



# A Linear Programming Methodology to Optimize Decision-Making for Ready-Mixed Cement Products: a Case Study on Egypt's New Administrative Capital

Ahmed A. Mawgoud<sup>1</sup> · Mohamed Hamed N. Taha<sup>1</sup> · Nour Eldeen Khalifa<sup>1</sup>

Received: 24 January 2022 / Revised: 7 September 2022 / Accepted: 8 September 2022 / Published online: 19 September 2022  
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## Abstract

Egypt has started constructing its New Administrative Capital since 2015. The new capital was designed to meet smart city standards, which presents a challenge for businesses to make the optimum business decisions given the set budget for such a project. As a result, reaching the optimum solution for allocating the needed materials to each building became important. Many researchers have considered the theory of constraints in their studies to determine the optimum product mix. Frequently, research considers the target of profit maximization to reach the optimum solution with one scenario. In this paper, we aim to solve the problem of product mix in cement production, which organizations face. The problem was formulated based on a case study in Egypt with two linear programming approaches. For this problem, many scenarios were presented under the consideration of two aspects, which are resource utilization and productivity. Data visualization was used in this paper to simplify the procedure of decision-making. Also, a dashboard web application was made for the decision makers to make it easier to create, analyze, and see different business scenarios.

**Keywords** Optimization · Linear programming · Industry · Decision-making · Egypt

## Introduction

The New Administrative Capital (NAC) is a huge project that has been under construction since 2015 in Egypt. The idea of this city was reaffirmed at the Egypt Economic Development Conference (Serag 2017). The main idea of this city is to gather all the governmental establishments and the headquarters of all ministers away from Cairo. It will be located about 45 km east of Cairo (El-Maksoud et al. 2019). It is estimated by the experts that the new smart city can handle a population of 6 million citizens. Following the idea of Wellington City in New Zealand, the New Administrative City will

function as the administrative and financial capital (Peirce and Ritchie 2007). In Table 1 below, a list of all the used abbreviations in this study with their descriptions is provided.

One of the main reasons for initiating this project was the need to relieve overcrowding in Greater Cairo, as it is expected that the overall population of Cairo — estimated to be 11.4 million in 2024 — is expected to be doubled in the following few decades (Chen 2018).

Various organizations around the world, including Egypt, have faced difficulties in optimizing their production inputs. The organization's stability in a competitive market place mainly relies on its capability to meet the highest rate of production with the lowest acceptable cost without affecting the product's quality.

The authors (Chen et al. 2021) have studied the companies' production rate challenges due to the COVID-19 pandemic crisis. The companies worldwide have faced the threat of production input deficiency and low utilization levels that have accordingly led to low levels of production output. The organizations have to design a management workflow that can help in monitoring their

✉ Ahmed A. Mawgoud  
aabdelmawgoud@pg.cu.edu.eg

Mohamed Hamed N. Taha  
mnasrtaha@cu.edu.eg

Nour Eldeen Khalifa  
nourmahmoud@cu.edu.eg

<sup>1</sup> Information Technology Department, Faculty of Computers and Artificial Intelligence, Cairo University, Cairo, Egypt

**Table 1** A description list for the used abbreviations in this study

Acronym	Description
CCRs	Capacity constraint resources
GA	Genetic algorithm
IEC	International electro-technical commission
ISO	International Organization for Standardization
MARR	Minimum attractive rate of return
NAC	New Administrative Capital
RMC	Ready-mixed concrete
TOC	Theory of constraints
WIP	Work in process

performance level in both operations and resource usage as the total profit of any industry is mainly affected by the budget used on the resources that contribute to the production process. There is a need for a strong infrastructure in the new capital to face the cyber threats facing the region and secure the whole buildings from being attacked as stated in (Mawgoud et al. 2019) and (Mawgoud and Ali 2020). As a result, the need for low-cost and secure housing projects is increasing in Egypt, housing costs, and the lack of financing solutions are all factors that contribute to this problem. Recently, ready-mixed companies have realized the need for increasing the product mix (Collard-Wexler 2006). RMC is considered the most well-known in the construction materials industry worldwide. Regularly, due to the technical necessities, the concrete is usually mixed in a small mixing station, and then it is transported to the building site. Essentially, there are two core factors that affect the cost of RMC: transportation and the material itself. Producing different types of cement products increases the possibility of the organization being profitable and providing the target market with its needs. Non-financial performance procedures in the organization, such as administration, customer service, and WIP, can have an impact on product mix optimization (Abinesh 2019).

### Linear Programming for Cement Industry

Linear programming is considered an effective operational research approach that is used to assign an organization's best practice solution for optimum production resource usage. This approach is widely used in international business as a tool for determining optimal resource usage. Multiple products need various production amounts of resources, with various costs, and revenues for each stage in the production cycle. By one way or another, the importance of product mix decisions has become essential for cement organizations that produce multiple types of products (Vasant 2005).

The problem of cement products arises from difficulties that cement organizations face while assigning the available resources to the different types of activities, which can affect the production rate and lead to problems meeting the market demand (Yu et al. 2013). On the contrary, the availability of productive resources in most cases can lead to a lack of use of all those resources together in an efficient approach. The applied methodology in this paper is a constraint-based approach, which can deal with the market's needs and supply of raw materials. The main reason behind using the TOC is to reach the targeted throughput or revenue rather than the produced quantity (Eastman and Pande 2010). Throughput represents the main factor in TOC operational indicators (Brink 2019). The theory of constraints approach can identify the total profit margin for every possible ready-mixed product. This allows the decision makers to choose the most suitable ready-mixed product that maximizes the profit within the constraint set. In order to generate scale economies, it is preferable to choose products that share the same cost (Woubante et al. 2019).

### Paper Contribution

The high demand for ready-mixed products in the NAC project necessitates a strategy for ready-mixed businesses to help in the decision-making phase and maximize profits using the obtainable cement products (Fig. 1). The goal of this study is to find the best way to train, hire, and distribute building materials to meet supply and demand. The proposed method suggests a training and hiring strategy based on a project's timeline or demand pattern, as well as the amount of construction materials already on hand. The model reduces construction material expenses while meeting project needs. The optimization-based approach is versatile. A corporation developing a project might use the model to guide its construction strategies. With modest tweaks, a company can use the model to analyze multiple construction tactics over several projects, including the number of workers to be relocated from one jobsite to another, the number of workers to be hired, and the number of workers to train. The model can be adapted to assist a regional planning group with near-future workforce predictions. The approach should be able to provide the most cost-effective way to overcome shortage issues based on demand and supply estimates. This will be done in this study through the following points:

- Linear programming is used to show the proposed solution formula for ready-mixed cement through an applied case study done in Egypt. The goal is to show a simulation and a solution for ready-mixed cement.

