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Determining the effectual factors in enhancing efficiency in non-homogenous Decision-Making Units By utilizing the NDEA Approach (Case study: Cement Production Process)

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Abstract. Computing efficiency without considering its enhancement is not ideal, and organizations typically assess efficiency with the goal of improvement, on the basis of targeting improvement assess efficiency. In the research presently conducted, on the fundaments of the efficiency gaged, in the numerous decision-making units (DMUs) of cement producers, the effectual factors influencing the enhancement of efficiency have been considered. The efficiency of the DMUs have been calculated by taking advantage of the NDEA technique and the efficiency status of each one of the cement factories and its processes have been determined and compared to that, of the other factories. By utilizing this information, the root causes are primarily specified on the basis of the experiences of the experts, well versed in this subject-matter and consequently, by employing the Hierarchical Analysis Approach and the Wasserman's Communication Technique, the factors influencing the efficiency of the cement production process, are focused on or prioritized. This method, from the viewpoint of a data collection method is descriptive, as well as, is accounted for being a Delphi survey procedure The results indicate that, four factories have an unwarranted consumption of alkaline materials whereas, eight factories are inclined towards calcareous materials. The treatment of chlorine, material-mixing time, the crushing of material, hardness and uneven texture, including, the sodium and potassium feeding rates are respectively, amidst the most crucial aspects, entangled, in an unsuitable consumption of alkaline and calcareous materials, on the grounds of which, solutions based on providing enhancement can be determined.

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1. Introduction

Organizations pursue objectives by utilizing available resources effectively and efficiently [26]. The assessment of efficiency is a gauge to specify ranges of enhancement or improvement in the organization; and this is determined by the analysis of its information; as to whether, the route of activities is a consistent one, or that, continuous modifications improvising unswerving improvement to re-engineering attributes, are to be stipulated in it [6]. In the current epoch, the advancement and evolution of knowledge in

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the way of ‘management’, has made its presence a necessity and is inevitable and essential, where, the system of assessment is concerned in organizations. This is to an extent that, an absence of such an assessment system, which measures the utilization of resources and facilities; and indicates the extent of achieving the objectives is considered as one of the warning signs or symptoms of organizational malady [22]. Nowadays, experts and intellectuals, in the sphere of management, lay an emphasis on the magnitude, development and status of management of efficiency, including assessment models, as being one of the most reliable indices of the development of societies and organizations, in addition to being a vital key, where, the awareness of development objectives, in individual and social dimensions are concerned [21].

Efficiency reflects the extent to which an organization utilizes its resources, in generating outputs, in comparison to its optimal efficiency at a certain point in time [29]. Till date, several approaches have been exercised to compute and analyze efficiency, as an index of optimal utilization of resources in diverse organizations. In appraising or measuring the efficiency of its sub-units, a business can make an assessment and be aware of the effectuality of its practices in management [34]. Farrell [13] concentrated on forming a virtual unit by combining weighted units and suggested this as a conventional approach for the measurement of technical efficiency. The benchmark which Farrell rendered, comprised of one input and one output. But Charnes, Cooper and Rhodes [8], revised the deficiencies of this method and presented a model which could be manipulated to assess the relative efficiency of DMUs, in a classified method, in the context of inputs and outputs [9]. The Data Envelopment Analysis (DEA), is the name by which the approach, that Charnes, Cooper and Rhodes [8] presented was known; and the assessment of efficiency and optimization, utilizing DEA are utilized widely, being a significant approach in regards research operations [3]. With its uniqueness and special characteristics and capacities, DEA as a multi-criterion assessment technique, which in the sphere of management has been able to grant the concept of high transparency, clarity and accuracy [22]. In the conventional DEA model, units are considered as black-boxes and their inputs and outputs are given attention to only; although, their internal structure is ignored. Consequently, the source of inefficiency is not identified for inefficient units. In order to address the inefficiencies of the conventional models, The Network Data Envelopment Analysis (NDEA) model, which investigates the process operations and components in the assessment of the efficiency of the system [31]. Practically speaking, similar businesses or DMUs, utilize different administrative processes [36]. The models often assume homogeneity among DMUs, which may not accurately reflect reality. Hence, in recent years by focusing on non-homogenous DMUs, wide-scale researches have been performed [16]. The conventional DEA model is based on the assumption that in a multiple-input multiple-output setting, all inputs impact all outputs, or that detailed input to output relations are not closely examined. Furthermore, it is assumed in the conventional DEA model that the set of DMUs under investigation constitute a homogeneous set. This means that all DMUs have the same inputs and produce the same outputs. There are many situations in which the above assumptions are violated. Regarding the assumption that all inputs affect all outputs, consider the situation in a manufacturing setting where one of the inputs is packaging resources. Clearly, this input only impacts outputs that require packaging [20]. A non-homogenous aspect of inputs and outputs in a given process, may be due to the sort of technology, the kind and number of inputs, type and number of outputs, or the kind of feedback involved. Techniques on the basis of DEA do exist, which enable the specification of the optimal practices in the presence of non-homogeneity [30]. Computing efficiency without being attentive to its enhancement and determining the necessary steps for this assignment, proves to be unappealing; and organizations characteristically conduct efficiency assessments with the objectives of improvement or modification [24]. The enhancement process comprises of varied stages. The primary and most critical step is to develop a program or specify executive measures. These actions should entail clarity, be significant and maintain sustainability by comprehensive decision-making and be affiliated with the organizational objectives [29]. By specifying undesirable efficiency-related cases, enhancement priorities can be determined; and by detecting the range of root causes and factors, areas and points in need of enhancement can be specified. The cement industry is one of the most imperative business hubs in every country and in other words, Iran. Cement is a material which is utilized in a widely-ranged facade, in most constructional activities. As a fundamental industry, this industry is responsible for playing a dynamic role in the economic development of any country. The mentioned industry was always in a developing process in our country, such that, within the recent years, in relevance with Iran, its status in cement production and exports has been expanding in growth, amongst the other cement producing countries. The cement market, is one of the most focal commodity markets in the economy of Iran. The crucially of this commodity surges from the fact, of its role, as a supplier, for basic constructional activity requirements. Furthermore, the pricing of cement has direct impacts on the overall cost of several projects. Thereby, modifications in the mentioned industry (including production, consumption and changes in price) shall instantly and imposingly reflect on the challenging and sub sequential industries. This industry is confronted with issues and encounters, including sanctions and a reduction in trade-partners in Iran, foreign exchange fluctuations, domestic market recessions, a restricted diversity in the cement produced in the country; and such similar cases can be indicated. Thus, addressing such deficiencies, namely, a reduction of resource raw material wastage will propel a momentous impact on this segment and subsequently, on other economic activities. With due attention to the climatic conditions, innumerable technologies are manipulated for cement production, on the basis of dry or wet production processes.

Technology related to the production of cement, with due attention to the accessibility to the type of material, fuel and in other terms an important source which is water, is diverse and on these basis, dissimilar inputs and outputs for each technology creates non-homogenous aspects amidst the factories. Even though, on the grounds of the mentioned technologies, the raw materials utilized in the different cement technologies are not similar, the final product is generally corresponding. An approach to measure efficiency, by utilizing a non-homogenous DEA network method was rendered; and the efficiencies of 9 factories producing cement were taken under assessment [1]. In this study the efficiency of the DMUs of the cement producers were calculated and the effectual efficiency-related factors were identified and prioritized, as well as being under consideration to enhance efficiency by taking appropriate measures The innovation of this study is to prioritize enhancement spheres by utilizing the Analytical Hierarchy Process (AHP), including the purpose of the greatest effectual factors impacting efficiency in utilizing the Wasserman's Connection Matrix technique. Therefore, main unique contribution of current study is as follow:

- The research identifies and analyzes specific performance indicators that significantly affect efficiency in cement production. By highlighting these key factors, the study provides actionable insights for industry stakeholders, enabling them to focus on areas that can lead to substantial improvements in operational performance.
- The research contributes to the decision-making practices of managers and policymakers in the cement industry by providing a structured framework for evaluating efficiency. The insights gained from the NDEA analysis can inform strategic decisions, resource allocation, and process improvements, ultimately leading to enhanced competitiveness and sustainability.
- The research contributes methodologically by refining the NDEA approach to better accommodate the unique characteristics of non-homogeneous DMUs. This

enhancement not only improves the robustness of the analysis but also encourages further methodological advancements in efficiency evaluation techniques.

In continuation, the paper unfolds as follows: Section 2 renders the theoretical fundaments and literature review. Section 3, depicts the research methodology. Section 4, issues the particulars of the research findings; and finally, Section 5, denotes the conclusion of the paper.

2. Theoretical fundaments and literature review

Primarily, this section offers the theoretical background in four sub-sections, which are:

- Data Envelopment Analysis (DEA) in non-homogenous status
- Analytical Hierarchy Process (AHP)
- Wasserman's Connection Matrix Technique and the cement production process; and subsequently, the
- Literature Review.

