical models are overcome by adopting the data envelopment analysis in solving the problem. Interestingly, the production function, a term which could be replaced with the mathematical function in the present study does not require an explicit specification. Moreover, the DEA method shows tremendous capability in addressing many outputs and inputs. Also, it has wide applications in input and output systems such as the electrohydraulic forming process discussed in the present study.

Furthermore, in contrast with earlier reports on the electrohydraulic forming process, this article displays novel attributes that dismiss an explicit specification of the problem in mathematical terms with the data envelopment analysis. Although an earlier study by Oke et al. [25] demonstrated the feasibility of applying a wide range of multicriteria methods, including CRITIC, FAHP, AHP, entropy and BWM to assess the parameters of the electrohydraulic forming process and place them against one another, this article builds on their ideas by focusing on parameters of the electrohydraulic forming process. However, as a divergence, this article established the principles of return to scale, multi-staging, slacking and technical efficiency, among others to establish the performance of entities relative to their efficiency levels. The idea of a zero output slack score to track and control waste to the value of zero was introduced. Though Oke et al. [25] successfully analysed the relative performance of the parameters of the electrohydraulic forming process, the present study closely examines the shortcomings of the previous studies. We analyzed the variation in average input slack score to determine if entities within the process improve or decay in performance on the usage of their input resources to attain the utmost outcomes.

Through the present novel study, our contribution to advancing the electrohydraulic forming process is significant to gaining insights into the process and establishing the application of the DEA method as a worthwhile approach. The present study provides solutions to a real-world problem and establishes how the technical efficiency of the electrohydraulic process can be evaluated.

2. Literature review

This section discusses a few literature sources on electrohydraulic forming by viewing from the standpoint of revealing a gap in the technical efficiency measurement of the forming process. Technical efficiency is defined as the consciousness and capability of the forming process to achieve the highest possible peak strain during the forming process. Peak strain in the electrohydraulic forming process is often attained alongside the movement of the maximum strain. From the above discussion, technical efficiency is pivotal to the achievement of forming goals but research on this idea is hardly mentioned in the literature. Furthermore, within the area of electrohydraulic forming, relevant research seems to be focused on several aspects, including the analysis of the interaction between start energy and dome height during forming [40]. In particular, Zohoor and Mousavi [40] used simulation methodologies to analyse the process variables and demonstrate the practicality of the Lagrange-Euler and smoothed particle hydrodynamics approaches. While the study promotes savings in energy with a consequential saving in the forming cost, information on the possible attainment of the highest possible peak strain was not provided by the authors.

Moreover, Woo and other researchers conducted several interesting studies with a central focus on the development of experiments ([31, 32, 33], modelling [34] and material property evaluation [35, 36]. Within the framework of material property evaluation, Woo et al. [36] deformed the Al6061T6 at a speed of 100mls and simulated the deformation by using the LSDYNA programme but declared satisfaction with the experimental results. The experiment conducted by Woo et al. [35] aimed to improve the working environment for humans considering the high velocity and high pressure of the electrohydraulic forming process. The researchers concluded that the Kiging method is better than the initial one while they support excessive pace forming. Next, regarding modelling, Woo et al. [34] followed the MK theory with experimental data to analyze the forming limit diagram using the Al6061 T6 as the material. They concluded that the ability of a metal to form is more dependent on the tensile index condition compared to the quasi-static conditions. Moreover, experimental developments were addressed by Woo et al. [31] to understand the electrohydraulic influences and concluded obtaining satisfactory experimental apparatus, which showed adequate energy storage for the blank deformation into the die. In Woo et al. [32], numerical experiments were conducted using LS-DYNA software. The conclusion is that the maximum strain rate for the blank attained roughly 2300s-1. Woo et al. [33] conducted numerical experiments on the Al6061-T6 sheets to gain further insights into the material. It was concluded that an increase in the pressure within the fluid parts existed and was trigged by the water movement and electric energy to deform the blank into the die. The above studies are based on strain rate analysis and improvement, understanding electrohydraulic influences and material behaviour, particularly for the A1606I T6 alloy. However, there is no consideration for the comparative efficiency of the system in its entities as firms and its parameters.

Hassannejadasl et al. [10] performed research on the behaviour of DP590 during electrohydraulic free-forming and die-forming using a numerical model. The scholars concluded that the experiment result and observation when compared to the numerical value obtained were very close. Kim et al. [13] performed research by comparing the result obtained from forming a metal sheet into a V-shape by the use of an electrohydraulic forming process and the conventional method. The desired shape was achieved which electrohydraulic forming but it was not achieved with the conventional method. Stöbener et al. [30], performed an experiment on micro samples behavior while undergoing EHF(Electrohydraulic forming. These scholars concluded that for metals like bronze digital speckle photography is the best method because of its image contrast ability. Li et al. [17] studied logistics operation in the electrohydraulic sheet metal forming process. At the end of the research, the researchers achieved their aim, which is to observe the effect of the process on the metal which is a 20% increase in the mould height. Ahmed et al. [3] performed an experiment using various tools and materials on the AA5052 to analyze the effect of various parameters on the ability to fit to shape in the EHF process. The following was observed by the researchers: the direction of loading, the highest possible dome height, the maximum range of strain, and the percentage of kinetic effort, these factor contributes to the ability of the DP590 DUPLES stainless steel to take proper shape.

Shim et al. [28] reflected on the application of EHF in metal shaping and forging and also the importance to human day-to-day experience. They concluded that the EHF process saves a lot of time and it is more efficient. Prasath et al. [27] performed an EHF experiment on 0.25 mm-thick AISI 304 austenitic stainless steel to know the best process parameters need to achieve a better result. The scholars were also satisfied with the experiment value they obtained when compared with the predicted value, it was also noted that the variance between the empirical values and anticipated value was 3.156% with is okay. Zheng et al. [38] wanted to know the major reason for the hyperplastic multiscale occurrence of DP600 sheets during the electrohydraulic forming process by putting it under uniaxial stress at a high strain rate. These scholars concluded that the initial effect plays a major role in the deformation of the material. Zia et al. [39] experimented to compare the result of the electrohydraulic forming and worm electrohydraulic forming (which is the combination of the hot forming process and electrohydraulic forming process). The scholars concluded that elongation that took place at the breakpoint increased by 23.6 for the WEHF when compared to EHF. Maris et al. [20] compared the electrohydraulic forming method and quasi-static method by experimenting with two metals which are DP600 and AA5182. They concluded that a 5% major strain increase for DP600 was noticed while an 8% increase for AA5182. Golovashchenko et al. [8]

experimented to study the ability of a metal to form in dual-phase steel. They noticed an improvement between 63% and 190% in plane strain formability. Mamutov et al. [19] experimented to verify if electrohydraulic forming is suitable for the low-volume production of metal from flat sheets. These scholars concluded that the electrohydraulic forming process is feasible for low-volume production. Kinsey et al. [14] did research on high-speed forming by focusing on the input parameter and output result. The researchers made it clear that the reliability of this method has not been looked into and also when compared to the electrohydraulic forming process, the reproducibility was lesser. The above studies are certainly deficient in information regarding efficiency measurement.

