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Linear programming as a tool to design the mix of cement plant raw materials

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Abstract

This study uses linear programming to develop a methodology for selecting the best raw material mix in an ASCOM cement plant in Egypt. In cement factories, this type adheres to Egyptian chemical composition criteria for raw feed (e.g. 82.5% calcium carbonate, 14.08% silica, 2.5% alumina and 0.92% iron oxide). Furthermore, the model is bound by industry-specific characteristics (e.g. lime saturation factor, silica modulus, alumina modulus and loss of ignition). The results reveal that the model is able to accurately reproduce the mixing of high-quality feed with varying constituent percentages. It is also capable of determining the combining limitations of each ingredient. Furthermore, it demonstrates optimality for additive sourcing short-term planning and capping limestone quality to meet changeable component combinations. Additionally, improving the raw mix reduces limestone feed quality from 51 to 50.6%, resulting in the inclusion of extra limestone reserves.

Keywords:
raw mix; cement industry; linear programming; blending operations

1. Introduction

Limestone, a calcium carbonate source, as well as silica stone, clay, and iron sand, make up the majority of the cement intake. Various materials, such as lime, are thought to be possible addition sources. The cement plant is run by ASCOM-Egypt, and it gets its silicon dioxide from serpentine rock. Due to the wide range of oxide percentiles produced by various mixed components, maintaining proper clinker integrity is difficult. In increasingly competitive markets, supply chain planning is seen as the vital backbone of a company (**Farahani, 2014**). Any plan that isn't properly implemented can lead to supply chain disaster (**Mirmohammadi, 2017**). Supply chain management is crucial in assuring sales and company accessibility at key revenue locations (**Hugos, 2018**). It has been a crucial part of organizations in the plant because it aims to improve customer service (**Sawik, 2015**), minimize operating expenditures (**Rabbani, 2020**), and increase corporate profitability (**Fracassi, 2016**). Supply change management has emerged as a critical component of business growth and customer satisfaction (**Kržanović et al., 2015; Babazadeh, 2019**).

Cement use has increased over the world as a result of recent developments. As a result, the pressure on limestone and other additive materials, such as sand, clay, and iron oxides rose. The scarcity of high-quality raw materials stimulated research into strategies for regulating raw feed design and producing high-quality clinker. Ordinary Portland Cement (OPC) is a significant building and construction material, as well as a key component of concrete. There are several forms of cement, all of which are dependent on hydraulic cement and have become adhesive as a consequence of the interaction. The cement business is reliant on raw materials and their quality to produce a finished product that meets the demands of economic development, infrastructural enhancement, and expansion. All processes and products are required to adhere to Egyptian regulations. Previous research has been presented, explained, and achieved in

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order to determine an appropriate raw mix based on the raw material base component, but this study will focus on the integration of raw materials and clinker. Limestone, clay, or natural mixtures such as marl (**Schneider, 2011**) are four components that have a role in the cement business. Typically, 75% of the blend is made up of limestone, with 25% of the blend made up of clay inserts as additives and correctives (**Qureshi, 1991**). Lime oxide, silica oxide, alumina, and iron oxides are among the components of OPC. Concrete is made up of OPC that interacts with water and solidifies (**Ambriško et al., 2015; Awadh, 2020; Kosmatka, 2002**).

Mining is a multistep process in which the processes associated with each stage must seamlessly transition to those associated with the following step. In the first step, the ore is mined out from the quarries. Ore blending, the second stage, is the result of all mining processes, such as ore dressing and transport to a remote location. Before reaching their final destination, materials are treated and admixed. Typically, linear programming algorithms (**Heaton, 1971**) are used to complete the system controls of blending operations (**Asad, 2010**) and transportation to give optimal results (**Hoerger, 2019**). When it comes to tackling optimization challenges, linear programming (LP) is a must-have instrument (**Saul, 1990; Graham-Taylor, 1992**). This method is a mathematical approach for evaluating linear models under certain restrictions, and in this case, for determining the best mine production results (**Ramazan, 2001**). Many scholars have suggested algorithms for identifying the essential constraints for LP models, and many have utilized various algorithms to express the problem and solve for the best solution. LP issues have been established and they can be used in real-world situations (**Park, 2016**).

