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RESOURCE ALLOCATION IN A STEEL MANUFACTURING PLANT IN NIGERIA USING LINEAR PROGRAMMING

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ABSTRACT
The Nigerian iron and steel industry has immense potential for economic growth. However, it faces challenges due to poor planning, implementation, and sub-optimal resource allocation. This study was centred on optimising resource allocation in a Nigerian steel manufacturing plant using a Linear Programming approach. A comprehensive research design was used to investigate the complexities of resource allocation and key factors influencing decision-making processes. The model's assumptions included known or estimable uncertain parameters and linearity of relationships. Lingo 18.0 software was utilized to compute the obtained data and solve the model, and it was also used for sensitivity analysis evaluation. Critical resource allocation factors in the selected steel manufacturing plant included material mix, plant constraints and market demand. The optimum objective value obtained from the resulting model was ₦8,369,598,000, representing the value of the objective function when all optimal decision variables were considered. The optimal quantity for each decision variable, including Iron ore (g_{11}), Coke (g_{21}), and Limestone (g_{31}), were 19,630, 8,083 and 577 respectively. Sensitivity analysis showed wide allowable increase ranges for the cost of raw materials: Iron ore (g_{11}), Coke (g_{21}), and Limestone (g_{31}) with increase ranges of ₦426,357, ₦1,035,439 and ₦14,496,140 respectively and allowable decrease ranging to infinity as the cost is to be minimised. It is crucial for management to continuously monitor the factors influencing resource allocation, as this will ensure that model inputs accurately reflect the changing industry dynamics and enable better optimization of allocated resources.
Keywords: Linear programming (LP), Economic growth, Resources, Efficiency, Sensitivity analysis

1. INTRODUCTION

Nigeria is blessed with a wealth of natural resources, which include an estimated 3 billion metric tonnes of iron ore [1], [2], 303 million metric tonnes of coal [3], millions of metric tonnes of limestone and 187 trillion SCF (standard cubic feet) of natural gas [4], among others. These resources serve as vital ingredients for producing iron and steel, establishing Nigeria as one of the leading nations worldwide regarding such abundant reserves. Manufacturing is a major source of income for a nation and a wealth-creation aspect of a country's economy as it adds value to the resources (raw materials) being converted [5]. Despite this remarkable potential, the Nigerian steel industry remains underdeveloped. Ajaokuta Steel Company (ASC), which can generate around 15,000 jobs and represents one of the best opportunities to propel Nigeria's industrial era, has failed to commence operations fully.

Moreover, Delta Steel Company (DSC) and three government-owned inland and satellite rolling mills in Oshogbo, Jos, and Katsina are either operating at sub-optimal capacity or have been privatised [2]. Planning for iron and steel in Nigeria started in 1958 [3], while iron ore exploration started in 1963. Steel is a metal with iron content in the range of 97.9 to 99.998% and a carbon content of 2.1 to 0.002% with varying weight percentages of impurities [6]. By 1972, a commercial quantity of iron ore was discovered at Itakpe [7]. Implementing effective production planning while considering practical resource limitations contributes to the success of a production system [8]. Effective resource allocation within the steel manufacturing industry is pivotal in attaining production objectives and maximizing profitability. However, due to several factors, including logistical and managerial, technical challenges and political, major iron and steel sector projects are yet to kick off, threatening steel product companies who then have no choice but to depend on relatively expensive, imported billets, which have been claiming a huge portion of Nigeria's forex reserves [4]; [9]. The process of iron ore conversion to steel involves several steps, including (1) Pig iron extraction [10], (2) Smelting [11], (3) Casting [12], and (4) Rolling [13]. In the quest for a lasting solution to the allocation problem, a Radio Frequency Identification-based Resource Allocation System (RFID-RAS) has been presented [14]. A resource input/output framework for steel and iron manufacturing was also established [15]. Developing efficient allocation algorithms for industrial use was also focused on [16]. Specifically, a team of researchers proposed a load-balancing mechanism based on Jena reasoning and Contract-Net Protocol, CNP technology to automate resource allocation [27]. One relevant study explored using Deep Reinforcement Learning (DRL) multi-agent systems for intelligent resource allocation [18]. Moreover, there has been a proposal on demand prediction and optimisation methods for workshop manufacturing resource allocation [19]. A proposed model for the allocation of tasks and resources in shared manufacturing environments is also in existence [20].