Furthermore, in several literature sources, discussions on voltage and electrode gap are widespread. Nevertheless, information on stand-off distance and medium is weakly narrated. Then, it is rare to obtain a single source where all the four parameters of voltage, electrode gap, standoff distance, and medium are treated properly in performance evaluation. More disturbing is that while some of these parameters are widespread, their technical efficiency and contributions to output such as peak strains and final desired shapes have not been reported. Although it is promising to analyze the technical efficiency of voltage, electrode gap, stand off distance and medium are independent variables against peak strain and the final desired shape of the product as dependent variables, the limitation of experimental data to peak strain alone, provided by Shrivastava et al. [29] makes the ambition to explore the technical efficiency of the four parameters not feasible to two output but only but only peak strain at the moment. From the above analysis, a research gap on the electrohydraulic forming process exists in the following aspects:

1) Limited number of parameters exists in the application data of Shrivastava et al. [29] since only four parameters are considered. These are voltage, electrode gap, standoff distance, and medium. However, a literature search reveals an opportunity to investigate more parameters such as pressure ,velocity, and discharge energy
2) There is absence of integrated survey results and data envelopment analysis studies. Here, process engineers in multinational forming companies could serve as respondents while their thoughts are factored in a modified data envelopment analysis structure that could absorb weights for each parameter. In this respect, the importance of each parameter could be accounted for without necessarily incorporating fuzzy weights or a 0/1 knapsack dynamic programming idea as weights for the importance of parameter determination
3) The technical efficiency of the electrohydraulic forming process involving the peak strain as output and inputs as voltage ,stand off distance as voltage, standoff distance, electrode gap, and medium have not been studied
4) The exclusion of simulation labs regarding technical efficiency measurement and the application of data envelopment analysis in particular have been noticed in the literature. However, simulation is crucial to understanding the electrohydraulic forming process. It brings confidence to tackling high-pressure conditions. Unfortunately, simulation has not been applied to this problem despite the environmental hazard the process exposes workers to nonetheless, some leads are available that could be leveraged on simulation could be performed in this instance, using the limited parameters mentioned in an enclosed setup because hazards are to be presented. Simulation results in extreme cases are considered to provide information on whether to implement the parametric levels or not the real situation.

From the above literature gaps, it seems that only the measurement of the technical efficiency of the electrohydraulic process, mentioned in item (3) above is feasible given the experimental data obtainable from Shrivastava et al. [29] used in the present work. Therefore in the other parts of this work, the goal pursued will be relevant only to item (3) mentioned earlier.

3. Methodology

The data envelopment analysis model is as follows [41, 42]:

$$H_k = \frac{1}{g_k} \tag{1}$$

$$g_k = \min\left(\sum V_g x_{ijk}\right) \tag{2}$$

Subject to;

$$-\sum_{r=1}^{u} u_r y_{rk} + \sum_{i=1}^{m} v_g x_{ijk} \geq 0 \quad \text{for j} = 1,\ldots,\text{n} \tag{3}$$

$$\sum_{r=1}^{u} u_r y_{rk} = 1 \tag{4}$$

$$V_g \geq 0, i = 1,\ldots,m$$

where *n* is the number of alternatives/DMUs
m is the number of input criteria

s is the number of output criteria

x_{ij} and y_{rk} denote the value of the i^{th} input criteria and r^{th} output criteria for the k^{th} alternative

u_r and V_g are the non-negativity variable weights to be determined by the solution of the minimization problem

H_k is the efficiency measure of the k^{th} DMU

The flow of work in the present article is as follows, Figure 1. In this work, we have four inputs and one output (Table 1).

Table 1. Inputs and output for the electrohydraulic process [29]

S/No.	Parameter	Operation
1	Stand of distance	Input
2	Electrode gap	Input
3	Voltage	Input
4	Medium	Input
5	Peak strain	Output

The non-parametric technique was used in this paper to obtain the efficiency value of each firm by converting multiple inputs into Output. This method is said to be one of the best methods in the industry. The efficiency was obtained by using popular software called DEAP2 which has been tested and verified. Here is how DEAP2 obtains its efficiency:

Setting Instruction for the DEAP analysis (Note: This procedure is from the software):

eg1-dta.txt DATA FILE NAME
eg1-out.txt OUTPUT FILE NAME
9 NUMBER OF FIRMS
1 NUMBER OF TIME PERIODS
1 NUMBER OF OUTPUTS
4 NUMBER OF INPUTS
0 0=INPUT AND 1=OUTPUT ORIENTATED
0 0=CRS AND 1=VRS
0 0=DEA(MULTI-STAGE), 1=COST-DEA, 2=MALMQUIST-DEA, 3=DEA(1-STAGE), 4=DEA(2-STAGE)