2.1 *Network data envelopment analysis (NDEA)*

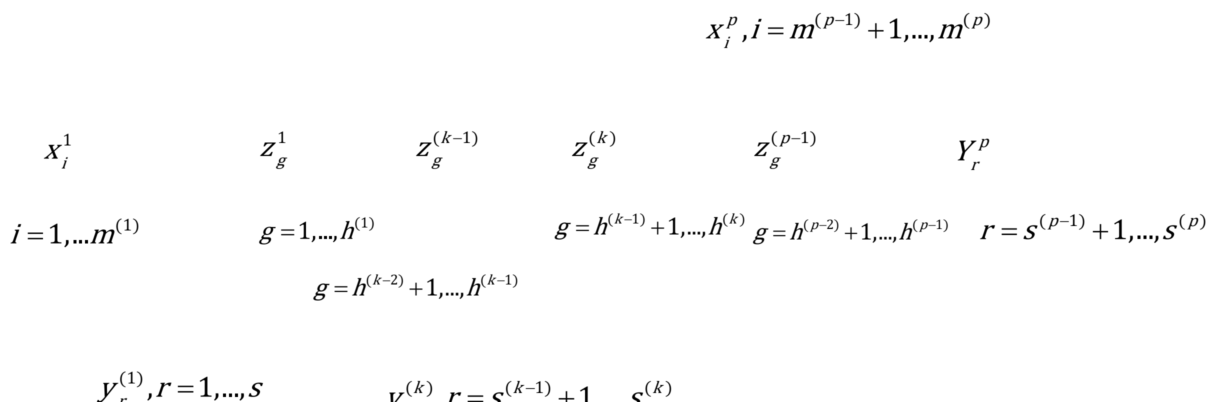
The conventional Data Envelopment Analysis Model (DEA) was initially introduced by Charnes et.al [8] and in this model homogenous DMUs were presumed. The suggested model by Charnes et.al [8] is as given hereunder:

$$
\begin{aligned}
& max\,\theta_q = \frac{\sum_{k=1}^{r} u_{kq}}{\sum_{j=1}^{m} v_j x_{jq}} \\
& st: \\
& \frac{\sum_{k=1}^{r} u_k y_{ki}}{\sum_{j=1}^{m} v_j x_{ji}} \le 1, i = 1, \dots, n \\
& v_j \ge \varepsilon, j = 1, \dots, m \\
& u_k \ge \varepsilon, k = 1, \dots, r
\end{aligned} \tag{1}
$$

Since this model is not linear, it is essential to employ the model proposed by Charnes et.al [8], to be converted into a linear model. The mentioned model can be in the following configuration:

$$
\begin{aligned}
& max\,\theta_q = \sum_{k=1}^{r} u_k y_{kq} \\
& st: \\
& \sum_{k=1}^{r} u_k y_{ki} - \sum_{j=1}^{m} v_j x_{ji} \le 0, i = 1, \dots, n \\
& \sum_{j=1}^{m} v_j x_{jq} = 1 \\
& v_j \ge \varepsilon, j = 1, \dots, m \\
& u_k \ge \varepsilon, k = 1, \dots, r
\end{aligned} \tag{2}
$$

Nevertheless, the models rendered here, are on the grounds of presumption of being homogenous, amidst the DMUs, which may not coincide with reality. Hence, in the past years, research has been performed in an extensive manner, focusing on the non-homogenous aspect of the DMUs [16]. Network systems having serial, parallel and combined or mixed structures, are often accounted for as being non-homogenous. The analysis of efficiency in these kinds of models is of great importance. Du et.al [11]and Barat et.al [5]have been attentive towards non-homogeneity in the network conditions of DMUs.If the working system is considered within an outline, comprising of a series of processes as in Fig. (1), a calculation for efficiency for each stage can be modeled as given below [17].



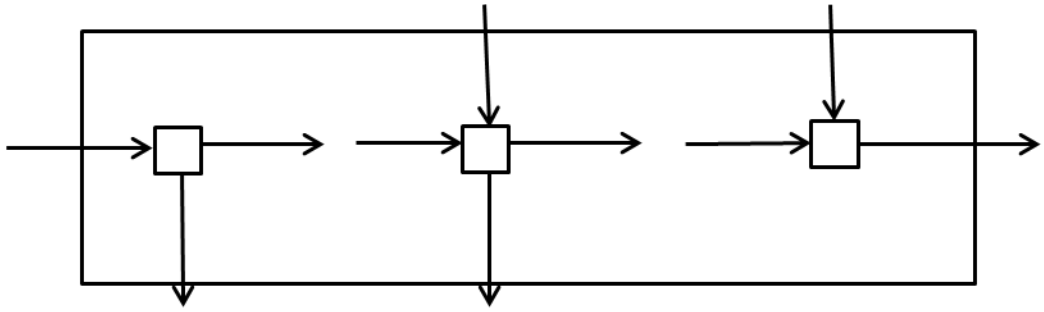


Figure 1. Schematic depiction of a serial process workflow configuration.

$$E_0^{(1)} = max.\frac{\sum_{r=1}^{s^{(1)}} u_r y_{r_0}^{(1)} + \sum_{g=1}^{h^{(1)}} w_g z_{g_0}^{(1)}}{\sum_{i=1}^{m^{(1)}} v_i x_{i_0}^{(1)}}$$
$$s.t.:$$
$$\sum_{r=1}^{s^{(1)}} u_r y_{r_j}^{(1)} + \sum_{g=1}^{h^{(1)}} w_g z_{g_j}^{(1)} - \sum_{i=1}^{m^{(1)}} v_i x_{ij}^{(1)} \leq 0 \tag{3}$$
$$u_r, v_i, w_g \geq \varepsilon, \forall r, i, g$$

$$E_0^{(K)} = max.\frac{\sum_{r=s^{(k-1)}+1}^{s^{(k)}} u_r Y_{r_0}^{(k)} + \sum_{g=h^{k-1}}^{h(k)} +1^{w_g z_{g_0}^{(k)}}}{\sum_{i=m^{(k-1)}+1}^{m(k)} v_i x_{i_0}^{(k)} + \sum_{g=h^{(k-2)}}^{h^{(k-1)}} +1_{g_0}^{(k-1)}}$$
$$s.t.:$$
$$\sum_{r=s^{(k-1)}+1}^{s^k} u_r y_{rj}^{(k)} + \sum_{g=h^{(k-1)}+1}^{h_k} w_g z_{g_j}^{(k)} - \left(\sum_{i=m^{(k-1)}+1}^{m^{(k)}} v_i x_{ij}^{(k)} + \sum_{g=h^{(k-2)}+1}^{h^{(k-1)}} w_g z_{g_j}^{(k-1)} \right) \leq 0$$
$$u_r, v_i, w_g \geq \varepsilon, \forall r, i, g$$
$$E_0^{(P)} = max.\frac{\sum_{r=s^{(p-1)}+1}^{s^{(p)}} u_r y_{r_o}^{(p)}}{\sum_{i=m^{(p-1)}+1}^{m(p)} v_i x_{i_o}^{(p)} +1^{w_g z_{g_0}^{(p-1)}}}$$
$$s.t.:$$
$$\sum_{r=s^{(p-1)}+1}^{s(p)} u_r y_{r_j}^{(p)} - \left(\sum_{i=m^{(p-1)}+1}^{m(p)} v_i x_{ij}^{(p)} + \sum_{g=h^{(p-2)}+1}^{h(p-1)} w_g z_{gj}^{(p-1)} \right) \leq 0, j = 1, \dots, n.$$
$$u_r, v_i, w_g \geq \varepsilon, \forall r, i, g$$

Similarly, the inputs of each stage can be impacted by the responsive outputs, from the other stages considered in the mathematical modeling process.
In this research, from the NDEA which is rendered in [1], is utilized for the calculation of efficiency of units.
The Network Data Envelopment Analysis (NDEA) model is a sophisticated extension of traditional DEA that is specifically designed to analyze the efficiency of decision-making units (DMUs) that operate in a network structure. One of the key advantages of the Network-DEA model is its ability to account for non-homogeneity in inputs, outputs, and processes among different DMUs. The Network-DEA model allows for the representation of DMUs as multi-stage processes, where inputs are transformed into outputs through various intermediate stages. This structure reflects the real-world operations of many organizations, where activities are interlinked and not homogeneous. By modeling the flow

of resources through different stages, the Network-DEA can capture the complexity and interdependencies of processes, which is essential for understanding how non-homogeneous inputs and outputs interact. The Network-DEA model can accommodate multiple types of inputs and outputs, allowing for the analysis of heterogeneous DMUs that may utilize different resources and produce various products or services. This flexibility enables the model to consider the unique characteristics of each DMU, ensuring that the efficiency assessment reflects the specific context and operational realities of each unit. The model allows for the assignment of variable weights to different inputs and outputs, which can be tailored to reflect the importance of each factor in the context of the specific DMU being analyzed. This feature is particularly useful for non-homogeneous DMUs, as it acknowledges that different units may prioritize different inputs and outputs based on their operational strategies and market conditions. The Network-DEA model evaluates the efficiency of each stage of the process separately, allowing for the identification of inefficiencies at specific points in the network. This is crucial for non-homogeneous DMUs, as it enables a more granular analysis of performance. By assessing the efficiency of each process stage, the model can pinpoint areas for improvement, even when the overall efficiency of the DMU may appear satisfactory. The model recognizes intermediate outputs that result from various stages of production or service delivery. This feature is essential for non-homogeneous DMUs, as it allows for the evaluation of how well resources are utilized at each stage before reaching the final output. By incorporating intermediate outputs, the Network-DEA model provides a more comprehensive view of efficiency, capturing the nuances of how different processes contribute to overall performance. The Network-DEA model can accommodate non-constant returns to scale, which is vital for analyzing DMUs that do not operate under uniform conditions. This flexibility allows the model to reflect the realities of varying operational scales and efficiencies. By allowing for different returns to scale, the model can better capture the efficiency dynamics of heterogeneous DMUs, providing insights that are more aligned with real-world scenarios.