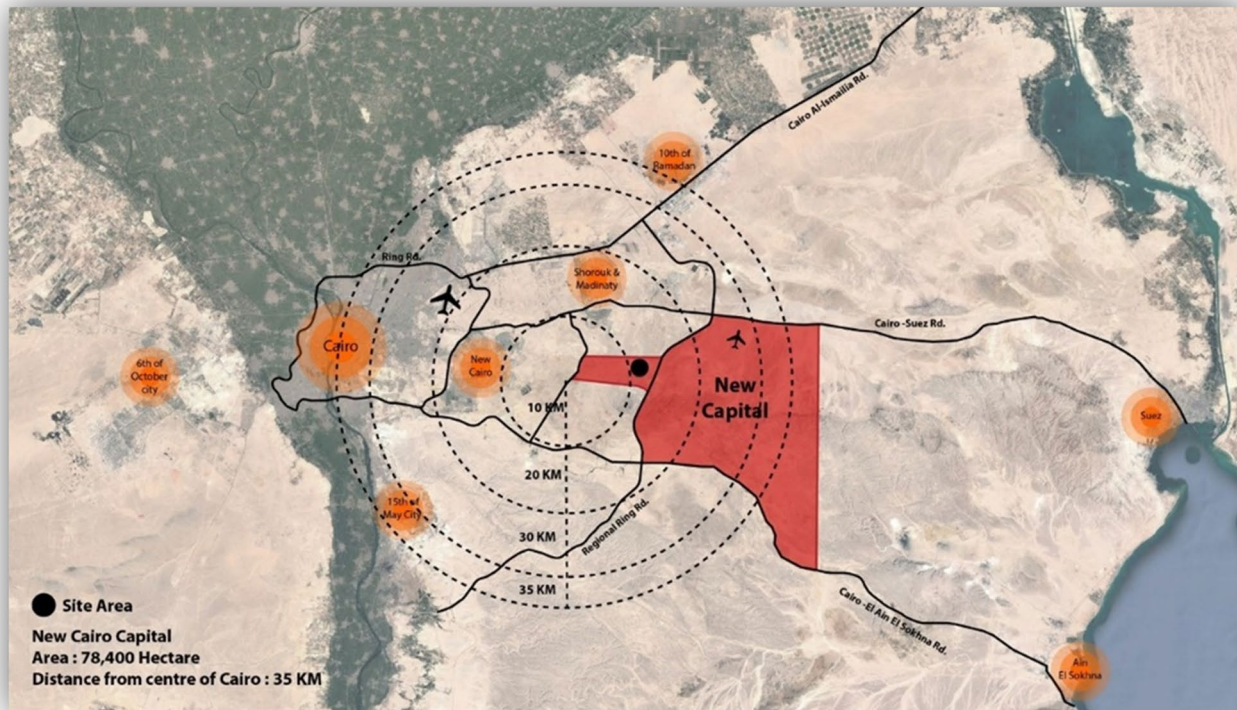


Fig. 1 A geographical map for the position of the NAC of Egypt

- Maximize profit and obtain a high utilization of the generated situations rate by doubling the CCRs, respectively.
- Utilize two linear programming strategies to solve the presented problem in the existing case study.
- Increase the utilization rate to reach a level of at least 85%, there should be an increment for both the minimum and the maximum production requirements in accordance with the presented mathematical formula.

## Paper Organization

Based on real-life data, this paper proposes an under-study optimum solution for the problem of product mix. Furthermore, this study presents product mixes for ten business scenarios for the current problem. The approach to creating other business scenarios depends on the business constraints. Finally, the scenarios analysis is presented based on resource usage and productivity procedures. This paper is organized as follows: “[Literature Review](#)” is a review of the literature for previous other approaches that studied various problems in the same domain. “[Problem Statement](#)” states the main problem of cement-ready-mixed production in general.

“[Mathematical Model](#)” is the proposed mathematical formulation through linear programming. In “[Results and Analysis](#),” both results and analysis were made to state the solution’s effectiveness. “[Discussion and Results Analysis](#)” is a discussion and analysis of the results for the optimum solution to our case study. “[Conclusion](#)” is a conclusion that summarizes the overall idea of the paper.

## Literature Review

As off-site construction techniques and modular building technologies have become more popular, it has become a lot harder to manage the supply chain of materials for construction projects. There is still a lack of research on construction material costs that explicitly considers dynamic material costs as a limitation in analytically calculating construction plans and addressing the impact of uncertainty in material delivery on project budgets. As a result, sustainable building research has sought to eliminate all non-value-adding procedures and material waste from the material distribution chain. In the construction industry, for example, a lot of research has been done on

how to use “just-in-time” (JIT) delivery for ready-mixed cement or steel.

The authors (Hasuike and Ishii 2007) have considered both problems, the production planning and the product-mixed decision models, under specific conditions, which are multipurpose models for answering the product-mixed issue. The proposed formulas consist of resultant random from statistical analysis built on old information, the instinct of the decision maker, the data quality, and the ability to achieve the original plan. Therefore, the researchers propose an elastic product-mixed problem through the usage of the theory of constraints (TOC) and come up with an effective solution approach. After that, a numerical example was provided to calculate the model’s effectiveness against other previous basic approaches. Flexibility and efficiency were reached when the proposed methods were tested in different situations, like when changes were made based on estimates of future revenue.