This is the content in the instruction file and what it means

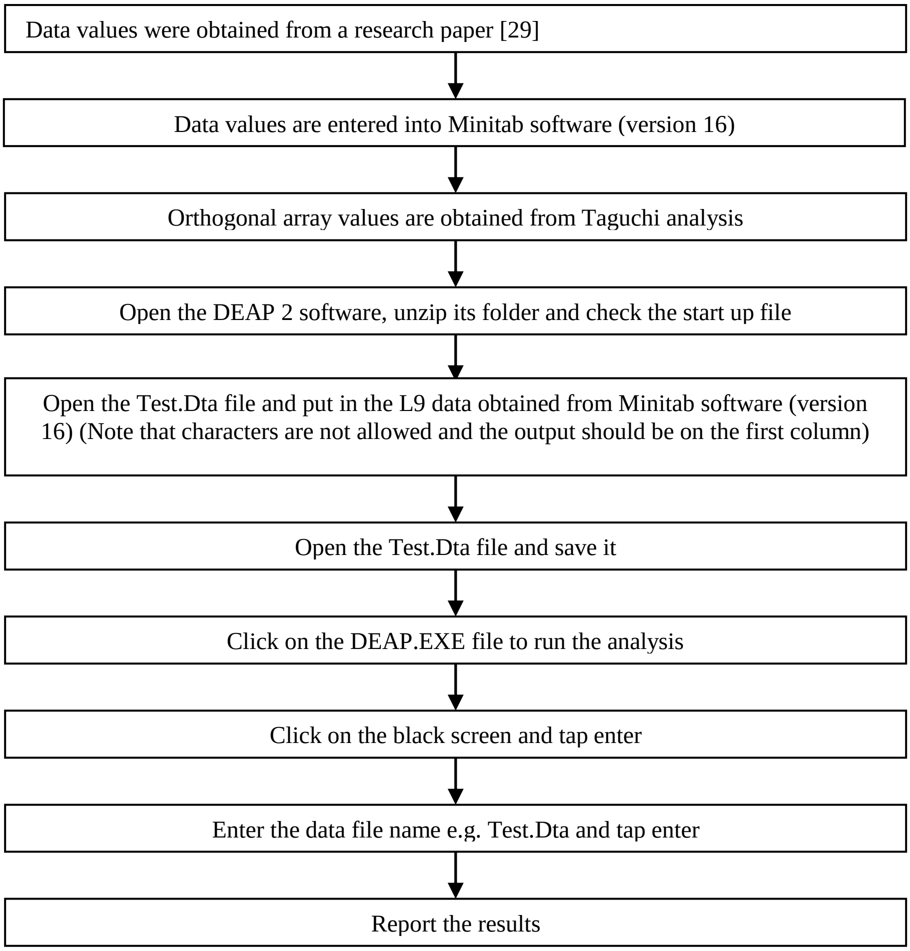

Figure 1. Research flow for the application of data envelopment analysis to the electrical machining process

4. Results and discussion

This section shows the result obtained from DEAP 2 software providing an insight into the efficiency of each firm, represented by the experimental tails generated when the four factors of the electrohydraulic process are placed side by side with the number of levels, which is 3 (Table 2). Table 2 shows the data extracted from Shrivastava et al. [29] which contain 4 factors, namely, stand-off distance, electrode gap, voltage, and medium. The levels are levels 1, 2, and 3. This yielded an orthogonal array of L9 for which the efficiency of each firm was completed. Notice that the aim at this point is to generate experimental trials which are to be used as the different firms used for analysis in the present work for the evaluation of the electrohydraulic process. The data envelopment analysis (DEA) used in this work is based on the assumption of constant returns to scale (CRS). This phenomenon is set to occur as any of the input such as man hours to run the electrohydraulic forming machine and the capital of the engineering business triggers a proportional increase in output. The framework of the DEAP 2 software application is built upon certain terms which are defined as follows. At the outset, the term efficiency summary is prompted as the final set of results to be observed. Efficiency is estimated as the process response which allows an understanding of the investor if the process engineer is "doing things right" [12]. The DEAP 2 software is based on the premise that efficiency properties examine the degree of accomplishment in the use of the electrohydraulic forming machine and the responsibility of the process owner for the triggered by defective tubular-shaped parts sold to customers. The efficiency measure computes the rate of returns of defective tubular parts manufactured by the process. By implication, it reveals the use of raw inputs for manufacturing and the machine hours engaged for the forming process. Moreover, this work on efficiency is pursued so that process engineers can cut down costs while concurrently enhancing the output of the electrohydraulic forming process. In this case, increased sales and income to the mechanical-based company are guaranteed. The next term that feature's the use of the DEAP 2 software to solve the technical efficiency problem of the electrohydraulic forming process is the output slack, this is a scalable measure that impacts the excesses of the input as well as the shortfalls of the output, in the context of a decision making unit. For the electrohydraulic system, the output slack helps to establish the availability of the electrohydraulic process in the attainment of the technical efficiency of the system. In this case, the electrohydraulic forming process is said to be active if the machine is on and produces the desired output or shape. The structure of input slack is similar to the earlier discussion for output slack. It differs from the output slack, in that focus is made on the input rather than the output.

Table 2. Control factors and their levels [29]

Control Factor	The Symbol for coded value	Number of levels		
		1	2	3
Stand-off distance	A	10mm	20mm	30mm
Electrode gap	B	20mm	30mm	40mm
Voltage	C	220V	260V	300V
Medium	D	Water (0.89cP*)	Oil (1.53cp*)	Air (0.01837***)

Key ** and *** are modified values according to the present authors

Table 3 . Orthogonal array and its translation

Stand-off distance (SOD) (mm)	Electrode gap (mm)	Voltage (V)	Medium (cP)	SOD (mm)	Electrode gap (mm)	Voltage (V)	Medium (cP)	Peak strain
1	1	1	1	10	20	220	0.89	5.38
1	2	2	2	10	30	260	1.53	7.35
1	3	3	3	10	40	300	0.01837	2.4
2	2	2	3	20	20	260	0.01837	2.74
2	2	3	1	20	30	300	0.89	12.4
2	3	1	2	20	40	220	1.53	6.63
3	1	3	2	30	20	300	1.53	13.32
3	2	1	3	30	30	220	0.01837	1.44
3	3	2	1	30	40	260	0.89	5.81

To achieve the needed experimental trials, the orthogonal array is extracted from the Minitab software. By entering 3 factors and 4 levels into the Taguchi statistical function, an L9 orthogonal array is developed (Table 3). The next step is to translate the orthogonal array into a value which is done in Table 3, in Table 3 there exist 5 columns and 9 rows. Usually, the first 4 columns represent each of the parameters namely Stand-off distance (SOD), electrode gap, voltage, and medium, however, the last column, column 5 is introduced as the output, which also runs through from rows 1 to 4. The original data of Shrivastava et al. [29] displays the peak strain in two measures S_1 and S_2. In the work, the average of S_1 and S_2 of each of the experimental trails, covering all the experimental trails is obtained. For experimental trials 1 to 9, the averages observed are 5.38, 7.35, 2.40, 2.74, 12.4, 6.63, 13.32, 1.44 and 5.81. We proceed from here to obtain results from the DEAP tool software developed by Tim Coelli who is affiliated with the Centre for Efficiency and Productivity Analysis of the University of Queensland, Australia. However, the software is developed not to accept letters and has a special structure such that a new format needs to be presented from Table 2 where the first column which contains output (peak strain) is introduced. The other 4 columns are meant for the parameter of the electrohydraulic forming.