The Network-DEA model effectively addresses non-homogeneity in inputs, outputs, and processes through its multi-stage structure, flexible definitions of inputs and outputs, variable weights, and the integration of intermediate outputs. These features enable the model to provide a nuanced and comprehensive analysis of efficiency in heterogeneous decision-making units, allowing for targeted improvements and a better understanding of operational dynamics. By recognizing the complexity and diversity of real-world processes, the Network-DEA model stands out as a powerful tool for performance evaluation in various sectors.

2.2 *The analytical hierarchy process (AHP)*

The Analytical Hierarchy Process (AHP) is an adaptable, influential, and simple approach utilized for decision-making in circumstances where multiple and incompatible decision-making criterions make it difficult to select from amongst challenging options. In other words, the core of this model lies in the selection of one option amidst several options; and is determined by contemplating on multiple explicit criterions. By exploiting the AHP approach and benchmark, difficult and complex issues can be converted into a simple configuration and thus resolving them. Strengths of AHP is as follow: AHP provides a systematic framework for structuring complex decision problems. It breaks down the decision-making process into a hierarchy of criteria and sub-criteria, allowing for a clear visualization of relationships and priorities. AHP utilizes pairwise comparisons to evaluate the relative importance of different criteria. This method captures subjective judgments effectively, enabling decision-makers to express preferences in a more intuitive manner. AHP includes a consistency ratio to assess the reliability of the judgments made during pairwise comparisons. This feature helps ensure that the decision-making process is coherent and rational. AHP allows for the integration of both quantitative data and qualitative assessments, making it suitable for evaluating diverse factors that influence efficiency in heterogeneous DMUs. Based on strength of AHP, it has consistency with NDEA follow as:

- AHP's structured approach aligns with the NDEA methodology, which seeks to identify and analyze the factors that contribute to efficiency in various DMUs. By establishing a hierarchy of criteria related to efficiency, AHP facilitates the identification of key performance indicators that can be quantitatively assessed through NDEA.
- The pairwise comparison aspect of AHP allows for the prioritization of factors that influence efficiency gains, ensuring that the most critical elements are highlighted in the NDEA analysis

This method has multiple applications in economic and social issues and embraces a distinct status in management affairs [4]. The three chief steps of the AHP approach comprises of, the model establishment and problem structure, configuring the pairwise comparison matrices and vectors of priority, including the formation of hierarchical matrices [23]. The digits used in the pairwise comparison have been illustrated in Table 1. When multiple respondents have responded to the pairwise comparison, the geometric mean method is employed to amalgamate them; and obtain a single integrated pairwise comparison matrix.

Table 1. Pairwise comparison scale for criterion and sub-criterion.

Code	1	3	5	7	9
Priorities	Equal Importance	Moderate Importance	Strong Importance	Critically of importance	Extreme Importance

In order to calculate the weights varied methods are capable of being exploited; and here, an exclusive (eigen) vector approach is denoted. In this method, the W_i values are determined in such a manner, so that it upholds validity for the following equation [4].

$$\begin{aligned} &a_{11}w_1 + a_{12}w_2 + a_{1n}w_n = \lambda.w_1 \\ &a_{21}w_1 + a_{22}w_2 + a_{2n}w_n = \lambda.w_2 \\ &. \\ &a_{n1}w_1 + a_{n2}w_2 + a_{nn}w_n = \lambda.w_n \end{aligned} \tag{4}$$

In which, a_{ij} represents the preference of the i^{th} component, over the j^{th} component. w_j is the weight of the i^{th} component; and λ is also a positive numerical. In actual fact, the Eigen vector method represents the matrix configuration, as shown hereunder as:

$$a * w = \lambda w$$

Where, A is the pairwise comparison matrix, w is the weight vector, and λ is the eigenvalue.

In which, A is the pairwise comparison matrix,$w$is the weight vector, and λ is a scalar. One of the methods for calculating the eigenvector is by solving the following equation:

$$det(A - \lambda.I) = 0$$

In solving this problem, the largest λ is regarded as the solution. By solving the matrix equation:

$$(A - \lambda_{max}.I).W = 0$$

In order to determine the weights of the effective factors as to the efficiency, the AHP method shall be resorted to.

2.3 *The wasserman's communication approach*

One of the appropriate approaches in order to link probable solutions and executive procedures to the determined objectives has been rendered by Wasserman. The correlations of the mentioned solutions with the proposed conformation is the Wasserman Approach, which is calculated with one another and also with the requirements or objectives in view, in relevance with this research [7].

In determining correlations, the desired comparisons can be utilized. Such that, when taking into account the reputed comparisons, the following digits can be indicated:

0 = without any correlation
1 = low correlation
3 = high correlation
9 = very high correlation.

The adjusted correlation between the requirements or objectives and the solutions can be premeditated through the following formula:

$$R_{ij}^{norm} = \frac{\sum_{k=1}^{n} R_{ik}.o_{kj}}{\sum_{j=1}^{n}\sum_{k=1}^{n} R_{ij}.o_{jk}} = \frac{v_i.o_j}{\sum v_i.o} \quad (5)$$

Where, o_{kj} stands for the correlation between the solutions and the affiliation between the requirements or objective. If the views of numerous decision-makers, are taken advantage of, in the completion of components, of the mentioned matrices, the correlation coefficient, of each component, is computed by extracting the mean or average. In order to prioritize the factors impacting efficiency, the Wasserman's communication approach will be exploited.

Strengths of Wasserman's Relationship Matrix is as follow: Wasserman's matrix provides a clear visual representation of the relationships between different factors and their impact on efficiency. This matrix helps in understanding how various elements interact and contribute to overall performance. The matrix allows for the quantification of relationships, enabling decision-makers to assess the strength and significance of connections between factors systematically. Wasserman's matrix can accommodate various types of relationships, including linear and non-linear interactions, making it versatile for different contexts and datasets. Also, consistency it with NDEA is follow as:

- The relationship matrix complements the NDEA framework by providing a detailed analysis of how specific factors contribute to efficiency gains. By mapping out the relationships between identified factors, decision-makers can pinpoint areas for improvement and optimize resource allocation.
- The quantitative nature of Wasserman's matrix supports the NDEA's focus on measuring efficiency and effectiveness across heterogeneous DMUs, allowing for a more nuanced understanding of performance drivers

2.4 *Cement production process*

In general, for making cement, four approaches are employed. These are namely, a wet approach, a semi-wet approach, a semi- dry and a dry approach. The first and second techniques are in such a manner, where, from clay a slurry is prepared and a slurry making device is used for this. Subsequently, by adding limestone and pulverized raw materials to this slurry, its consistency is incremented. This combination is then surveyed in the laboratory and utilized as a kiln feed. In the semi-wet method, a substance resembling slurry exits the apparatus. At this point the water which is present in the mixture is eliminated by using a filter press; and it is used in the shape of a cake or pellets to feed the kiln. In the semi-dry technique, the raw materials which are in a dry condition are combined together and utilized to feed the section of the mill, of the raw material. The material exits the mill in a powdered form. Before the powder is added to the kiln, an amount of water is sprayed on it and then it is converted to pellets and ultimately, this is used as kiln feed. For the production of cement in the dry method, primarily, the dry raw material is entered into the mill; and after the exiting powder is examined in the laboratory, it is employed as kiln

feed.
In spite of variances in some parts of various cement manufacturing methods, the overall process can be defined as follows:

- First Step: Extraction of raw material

Initially, the raw material to make cement must be attained; and in this context, this material could be indicated as to as, limestone, marl, gypsum, clay and … which, must be provided for cement production and are in the form of open-pit mines. Materials, such as, limestone, gypsum, and iron ore are extracted, by drilling and dynamite blasting.

- Second Step: The pulverizing of raw materials

The raw material which has come to hand, are crushed using mobile or static crushers. The crushing procedure is performed in several stages, so that extremely minute pieces are obtained.

- Third Step: Material reserves and Storage
- Fourth Step: Combining the raw materials

Upon crushing the raw materials, these raw materials are sent to the mill; where, in an antechamber, they are combined together slightly. This chamber is utilized for storage and the maintenance of raw materials. Some cement factories are located in regions with precipitation. This in itself causes the clay to get somewhat humid; and due to this humidity, the raw material cannot be used directly. In order to eliminate this issue, the raw materials go through a drying operation.