Many academics have updated the various algorithms to apply LP optimization in various disciplines, particularly in mining engineering and cement production (**Oyepata and Obodeh 2015**), in order to reduce costs and increase income in mining operations, in recent years. The link between the primary LP problem and the dual LP problem was further discussed (**Ricciardone, 2001; Michalakopoulos, 2017**). LP has been used in a variety of industries, including manufacturing, finance, and agriculture. LP is one of the most extensively used strategies in mining operations, and it may be used to design both surface and underground mines, taking into account all activities and restrictions (**Straka and Malindzak, 2009; Straka et al., 2018**).

This research builds on the strategic LP branch strategy, which was previously used to solve the mining blending problem. The fundamental objective of this research is to discover the appropriate requirements for a raw mix of cement plant raw feed by integrating entire raw material chemical compositions. This article examines the dynamic blending of various ore samples (minerals) and reports the amounts required in the blending process in the mine and in stock. To determine the correct amounts imported from various quarries, the suggested system employs flexible and dynamic mixing. The volumes transported between different mining areas are determined via dynamic blending. The proposed method was based on past research findings, which included merging production and supply chain research, lowering prices and delivery times, and thereby improving the supply chain (**Taghipour, 2013; Ivanov 2013; Zegord, 2010**). Variations in physical and other operating constraints affect the extraction step, which must be factored into the planning process. The following are the five major constraints:

1. During mining, according to the quality of the mined ores, extract ore blocks from the horizon.
2. Remove any inclination restrictions for all ores in a non-overlapping order.
3. To ensure balance, assess the amount of ore and overburden.
4. To fulfil the ore processing unit's requirements, make sure the total tonnes of ore extracted equal the total tonnes of ore.
5. Make sure that the entire amount of metal recovered during the time period is less than the total amount of material sold (**Ricciardone, 2001**). We assume that the complete amount of tonnes is handled in the same amount of time.

The goal of this contribution is to create a solution follow-up LP model that takes into account four or more materials with diverse chemical compositions and all requirements. It aids management in making appropriate control decisions in raw mix plants, not just in the cement business but also in a variety of mining industries. Aside from that, there is the interpretive analysis of the optimal solutions or alternative solutions based on the problem description; it is referred to as a dynamic solution since it is dependent on the chemical composition of raw materials changing. The purpose of this paper is to propose a solution to a material handling model that takes into account four raw materials in various conditions for the cement industry. It assists mining engineers in making accurate long-term and short-term judgments for feed material, not only in furnaces but also in stockpiles. This paper is divided into five sections. Section 2 gives a summary of relevant studies reported in the linked literature review. Section 3 discusses the methodology problem created and subscribed to data collection, restrictions and problem formulation, raw material requirements and implementation based on analytical methodologies, and Section 4 explains the results and discussions. Finally, Section 5 summarizes the findings of this research.

Many researchers have examined mine production planning in terms of optimization, but without taking into account metallurgical units or raw feed with more than three components. In this article, four components are considered. They concentrated on raw mix design (**Petrasinovic et al., 1986; Ponnusamy, 2020**) in order to produce high-quality raw materials for a big volume of raw materials in the cement industry (**Lamghari, 2012; Duda, 1985**), Egyptian industry focused on stone, cement, and ceramics as raw resources, which expanded. Another study looked at how mines supply resources and how much energy is utilized in both production and transportation. They proposed that alternative raw materials be added to the raw cement mixture at a set pace to construct the cement's composition (**Folsberg, 2002**), and that numerous researchers study and apply various methods to find the optimum linear programming tools. They developed linear programming to solve transportation problems, and it is now utilized in a variety of applications. They concentrated on solving a variety of business problems in order to determine the maximum or minimum value for the target function, with the goal of lowering the overall cost of shipping from the mine to the destination (**Eiselt, 2010; Loomba, 2000; Ghazali, 2012**). Hoerger (**Hoerger et al., 2019**) investigated the outcomes of linear programming as sensitive instruments, which can be used in a variety of industries, including mining operations (mining, dressing and metallurgical unit). Controlled in risk management for unforeseen conditions for any system is the focal topic of this research (**Bamoumen, 2018**). LP as simplex methods were used to address a variety of mining problems, including combining different grades of resources from various places (**Azzamouri, 2018; Bengtsson, 2013**).