At this stage we proceed to set up the instruction file, the important constituency of the instruction file is the number of firms which is 9. In the present case since an L9 orthogonal array is deployed in solving the current problem. Next, an attempt is made to run the analysis by clicking on the DEAP 2 application. At this point, the software opens, and a message comes up to request the name of the file which contains the data to be used in the analysis. On pressing the enter key the software retrieves the data and runs the analysis. The result is then stored in the eng.out.textfile. By considering the result the efficiency summary is a major aspect of the output. In our case, technical efficiency is expected to be evaluated by the DEAP 2 software. In our case 9 elements are regarded as the technical efficiency values, thus there is technical efficiency for firms 1-9 which are 0.817, 1.00, 1.00, 1.00, 1.00, 1.00, 0.692, 1.00, 0.613, 0.532 and 0.850, respectively, the mean efficiency which is the average of all the technical efficiency for the nine firms is 0.85. The technical efficiency value ranges from 0.532 to 1.000. However, firms with technical efficiency of 1 show that they are operating optimally. Next in the result displayed is the summary of output slack. This reveals that all input has been utilized when it is zero. However, when it is not zero, it means that not all inputs have been initialized. The output slack shows the value of the unexploited resources for each firm. In the present case for each of the experimental trails one to nine all inputs have been utilized and hence yielded zero. The mean of the output is zero, next is the summary of the input slack which has 5 columns the first column shows the firm input ranging from one to nine, and the second to the fifth column are for the individual parameter namely stand-off distance, electrode gap, voltage and medium. Consider the firm input 1 relative to the standoff distance zero units is recorded, which electrode gap is zero, voltage is 27.41 and medium 0.068. The input has their respective means of 1.531, 3.620,3.027 and 0.049. Next is the summary of peers for each of the firms which is (5,2) for firm one, (2) for firm two, (3) for firm three,(4) for firm four,(5) for firm five, (7,5) for firm six, (7) for firm seven, (5,4) for firm eight and (7,5) for firm nine. Next, the summary of the peer weight of the respective firm is (0.272, 0.272) for firm one, (1) for firm two, (1) for firm three, (1) for firm four, (1) for firm five, (0.39, 0.18) for firm six, (1) for firm seven, (1) for firm eight, (1) for firm nine. Furthermore, the peer count summary for firm one to nine is (0) for firm one, (1) for firm two, (0) for firm three, (1) for firm four, (4) for firm five, (0) for firm six, (2) for firm seven, (0) for firm eight and (0) for firm nine.

4.1 Peer weight and peer count

Peers are very important when it comes to efficiency measurement as it gives room for comparison between firms and also give room for another firm to improve its productivity. And also models could be drawn from the best firm in other for other firms to mimic it. Peer comparison also serves as a way to audit the system. One of the advantages of peer efficiency measurement is to pick out the best firm and also pick out the firm that needs improvement, and also give room for a firm with smaller efficiency to attain maximum efficiency. The next value we have to look at is the peer weight, this value makes sure there is equality between each firm and also fairness between peer values. It also shows a firm that can perform excellently well under high load. And also shows the impact of the peers on the efficiency value. The number of times each comparable peer was compared is what is called firm per count. The number of peer count done shows the level of authenticity, which mean the result obtained from a firm of four peer count is more accurate than that of one peer count. Firm-by-firm results are obtained after each analysis, Each firm result contains a technical efficiency score, radial movements, projection summary, original values slack values, and projected values for the output and input variables.

4.2 Original value

In this work, the best-performing firms are firms 2, 3, 4, 5 and 7. Based on this result other firms are compared both in output changes and changes in inputs (Table 4). Recall that as indicated in the present work firms refer to the experimental trials generated through the orthogonal arrays, which is L9. For the output analysis, and based on the original value indicated in DEAP 2 Software the performance of firm 1 relative to 2 decreased by 26.8%, firm 6 relative to firm 2, firm 8 relative to firm 2 and firm 9 relative to firm 2, the performance also dropped by 9.8%, 80.4% and 21% respectively, which gives a total decrease in performance of 138% and an average decrease in performance of 34.5%. Now concerning the changes in input 1 of firm 1 relative to firm 2, firm 6 relative to firm 2, firm 8 relative to firm 2, and firm 9 relative to firm 2, there is no drop in performance, 100% increase in performance, 200% increase in performance, 200% increase in performance, the total increase in performance is 500% while the average decrease in performance is 125%. Concerning input 2 the relative performance of firm 1 compared to firm 2, firm 6 compared to firm 2, firm 8 compared to firm 2 and firm 9 compared to firm 2 is a decrease of 33.3%, an increase of 33.35%, no drop in performance and an increase of 33.3%, respectively. For input 3 by comparing firm 1 to firm 2, firm 6 to firm 2, firm 8 to firm 2 and firm 9 to firm 2 a drop in performance of 15.4 %, a decrease in performance of 15.45%, and no change in performance respectively was observed. For input 4 concerning firm 1 relative to firm 2, firm 6 relative to firm 2, firm 8 relative to firm 2 and firm 9 relative to firm 2, a 41.8% decrease, no changes in performance, 98.8% decrease in performance and 41.8% decrease in performance were noted. For input 2 the total increase is 66.7%, while the total decrease is 33.3%, for input 3 the total increase is 0%, while the total decrease is 46.2%. For input 4 the total decrease is 182.5 % while the total increase is 0%.

Table 4. Firm descriptions

Firm 1				
Variable	Original Value	Radial Movement	Slack Movement	Projected Value
Output 1	5.380	0.000	0.00	5.380
Input 1	10.000	-1.828	0.00	8.172
Input 2	20.00	-3.656	0.00	16.344
Input 3	220.00	-40.213	-27.241	152.547
Input 4	0.890	-40.213	-0.068	0.659
Firm 2				
Output 1	7.350	0.000	0.00	7.350
Input 1	10.000	0.000	0.00	10.000
Input 2	30.00	0.000	0.00	30.000
Input 3	260.00	0.000	0.00	260.000
Input 4	1.530	0.000	0.00	1.530
Firm 3				
Output 1	2.400	0.000	0.00	2.400
Input 1	10.000	0.000	0.00	10.000
Input 2	40.00	0.000	0.00	40.00
Input 3	300.00	0.000	0.00	300.00
Input 4	0.018	0.000	0.00	0.018
Firm 4				
Output 1	2.400	0.000	0.00	2.400
Input 1	10.000	0.000	0.00	10.000
Input 2	40.00	0.000	0.00	40.00
Input 3	300.00	0.000	0.00	300.00
Input 4	0.018	0.000	0.00	0.018
Firm 5				
Output 1	12.40	0.000	0.00	12.40
Input 1	20.000	0.000	0.00	20.000
Input 2	30.00	0.000	0.00	30.00
Input 3	300.00	0.000	0.00	300.00
Input 4	0.890	0.000	0.00	0.890
Firm 6				
Output 1	6.630	0.000	0.00	6.630