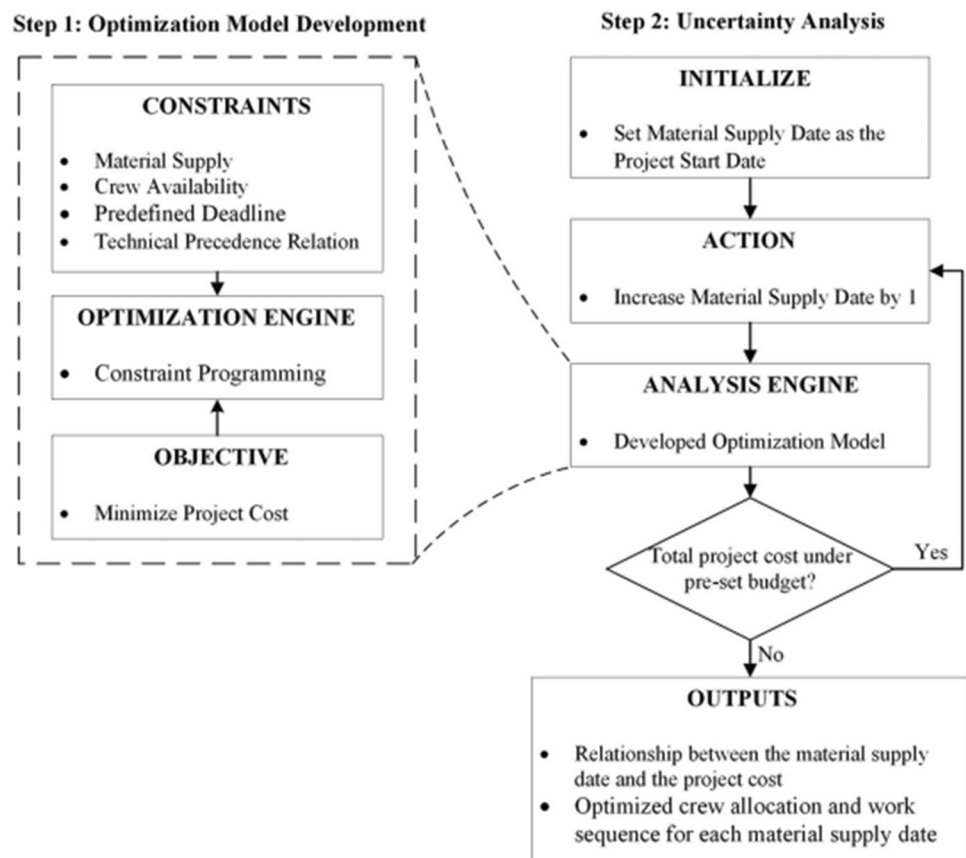
In Liu and Lu (2018), a case study was presented which shows how to handle variable material delivery schedules using the optimization model from both the project planning and project control perspectives. To test the model’s validity and practicality, an impartial modelling model

was constructed for the same case problem, their proposed methodology workflow is being represented in Fig. 2 below.

Even before it is validated, the modelling approach assesses the impact of material order fulfilment on the project budget. In the same case, the relationship between material delivery time and project cost is quantified and visualized. The budget-constrained material delivery time window can help practitioners figure out what is a good range of time for delivering important materials so that the project budget stays within limits that have already been set.

In their work, the researchers (Maghrebi et al. 2013) discussed both the modulation of the optimization problem for ready-mixed concrete. This was achieved through the application of both linear and heuristic approaches. The main aim was to find the optimum solution without the utilization of any optimization algorithm. Therefore, their experiment was done using GA in an isolated area that was divided into seven blocks and included four concrete batch plants. The appliance of both linear programming and genetic algorithms was important for reaching the optimum solution through a comparative analysis. Their results prove the efficiency of linear programming due to the constraints’ limitations.

**Fig. 2** The main two steps proposed in (Liu and Lu 2018) for material supply optimization and analysis



The study (Priya and Yuvaraj 2019) proposed a linear programming formula to solve the problem of ready-mixed concrete delivery, which appears to be a difficult process. Their main objective was to propose a technique for choosing the optimum delivery solution for concrete supplied in a specific area. The aim of the solution is to choose the best delivery method as well as achieve the highest cement product profits. The experiment database was obtained from actual corporate and logistic organizations. Four different approaches were made as a computational experiment.

The Ethiopian industrial unit was considered as a case study in (Woubante 2017). Various variables were taken into consideration (resources, profit, production rate, and product volume). The collected data was used for estimating the linear programming formula parameters. The experiment was done using the LINGO 16.0 application. The study results proved that the improvement in corporate profit was 59.84%. If the orders from customers were not taken into account in the linear programming

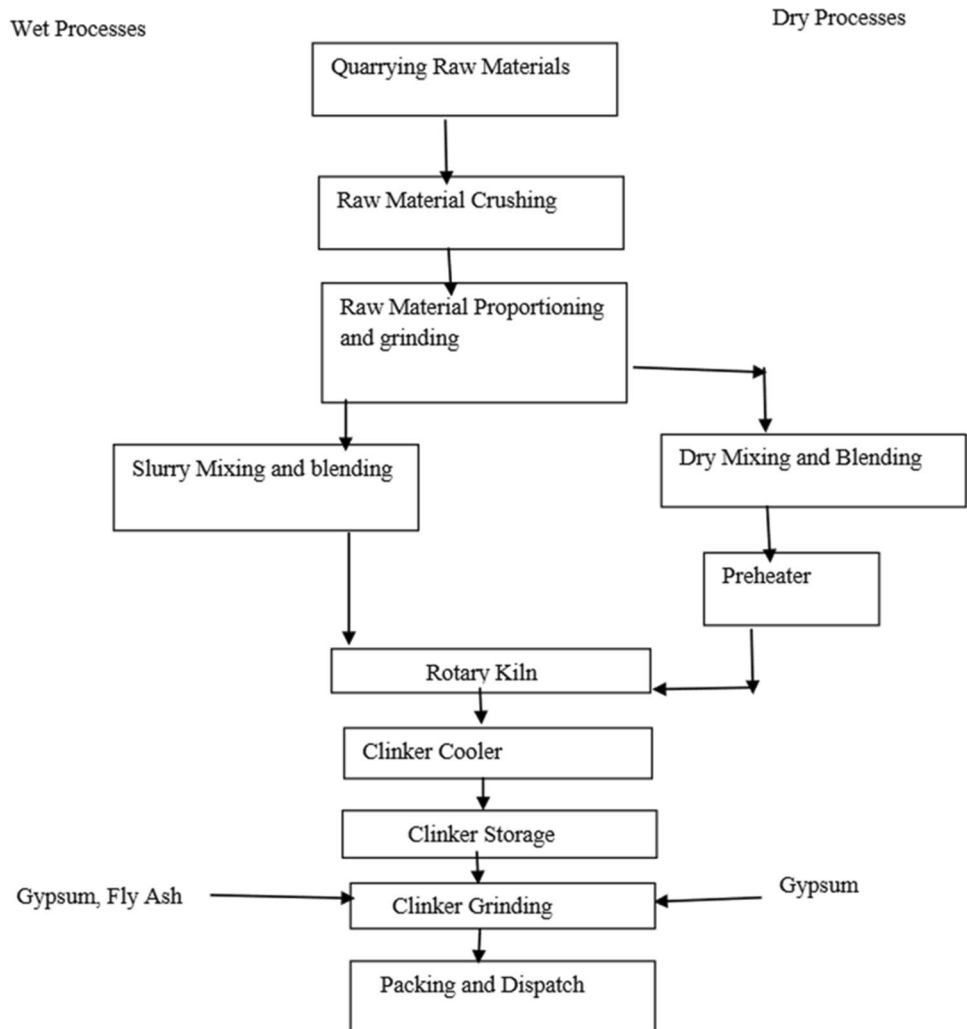
formula, the total monthly profit of 465,456 Ethiopian Birr could be increased by 7.2%.