2. Methodology of Linear Programming

2.1. Problem definition

In Egyptian cement plants, raw material variability is a well-known problem. Some of the raw materials used to make cement are natural minerals, while others are waste streams from other industries. Limestone (a calcium source) and smaller amounts of clay, shale, and sand are among the constituents (e.g. source of silica, aluminum and iron). Clinker should have a chemical composition of 64% Cao, 22% SiO_2, 22% Al_2O_3, and 22% Fe_2O_3. Therefore, the interaction of the four oxides has a significant impact on mixture properties. **Table 1** gives the normal assay date of the raw materials. As can be seen, the variability percent is significant and can be adjusted by taking into account the collective ingredient mineralogical composition. The global manufacturing process at a typical dry-method cement factory is depicted in **Figure 1**. (Misr Cement Company, Minia Portland Cement). The enclosed area began with blending the section's machinery for combining raw materials and ended with batching silos. Our main research focus is on the blending portion.

2.2. Limitations and the formulation of a problem

There are two primary points that must be addressed in order to achieve the best possible result. The two points are addressing feedstock oxide percentages and product testing restrictions in order to comply with code of standards. **Table 2** shows the percentages of four ingredients required to make a standard raw meal (**Ali, 2012; Ali et al., 2018**).

2.3. Formulation of the raw material requirements

The raw input is governed by a set of limitations known as the number of ratios modulus. The lime saturation factor, silica modulus, alumina modulus, and loss of ignitions are among these restrictions. According to Egyptian standards, equations 1 to 4 describe the relationships between components and the percentage of primary component in raw materials. To create clinker with the proper raw material composition that meets the regulating modulus, linear programming is used. For each raw material, the LP model will correct variations in chemical composition as detected as a fluctuation of oxides (limestone, iron oxides, bauxite and shale).

Equation 1 gives the saturation factor of lime:

$$LSF = \frac{CaO}{2.8\ SiO_2 + 1.18\ Al_2O_3 + 0.65\ Fe_2O_3}\ x100 = 97\% \quad (1)$$

Equation 2 gives the modulus of silica (SM):

$$SM = \frac{SiO_2}{Al_2O_3 + Fe_2O_3} \quad (2)$$

Table 1: Assay of raw materials ASCOM, Egypt

Samples	Chemical analysis (%)							
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	SO_3
Limestone	3.3	0.79	0.39	51.00	1.24	0.5	0.2	0.1
Shale	74.98	8.8	6.3	0.98	0.24	0.3	0.2	0.2
Iron oxide	9.35	2	83.16	0.06	0.41	0.2	0.07	0.07
Bauxite	9	50	13.75	5.5	0.5	0.1	0.1	0.05