To produce cement using the dry method, it is essential that the raw materials are powdered. Then, they enter the kiln. For this purpose, the crushed raw materials are powdered, by operating raw material ball and roller mills. After regulating the raw materials, they are stored in silos. If the raw materials are well combined and their composition is homogeneous, the quality of the final product upsurges.

- Fifth Step: Heating

Heating and baking operations of the materials are performed in the kilns. The kiln is a metal cylinder, which has a diameter and length proportional to the factory's capacity.

- Sixth Step: Cooling

The heated granules (clinker) which exit the kilns, are of a temperature of approximately 1000-1200 degrees Celsius and are extremely hot. This makes it difficult for shifting and the recovering of the granules. Hence, it is essential to reduce the temperature of the granules. Cooling the clinker causes crystal formation and intensifies the quality of the granules. After the clinker temperature decreases, they are stored in silos, warehouses, or antechambers and then milled. After completing these stages, the readied cement is packaged.

2.4.1 *Portland cement*

The key components of the Portland cement are as given below:

- High-level lime materials such as, limestone, sea shells, marl and gypsum, which form a chalky combination
- Clay, shale, slate, fly sands or sand to secure silica and alumina
- Iron ore, oxide bits or similar materials to secure iron or iron compounds.

The quantity of raw material required in each factory varies and depends on the chemical structure of these materials. A specimen of the raw material of the mixture can be such that, after combustion, the clinker is composed of approximately, 65 percent of CaO, 21 percent of SiO_2, 5 percent of AI2O3, 3 percent of Fe2O3, and minor amounts of subordinate composites. So as to attain a uniform and suitable mixture, the raw materials are under persistent sampling actions and tests; and hence the required decisions are taken as to the material percentages or proportions during incorporation. In most of the mines, the materials are inconsistent and a diversity exists in relevance with materials in various parts of the mine. Limestone from different mines differ from the viewpoint of quality, coarseness (texture) and chemical composition with each other; and this leads to differences in quality in the various types of cement. After extraction, the initial operation of the first stage is the crushing of material. The extracted stone goes through the primary crushing device, which usually rotates. This apparatus crushes the stone pieces into 1.5 meters in diameters, converting it into a size of 15 centimeters in the maximum. Next, this product is conducted into a second crusher (which is rotary with a high speed or hammer mill), which reduces the dimensions of these stones to approximately 12.5 millimeters. From the chemical point of view, the key components of the cement comprise of a combination of calcium silicate and a small amount of calcium aluminate, which reacts with water and hardens. Calcium is attained as a basis of silica and alumina from limestone and clay, or ash and shale. The amalgamation of these materials with the supplementation of a percentage of gypsum or calcium sulfate crystals produces cement.

2.5 *Research background*

the efficiency of the five operational processes of cement production (dry, semi-dry, humid, slurry-wet and semi-wet); in four companies having an overall of nine factories, across a time-period of four years from 2017-2020 and is calculated on the basis of a DEA network in non-homogenous conditions, of a three-stage method, after modeling [1].

In a survey conducted study titled “Andazeh giri karaie Sherkatha-ye-bahrehbardari-ye-jangal) (Case-Study: Guilan Province); in the presence of undesirable outputs; and by taking the pollutants in view, as an undesirable output, the DEA technique was employed by the mentioned study-group. The datum was under investigation for over a ten-year period (2007-2016) for twelve companies. The results illustrate that, whilst considering the cruciality of the undesirable outputs, namely, air pollution, a number of companies such as, “Sherkat-e-Rukesh-e-Choobi Iran and “Taavoni-Jangal-e-Leil”, though, from the viewpoint of efficiency, are in the presence of immense undesirable output and stand in a good ranking position. Given the presence of undesirable outputs, such as, air pollution, in forest exploitation companies, a reduction of pollution can enhance the performance of companies with high efficiency, along with the undesirable outputs [23].

The effectual, factors in relevance with the efficiency and the organizational performance of governmental office employees. They scrutinized and researched the domestic and external aspects in relative to the effective factors, in respect to efficiency and organizational performance of employees and recognized the effective factors. In accordance with the review of the prior study, the results illustrated that the following aspects have an impact on the efficiency and performance of the governmental office employees: capacity or ability, learning, personality, perception, incentive, organizational support, employee credibility, increased educational opportunities, performance-based payment, improved work environment, increased motivation, cultural factors, social relationships, based on collaboration and alliance, level of education and health, knowledge and expertise, organizational space, earnings or salaries and wages, employee training, technology, inspiration and remuneration, organizational principles, quality of work life, management style and method, human resource planning, employee performance measurement, based on determined standards and indices, emphasis on results, promotion of directives and discipline in the organization, designation of more authorities, decision-making supremacy, sense of wellbeing, health and vivacity, sense of job security and stability, participation and active role in the organization, opportunity for personal development, being seen at work by the manager, promotion/advancement and the level of responsibility. These factors are among the indices that can intensify employee performance and efficiency in government organizations by creating them; and to some degree, improve organizational performance, since an organization's accomplishment is consequential from the enactment of its employees; and if, an organization comprises of

employees, who are at the maximum level of performance, they can support the organization by developing and promoting its level of implementation or efficiency.
In their survey [2].
The incrementing importance in relative to a day-to-day upsurge in sustainable development in the past years, within international societies and its critical role in modifying management, elevating infrastructure and empowering the capacities of each country. They elaborated on two elements of development and sustainable essentials, taking sustainability into contemplation under three crucial dimensions, namely, economic, social and environmental. In their study they took advantage of the integrated DEA model and the inverse integrated DEA model, to compute the sustainability of countries and offer enhancement values for a supreme or ultimate sustainability. In the integrated model, the percentage or rate of sustainability was calculated for 42 countries, by considering both, the inputs and outputs synchronously. Moreover, in the inverse integrated model, modifications were introduced in the optimum input and output values, but at the same time a stability was preserved in regards efficiency or stability. Ultimately two countries, that is, Germany and Iran were compared. The results demonstrated that, there is a necessity for a reduction or stabilization of the undesirable inputs and outputs; and an increment or equilibrium in the desirable inputs and outputs [35]. The 'Deming Cycle' in the sphere of continuous enhancement and the procedure of each stage; they developed an objective (Deming) process model, on the fundaments of the DEA approach to assess the behavioral performance of eleven higher educational institutions situated in the province of northern Khorrassan. In this study, the mentioned institutions, were classified into the various stages of the Deming Cycle, such as, planning, action, control and feedback or result-orientated institutions. For each of the inefficient units, on the grounds of DEA, a number of efficient units were specified as sources, together with a coefficients to ascertain their impact [29].
The specifying factors impacting productivity in managerial organizations. The results of which, revealed that, since the resources of a country are restricted, an increment in productivity is a basic necessity concerning governmental and private organizations. A boost in productivity leads to a higher economic growth and social development. The major objective of any organization is to secure optimal productivity. This comes to hand when, the entire components of that organization observe professional integrities. Organizational productivity rests on numerous factors and enhances with intensified human productivity. Increasing the productivity level can acquire higher profits, without supplementing the number of staff; and achievement can be gained in the competitive markets. Hence, all the managers must be aware of the know-how, to measure productivity of their organizations and utilize the data which has come to hand, so as to eliminate obstacles in advancement and augment organizational productivity [14].
The efficiency and productivity of companies which were members of the cement industry of the Tehran Stock Exchange, exploited the grey DEA technique and likewise, the productivity assessing indices of the Malmquist method to measure the efficiency and productivity of the mentioned cement industry companies. It was for this purpose, that as the first step, procedures were followed to identify the appropriate financial relativities in relevance with appraising or assessing efficiency. Next, these relativities were computed for every fiscal year in the configuration of grey digits. Subsequently, these relativities were classified into input and output variables. Ultimately, the interval efficiency and productivity of the mentioned companies were approximated for the financial years of (2018-2019), by utilizing the CCR and BCC models pertaining to the gray data envelopment analysis and similarly, the gray Malmquist Index and its elements [18]. A network-based DEA model to assess the sustainable supply chain of efficiency in significance with the cement companies, which were listed on the Iran Stock Exchange, within the duration of the years 2014-2016 and thus, determined their productivity value