### Problem Statement

The process of creating cement needs carbonate and other calcareous rocks to be combined with both alumina and silica from both mud and rock. A massive rotary kiln is used to heat the raw resources to temperatures of around 1400 °C, at which point the mixture fuses and completely melts into cement after being ground into an extremely fine powder (Mishra and Jha 2019), as can be described in the process represented in Fig. 3 below.

Field and laboratory tests for the cement industry must be performed to assure the cement’s quality. The experiments are usually carried out according to ISO standards. ISO is a global federation of standardization organizations. Typically, ISO scientific panels are responsible for the development of industry standards. Every member

**Fig. 3** A diagrammatic representation of the process of producing cement (Mishra and Jha 2019)



organization with an interest in a subject on which a function has been defined and has been entitled to representation on that panel (Kikuchi 2001). Governmental and non-government international institutions collaborate with ISO to contribute to the work. ISO and IEC directly interact with all aspects of electro-technical standardization. International standards are written in compliance with the ISO/IEC Directives, part 2 guidelines. Expert panels' primary responsibility is to develop technical specifications. The member organizations vote on draft international standards that have been approved by the technical committees. Those sets of guidelines are provided through setlines documented under ISO 680 (Yang et al. 2006).

### ISO 680 Guidelines for Cement Testing

Throughout the whole process of making the international standard for the cement industry, performance as a measure of quality was taken into account. ISO/TC 71/SC 3 knows that some ISO members have made specific evaluations and standards for quality-cement based requirements. The use of cement as an alternative to a prescriptive approach is permitted to continue and develop under this international standard. These rules must be laid out in more detail. Rules for the use of component materials governed by international standards are incorporated into this international standard. The finest cement ought to always be employed in building. Cement's characteristics must consequently be examined. Although acceptable cement attributes can differ based on the type of construction, solid concrete often includes the following characteristics:

a) It supplies masonry with strength.

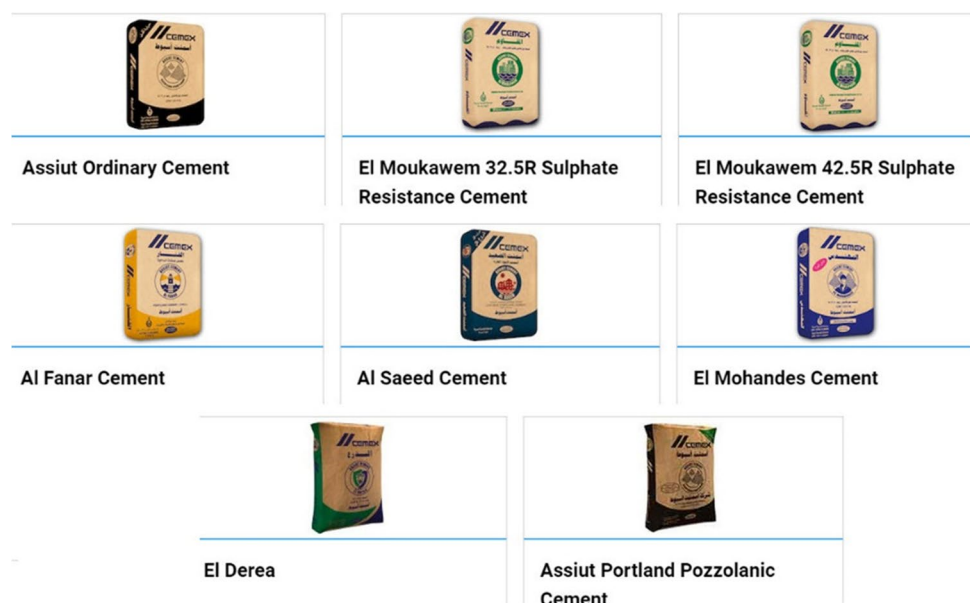
- b) Premature stiffening or hardening and equilibrium solubility.
- c) It exhibits good flexibility and easily manageable.
- d) A great construction material.

During the design and construction process, different people (i.e., the designer, the quantity surveyor, the builder, and the cement subcontractor) may give needed specifications at different times. Between the buyer and the supplier, it is the job of each link in the chain to tell the supplier what the buyer wants. This comprehensive set of requirements is referred to as the "cement specification" in the context of this international standard. It is possible for the same person to serve as both the identifier and the provider in some situations (e.g., a constructor doing design, production, and execution) (Yang et al. 2009).

**Table 2** Quantities example of ready-mixed cement products that are needed for a package

Number	Premium cement chemical mixture	
	Chemical properties	Average results (%)
1	MgO	1.2–1.6
2	SO <sub>3</sub>	2.5%–3.0%
3	Ignition loss	2.0%–3.0%
4	Insoluble residues	0.4%–0.7%
5	Chlorides contents	0.02–0.04
6	C <sub>3</sub> S	50–55%
7	C <sub>2</sub> S	20–25%
8	C <sub>3</sub> A	6.0–7.0%
9	C <sub>4</sub> AF	11–13%

**Fig. 4** Ready-mixed cement products that are being produced by organization (A)



## A Case Study of Organization (A) Cement Product

Organization (A) is a ready-mixed cement producer; the organization uses (Portland cement) to produce the different types of friendly cement that reduce CO<sub>2</sub> emissions by 15:20%. The company uses specific chemical properties to produce a competitive cement type in the Egyptian market (Uğur et al. 2019). The company mainly produces three products each month (cement, concrete, and aggregates). The company purchases eight different cement types each month, as shown in Fig. 4 below.

Different chemical mixes are used to produce various products in various quantities; the chemical properties of each cement type depend on different factors, as shown in Table 2 below.