Table 2: The proportion of raw materials used in the primary components

Mix (%)	Limestone	Shale	Iron ore	Bauxite	Raw meal
	82.50	14.08	0.92	2.5	100.00

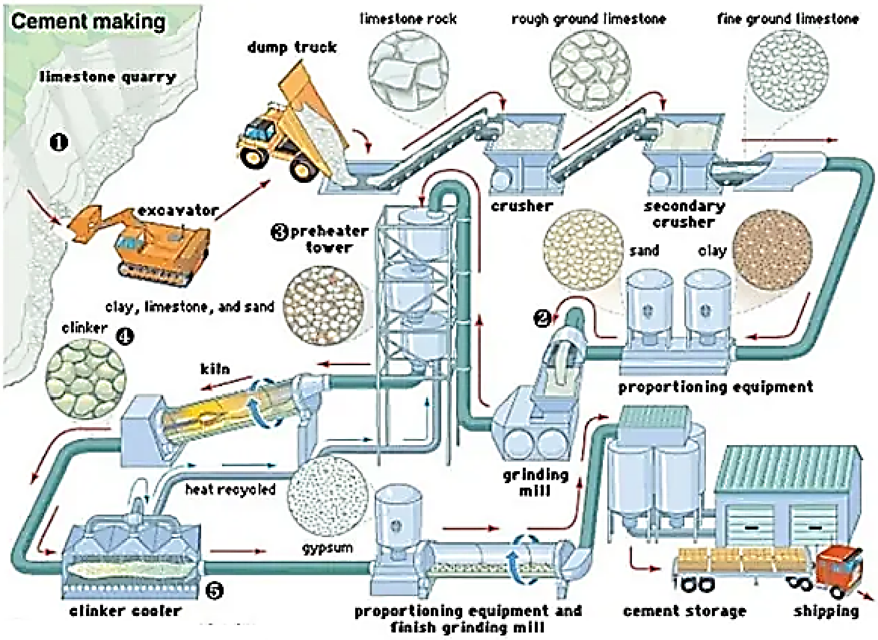

Figure 1: Cement production flow diagram (**Morant, 1988**)

Equation 3 gives the modulus of alumina (AM):

$$AM = \frac{Al_2O_3}{Fe_2O_3} \tag{3}$$

Equation 4 gives the loss of ignition (LoI):

$$LoI = \frac{m_1 - m_2}{m_1} x1000 \tag{4}$$

Where:

m_1 – the mass of the tested sample [g],

m_2 – the mass of heated test sample after cooling [g].

2.4. Identify the system's requirements

The LP model is used to figure out how to combine raw mix and material output planning. The data set for raw materials in oxides, modulus factors as quality control required by the cement industry, and final product parameters connected to Egyptian Standards are shown in **Figure 2**. The following information is needed to implement this model:

1. Data about the oxide content of the raw material.
2. Quality Control Constraints of Various Moduli.

2.5. Formulation of linear programming (LP)

For tackling optimization problems, linear programming (LP) is a must-have technology. The problem of calculating how much should be moved from a stockpile to a feed bin is a challenge (**Rijal et al., 2019**). The transportation optimization processes are the subject of a lot of research. Unified and compressive algorithms are still missing from the techniques (**Abu Halawa, 2016**). Computers were generally used to balance and optimize transportation processes in a basic manner and with limited programming techniques (**Farghaly et al., 2021; El-Beblawi et al., 2007**). The restrictions that define the current problem are as follows:

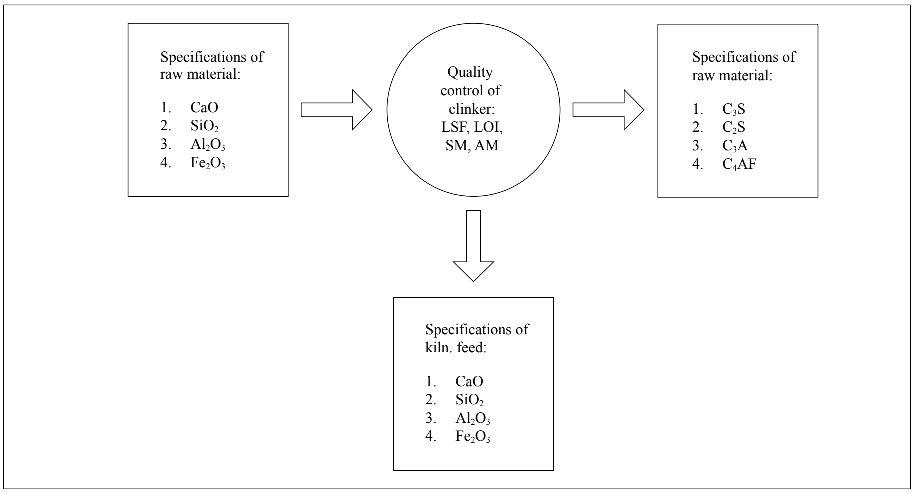

Figure 2: Designing a raw mix based on system criteria

A. Constraints Linear type, which can be summarized as follows:

1. $K_1 - K_4 = 1$ (It represents the four ingredients and assigns a value of 1 to ensure that they are present in the composition). (5)