in accordance with the Malmquist Index. This model introduces a sustainability criteria in the supply network; and provides more genuine results, by measuring them on the supply chain, since, it takes both, quantitative and qualitative constraints and undesirable outputs into consideration. The results specify a reduction in the total productivity of companies; and amidst these companies, there are only seven companies which have preserved their efficiencies, whereas, the others showed fluctuations in their performance [12]. The efficiency of bank management by means of data envelopment analysis (in a case study of various branches of the Tehran banks) on the fundaments of black-boxes. They assessed the total and thorough efficiency of 19 branches of the private banks. Results indicate that collective models of a network- based nature, have a lower number of efficient units, in comparison to the simple collective models. Moreover, the efficiency secured in the collective network-based models offers information with more accuracy for managers, in comparison to the simple collective model, by means of a capacity to specify and address deficiencies (weaknesses) in each section and eliminate them [25].
The efficiency was measured and finally, the inputs and outputs analyzed. In their research, in addition to estimating and ranking of the units under survey, they also elucidated on the sources of efficiency and inefficiency. So as to calculate efficiency, they manipulated the DEA method and then, utilized benchmarks pertaining to multiple univariate regression to recognize factors, elaborating on the empowerment of the basic EFQM for the efficiency of insurance banks. On this bases, aspects impacting the efficiency of the Mellat Insurance and Ma Insurance branches, were staff, partnership and resources, process and products, services, strategy and leadership [28]. The relative efficiency of the cement industry listed in the Stock Exchange of Iran. This was taken as an index to measure the capacity of the management with a new benchmark. For this purpose, data pertaining to fiscal statements from the cement factories from 2011-2014 were utilized. Initially, by executing the DEA approach, the relative efficiency of each of the companies assessed and the efficient units were also ranked by means of the Anderson-Peterson (AP method). Then, a regression method was utilized, to calculate the management capability for each company by using an appropriate model. The research findings indicated that, efficiency or the absence of efficiency of companies can be relevant to an intrinsic (fundamental) and integrated management capacity. On these grounds, the results declare that, companies which have been claimed as being efficient, such as, “Iran Gach and Ceman-e-Ardabil” has not only been guaranteed for the fact, of having high abilities, due to their managers/management; whereas, some companies which have been labelled as being efficient, like, (Ceman-e-Khuzistan and Ceman-e- Mazandaran), due to the management capacities of their managers, which, have also been dominant or high [35]. The most effectual factors, to elevate organizational productivity. In order to collect research data, a questionnaire was utilized and analysis was performed by exploiting the DEMATEL model. The correlation between the criterions of cause and effect were converted into a smart structure for the system. Their objective was to rank and specify the effectual indices, of productivity with this model, for the Student Welfare Fund Organization of the Ministry of Health and Medical Education. The results attained from this survey demonstrate that, the socio-psychological factors, have an incredible impact on the organization's productivity [19].
The aspects, which laid impacts on the cement industry on the fundaments of the Borda Method. The criterions which were investigated upon in their research comprised of, money-supply, profitability, activities, financial leverage and growth. The descriptive study research approach is on the grounds of the kind of objective applied. The spatial realm is the Tehran Stock Exchange and the temporal realm is the time series data of the years 2000-2009. On the basis of the research results, the Ardabil cement company and the limestone company of Azar Shahr, were referred to as the optimum options for investments, in cement companies, in the stock exchange and the other companies rank in succession. Similarly, the result achieved is that, money-supply, profitability, activities

financial or fiscal leverages and growth, have an impact on the efficiency of the cement companies and this has caused the companies to be positioned in diverse rankings [15]. The effective factors, laying an impact on empowerment and the execution of knowledge management, in organizations; and similarly, the impact of knowledge management as to the organizational performance. They also studied the intermediating role of human capital in relevance with knowledge management and the efficiency of the steel factory of Kabul, which is the largest steel factories of Afghanistan. The primary data was collected by means of a questionnaire which consisted of 48 questions. The participants were namely, the managers and administrative employees of the company and comprised of 108 persons. The collected data was analyzed by the SPSS and Smart PLS Software. The theories relevant to the strategy impact and technology on knowledge management were ignored by manipulating the correlation analysis and the t-test statistics. Eventually, the findings illustrated a positive impact, in concern with the structural variables, precept, leadership and conviction in the context, of knowledge management, in an organization. Likewise, knowledge management, both, in a direct manner and also by the means of mediation of human investment, has an impact on organizational performance [27]. The efficiency of a number of 1,674 knowledge-based companies in Italy. By utilizing the DEA approach within a duration of the years, 2012-2017. In this research, the aspects taken into consideration were, the input variables of the number of staff, the overall assets, as well as the output variables of income arising from sales and services. In continuation, in order to verify and validate the final information, in relevance with the return of equity (regards the shareholder returns and leverage ratio). The results illustrate a high-level correlation, in the efficiency values, the shareholder return and the leverage ratio [10]. The collective two-stage DEA technique, so as to assess the efficiency of the mercantile banks of China. The most spectacular and important findings as to their research was that, the two-stage DEA model is much more effectual than the conventional DEA one. Another aspect is that, the total efficiency of the Chinese banking system has enhanced during the period of study, owing to reforms [32]. A summary of the papers appraised, have been illustrated in Table 2.

Table 2. A summary of the papers surveyed.

Type of Industry	Factor Recognition Tool	Specifications of Effective Factors	Efficiency Computation Tool	Calculation of Efficiency	Year	Author
Cement			Non-homogenous NDEA	✓	2023	Abedi et.al
Forest Exploitation			DEA	✓	2022	Malaei Bousari et.al
Employees of the Government Sector	Questionnaire and Statistical Analysis	✓			2021	Akbari et.al
Sustainable Development of Countries			Inverse DEA	✓	2021	Youssefi and Mousavi Kashi
Higher Educational Institutions			DEA and the Deming Cycle	✓	2020	Shariatnia and Sheikh
Governmental Institutions	Questionnaire and Statistical Analysis	✓			2020	Foroughi
Cement			Grey DEA and the	✓	2020	Kaydipour et.al

			Malmquist Productivity Measurement Index			
Cement			NDEA	✓	2019	Darvish Motavali et.al
Bank			DEA	✓	2019	Ramazaniyan et.al
Bank - Insurance	EFQM	✓	DEA	✓	2018	Sadeghi et.al
Cement			Regression DEA	✓	2017	Valizadeh et.al
Student Welfare Fund Organization of the Ministry of Health and Medical Education	Questionnaire and DEMATEL	✓			2015	Kianifar and Radfar

With due attention to the literature review rendered in the present paper; and in accordance to the approach presented in Abedi et.al [1], the efficiency of numerous cement producing DMUs, were calculated and subsequently, by utilizing a mutual AHP Technique and the Wasserman's Communication Approach, the effectual factors in regards to efficiency and prioritization were specified. Thus, determining procedures in the way of enhancement.

3. Research method

From the viewpoint of the objective, this research, is applicable; and it is descriptive, in terms of the data collection approach. By being attentive to the fact that, for identifying improvement procedures, the opinions of experts have been resorted to; and it is also accounted for as being a Delphi-survey, in the context of a data collection technique. In particular, by manipulating the method suggested in this study, so as to assess the efficiency of several profit-making initiatives, the status of efficiency, in relative to each of the cement factories; and its processes, has been computed and compared with the others. By utilizing this information, the root causes have been specified and the essential procedures for enhancement have been determined. The models which have been employed in this study are attained from the contextual exploration of the subject concerned; and in implementing the research, the performance of four cement companies have been taken under discussion. This procedure was carried out over a time-period of four years, with modifications in their numerical and figures; and at times, presumptions in diverse factories and processes have been deliberated upon. In this study mutual models have been used to assess efficiency in non-homogenous circumstances, by means of the categorization of the executive procedures and relevant data. The hierarchical analysis method has been performed to prioritize the enhancement intervals and the Wasserman's Communication Matrix Approach, has be manipulated, so as to determine the most significant causes affecting efficiency. The main participants of this study were selected from among the top managers of four cement companies in Iran. The main characteristics of the managers were that they had at least 15 years of work experience, were at least 40 years old, and had at least a bachelor's degree. A standard questionnaire with five options was used to collect data. Given that the nature of the research is the use of mathematical models of data envelopment analysis, appropriate archived documents in factories have been used to implement the data model.

However, a questionnaire has been used to identify the effective factors of input and output. Also, in order to measure the reliability of the factors, Cronbach's alpha coefficient has been calculated.

4. Findings

The performance of the four cement producing companies, have been scrutinized and explored in the form of dry, semi-dry, humid or wet, slurry-wet and semi-wet processes, through a period of four years. Some of these companies utilize only one method for production purposes, whilst other take advantage of both the methods, for production. The specifications of the relative factories have been brought in Table 3. The first, second and fourth companies, each have two factories, whilst, the third company has three factories. The technology which is exploited in the entire factories is demonstrated in this Table. Due to the fact that, each of the factories utilizes a different method of production, this has brought about non-homogenous characteristics between the processes manipulated by these companies and the efficiencies of the companies have been assessed on these bases [1].

Table 3: Specifications of companies, factories and the relevant technologies.

Serial Number	Company Title	Factory Title	Type of Technology
1.	First Company	Factory 1	Dry
		Factory 5	Semi-dry
2.	Second Company	Factory 2	Semi-dry
		Factory 8	Dry
3.	Third Company	Factory 3	Slurry-wet
		Factory 6	Humid or wet
		Factory 7	Semi-wet
4.	Fourth Company	Factory 4	Semi-wet
		Factory 9	Slurry-wet

In accordance with Table 4, the variables relevant to the inputs and outputs of each one of the stages have been classified. In total, there are 12 inputs and outputs, utilized in the cement production technologies. In the entire technologies, three processes have been employed, within the pattern of stages 1, 2 and 3. Furthermore modeling has been conducted on the basis of this. The inputs and outputs of all the stages of production are determined; and all the inputs of the raw materials have been initially specified byx_i; and the input of the raw materials, which enter the system and are peripheral to the process are symbolized asz_j. Whereas, the outputs denoted by$y_r$have also been indicated [1].