Input 1	20.000	-6.164	0.00	13.836
Input 2	40.00	-12.329	-16.141	11.530
Input 3	220.00	-67.809	0.00	152.191
Input 4	1.530	-0.472	-0.371	0.688
Firm 7				
Output 1	13.320	0.000	0.000	13.320
Input 1	30.000	0.000	0.000	30.000
Input 2	20.00	0.000	0.000	20.00
Input 3	300.00	0.000	0.000	300.00
Input 4	1.530	0.000	0.000	1.530
Firm 8				
Output 1	1.440	0.000	0.000	1.44
Input 1	30.000	-11.605	-8.024	10.370
Input 2	30.00	-11.605	-8.004	10.390
Input 3	220.00	-85.106	0.000	134.894
Input 4	0.018	-0.007	0.000	0.011
Firm 9				
Output 1	5.810	0.000	0.000	5.810
Input 1	30.000	-14.034	-5.754	10.211
Input 2	40.00	-18.713	-8.437	12.850
Input 3	260.00	-121.632	0.000	138.368
Input 4	0.890	-0.416	0.000	0.470

4.3 Radial movement

In applying the concept of radial movement, DEAP 2 software omits an account of the radial movement. However, it is thought that its explanation would help the users of DEAP 2 to understand the intention and how the radial movement works. Therefore in divergence from most works that just applied the DEAP 2 software, we explain how the radial movement calculation has been obtained. The idea of radial movement is domicile in vibration studies where the element in contact with the peripheral of the circular boundary moves inward towards the centre of the circle. This idea is brought to electrohydraulic forming parametric data where the data obtained for parameters (factors), distributed at various levels, is holistically treated as being spread in a circle, intending to converge at the centre of the circle. In this instance, the movement of the element may be seen to create energy. The data of each parameter is perceived to move spirally within the arc of contact within an energy framework. In vibration, the material considered is sheaves which are tied in bonds and are therefore considered elastic. This elasticity concept permits the idea of radial movement applied to our current data on the forming process. Here the idea of radial movement is that the contact element moves in the radial direction towards the sheaves until the innermost point of the circle is attained. From this point, changes are observed in the direction of the comparative velocity. This is followed by the movement of the element out of the sheaves. This pattern of movement is a trajectory, having a velocity designated as V_0 and changing with an angle. This angle moves in and out and may be described as representing an azimuthal position within the area of contact [15].

Furthermore, radial movement and slack movement is the difference between the projected value and the original value. In analyzing the radial movement indices, we attempted to use the best firm which is any of firms 2,3,4,5 and 7. However in our analysis to compare the result based on the output and input, it was challenging to progress with the calculation because zero values were obtained throughout for the output and input, which gives an undefined value as a result. To resolve the problem, we chose firm 1 as the base period because it is next to the best-performing firms the following results are therefore obtained. For the output analysis and based on the original values indicated in DEAP 2 software the performance of firm 6 relative to firm 1 did not show any changes, likewise, firm 8 relative to firm 1 and firm 9 relative to firm 1 had 0%, 0% change respectively. Now, concerning the changes in input 1 of firm 6 relative to firm 1, firm 8 relative to firm 1 and firm 9 to firm 1, there is a 237.2% decrease in performance, 534.8% decrease in performance and a 667.7% decrease in performance, the total decrease is 1439.8% while the average performance is 479.9%. Concerning input 2 the relative performance of firm 6 compared to firm 1 is a decrease of 237.2%, decrease of 217.4% and a decrease of 411.8% respectively, the total decrease in performance is 886.5 % and the average decrease in percentage is 288.8%. For input 3 by comparing firm 6 to firm 1, firm 8 to firm 1 and firm 9 to firm 1, a decrease in performance of 68.6 %, a decrease in performance of 111.6% and a decrease in performance of 202.5 respectively was observed, the total decrease in performance is

127.6%, while the average decrease is 127.6%. For input 4 by comparing firm 6 to firm 1, firm 8 to firm 1 and firm 9 to firm 1, a 98.9% increase, 100% increase in performance and 99% increase in performance was noted, the total increase is 297.8%, while the average increase is 99.3 %.

4.4 Slack movement

In analyzing the slack movement indices, we attempted to use the best firm which is any of firms 2, 3, 4, 5 and 7 (Table 5). However in our analysis to compare the result based on the output and input, it was challenging to progress with the calculation because zero values were obtained throughout for the output and input, which gives an undefined value as a result. To resolve the problem, we chose firm 1 as the base period because it is next to the best-performing firms the following results are therefore obtained. For the slack movement analysis and based on the original values indicated in DEAP 2 software the performance of firm 6 relative to firm 1 did not show any changes, likewise, firm 8 relative to firm 1 and firm 9 relative to firm 1 had 0%, 0% change respectively. Now, concerning the changes input 1 of firm 6 relative to firm 1, firm 8 relative to firm 1 and firm 9 to firm 1, did not show any changes, did not show any changes, did not show any changes and did not show any changes, respectively. Concerning the changes in input 2 of firm 6 relative to firm 1, firm 8 relative to firm 1 and firm 9 to firm 1, did not show any changes, did not show any changes, did not show any changes and did not show any changes, respectively. For input 3 by comparing firm 6 to firm 1, firm 8 to firm 1 and firm 9 to firm 1, an increase in performance of 100 %, increase in performance of 100% and an increase in performance of 100% respectively was observed, the total increase in performance is 300 %, while the average increase in performance is 100%. For input 4 by comparing firm 6 to firm 1, firm 8 to firm 1 and firm 9 to firm 1, a 445.6% decrease, 100% increase in performance and 100% increase in performance was noted, the total decrease is -245.6%, while the average decrease is 81.9 %.