2. $K_5 = 100$ (K_5 denotes a batch total that satisfies the required tonnage). (6)

3. Alumina modules (AM):

$K_6 L = AM \times \%Fe_2O_3 - \%Al_2O_3$ (Limestone) (7)

$K_7 S = AM \times \%Fe_2O_3 - \%Al_2O_3$ (Shale) (8)

$K_8 I = AM \times \%Fe_2O_3 - \%Al_2O_3$ (Iron oxide) (9)

$K_9 B = AM \times \%Fe_2O_3 - \%Al_2O_3$ (Bauxite) (10)

4. Silica modules (SM):

$K_{10} L = SM \times \%Al_2O_3 + SM \times \%Fe_2O_3 - \%SiO_2$ (Limestone) (11)

$K_{11} S = SM \times \%Al_2O_3 + SM \times \%Fe_2O_3 - \%SiO_2$ (Shale) (12)

$K_{12} I = SM \times \%Al_2O_3 + SM \times \%Fe_2O_3 - \%SiO_2$ (Iron oxide) (13)

$K_{13} B = SM \times \%Al_2O_3 + SM \times \%Fe_2O_3 - \%SiO_2$ (Bauxite) (14)

5. Lime saturation (LM):

$K_{14} L = 2.8 \times LM \times \%SiO_2 + 1.18 \times LM \times \%Al_2O_3 + 0.65 \times LM \times Fe_2O_3 - 100 \times CaO$ (Limestone) (15)

$K_{15} S = 2.8 \times LM \times \%SiO_2 + 1.18 \times LM \times \%Al_2O_3 + 0.65 \times LM \times Fe_2O_3 - 100 \times CaO$ (Shale) (16)

$K_{16} I = 2.8 \times LM \times \%SiO_2 + 1.18 \times LM \times \%Al_2O_3 + 0.65 \times LM \times Fe_2O_3 - 100 \times CaO$ (Iron oxide) (17)

$K_{17} B = 2.8 \times LM \times \%SiO_2 + 1.18 \times LM \times \%Al_2O_3 + 0.65 \times LM \times Fe_2O_3 - 100 \times CaO$ (Bauxite) (18)

6. Limiting constraints:

Alumina modules, % ($AM \geq 1.4 - 1.6$) (19)

Silica modules, % ($SM \geq 2.4 - 2.6$) (20)

Lime saturation factor, % ($LM \geq 97 - 110$) (21)

B. Objective functions, Linear Objective Function are Equations 1-5:

X_1 (Limestone) = Sum $[(K_5 \times K_7 \times K_{12} \times K_{17}) + (K_5 \times K_8 \times K_{13} \times K_{15}) + (K_5 \times K_8 \times K_{13} \times K_{15}) - (K_5 \times K_9 \times K_{12} \times K_{15}) + (K_5 \times K_7 \times K_{13} \times K_{16}) + (K_5 \times K_8 \times K_{11} \times K_{17})]$ (22)

X_2 (Shale) = Sum $[(-K_6 \times K_5 \times K_{12} \times K_{17}) + (K_6 \times K_5 \times K_{13} \times K_{16}) + (K_{10} \times K_5 \times K_8 \times K_{17}) - (K_{10} \times K_5 \times K_9 \times K_{16}) + (K_{14} \times K_5 \times K_8 \times K_{13}) + (K_{14} \times K_5 \times K_9 \times K_{12})]$ (23)

X_3 (Iron Oxide) = Sum $[(-K_6 \times K_5 \times K_{13} \times K_{15}) + (K_6 \times K_5 \times K_{11} \times K_{17}) + (K_{10} \times K_5 \times K_9 \times K_{15}) - (K_{10} \times K_5 \times K_7 \times K_{17}) - (K_{14} \times K_5 \times K_9 \times K_{11}) + (K_{14} \times K_5 \times K_7 \times K_{13})]$ (24)