Ready-mixed cement requirements of constructions are changeable based on many factors (Haddad et al. 2013). The ready-mixed cement requirements usually change based on the utilization. There are eight main products that are being produced by Organization A:

- a) *Assiut Ordinary*: It is the first and most common type of cement produced. It is defined as a binder hydraulic material, and it is a fine gray powder resulting from the grinding of the dry mixture of clinker and gypsum, which hardens by adding water to it in the presence of air and resists the water after hardening.
- b) *El Moukawem 32.5R*: It is one of the types of cement, and it is defined as a binder. It is a fine product resulting from the grinding of the dry mixture of clinker and gypsum, which solidifies by adding water to it in the presence of air and resists the water after hardening it.
- c) *El Moukawem 42.5R*: It is one of the types of cement, and it is defined as a binder. It is a fine product resulting from the grinding of the dry mixture of clinker and gypsum, which solidifies by adding water to it in the presence of air and resists water after hardening. It also resists the effect of sulfate salts present in the surrounding medium, such as clay soil.
- d) *Al Fanar*: A type of Portland cement that results from the reaction with water resulting in an average amount of heat; in addition to that, it has a balanced resistance to both sulfate and chloride salts.
- e) *Al Saeed*: A low-temperature Portland cement. It is made by grinding and smoothing the product of burning limestone and clay materials or limestone materials with silica and iron oxide to the temperature of clinker, as long as these materials are well mixed to a certain percentage before the burning process.
- f) *El Mohandes*: A special formula of ordinary Portland cement, aimed at delaying the initial setting time and obtaining high early stresses. It is generally suitable for

use in pre-fabricated concrete mixing plants and pre-cast concrete units.

- g) *El Dereea*: Among the types of cement suitable for use in concrete, especially bulk concrete, and in concrete elements exposed to harsh conditions, it reduces the amount of heat produced during the rehydration process, resulting in fewer cracks in the concrete, making it the ideal solution for preserving concrete and rebar.
- h) *Assiut Portland Pozzolanic*: This product contributes to reducing carbon dioxide emissions by 15 to 20%, which is considered a new revolution in the cement industry.

The main objectives of this study are to identify the needed number for every product that can be produced to maximize profit and determine the resources' consistent usage. As a result, a mathematical formula was created, which is defined in "Mathematical Model" below.

## Mathematical Model

For any decision-making operation, there are three main features that face the economic agent.

1. The decision variables that are chosen by the decision maker.
2. The pre-defined constraints to know the possible values to choose from.
3. The objective function that converts the values into outcomes.

The decision maker usually makes the decision based on the outcome of this function (Del Missier et al. 2012). Finding the optimum ready mix with such a methodology has been evaluated to improve the overall production performance, which also surpasses the material requirement planning systems (Stricker et al. 2017). Using the linear programming method, the mathematical model is formed from both the linear objective function and the constraints that are presented in Strang (2012). CCRs are known as the resources that have a high possibility of being fully consumed, which can either lead to slowing down or stopping the overall production system (Mo et al. 2009), as the CCRs can affect the production system's ability to proceed as planned; it is necessary to define the performance measurement for such CCRs in organizations that produce ready-mixed cement products. Normally, the profit calculation is done by subtracting the total expenses from the total revenue. As it was mentioned in Pilipiec (2020), there is a relationship between time and performance. In this paper, the time periods that are presented in our case study are by month; the authors (Lea 2007) have illustrated the formulation of the product

mix, which can be formulated as follows:where  $Z$  is the total profit to be maximized.

- $p_j$  The product selling price  $j$
- $c_j$  The product production cost ( $j$ )
- $x_j$  The number of materials produced of product ( $j$ )
- $a_{ij}$  The resource amount ( $i$ ) used to produce product ( $j$ )
- $b_i$  The resource ( $i$ ) capacity
- $d_j$  The total market demand for product ( $j$ )
- $n$  The number of resources, and  $m$  is the number of products.

$$\text{Maximize } Z = \sum_{j=0}^n (P_j - C_j)x_j \tag{1}$$

$$\text{Subject to : } \sum_{j=1}^n a_{ij}x_{ij} \leq b_i \tag{2}$$

$i = 1, 2, \dots, m$  (resource constraint)

$$x_j \geq d_j \tag{3}$$

$j = 1, 2, \dots, n$  (resource constraint)

$$x_i \geq 0 \tag{4}$$

The mathematical model of the product mix shows the relation between the product mix, and the decisions are affected by five main factors (product name, product cost, resources' amount, resources' capacity, market demand).

Let ( $i$ ) represent the product name; ( $P_i$ ) represents the selling price for each bag of product ( $i$ ) that is essential for the objective function. As an example, as shown in Table 3, P2 represents the price of product 2, which is 250 EGP. As the company has 8 products,  $i = 1, 2, 3 \dots 8$ .

**Table 3** The selling fees for each ready-mixed cement package

#	Product information	
	Product	Product price (EGP) package ( $P_i$ )
a)	Assiut Ordinary Cement	70
b)	El Moukawem 32.5R Sulfate Resistance Cement	75
c)	El Moukawem 42.5R Sulfate Resistance Cement	77
d)	Al Fanar Cement	70
e)	Al Saeed Cement	70
f)	El Mohandes Cement	71
g)	El Derea	78
h)	Assiut Portland Pozzolanic Cement	75

**Table 4** Both quantities and fees for the ready-mixed cement materials

Number ( $j$ )	Ready-mixed cement data		
	Cement name	Quantity kg ( $W_j$ )	Value/kg ( $C_j$ )
1	MgO	1000	15.3
2	SO <sub>3</sub>	950	11.3
3	Ignition loss	600	8.3
4	Insoluble residues	850	10.3
5	Chloride contents	200	19.3
6	C <sub>3</sub> S	200	17.3
7	C <sub>2</sub> S	30	12.3
8	C <sub>3</sub> A	60	22.3
9	C <sub>4</sub> AF	30	52.3

( $j$ ) represents the number of supplied cement bags monthly

( $W_j$ ) represents the weight in kg of the supplied material ( $j$ )

( $C_j$ ) represents the material ( $j$ ) cost per kg.

As shown in Table 4,  $W_7 = 30$  kg that represents the weight of the 7th material C<sub>2</sub>S, and  $C_7 = 12.3$  EGP that is the price for each kg of the similar material. As the company has 8 materials' type, then  $j = 1, 2, 3 \dots 8$ .

The mathematical formula that is used in this study is illustrated in the following two points.

### Setting the Constraints

$X_i$  represents the bags' number that needed to be made from product ( $i$ ). As an example,  $X_1$  represents the bags' number to be made monthly from the 1st product.

Non-negativity constraint:

$$X_i \geq 0 \quad \forall(i) \tag{5}$$

Integrality constraint:

$$X_i \text{ is integer } \forall(i)$$

Raw material capacity constraint:

$$\sum_{j=1}^{27} \sum_{i=1}^6 (y_{ij}x_i) \leq Y_j \quad \forall(i, j) \tag{6}$$

where ( $y_{ij}$ ) represents the cement amounts.