As indicated in Table 4, the presence or absence of each of the inputs and outputs of the process has been exhibited by 1 and 0 respectively. The analogous equations conforming to the set of companies under survey, as well as the technologies utilized and the executive steps of the process, with due attention to the inputs and outputs, have been classified on the fundaments of similar outputs and inputs, as given in Table 5.

Hence, on the basis of Table 5, for example, in the first stage the production processes in relative to the dry and semi-dry technology is uniform. Thereby, the equations, in relevance, with the calculation of efficiency; on the fundaments of the DEA benchmark, can be placed alongside each other, for these two technologies, in the first stage; and perform the assessment. With due attention to the similarity of the technologies of each stage, the linear programming equations have been classified, based on the DEA approach, the result of which is disclosed in Table 6.

Table 4. Classification of variables in relevance with the type of cement production processes.

Variables	First Stage	Second Stage	Third Stage

Technology	Input				Output		Input				Output				Input		Output	
	Alkaline	Limestone	Water Inflow	Clay Slurry	Dry Mixture	Paste Mixture	Dry Mixture	Paste Mixture	Water Inflow	Fuel and Air	Exiting Water	Air and Water	Baked Powder	Exiting Water	Air and Water Vapor	Gypsum	Baked Powder	Cement Powder
	x_1	x_2	x_3	x_6	z_4	z_1	z_4	z_1	x_3	x_4	z_5	z_3	z_2	z_5	z_3	x_5	z_2	y_6
Dry	1	1	0	0	1	0	1	0	0	1	0	1	1	0	1	1	1	1
Semi-dry	1	1	0	0	1	0	1	0	1	1	0	1	1	0	1	1	1	1
Wet	1	1	1	0	0	1	0	1	0	1	0	1	1	0	1	1	1	1
Slurry-wet	1	0	0	1	0	1	0	1	0	1	0	1	1	0	1	1	1	1
Semi-Wet	1	1	1	0	0	1	0	1	0	1	1	0	1	1	0	1	1	1

Table 5. Classification of the variables relevant to the type of cement production processes.

Processes of the set of Equations	First Stage	Second Stage	Third Stage
First	Dry, Semi-dry	Dry	Dry, Semi-dry, Humid, Slurry-wet
Second	Humid, Semi-humid or wet	Semi-dry	Semi-wet
Third	Slurry-Wet	Humid, Slurry-wet	-----
Fourth	-----	Semi-wet	-----

Table 6. Classification of efficiency calculation models in the configuration of homogeneous equations.

Serial Number	Company Title	Factory	First Stage	Second Stage	Third Stage
1	First Company	Factory 1: Dry	Classification 1-1	Classification 2-1	Classification 3-1
		Factory 5: Semi-dry			
2	Second Company	Factory 2: Semi-dry	Classification 1-1	Classification 2-2	Classification 3-1
		Factory 8: Dry	Classification 1-1	Classification 2-1	
3	Third Company	Factory 3: Slurry-wet	Set 1-3	Classification 2-3	Classification 3-1
		Factory 6: Humid	Classification 1-2	Classification 2-3	Classification 3-1
		Factory 7: Semi-wet	Classification 1-2	Classification 2-4	Classification 3-2
4	Fourth Company	Factory 4: Semi-wet	Classification 1-2	Classification 2-4	Classification 3-2
		Factory 9: Slurry-wet	Classification 1-3	Classification 2-3	Classification 3.1

To compute each of the efficiency elements, appropriate modeling was performed, which is indicated here, as an example of calculating the efficiency of Factory 4, in 2017 for classification 24.

$$
\begin{aligned}
&Max\ 2y_3 + 6t_1\\
&S.t.\\
&7y_2 + 2x_5 = 1\\
&3y_3 + 7t_1 - 8y_2 - 3x_5 \le 0\\
&2y_3 + 7t_1 - 7y_2 - 2x_5 \le 0\\
&y_3 + 5t_1 - 5y_2 - 2x_5 \le 0\\
&2y_3 + 6t_1 - 7y_2 - 2x_5 \le 0\\
&3y_3 + 7t_1 - 8y_2 - 3x_5 \le 0\\
&2y_3 + 7t_1 - 7y_2 - 2x_5 \le 0\\
&y_3 + 5t_1 - 5y_2 - 2x_5 \le 0\\
&y_2 \ge 0\\
&x_5 \ge 0\\
&y_3 \ge 0\\
&t_1 \ge 0
\end{aligned}
\tag{6}
$$

By calculating the efficiency of each classification and computing the average efficiency of each factory and ultimately, the company, the results have been given in Table 7 [1].

Table 7. The calculated efficiency values for the processes of the four companies in the years 2017 – 2020.

Total Efficiency	Efficiency of the third stage	Efficiency of the second stage	Efficiency of the first stage	Factory	Company Title	Year
0.62	0.62	1	1	Factory 1: Dry	First Company	2017
0.39	0.5	1	0.77	Factory 5: Semi-dry		
0.52	0.67	1	0.77	Factory 2: Semi-dry	Second Company	
0.59	0.763	1	0.77	Factory 8: Dry		
0.73	0.85	1	0.857	Factory 3: Slurry-wet	Third Company	
0.83	1	1	0.833	Factory 6: Wet		
0.91	0.91	1	1	Factory 7: Semi-humid		
1.00	1	1	1	Factory 4: Semi-humid or wet	Fourth Company	
0.66	0.9	0.78	0.947	Factory 9: Slurry-wet		2018
0.61	0.735	1	0.833	Factory 1: Dry	First Company	
0.44	0.62	1	0.714	Factory 5: Dry		
0.51	0.71	1	0.714	Factory 2: Semi-dry	Second Company	
0.70	0.98	0.8	0.892	Factory 8: Dry		
0.60	0.76	1	0.79	Factory 3: Slurry-wet	Third Company	
0.58	0.814	0.83	0.857	Factory 6: Wet		

0.85	0.854	1	1	Factory 7: Semi-wet		
0.80	0.795	1	1	Factory 4: Semi-wet	Fourth Company	
1.00	1	1	1	Factory 9: Slurry-wet		
0.72	0.812	0.89	1	Factory 1: Dry	First Company	2019
0.57	0.89	1	0.641	Factory 5: Semi-dry		
0.58	0.91	1	0.641	Factory 2: Semi-dry	Second Company	
0.76	0.886	0.857	1	Factory 8: Dry		
0.75	0.09	0.83	1	Factory 3: Slurry-wet	Third Company	
0.80	0.91	1	0.875	Factory 6: Humid		
0.78	0.833	1	0.933	Factory 7: Semi-wet		
0.77	0.903	1	0.857	Factory 4: Semi-wet	Fourth Company	
0.89	1	0.89	1	Factory 9: Slurry-wet		
0.54	0.703	1	0.77	Factory 1: Dry	First Company	2020
0.43	1	0.6	0.714	Factory 2: Semi-dry		
0.55	0.77	1	0.714	Factory 2: Semi-dry	Second Company	
0.71	0.71	1	1	Factory 8: Dry		
0.55	0.88	1	0.625	Factory 3: Slurry-wet	Third Company	
0.77	1	0.83	0.923	Factory 6: Humid		
1.00	1	1	1	Factory 7: Semi-humid		
1.00	1	1	1	Factory 4: Semi-humid	Fourth Company	
0.83	1	0.83	1	Factory 9: Slurry-wet		

In the current paper, for each of the three stages in respect to cement production processes, the efficiency gap was computed and the percentage of both, relativity and cumulative abundance was extracted; the results of which, are shown in Table 8. ‘The cumulative frequency percentage,' specifies that, the semi-dry technology, has the highest frequency of inefficient performance, taking place, in 80 percent of the cases. This advocates that the semi-dry technology has a detrimental efficiency, in comparison to other technologies. Similarly, the frequency Tables designed for the second and third stages display that the slurry-wet and semi-dry technologies have the worst and appalling efficiency, respectively.