X_4 (Bauxite) = Sum $[(-K_6 \times K_5 \times K_{11} \times K_{16}) + (K_6 \times K_5 \times K_{12} \times K_{15}) + (K_{10} \times K_5 \times K_7 \times K_{16}) - (K_{10} \times K_5 \times K_8 \times K_{15}) - (K_{14} \times K_5 \times K_7 \times K_{12}) + (K_{14} \times K_5 \times K_8 \times K_{11})]$ (25)

X_5 (Total raw meal) = Sum $[(K_7 \times K_{12} \times K_{17}) + (K_8 \times K_{13} \times K_{15}) + (K_9 \times K_{11} \times K_{16}) - (K_9 \times K_{12} \times K_{15}) - (K_7 \times K_{13} \times K_{16}) - (K_8 \times K_{11} \times K_{17}) - (K_6 \times K_{12} \times K_{17}) - (K_6 \times K_{13} \times K_{16}) - (K_6 \times K_{11} \times K_{16}) + (K_6 \times K_{12} \times K_{15}) + (K_6 \times K_{13} \times K_{16}) + (K_6 \times K_{11} \times K_{17}) + (K_{10} \times K_8 \times K_{17}) + (K_{10} \times K_9 \times K_{15}) + (K_{10} \times K_7 \times K_{16}) - (K_{10} \times K_8 \times K_{15}) - (K_{10} \times K_9 \times K_{16}) - (K_{10} \times K_7 \times K_{17}) - (K_{14} \times K_8 \times K_{13}) - (K_{14} \times K_9 \times K_{11}) - (K_{14} \times K_7 \times K_{12}) + (K_{14} \times K_8 \times K_{11}) + (K_{14} \times K_9 \times K_{12}) + (K_{14} \times K_7 \times K_{13})]$ (26)

C. Non negative all $X1\text{-}X5 \geq 0$

This formula was created using the Excel solver in an active function. To come up with the best solution, objective functions and constraints are applied. In the following section, we'll go over the findings. The active Excel sheet design accepts all input data for four materials, the constraints linked to all moduli as mentioned above, the objective functions are compiled by links between chemical composition of raw materials and modulus factors, and finally the optimum solution was given and the check of optimality for this model was assessed.

3. Results and Discussion

The connected functions were created using data provided in Excel. All functions were written with the restrictions and modulus factors for chemical composition. The active Excel sheet was created to receive chemical composition input data and to be used in conjunction with a mathematical model that articulated the relationship between chemical composition and constraints. Since it may be utilized with different raw material compositions, this type is suitable for the cement industry. Obtaining the ideal answer for that problem is an alternative solution. The system can then be used or the units can be changed according to the clinker standard. The results provide an ideal solution for linear issues in mining and metallurgical processes, which were solved utilizing an Excel sheet with active solutions. However, because mine blending models are more comprehensive than the suggested model, there are a number of issues. There were numerous challenges during the cement manufacturing process, including variations in chemical composition for raw materials, quality control in the stockpile, and meeting the cement manufacturing criteria. The evaluation of raw materials was based on the total amount and assay for each material. As a result, it appears that batch size and blending decisions must be made at the same time. The optimal solution is obtained by considering the quality of a mixture of ingredients (e.g., assay and total amount of mine production) to obtain the optimal solution, which indicates the number of materials such as limestone, shale, iron oxide, and bauxite. This section discusses the base case schedule implementation, which was calculated using the optimal solution. All raw material amounts should be entered into the model and the final amount should meet the clinker specifications as given in **Table 3**.