( $j$ ) represents the consumption to manufacture one bag of product ( $i$ ).

( $y_j$ ) represents the overall cement amount provided monthly of the type ( $j$ ).



### The Objective Function

$$Y(\text{Revenue})\text{Maximization} = \sum_{i=1}^6 (P_i X_i) \tag{7}$$

The profit calculations are as the following:

$$Z(\text{Profit}) = \text{Total revenue} - \text{Total cost}$$

$$Z(\text{Profit}) = \sum_{i=1}^6 (P_i X_i) - \sum_{j=1}^{27} (W_j C_j) \tag{8}$$

**Table 5** A base model represents the production quantities

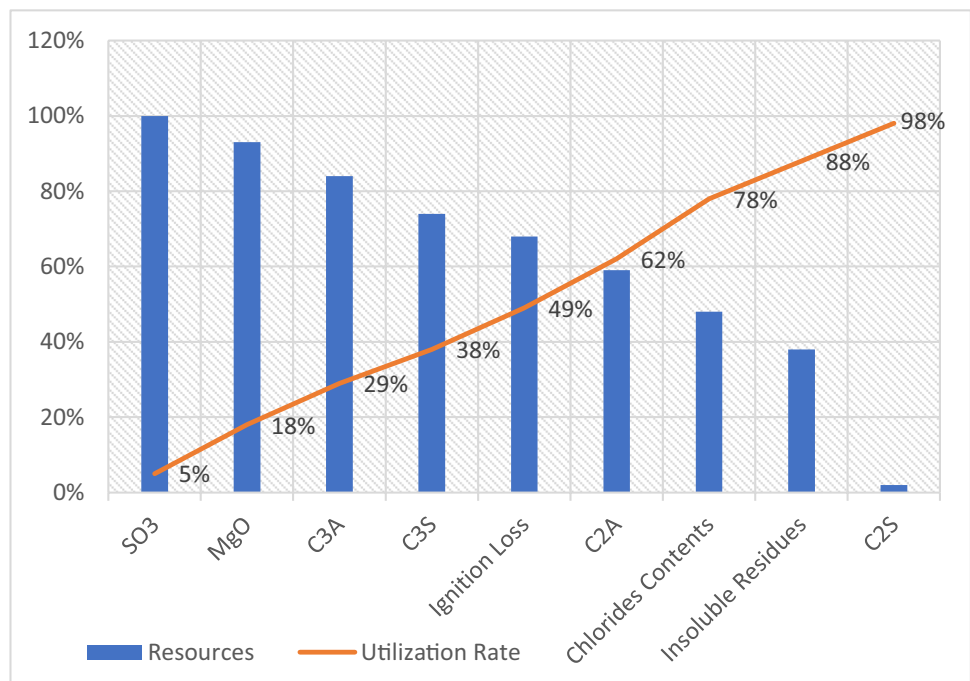
Number	Product information	
	Product	Package number ( $P_i$ )
1	Assiut Ordinary Cement	0
2	El Moukawem 32.5R Sulfate Resistance Cement	20
3	El Moukawem 42.5R Sulfate Resistance Cement	38,540
4	Al Fanar Cement	4052
5	Al Saeed Cement	22,560
6	El Mohandes Cement	0
7	El Derea	50
8	Assiut Portland Pozzolanic Cement	73

### Results and Analysis

The conclusion after the solving of the model is that the company profit will be maximized, according to the quantities of production that are presented in Table 5.

This will lead to a monthly revenue of 2,255,459 EGP. After subtraction of the materials cost, the organization profit ( $Y$ ) is 388,452 EGP per month. The profit rate is 35.21789% of the revenue. Based on the resultant solution from the mathematical formula above, just four resources were entirely used while the rest were under 60% of utilization. Only four resources were entirely consumed, which can be considered as CCRs. That proves that many cement types were sold in portions larger than what was wanted. As a result, these are taken into consideration as excess resources. The four CCRs should be sold in larger quantities to achieve production continuity and reach a higher profit. A production shortage may occur in the event of any delay in providing such resources. A chart was created to provide a better visualization of the usage rate in descending frequency order. The total rate is presented in the secondary axis with a cumulative line. As presented in Fig. 5 below, the cumulative line indicates that the resource usage rate differs expressively among resources. The usage rate has been found to range from 0 to 100%, with an average of 65%, which is considered low.

**Fig. 5** A representation of the initial solution for the material usage



### Discussion and Results' Analysis

The company management team needs to consider producing products that contains (C<sub>2</sub>S – Insoluble residues—C<sub>2</sub>A). Additionally, the resource utilization target can be risen to reach 85%. The company should produce at least 700 to obtain the new-targeted utilization rate of 90%. Consequently, a new constraint was added to the company production should be at least 700 packages with a maximum of 6000 of each product, as it can be seen in Eq. (9) below the mathematical formula.

$$700 \geq X_i \geq 6000 \quad \forall(i) \tag{9}$$

### Generating Scenario Approaches

In “Problem Statement”, the mathematical formula was augmented with constraint 9. This will be referred to as the “augmented formula” in the rest of the paper. The Excel solver was used to solve the augmented formula. The results of the base mathematical formula have provided a result lower than 90% utilization. In order to reach the optimum profit solution, the solution was solved ten times iteratively until reaching the targeted resource utilization of 90%. Doubling the CCRs for each iteration from the previous one is considered. Each solution represents a new scenario according to the company’s profits, revenues, and material utilization. We have to highlight that the market’s needs are unlimited, but they are changeable from one time to another, and thus all the production is sold.

### Scenario Results

Figure 6 proves that the utilization is changeable because of doubling the CCRs. This proves that doubling the CCRs can sometimes be a material waste if other resources were consumed.