Table 8. Table for data frequency for the cement production process stage

Cumulative gap frequency percentage	The percentage of relative frequency of gaps	Efficiency Gap	Efficiency of the First Stage	Factories	Company Title	Year
8.22	8.22	0.38	0.62	Factory 3: Slurry-wet	Third	2020
16.10	7.87	0.36	0.64	Factory 5: Semi-dry	First	2019
23.97	7.87	0.36	0.64	Factory 2: Semi-dry	Second	2019
30.24	6.27	0.29	0.71	Factory 5: Semi-dry	First	2020
36.51	6.27	0.29	0.71	Factory 5: Semi-dry	First	2018
42.79	6.27	0.29	0.71	Factory 2: Semi-dry	Second	2018
49.06	6.27	0.29	0.71	Factory 2: Semi-dry	Second	2020
54.10	5.04	0.23	0.77	Factory 5: Semi-dry	First	2017
59.14	5.04	0.23	0.77	Factory 2: Semi-dry	Second	2017
64.19	5.04	0.23	0.77	Factory 1: Dry	First	2020
69.23	5.04	0.23	0.77	Factory 8: Dry	Second	2017
73.84	4.61	0.21	0.79	Factory 3: Slurry-wet	Third	2018
77.50	3.66	0.17	0.83	Factory 1: Dry	First	2018
81.16	3,66	0.17	0.83	Factory 6: Humid	Third	2017
84.30	3.14	0.14	0.86	Factory 6: Humid (Wet)	Third	2018
87.43	2.74	0.14	0.86	Factory 3: Slurry-wet	Third	2017
90.57	2.37	0.14	0.86	Factory 4: Semi-wet	Fourth	2019
93.31	1.69	0.13	0.87	Factory 6: Wet	Third	2019
95.68	1.47	0.11	0.89	Factory 8: Dry	Second	2018
97.37	1.16	0.08	0.92	Factory 6: Wet	Third	2020
98.84	0.00	0.07	0.93	Factory 7: Semi-wet	Third	2019
100.00	0.00	0.05	0.95	Factory 9: Slurry-wet	Fourth	2017

100.00	0.00	0.00	1.00	Factory 1: Dry	First	2017
100.00	0.00	0.00	1.00	Factory 8: Dry	Second	2018
100.00	0.00	0.00	1.00	Factory 1: Dry	First	2019
100.00	0.00	0.00	1.00	Factory 3: Slurry-wet	Third	2019
100.00	0.00	0.00	1.00	Factory 8: Dry	Second	2019
100.00	0.00	0.00	1.00	Factory 4: Semi-wet	Fourth	2018
100.00	0.00	0.00	1.00	Factory 9: Slurry-wet	Fourth	2020
100.00	0.00	0.00	1.00	Factory 7: Semi-wet	Third	2018
100.00	0.00	0.00	1.00	Factory 9: Surry wet	Fourth	2019
100.00	0.00	0.00	1.00	Factory 7: Semi-wet	Third	2017
100.00	0.00	0.00	1.00	Factory 4: Semi-wet	Fourth	2017
100.00	0.00	0.00	1.00	Factory 9: Slurry-wet	Fourth	2018
100.00	0.00	0.00	1.00	Factory 7: Semi-wet	Third	2020
100.00	0.00	0.00	1.00	Factory 4: Semi-humid	Fourth	2020
TOTAL :	100	4.26				

As can be noted in Table 8, the status of each factory has been organized in ascending order, that is, from the lowest efficiency to the highest one. The efficiency gap is ascertained by deducting the efficiency assessed, from the optimum possible efficiency of 1. So as to specify the inputs with extreme consumption, the Russel measures have been taken advantage of. The mentioned measures were presented by Fare and Lovell in 1987. This model decrements each output in proportion; and similarly, increments each output [30]. In this technique, initially, the entire inputs and outputs are normalized, on the fundaments of the output value. Consequently, the conforming input values are put to comparison with the respected benchmark. In Table 10, the Russel values are computed for classification 11; which, encompasses the first stage of dry and semi-dry technologies, revealing the highest deficiency, where, efficiency is concerned.

Table 9. Calculation of the Russell Measurements for Classification 11

Serial Number	Limestone Material	Alkaline Material	Dry Mixture	Efficiency	Limestone Material	Alkaline Material	Dry Mixture	Efficiency	pattern (row)	Ratio x_1	Ratio x_2	Final Ratio
	X1	X2	Y1		X1	X2	Y1					
1	4	1	4	1	1.00	0.25	1	1	1	1.00	1.00	1.00
2	5	2	5	0.83	1.00	0.40	1	0.83	1	1.00	0.63	0.81
3	5	3	6	1	1.00	0.50	1	1	1	1.00	1.00	1.00
4	6	3	6	0.77	1.00	0.50	1	0.77	1	1.00	0.50	0.75
5	4	2	4	0.77	1.00	0.50	1	0.77	1	1.00	0.50	0.75
6	4	3	4	0.71	1.00	0.75	1	0.71	1	1.00	0.33	0.67

7	6	3	5	0.64	1.20	0.60	1	0.64	3+1 (2)	0.64	1.00	0.82
8	5	3	5	0.71	1.00	0.60	1	0.71	1	1.00	0.42	0.71
9	3	1	3	0.9	1.00	0.33	1	0.9	1	1.00	0.75	0.88
10	4	2	3	0.58	1.33	0.67	1	0.58	16+15	0.54	1.00	0.77
11	5	3	4	0.57	1.25	0.75	1	0.57	3+1	0.53	1.00	0.77
12	5	3	5	0.71	1.00	0.60	1	0.71	1	1.00	0.42	0.71
13	4	2	4	0.77	1.00	0.50	1	0.77	1	1.00	0.50	0.75
14	4	3	5	0.89	0.80	0.60	1	0.89	3+1 (2)	0.96	1.00	0.98
15	5	4	7	1	0.71	0.57	1	1	15	1.00	1.00	1.00
16	5	3	7	1	0.71	0.43	1	1	16	1.00	1.00	1.00
16+5					0.71	0.67	1	1				
3+1					0.67	0.75	1	1				
1+3 (2)					0.77	0.60	1	1				

A novel ingenuity has taken place in these calculations. With due attention to the fact that, for row (10, 11, 12 and 14) of the Table, a benchmark was not present. A combination of the linear rows 15 and 16, was utilized as the benchmark for (10); and from the linear combination of rows (1 and 3), a benchmark for row (11) was manipulated. For rows (12 and 14), a linear repetitive amalgamation was repeated again, of rows (1 and 3) and utilized. By being attentive to the fact that, rows (15 and 16), illustrate an efficiency of 1, their linear combination will also be equivalent to 1. The coefficients of the linear combination for these two cases are made known in the Table hereunder. As can be perceived, the sum of the coefficients is 1; and in fact, these figures have come to hand, from a system of two equations with two nonentities.

Serial	Linear Combination
1+3	2*1-3*1
15+16	1.67*0.67*-15*16
1+3 (2)	1.4* 0.4-3*1

The results offered in Table 10, present a summary of the normalized raw material consumption and efficiency of the factories utilizing dry and semi-dry technologies. A complete analysis demonstrates that twelve factories are enduring efficiency deficiencies, due to excessive consumption of raw materials. Four factories, in particular, indicate high limestone consumption; whilst, a high consumption of alkaline material is evident, in the case of the other eight factories. The linear method was used to normalize the data in Table 10. For this purpose, the equation 7 was used.

$$\frac{x_i}{\sum_{j=1}^{n} x_{ij}} \tag{7}$$

Linear normalization makes it easy to compare different criteria. This feature is especially useful when the criteria are of different types. Linear normalization helps with sensitivity analysis because decision makers can see the impact of changes in the criteria on the final results. This allows them to better understand the strengths and weaknesses of the options.

Table 10. Normalized values for variables and efficiencies for dry and semi-dry technologies

Factories	**Variables**	Limestone Material	Alkaline Material	Dry Material	Efficiency
		x1	x2	y1	
Dry: 1	2017	0.066667	0.02924	0.0625	1.00
Dry: 1	2018	0.066667	0.046784	0.0625	0.81

Dry: 1	2019	0.066667	0.05848	0.0625	1.00
Dry: 1	2020	0.066667	0.05848	0.0625	0.75
Semi-Dry: 2	2017	0.066667	0.05848	0.0625	0.75
Semi-Dry: 2	2018	0.066667	0.087719	0.0625	0.67
Semi-Dry: 2	2019	0.08	0.070175	0.0625	0.82
Semi-Dry: 2	2020	0.066667	0.070175	0.0625	0.71
Semi-Dry: 5	2017	0.066667	0.038596	0.0625	0.88
Semi-Dry: 5	2018	0.088667	0.078363	0.0625	0.77
Semi-Dry: 5	2019	0.083333	0.087719	0.0625	0.77
Semi-Dry: 5	2020	0.066667	0.070175	0.0625	0.71
Dry: 8	2017	0.066667	0.05848	0.0625	0.75
Dry: 8	2018	0.053333	0.070175	0.0625	0.98
Dry: 8	2019	0.047333	0.066667	0.0625	1.00
Dry :8	2020	0.047333	0.050292	0.0625	1.00

Ensuing a detailed analysis of technical aspects, field observations, and consultations with industry experts, 13 key factors impacting efficiency in dry and semi-dry cement technologies were documented. Table 11, which, illustrates the correlation between these factors that are classified into four levels, such as, 0, 1, 3 and 9.