Table 5. Summary of input slacks and efficiency

Firm Inputs	Input slack 1	Input slack 2	Input slack 3	Input slack 4	Efficiency
1	0.000	0.000	27.241	0.068	0.817
2	0.000	0.000	0.000	0.000	1.00
3	0.000	0.000	0.000	0.000	1.000
4	0.000	0.000	0.000	0.000	1.000
5	0.000	0.000	0.000	0.000	1.000
6	0.000	16.141	0.000	0.371	0.692
7	0.000	0.000	0.000	0.000	1.000
8	8.024	8.004	0.000	0.000	0.613
9	5.754	8.437	0.000	0.000	0.532
Mean	1.531	3.620	3.027	0.049	0.850

4.5 Projected value

In analyzing the projected value indices, we attempted to use the best firm which is any of firms 2, 3, 4, 5 and 7. However in our analysis to compare the result based on the output and input, it was challenging to progress with the calculation because zero values were obtained throughout for the output and input, which gives an undefined value as a result. To resolve the problem, we chose firm 1 as the base period because it is next to the best-performing firms the following results are therefore obtained. For the projected value analysis and based on the original values indicated in DEAP 2 software the performance of firm 6 relative to firm 1 did not show any changes, likewise, firm 8 relative to firm 1 and firm 9 relative to firm 1 had 0%, 0% change respectively. Now, concerning the changes in input 1 of firm 6 relative to firm 1, firm 8 relative to firm 1 and firm 9 to firm 1, a decrease in performance of 23.2 %, an increase in performance of 73.2% and a decrease in performance of 8 % respectively was observed, the total increase in performance is 42 %, while the average increase in performance is 10.5%. Concerning the changes in input 2 of firm 6 relative to firm 1, firm 8 relative to firm 1 and firm 9 to firm 1, a decrease in performance of 69.3 %, a decrease in performance of 29.9 % and a decrease in performance of 25.0 % respectively was observed, the total increase in performance is 87.3 %, while the average increase in performance is 29.1%. For input 3 by comparing firm 6 to firm 1, firm 8 to firm 1 and firm 9 to firm 1, an increase in performance of 0.2 %, an increase in performance of 11.6% and an increase in performance of 9.3% respectively was observed, the total increase in performance is 21.1 %, while the average increase in performance is 7.%. For input 4 by comparing firm 6 to firm 1, firm 8 to firm 1 and firm 9 to firm 1, a 4.4% decrease, 98.3% increase in performance and 28.9% increase in performance was noted, the total increase is 122.6% while the average increase is 40.9 %. Table 6 is the summary of the peers and lambda weight.

Table 6. Summary of peers and lambda weights

Firms	Peers	Lambda weights
1	5, 2	0.272, 0.272
2	2	1.00
3	3	1.00
4	4	1.00
5	5	1.00
6	7,5	0.369, 0.138
7	7	1.00
8	5,4	0.002, 0.517
9	7,5	0.099, 0.363

4.6 Validation of the method

In this article, the technical efficiency of an electrohydraulic forming process was tested with practical data extracted from Shrivastava et al. [29], which reveals the forming characteristics of an automobile panel using the AA1100 sheets. The DEAP 2 software was used for this efficiency evaluation. However, there is a need to verify that the efficiency measurement method using the data envelopment analysis (DEA) of the DEAP 2 works in other situations. This ascertains that the DEA method works according to its design objectives and its practical usage. Thus, to confirm that the DEA method is sound, a new set of data on the cryogenic machining process of medium carbon low alloy steel EN-19 was analyzed by the technical efficiency measure of the DEA method [39]. The data analyzed is the translated form of orthogonal arrays using the actual values of parameters at different levels instead of the level representations of 1, 2 and 3. In all, 27 experimental courts, three levels (levels 1, 2 and 3) and three parameters are involved. The parameters are the speed, which was indicated as SP, feed rate, and depth of cut, represented as FR and DOC, respectively. By applying the DEA method using the DEAP 2 software, each experimental trial is regarded as a firm.

4.6.1 Efficiency

In this section, we have 27 firms which range from 0.709 to 1 (Table 7). The efficiency measures how well the input parameters are utilized to give an output parameter, signal-to-noise ratio. Peak efficiency value is the predicted highest value any system can achieve, in our case the predicted value is 1 However 18 firms have an efficiency score of 1 which are firms 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 19, 20, 21, 22 and 25. It means that they use all input resources to give maximum output. These firms are what are used as measurement and benchmark for another firm with an efficiency value less than 1, other firms that have an efficiency value of less than 1 are firms 14, 15,16,17,18,23,24,26 and 27, and these firms have values of 0.719, 0.719, 0.719,0.719,0.561, 0.709, 0.709, 0.709 and 0.562 respectively. The mean of all these efficiencies is 0.904. Firms can be ranked using their efficiency value. The results show a range of efficiency of 0.561 (firm 18) being the least efficient firm to 1(firms 1 to 13, 19 to 22 and 25. The mean of the efficiency of firms 1 to 27 is 0.904. This is higher than the efficiency process, which is0.850. The cryogenic machining case has a higher efficiency than the electrohydraulic process by 6.35%.

4.6.2 Summary of input slack and output slack

This summary shows a table that contains all input slack values (Table 7). Input slack is a value that indicated the amount of unused inputs of each input parameter value in a firm. In our case, for firm 1 the amount of unused value of speed is 0 l, which mean the total value was utilized, for feed rate and depth the value is 0, which mean all the input were utilized. For firm 2, the total speed value was utilized which means the input slack value is zero, same scenario for the feed rate but for that of depth 75% of its value was utilized with a mean of 25% was not utilized in the input slack value is 0.25. For firm 3 the input slack value for speed and feed rate are both zero which mean all input value were used but for depth, 50 % of its total value and its input slack value is 0.5. For firm 4 the total value for speed was utilized which means its value is 0, while 95% of the value of feed rate was utilized and its input slack is 0.05 which means 5% of the value was not utilized and finally for depth the total value was utilized. For firm 5 the input slack value for speed is 0% which means the total input value was utilized, for feed rate the input slack value is 5% and for depth 75% of the value was utilized which means 25% was not used. For firm 6 the total speed value was utilized which means the value is 0%, while 95% of the feed rate value was utilized, and the input slack value for depth is 5% which means 95%C of it was utilized. For firm 7, the input slack value is 0% which mean all other it value were utilized, while the feed rate of that firm has an input slack value of 0.1 which means 90% of the feed rate value was utilized and for depth, all the value was utilized. For firm 8 to firm 27, the speed values were all utilized which implies that they have a value of 0%. However, the feed rate input slack value for firm 8 to firm 27 are 0.1, 0.1, 0, 0, 0, 0.05, 0, 0.1, 0.036, 0, 0, 0, 0, 0.05, 0, 0, 0.1, 0.035 and 0 respectively. And for depth the input slack values for firm 8 to firm 27 the values are 0.25, 0.5, 0, 0.25, 0.5, 0, 0, 0.18, 0, 0, 0, 0, 0.250, 0.5, 0, 0, 0.177, 0, 0 and 0, respectively. However, the output slack value of all firms which are firm 1 to firm 27 is zero.