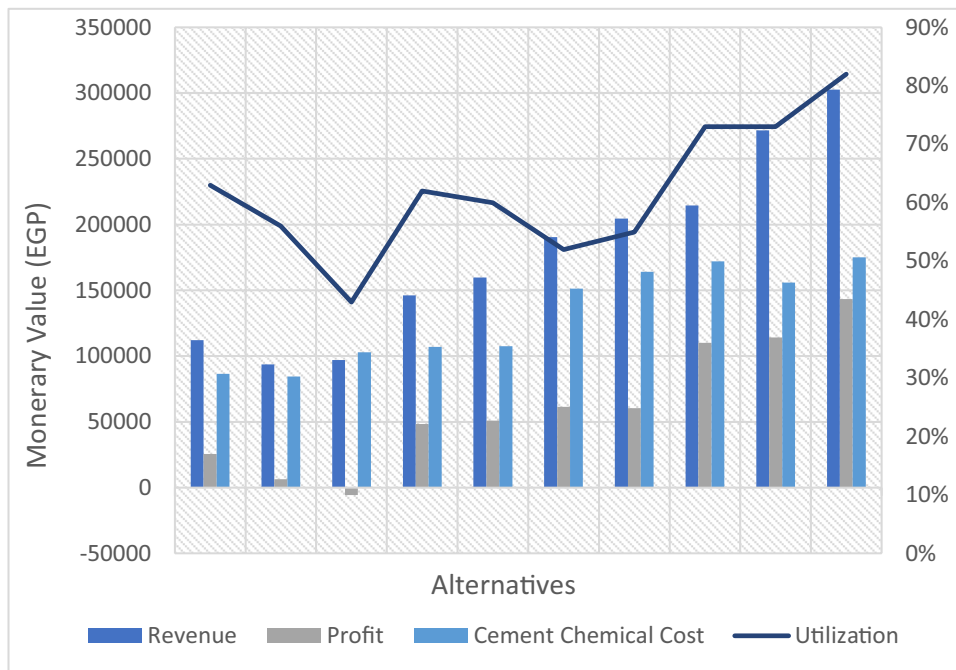
As a result, if any amount of the doubled resource is consumed, the rest of the resource will be considered as a waste and will affect the overall, both of profit and of utilization at a negative rate. Nevertheless, if there is an increment of the doubled amount, the overall use will be much less than before, after investigating the replacements for (3, 5, and 6).

### Productivity

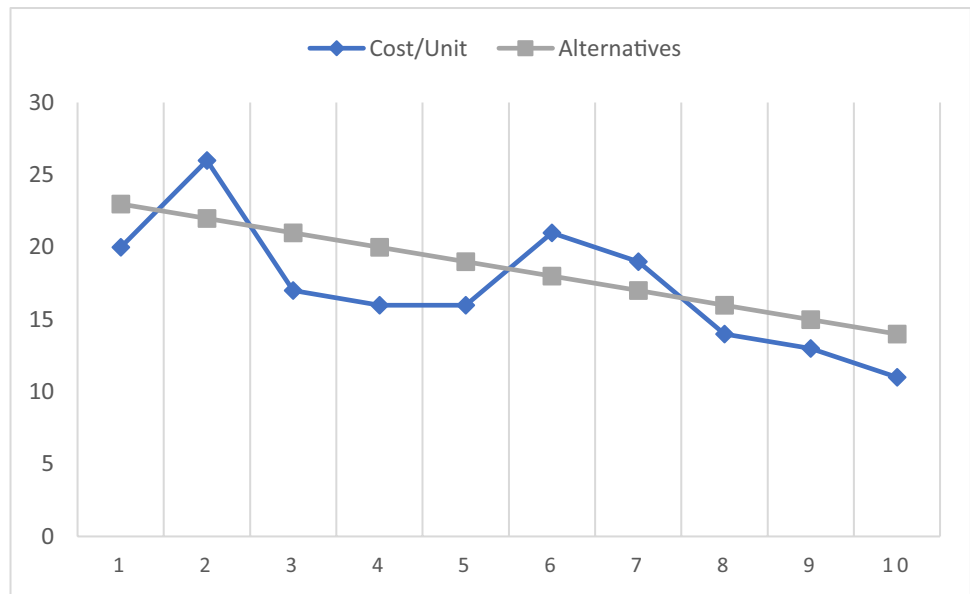
Productivity can be described as the output unit for each input unit. It is a very important variable for both the working environment and the decision-making operation. The production improvement results in a manufacturing cost reduction. One of the main factors in production is the average cost per product (Tamminen et al. 2016). Consequently, a small adjustment was made to the cost per product. In Fig. 7, a representation of the cost per product for every alternative is shown.

From the final recommended scenario (10th scenario), it is clear that the average cost for each product has decreased from 24.2568 EGP/bag (achieved from the base mathematical formula) to reach its lowest cost with 14.201 EGP/bag. Hence, we can conclude that the 10th scenario is considered as the best-case scenario for our proposed solution.

**Fig. 6** The usage of every alternative (revenues, profits, and cement material cost)



**Fig. 7** The cost of each product through the ten alternatives



**Table 6** Recommended production quantities (augmented model)

Number	Product information	
	Product name	Number of packages
1	Assiut Ordinary Cement	4408
2	El Moukawem 32.5R Sulfate Resistance Cement	2940
3	El Moukawem 42.5R Sulfate Resistance Cement	3589
4	Al Fanar Cement	2784
5	Al Saeed Cement	4827
6	El Mohandes Cement	3275
7	El Derea	2864
8	Assiut Portland Pozzolanic Cement	3658

**Best Case Scenario**

The result of analyzing the charts’ results is that it is recommended to use the 10th scenario, as it refers to the best usage rate and consecutively maximizes the overall profit. Based on the 10th scenario, the recommended amount to be produced is shown in Table 6 below.