Table 11. Correlation matrix of factors impacting efficiency in the primary, dry and semi-dry stages of factories

Effective Factors	1	2	3	4	5	6	7	8	9	10	11	12	13
Crushing of materials	9	3	0	0	0	0	0	1	1	1	1	0	0
Mixing -time of materials	3	9	0	3	1	1	1	1	1	1	0	0	1
Chlorine Treatment	0	0	9	0	1	1	1	0	0	1	1	1	3
Hardness and uneven texture	3	3	0	9	0	3	3	1	1	1	3	3	1
Sodium and Potassium feeding rate	0	1	1	0	9	1	1	1	1	1	1	1	9
Feeding rate of magnesium oxide melting aid	0	1	1	3	1	9	3	3	3	3	3	3	1
Feeding rate of Iron oxide melting aid	0	1	1	3	1	3	9	3	3	3	3	3	1
(Richness) of Silica content of clay	1	1	0	1	1	3	3	9	0	0	1	1	0
(Richness) of Aluminum content of clay	1	1	0	1	1	3	3	0	9	0	0	0	0
(Richness) of Iron oxide content of clay	1	1	1	1	1	3	3	0	0	9	3	3	0
Purity of iron oxide smelting aid	1	0	1	3	1	3	3	1	0	3	9	3	0

Purity of magnesium oxide melting aid	0	0	1	3	1	3	3	1	0	3	3	9	0
Mixture acidity standardization	0	1	3	1	3	1	1	0	0	0	0	0	9

In continuation, on the fundaments of Table 12, the impact of each factor on the consumption of excessive raw material, was assessed. The impact of these factors is displayed on a four-level scale (0, 1, 3, and 9) for each plant, based on expert opinions. As can be noted in Table 5, the actual impact of each potential high-consumption factor was determined by an accord between the field experts. The high-consumption material was specified at each stage.

Table 12. The impact of various factors on the efficiency gap of the first stage of dry and semi-dry factories

Factories	**Efficiency Gap**	**High-consumption material**	**Crushing of Materials**	**Mixing -time of**	**Chlorine Treatment**	**Hardness and uneven texture**	**Sodium and Potassium feeding rate**	**Feeding rate of magnesium oxide**	**Feeding rate of iron oxide melting aid**	**(Enrichment) of clay in terms of Silica**	**(Enrichment) of clay in terms of Alumina**	**(Enrichment) of clay in**	**Purity of Iron oxide**	**Purity of magnesium oxide melting aid**	**Standardized Acidity**
Dry: 1	0.19	Alkaline Material	3	1	1	3	0	1	1	0	1	1	1	1	9
Dry: 1	0.25	Alkaline Material	9	1	1	9	9	1	1	0	1	1	1	1	9
Semi-dry: 2	0.25	Alkaline Material	3	1	1	9	9	1	1	0	1	1	1	1	9
Semi-dry: 2	0.33	Alkaline Material	9	1	1	9	9	1	1	0	1	1	1	1	9
Semi-dry: 2	0.18	Limestone Material	3	3	1	3	0	0	0	3	1	3	0	0	9
Semi-dry: 2	0.29	Alkaline Material	9	1	1	9	9	1	1	0	1	1	1	1	9
Semi-dry: 5	0.12	Alkaline Material	3	1	1	3	9	1	1	0	1	1	1	1	9
Semi-dry: 5	0.23	Limestone Material	9	3	1	9	0	0	0	3	0	1	0	0	9
Semi-dry: 5	0.23	Limestone Material	9	3	1	9	0	0	0	3	1	3	0	0	9
Semi-dry: 5	0.29	Alkaline Material	9	1	1	9	9	1	1	0	1	1	1	1	9
Dry: 8	0.25	Alkaline Material	9	1	1	9	9	1	1	0	1	1	1	1	9

Dry: 8	0.2	Limestone Material	1	1	1	3	0	0	0	1	1	1	0	0	3

By utilizing or with the help of the AHP, the required weights were determined by us, (efficiency reduction factors). Subsequently, by applying the Wasserman's Connection Matrix, the final relativity importance of every effectual factor, in the primary stage of cement production, in both, dry and semi-dry plants (factories) were extricated. The results of which, are illustrated in Table 13.

Table 13. Final impact of several factors on the efficiency gap in the first-stage of dry and semi-dry cement factories

Effective Factors	Abundance Relativity	Cumulative Abundance
Chlorine Treatment	11.59	11.59
Mixing-time of materials	11.04	22.62
Crushing of materials	10.34	32.96
Hardness and uneven texture	10.10	43.6
Feeding rate of sodium and potassium	7.70	50.76
(Enrichment) of clay in terms of Iron oxide	7.28	58.04
(Enrichment) of clay in terms of Silica	6.78	64.82
(Enrichment) of clay in terms of Alumina	6.20	71.02
Purity of magnesium oxide melting aid	6.05	77.04
Purity of Iron oxide melting aid	6.04	83.11
Feeding rate of magnesium oxide melting aid	5.92	89.02
Standardization of the acidity of the mixture	5.62	94.65
Feeding rate of iron oxide melting aid	5.36	100.00
TOTAL:	100.00	

As demonstrated in Table 13, the chlorine treatment has the most significant impact on the cement production efficiency reduction process. Thereby, it is possible to compute the final impact of varied factors, in relevance with the efficiency gap, or the high consumption of the incoming or input materials, at the diverse stages of the production process in other factories.

4.1. Sensitivity analysis

In this part of the research, by changing the amount of consumed inputs and reducing their amount compared to the efficiency score estimate, it has been done to measure the placement on the efficiency frontier of each of the factory technologies. This work determines how much of the inputs can be reduced, the factories can achieve efficiency. For this purpose, we reduce the inputs by 10 percent until the efficiency status of the factories is examined. According to the changes made, the efficient units increase from 4 units to 5 efficient units. In Table 14, efficiency results with changes in input values is shown.

Table 14. Efficiency results with changes in input values

Factories	Variables	Limestone Material	Alkaline Material	Dry Material	Efficiency
		x1	x2	y1	
Dry: 1	2018	0.0066667	0.0046784	0.00625	1
Dry: 1	2020	0.0066667	0.005848	0.00625	1
Semi-Dry: 2	2017	0.0066667	0.005848	0.00625	0.85
Semi-Dry: 2	2018	0.0066667	0.0087719	0.00625	0.77
Semi-Dry: 2	2019	0.008	0.0070175	0.00625	1
Semi-Dry: 2	2020	0.0066667	0.0070175	0.00625	0.81
Semi-Dry: 5	2017	0.0066667	0.0038596	0.00625	1
Semi-Dry: 5	2018	0.0088667	0.0078363	0.00625	0.87
Semi-Dry: 5	2019	0.0083333	0.0087719	0.00625	0.87
Semi-Dry: 5	2020	0.0066667	0.0070175	0.00625	0.81
Dry: 8	2017	0.0066667	0.005848	0.00625	0.85
Dry: 8	2018	0.0053333	0.0070175	0.00625	1

5. Conclusion

Irrespective of the presence of an abundant access to raw materials and the required resources, for cement production, an optimum utilization, during the course of the exploitation period, is an essential and crucial aspect. This, not only guarantees business stability and continuity, but correspondingly, deters other damages, such as, an over-use, or as a result, in the wear and tear of equipment and machinery, including, environmental impairment and other issues. Cement production involves colossal costs, where, excavation, transport and the crushing of materials are concerned. It is evident that, the utilization of inappropriate raw materials, considering the high volume of processed materials, inflicts unnecessary and major costs on the company. In this survey, primarily, the efficiency of four companies, having a total number of nine plants or factories, was computed throughout three stages, by employing the DEA approach, under non-homogenous conditions; and focus was placed, so as to identify the key factors impacting efficiency reduction, in the first stage of dry and semi-dry cement production in the factories. At this stage, the raw materials are combined only and physical operations, such as, crushing, mixing; and various chemical substances are added to it. Consequently, physical factors were expected to predominantly influence raw material waste, arising from activities and physical aspects. Though, the analysis disclosed and it was noted, that, the treatment of chlorine, which is accounted for as a chemical issue, has the most significant impact, due to inter correlations between factors. Other aspects of importance, usually pertain to a physical activities' categorization, which can be proclaimed to be the mixing-time of materials, crushing of materials, including the hardness and the uneven texture of the incoming material respectively. Hence, factories experiencing efficiency gaps, particularly, where, limestone and alkaline raw materials are concerned, can formulate enhancement strategies, by concentrating on the identified factors. It is imperative to adjust and regulate raw material quantities, on the basis of the standard requirements of raw materials for this stage.

The current study have some limitation, the accuracy of the NDEA results heavily relies on the availability and quality of data regarding inputs, outputs, and processes. In the cement industry, data may be incomplete, inconsistent, or difficult to obtain due to proprietary concerns or variability in reporting standards across different companies. The NDEA approach often relies on certain assumptions, such as the homogeneity of inputs and outputs within the model. In reality, cement production processes can vary significantly due to differences in technology, raw materials, and production methods, which may not be adequately captured by the model. The assignment of weights to different inputs and outputs can introduce subjectivity into the analysis. Decision-makers may have biases that affect how they prioritize certain factors, potentially skewing the results. The cement industry is subject to rapid changes due to technological advancements, regulatory shifts, and market dynamics. The NDEA results may become outdated quickly if they do not account for these changes over time. Future studies could focus on developing standardized data collection methods or frameworks that ensure comprehensive and consistent data availability across the industry. Also, could implement sensitivity analyses to assess how variations in weight assignments impact efficiency scores. Additionally, employing multi-criteria decision-making techniques could help mitigate subjectivity.

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