4.6.3 Peers Summary and peer weight

Peers summary is a table having the number of firms on the left and peer firms on the right (Table 7). Let us not forget that one of the functions of data envelopment analysis is to benchmark firms and compare firms with each other in other to improve. The set of data on the right is a set of data that each firm on the left can look up to, achieving maximum efficiency. In our case, firm 1's peer is firm 1, which means firm 1 has good efficiency. Firm 1 to firm 9 have firm 1 as their peer, while firm 10 to 13 has firm peer 10 which means if firm 10 to 13 wants to be better they can look up to firm 10 as a benchmark, which is the primary function on data envelopment analysis. firm 14 and firm 15 have two peers which are firm 10 and firm 1 to look up to for improvement. while for firm 16 its peer is firm 10, for firm `17 its peer is firm 10 and 1, for firm 18 its peer is 1, for firms 19, 20, 21 and 22 all have the same peer which is firm 19, while for firms 23,24 and 25 it peer is 10, for firm 26 it peer is 10 and lastly for firm 27 it peer are firm 1 and 10. on The other hand peer weight is a value that is needed to achieve maximum efficiency firm 1 to 13 have a value of 1, while firm 14 and 15 have two values which are because it has 2 peers, it has 0.359 and 0.719 as it peer weight, for firm 16 it peer weight is 1, while for 17 it peer weight are 0.359 and 0.719, for firm 18 its weight is 1.122, while for firm 19 to 22 it firm weight is 1, for firm 23 it firm peer weight is 1.063, for firm 24 and 26 have a peer weight of 1 and for firm 27 has two peer weight which is 0.562 and 0.562

4.6.4 Summary of input target and input target

The table displays the input and output values used to perform this analysis (Table 8). For the input summary table, we have 3 columns and 27 rows. It means that we have 3 parameters, namely, speed, feed rate and depth. For output, we have 1 output, which is the signal-to-noise ratio.

5. Conclusions

In this article, the technical efficiency of the electrohydraulic forming process is the basis of the evaluation of the system analysed with data drawn from Shrivastava et al. [29]. The data envelopment analysis was deployed and the parameters considered are the stand-off distance, electrode gap, voltage and medium, the data of Shrivastava et al. [29], which was used for analysis. Thus, the efficiency values obtained in this study are very important. We assumed constant return to scale and also used the input-oriented data envelopment analysis method in achieving our result. The multi-stage approach was used to calculate the slack. The following are the conclusions of the study:

(1) A score of 85% was obtained as the average technical efficiency of all firms which means that the performance of each firm is about 85% of its possible efficiency. Notice that any firm that has technical efficiency of 1.00, ran on its topmost efficiency level, and accordingly firms 2, 3, 4, 5, and 7 had an efficiency of 1.00. All firms had an output slack score of 0 which means resources were used fully and wastage of resources was avoided. (2) The average input slack score was not the same in all firms from the lower firm 4 had 0.049, firm 3 had 3.027, firm 2 had 3.620, and finally firm 1 to 1.531.

Table 7. Efficiency summary, summary of output slacks and summary of input slack and others

Firm	E	O	IS1	IS2	IS3	SOP	SOPW	PCS	SOOT	Summary of input targets (speed)	Summary of input targets (feed rate)	Summary of input targets (depth of cut)
1	1	0	0.000	0.000	0.000	1.000	1.000	13.000	49.540	300.000	0.1	0.5
2	1	0	0.000	0.000	0.250	1.000	1.000	0.000	49.540	300.000	0.1	0.5
3	1	0	0.000	0.000	0.500	1.000	1.000	0.000	49.540	300.000	0.1	0.5
4	1	0	0.000	0.050	0.000	1.000	1.000	0.000	49.540	300.000	0.1	0.5
5	1	0	0.000	0.050	0.250	1.000	1.000	0.000	49.540	300.000	0.1	0.5
6	1	0	0.000	0.050	0.050	1.000	1.000	0.000	49.540	300.000	0.1	0.5
7	1	0	0.000	0.100	0.000	1.000	1.000	0.000	49.540	300.000	0.1	0.5
8	1	0	0.000	0.100	0.250	1.000	1.000	0.000	49.540	300.000	0.1	0.5
9	1	0	0.000	0.100	0.500	1.000	1.000	0.000	49.540	300.000	0.1	0.5
10	1	0	0.000	0.000	0.000	10.000	1.000	11.000	55.560	600.000	0.1	0.5

11	1	0	0.000	0.000	0.250	10.000	1.000	0.000	55.560	600.000	0.1	0.5
12	1	0	0.000	0.000	0.500	10.000	1.000	0.000	55.560	600.000	0.1	0.5
13	1	0	0.000	0.050	0.000	10.000	1.000	0.000	55.560	600.000	0.1	0.5
14	0.719	0	0.000	0.000	0.000	10 , 1	0.359, 0.719	0.000	55.560	431.143	0.108	0.539
15	0.719	0	0.000	0.000	0.180	1, 10	0.719, 0.359	0.000	55.560	431.143	0.108	0.539
16	0.719	0	0.000	0.100	0.000	10.000	1.000	0.000	55.560	600.000	0.1	0.5
17	0.719	0	0.000	0.036	0.000	10 , 1	0.359 , 0.719	0.000	55.560	431.143	0.108	0.539
18	0.561	0	0.000	0.000	0.000	1.000	1.122	0.000	55.560	336.455	0.112	0.561
19	1	0	0.000	0.000	0.000	19.000	1.000	4.000	59.080	900.000	0.1	0.5
20	1	0	0.000	0.000	0.250	19.000	1.000	0.000	59.080	900.000	0.1	0.5
21	1	0	0.000	0.000	0.500	19.000	1.000	0.000	59.080	900.000	0.1	0.5
22	1	0	0.000	0.050	0.000	19.000	1.000	0.000	59.080	900.000	0.1	0.5
23	0.709	0	0.000	0.000	0.000	10.000	1.063	0.000	59.080	638.013	0.106	0.532
24	0.709	0	0.000	0.000	0.177	10.000	1.000	0.000	59.080	638.013	0.106	0.532
25	1	0	0.000	0.100	0.000	19.000	1.063	0.000	59.080	900.000	0.1	0.5
26	0.709	0	0.000	0.035	0.000	10.000	1.000	0.000	59.080	638.013	0.106	0.532
27	0.562	0	0.000	0.000	0.000	1, 10	0.562 , 0.562	0.000	59.080	505.918	0.112	0.562
Mean	0.904											