Furthermore, the numerous applications of linear programming models in making inventory planning decisions have been reported [21]. For instance, a set of researchers discussed using linear programming to optimise operating room efficiency in healthcare operations [22]. In addition, an inverse optimization model of linear programming for resource allocation in small and medium-sized manufacturing enterprises was proposed [23]. Similarly, the popularity of linear programming in operations research and its applications in production, finance, marketing, and distribution has been mentioned [24]. Research activities also covered the use of linear programming to examine the optimal allocation of scarce resources in farmland diversification in Bangladesh [25]. Similarly, researchers have explored the potential of linear programming-based land use modelling to enhance smallholder crop production in Ethiopia [26]. A certain research also emphasized the significance of linear programming on the economic objectives of firms in production planning [27]. In the healthcare sector, some researchers' works involved using linear programming models to improve the efficiency of resource allocation [28]. In addition, linear programming has been used in other sectors, such as business, manufacturing, and decision sciences. Linear programming models help in determining the optimal plan or solution for resource allocation. Manufacturing environments are usually constrained by a number of uncertainties (fluctuating demand, machine breakdowns and material shortages), which affect production schedules and resource allocation decisions [29]. Steel manufacturing involves multiple operations that need to be sequenced and coordinated. Approaches for resource allocation and optimisation in the steel manufacturing industry have been widely investigated. For example, agent-based approaches have been explored for distributed manufacturing process planning (Shen, Wang, & Hao, 2006 30). Another research study was aimed at determining the most suitable combination of orders and materials based on various factors (Yanagisawa, 2007 31). These factors included order due dates, preferences for matches, allocated weights, surplus weights of materials, and other relevant considerations. Efficient resource allocation is crucial for optimising production and meeting customization requirements [32].

However, it requires effectively allocating resources and coordinating tasks distributed across different locations [33]; [34]. Addressing these problems is crucial for optimising production processes and meeting customer demands. Therefore, this research paper proposes a solution to addressing the issue of poor planning by applying an operations research technique. The research was aimed at contributing to the advancement of the Nigerian steel sector by presenting a model that can effectively enhance the manufacturing process. By employing linear programming techniques, the model takes into account the inherent uncertainties associated with the manufacturing process, offering a dependable solution for resource allocation. Hence, the objectives of this research include: (1) Identifying the principal factors influencing resource allocation in a Nigerian steel manufacturing plant. (2) Developing a linear programming model designed for resource allocation in a Nigerian steel manufacturing plant. (3) Determining the optimum strategy for resource allocation in the steel manufacturing plant.

1.1 Definition of Relevant Terms

Optimisation refers to the process of developing mathematical models or algorithms for engineering decisions to find the best analytical solution to a problem with respect to a set of constraints and objectives.

Iron ore: is a naturally occurring mineral resource from which metallic iron can be extracted for steel production. It primarily contains iron oxides and other minerals.

Decision variable: is an unknown quantity in a mathematical model that represents a decision that needs to be made to achieve a certain objective.

Constraint: a constraint is a condition that must be satisfied for the model's solution to be valid. Constraints are typically expressed as equations or inequalities limiting the values the decision variables can take.

Objective function: is a mathematical expression that represents the objective or goal of a decision-making problem. It is typically a function of the decision variables and is used to quantify the performance of a particular solution. Optimisation aims to find the values of the decision variables that maximize or minimize the objective function, subject to the problem's constraints.

2. METHODOLOGY

2.1 Research Question

The research questions for this study are:

i. What key factors affect resource allocation in a steel manufacturing plant in Nigeria?
ii. Can linear programming be used to optimise resource allocation in a steel manufacturing plant?
iii. What is the optimum strategy for resource allocation given by the developed model based on data from the steel manufacturing plant?

A blend of qualitative and quantitative data was requisitioned to address the research questions. Interviews and conversations with industry experts were used to collect qualitative data, enabling the acquisition of insightful knowledge about the circumstances and difficulties affecting resource allocation in the steel manufacturing plant. On the other hand, quantitative data were harnessed to create the optimisation model. This data was sourced from historical records encompassing production records, financial reports, and relevant operational data obtained from a steel manufacturing plant, ensuring a comprehensive analysis.