Table 3: Design of raw materials for cement manufacturing

Raw materials Oxides	Lime-stone	Shale	Iron ore	Bauxite	Raw feed	Raw feed Targets	Coefficients*		Matrix Determin-ants	Quantity
Mix %	82.50	14.08	0.92	2.50	100.00		K1	1	Limestone	53419838949
SiO_2	3.30	74.98	9.35	9.00	13.59		K2	1	Shale	9144396153
$A_{l2}O_3$	0.79	8.80	2.00	50.00	3.16		K3	1	Iron oxide	601249657.5
Fe_2O_3	0.39	6.30	83.16	13.75	2.32		K4	1	Bauxite	1819376846
CaO	51.00	0.98	0.06	5.50	42.35		K5	100	Total raw meal	649848616.1
MgO	1.24	0.24	0.41	0.50	1.07	Lime Saturation	K6	-0.244		
K_2O	0.50	0.30	0.20	0.10	0.46	97.00	K7	0.02	Raw materials %	
Na_2O	0.20	0.20	0.10	0.10	0.20		K8	114.424	Limestone	82.20
SO_3	0.10	0.20	0.07	0.05	0.11	Silica Modulus	K9	-30.75	Shale	14.07
L.O.I.	42.48	8.00	4.65	21.00	36.74	2.40	K10	-0.468	Iron oxide	0.925
TOTAL	100.00	100.00	100.00	100.00	100.00		K11	-38.74	Bauxite	2.8
S.R.					2.48	Alumina Modulus	K12	195.034	TOTAL	100
A.R.					1.36	1.40	K13	144		
L.S.F.					97.83		K14	-4088.71		
							K15	21671.03		
							K16	8005.618		
							K17	8484.338		

*In order to calculate the raw feed, the coefficients K1-K17 are treated as constants.

$$\mathrm{SiO_2} = \frac{Mix\%\ \ Limestone\ x\ SiO2\ \% + Mix\%\ Sahl\ x\ SiO2\ \% + Mix\%\ Iron\ ore\ \%\ x\ SiO2\% + Mix\%\ Bauxite\ \%\ x\ SiO2\ \%}{100} \quad (27)$$

$$\mathrm{Al_2O_3} = \frac{Mix\%\ \ Limestone \times Al_2O_3\ \ \% + Mix\%\ Sahl \times Al_2O_3\ \ \% + Mix\%\ Iron\ ore\ \%\ x\ Al_2O_3\ \ \% + Mix\%\ Bauxite\ \%\ x\ Al_2O_3\ \ \%}{100} \quad (28)$$

$$\mathrm{Fe_2O_3} = \frac{Mix\%\ \ Limestone \times Fe_2O_3\ \ \% + Mix\%\ Sahl \times\ \ Fe_2O_3\ \ \% + Mix\%\ Iron\ ore\ \%\ x\ \ Fe_2O_3\% + Mix\%\ Bauxite\ \%\ x\ \ Fe_2O_3\ \%}{100} \quad (29)$$

$$\mathrm{CaO} = \frac{Mix\%\ \ Limestone \times\ CaO\ \% + Mix\%\ Sahl \times\ CaO\ \% + Mix\%\ Iron\ ore\ \%\ x\ CaO\% + Mix\%\ Bauxite\ \%\ x\ CaO\ \%}{100} \quad (30)$$

First and foremost, the general percentage of raw materials was established based on the Egyptian and European standards. The percentages of raw ingredients are shown in **Table 3** (limestone, shale, iron oxide and bauxite). Calculate the SiO_2 percentage inside raw feed using **Equations 6 to 9**, and have the reader repeat the process for the remaining components. In addition, the equilibrium must follow our aim for modulus factors such as lime saturation factors, silica modulus, and alumina modulus. Finally, using coefficients to compute the number of raw materials required to keep the product as a standard.