Key: E _ Efficiency, O – Output, IS1 - Input slack 1 (speed); IS2 - Input slack 2 (feed rate); IS3 - Input slack 3 (depth of cut); SP - Summary of peers, SPW - Summary of peer weights, PCS - Peer count summary, SOT - Summary of output target, SITS - Summary of input targets (speed), SITFR - Summary of input targets (feed rate), SITDOC - Summary of input targets (depth of cut)

Table 8. Variable value, original value, radial movement, slack movement and projected value

	VV	OV	RM	SL	PV		VV	OV	RM	SL	PV
Firm 1	output	49.54	0	0	49.54	Firm 11	output	55.56	0	0	55.56
	Input	300	0	0	300		Input	600	0	0	600
	Input	0.1	0	0	0.1		Input	0.1	0	0	0.1
	Input	0.5	0	0	0.5		Input	0.75	0	-0.25	0.5
Firm 2	output	49.54	0	0	49.54	Firm 12	output	55.56	0	0	55.56
	input	300	0	0	300		Input	600	0	0	600
	input	0.1	0	0	0.1		Input	0.1	0	0	0.1
	input	0.75	0	-0.25	0.5		Input	1	0	-0.5	0.5
Firm 3	output	49.54	0	0	49.54	Firm 13	output	55.56	0	0	55.56
	input	300	0	0	300		Input	600	0	0	600
	input	0.1	0	0	0.1		Input	0.15	0	-0.05	0.1
	input	1	0	-0.5	0.5		Input	0.5	0	0	0.5
Firm 4	output	49.54	0	0	49.54	Firm 14	output	55.56	0	0	55.56
	input	300	0	0	300		Input	600	-168.857	0	431.143
	input	0.15	0	-0.05	0.1		Input	0.15	-0.042	0	0.108
	input	1	0	0	0.5		Input	0.75	0.2111	0	0.539
Firm 5	output	49.54	0	0	49.54	Firm 15	output	55.56	0	0	55.56
	input	300	0	0	300		Input	600	-168.857	0	431.143
	input	0.15	0	-0.05	0.1		Input	0.15	-0.042	0	0.108
	input	0.75	0	-0.25	0.5		Input	0.75	0.2111	0	0.539
Firm 6	output	49.54	0	0	49.54	Firm 16	output	55.56	0	0	55.56
	input	300	0	0	300		Input	600	0	0	600
	input	0.15	0	-0.05	0.1		Input	0.2	0	-0.1	0.2
	input	1	0	-0.5	0.5		Input	0.5	0	0	0.5
Firm 7	output	49.54	0	0	49.54	Firm 17	output	55.56	0	0	55.56
	input	300	0	0	300		Input	600	-168.857	0	600
	input	0.2	0	-0.1	0.1		Input	0.2	-0.056	-0.036	0.108
	input	0.5	0	0	0.5		Input	0.75	-0.211	0	0.539
Firm 8	output	49.54	0	0	49.54	Firm 18	output	55.56	0	0	55.56
	input	300	0	0	300		Input	600	-263.545	0	336.45
	input	0.2	0	-0.1	0.1		Input	0.2	-0.088	0	0.112
	input	0.75	0	-0.25	0.5		Input	1	-0.439	0	0.561
Firm 9	output	49.54	0	0	49.54	Firm 19	output	59.08	0	0	59.08
	input	300	0	0	300		Input	900	0	0	900
	input	0.2	0	-0.1	0.1		Input	0.1	0	0	0.1
	input	1	0	-0.5	0.5		Input	0.5	0	0	0.5
Firm 10	output	55.56	0	0	55.56	Firm 20	output	59.08	0	0	59.08
	input	600	0	0	600		Input	900	0	0	900
	input	0.1	0	-0.1	0.1		Input	0.1	0	0	0.1
	input	0.5	0	-0.5	0.5		Input	0.5	0	0	0.5

Key: VV – variable value, OV – original value, RM – radial movement, SM – slack movement, PV – projected movement

Table 8 (Continued).Variable value, original value, radial movement, slack movement and projected value

	VV	OV	RM	SL	PV		VV	OV	RM	SL	PV
Firm 21	output	59.08	0	0	59.08	Firm 25	output	59.08	0	0	59.08
	input	900	0	0	900		input	900	0	0	900
	input	0.1	0	0	0.1		input	0.1	0	-0.1	0.1
	input	0.75	0	-0.5	0.5		Input	0.75	0	0	0.5
Firm 22	output	59.08	0	0	59.08	Firm 26	output	59.08	0	0	59.08
	input	900	0	0	900		input	900	-261.987	0	638.013
	input	0.15	0	-0.05	0.1		input	0.15	-0.044	0	0.106
	input	0.5	0	0	0.5		input	0.75	-0.218	0	0.532
Firm 23	output	59.08	0	0	59.08	Firm 27	output	59.08	0	0	59.08
	input	900	-261.987	0	638.013		input	900	-394.082	0	505.918
	input	0.15	-0.044	0	0.106		input	0.2	-0.088	-0.035	0.112
	input	0.75	-0.218	0	0.532		input	1	-0.438	0	0.562
Firm 24	output	59.08	0	0	59.08						
	input	900	-261.987	0	638.013						
	input	0.15	-0.044	0	0.106						
	input	1	-0.291	-0.177	0.532						

Key: VV – variable value, OV – original value, RM – radial movement, SM – slack movement, PV – projected movement

The variation in average input slack score shows that firms should improve on the usage of input resources in other to achieve maximum results. Weight and peer information of each firm was obtained through analysis. The amount of times each firm acts as a peer to another firm is called the peer count summary.

(3) Firms 4, 2, 9 and 7 had more impact and also appear as peers more than one time. The weights given to each firm are known as peer weight summaries. These weights affect the efficiency evaluation depending on their value. Finally, firm-by-firm results comprise the following variables; predictable values for inputs and outputs, technical efficiency and original values for inputs and outputs, and also give us the full understanding of the overall performance of each firm. At the end of the analysis, we can say firm 7,2,4,3, and 5 operated at the topmost efficiency, while firm 3, 1, and 2 needs to improve their consumption of input resources.

(4) In an application concerning the cryogenic machining of medium carbon low alloy steel EN-19, the application of data envelopment analysis was tested using the DEAP 2 tool. It was found feasibility and hence confirmed the validity of the data envelopment analysis method on the machining problem.

(5) Future studies may address combined numerical investigation and the present DEA method (see also Mohammed [40]).

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