**Decision Support Web System**

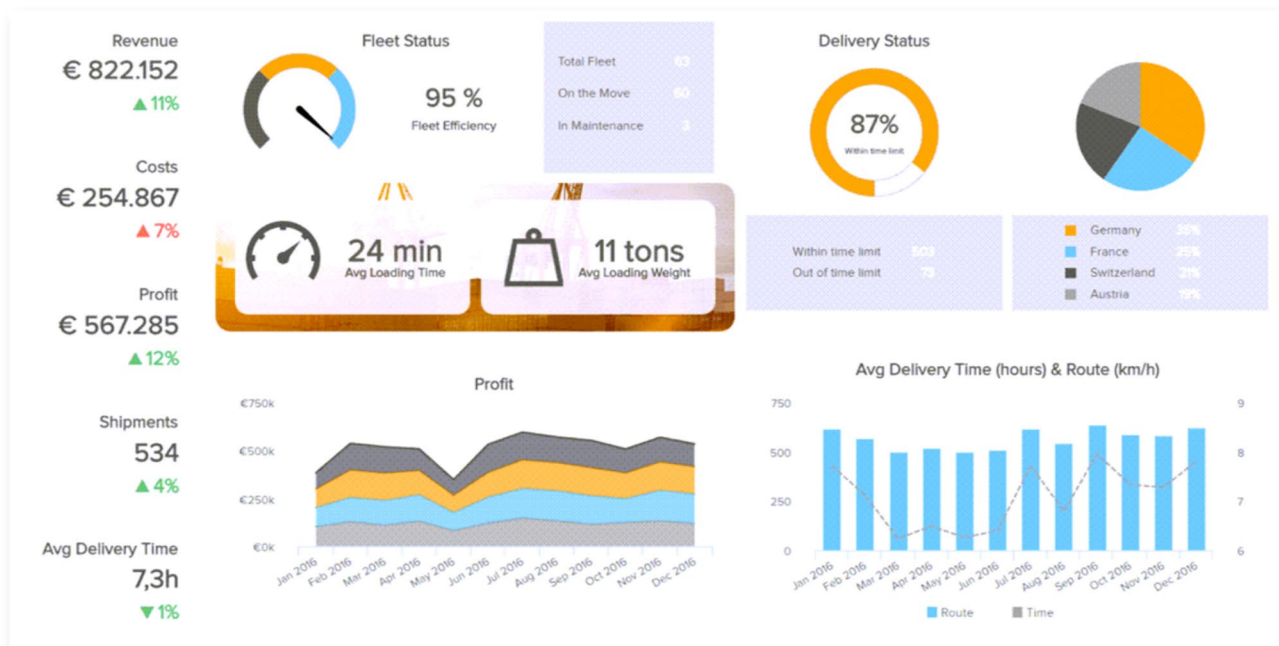
The main aim of creating a dashboard is to gather all the needed data requirements on one screen in a way that supports both the analysis and the decision-making process. The dashboard facilitates the testing of the production rate impact in different conditions. Simultaneously, the dashboard provides statistics for productivity, revenue, operations, and

expenses. In addition to the achieved solution from the base mathematical formula, ten other scenarios were concluded because of the added new constraints. For each scenario, many factors (revenue, profit, productivity, and utilization) were calculated. The obtained results show that sometimes the utilization increment does not occur even with doubling the CCRs. When the obtained results were analyzed in terms of material cost, productivity, utilization, and revenue, they revealed that the 10th scenario was the optimum solution. When this scenario is applied, the company’s monthly profit has increased from 25.3% (the obtained result of the base mathematical formula) to 48% of the overall revenue; the plan recommendation of the 10th solution has increased the overall utilization to 94%, instead of 73% (the obtained result of the base mathematical formula). A smart dashboard was designed for the company’s product development team to help them analyze their data in detail and make the right decision with high accuracy and in a short period of time, as shown in Fig. 8 below.

In addition to the achieved solution from the base mathematical formula, ten other scenarios were achieved because of the added new constraints. For each scenario, many factors were calculated (revenue, profit, productivity, and utilization).

**Results Analysis and Limitations**

As it was illustrated in Fig. 5 above, doubling the CCRs has led to a utilization decrement compared to other previous scenarios. The third scenario has led to the most financial loss; this is mainly because the cost of the materials is higher than the expected profit as a result of the waste materials from doubling the CCRs. The code is compiled again through



**Fig. 8** A screenshot shows the decision support web dashboard for enhancing visualization

generating more scenarios. Conversely, in this round, all the resources with more than 90% utilization were doubled. The resources' increment has led to better resource utilization, while the results in Table 6 have recommended a production strategy that leads to a revenue of 4,808,286 EGP monthly. After deducting the material costs, the organization's monthly profit will be 2,855,401 EGP. The profit represents 48% of the overall revenue. Because of resource expansion, a monthly change will occur in the supplied quantity of the raw materials. The change varies from 1 to 6 times the total quantity. There are many challenges to reaching the optimum solution. However, to make an efficient decision, there is a need for data visualization (Whyatt et al. 2017).

The obtained results show that sometimes the utilization increment does not occur even with doubling the CCRs. When the obtained results were analyzed in terms of material cost, productivity, utilization, and revenue, they revealed that the 10th scenario was the optimum solution, as by applying this scenario, the company's monthly profit has increased from 25.3% (the obtained result of the base mathematical formula) to 48% of the overall revenue. The plan recommendation of the 10th solution has increased the overall utilization to 94%, instead of 73% (the obtained result of the base mathematical formula). A smart dashboard was designed for the company's product development team to help them analyze their data in-depth and make the right decision in a short period of time. In future work, this experiment can be applied in cloud service providers' companies in

order to raise the service quality for both operators and subscribers (El Karadawy et al. 2020).

However, the optimization rate accuracy may suffer from some differences when the used materials in the proposed approach have wider scaling; this fault rate result will happen due to the differences in material parameter values (cost, quantity, and vendor). Because of this, future work should consider different practical matrices such as:

- Based on when the material is expected to be delivered, what are the best ways to send it at the lowest cost?
- Material cost resiliency in the located region is important because each project can be negatively impacted by changing material costs due to project budget constraints.
- Enhancing the linear programming optimum method through deep learning in the construction field.

This is to make sure that any future proposed linear programming optimization approach in the construction field could be used in different situations.

## Conclusion

Egypt has been in the process of constructing its New Administrative Capital since 2015. For ready-mixed companies, there is a need for an approach to fulfil the high demand for ready-mixed products regarding this project to

provide help in the decision-making process and achieve the highest profit with the available cement products.

In this paper, we have introduced a simulation and a proposed solution for ready-mixed cement products for company (A). The proposed solution was applied in a case study in Egypt. The problem was solved using two linear programming methods. The initial experiment of the solution was found to have low utilization of the raw materials. However, due to the restrictions that were imposed by the company on both the minimum and maximum production rates, there was a need to modify the primary solution. Regarding the presented mathematical formula, both the minimum and the maximum production requirements were augmented according to the formula. The utilization target was raised to 85%. This amendment led to the development of the second linear programming. An iterative approach was developed to generate more possible scenarios to select from. The main goals of the scenarios that are made are to make as much money as possible and get a high rate of use by doubling the CCRs. Future work on this study can be done by coming up with a way to evaluate each scenario through the MARR that uses engineering economic approaches.

**Author Contribution** All the authors contributed to the study's conception and design. Material preparation was performed by Ahmed A. Mawgoud. The first draft of the manuscript was written by Ahmed A. Mawgoud, and all the authors commented on the previous versions of the manuscript. All the authors read and approved the final manuscript.

**Data Availability** The data that support the findings of this study are available from author Ahmed A. Mawgoud, upon reasonable request.

## Declarations

**Ethics Approval** This material is the authors' original work, which has not been previously published elsewhere. The paper is not currently being considered for publication elsewhere.

**Conflict of Interest** The authors declare no competing interests.

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