The use and expansion of the resource are the main goals of mining engineering. The optimal limit of the solution is linked to the capability of using limestone less than (51 percent). The system is iterated by chang-

Table 4: The outcome of the limiting CaO percent satisfying the standard raw mix iteration

CaO	CaO variation	LSF	SM	AM
51%	0	97.83	2.48	1.36
50.9	0.1	97.64		
50.8	0.2	97.45		
50.7	0.3	97.27		
50.6	**0.4**	**97.07**		
50.5	0.5	96.88		
50.4	0.6	96.69		
50.3	0.7	96.5		
50.2	0.8	96.31		
50.1	0.9	96.12		
50	1	95.93		

ing the CaO by -0.1 percent at a time and observing the change for constraint satisfaction criterion satisfaction. When the CaO percent limit set by cement industry standards is reached, the experiments are terminated. **Table 4** shows that the ideal CaO percent ranged from 50.6 to 51% with acceptable fluctuations at SM and AM when all constraints were met.

4. Conclusion

The goal of this study is to optimize the raw mix of a cement plant using linear programming (LP). Therefore, this research proposes a practical optimization strategy for tackling a general constrained LP issue and obtaining the best blended solution. The following are the main points of the conclusions:

1. In the cement sector, the model is more useful for raw mix design. Since it takes into account all limits in order to meet raw material and clinker characterization standards.
2. This solver sheet application is open source rather than proprietary, which saves time and money.
3. The raw mix design model may be used to anticipate any type of cement under the constraints of raw mix calculations and chemical variation for all components.
4. The reduction in limestone CaO% from 50.6 to 51% adds a significant amount of low-quality resources into viable reserves, extending the quarry's life.

This type of optimization raises the quality of the final product, lowers costs, allows for more efficient use of natural resources, and stimulates the economy. Despite the fact that LP has previously been used in studies, such as ore blending. The LP, on the other hand, is a versatile and active Excel sheet that can be used in a wide range of applications by changing raw meal assay analysis and constraints. This research can be applied in a variety of fields, including concrete mix, drilling mud, and soil stabilization. Depending on the needs, this Excel sheet can be expanded to include more variables and constraints (e.g. four parameters in the cement industry).

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SAŽETAK

Linearno programiranje kao alat za projektiranje sirovinske smjese u tvornici cementa

Studija prikazuje metodu linearnoga programiranja uporabljenu sa svrhom odabira najbolje sirovinske smjese u tvornici cementa ASCOM (Egipat). Takva smjesa poštuje egipatske standarde kemijskoga sastava sirovine (npr. 82,5 % kalcijeva karbonata, 14,08 % silikata, 2,5 % aluminijeva oksida, 0,92 % željeznoga oksida). Također, model je uvjetovan industrijskim standardima (npr. faktorom zasićenja vapnom, silikatnim i aluminatnim modulom te gubitkom (oksida) žarenjem). Modelom se mogla točno izračunati visokokvalitetna mješavina različitih (postotnih) komponenti te je dokazan kao optimalan za brz izračun raznih aditiva i postizanje najveće kvalitete vapnenačke sirovine uz doziranje ostalih komponenti. Time je udjel vapnenca bilo moguće smanjiti na 50,6 – 51 %, što je otvorilo put eksploataciji dodatnih rezervi te sirovine.

Ključne riječi:
sirovina, industrija cementa, linearno programiranje, miješanje sirovina

Author(s) contribution

Mohamed Hassan (Lecturer, Ph.D., Mineral Processing/Ore Dressing) developed the linear programming (LP) concept and methodology, carried out the analysis, and assisted in the presentation and interpretation of the findings. **Salah Bader** (Lecturer, Ph.D., Mining and geotechnical engineering/Rock Mechanics) assisted in the formulation of raw material requirements using linear programming (LP) and the design of a raw mix based on system criteria. **Mahrous Ali** (Associate Professor, Ph.D., Mining Engineering/Rock Mechanics and Mine Design) wrote the introduction, provided the Linear Programming (LP) constraints, assisted in the interpretation of the results, and drafted the paper. **Wael Abdellah** (Associate Professor, Ph.D., P. Eng., Mining Engineering/Rock Mechanics) contributed to the introduction, participated in the results discussion, and reviewed the submitted paper. **Gamal Abdelhaffez** (Associate Professor, Ph.D., Mineral Processing/Ore dressing) contributed to the concept and methodology of Linear Programming (LP), assisted in the interpretation, presentation, and discussion of the results, and wrote the conclusions.