2.2 Identifying the Key Factors affecting Resource Allocation in a Steel Manufacturing Plant in Nigeria

To gain insights into the steel manufacturing process, a series of inquiries were posed to elucidate critical aspects such as the layout of the manufacturing system, the flow of resources, the precise quantities of resources employed in each process and the interdependencies among resources. The interviews conducted with stakeholders focused on gathering valuable information concerning the utilization of techniques and technologies for resource allocation, the effectiveness of previously or currently employed models, challenges encountered in resource allocation, hurdles experienced during implementation, constraints and goals of the manufacturing system, as well as discerning any discernible trends or seasonal fluctuations in the demand for steel.

2.3 Development of a Linear Programming Model for Resource Allocation in a Steel Manufacturing Plant

2.3.1 Model assumptions

In the development of the model, several key assumptions were made:

i. The model assumes that uncertain parameters, such as the demand for different steel products and the cost of raw materials, are either known or can be estimated reasonably.
ii. The model assumes demand is known.
iii. The model assumes that the underlying steel manufacturing system remains stationary over the planning horizon.
iv. The model assumes that the relationships between variables, such as the cost of raw materials and production quantities, can be adequately represented linearly.

2.3.2 Model limitations

i. Steel grades were not considered in the construction of the model.
ii. The energy required for the steel manufacturing process was not considered during the construction of the model.

2.3.3 Decision variables, parameters and notations

These are the variables that exist in the model.

i = input index,
j = output index,
g_{ij}, h_{ij}, q_{ij}, r_{ij},= decision variables,
c_{ij} = cost of a unit of material "i" required to produce a quantity of product "j",
g_{ij} =quantity of material "i" required during pig iron extraction to produce a quantity of product "j",
h_{ij} = quantity of material "i" required during smelting to produce a quantity of "j",
p_{ij} = selling price of a unit of steel product "j" produced from material "i",
q_{ij} = quantity of product "j" produced during casting from a quantity of "i",
r_{ij} = quantity of product "j" produced during rolling from a quantity of "i".

2.3.4 Objective functions

The objective function for the resource allocation optimisation problem included:

i. Minimize cost price of raw materials: Let f_{cost} represent the cost objective function.
ii. Maximize selling price of steel products: let f_{profit} represent the profit objective function.

Hence,

$$\text{Min } Z = f_{cost} - f_{price} \quad (1)$$

where;

$f_{cost} = \sum_{i=1}^{I} \sum_{j=1}^{J} c_{ij}.g_{ij} + \sum_{i=1}^{I} \sum_{j=1}^{J} c_{ij}.h_{ij}$ (2)

$f_{price} = \sum_{i=1}^{1} \sum_{j=1}^{1} p_{ij}.q_{ij} + \sum_{i=1}^{I} \sum_{j=1}^{J} p_{ij}.r_{ij}$ (3)

Inputting the values from the findings at the steel manufacturing plant, the objective function becomes:

Min $z = (85{,}580g_{11} + 100{,}230g_{21} + 7000g_{31}) + (115{,}000h_{21} + 85{,}910h_{31} + 40{,}370h_{41} + 7000h_{51}) - (380{,}200q_{11} + 456{,}100r_{11} + 418{,}000r_{12} + 450{,}000r_{13} + 432{,}000r_{14} + 415{,}000r_{15} + 475{,}000r_{16})$

(4)

2.3.5 Constraints

1. Capacity constraint: to ensure that the quantities of each variable do not exceed the machine capacity at these stages of the manufacturing process.

i. Pig iron extraction:

$h_{11} \leq 83{,}335$tonnes (5)

ii. Smelting:

$q_{11} + q_{12} \leq 83{,}333$tonnes (6)

iii. Casting:

$q_{11} + q_{12} \leq 76{,}167$tonnes (7)

iv. Rolling:

$r_{11} + r_{12} + r_{13} + r_{14} + r_{15} + r_{16} \leq 25{,}000$tonnes (8)

2. Proportion constraint: to ensure materials are mixed in the appropriate quantities to produce a product.

i. Pig iron extraction:

$g_{11} = 1.7 \times h_{11}$ (10)

$g_{21} = 0.7 \times h_{11}$ (11)

$g_{31} = 0.05 \times h_{11}$ (12)

ii. Smelting:

$h_{11} = 0.4 \times (q_{11}+q_{12})$ (13)

$h_{21} = 0.5 \times (q_{11}+q_{12})$ (14)

$h_{31} = 0.002 \times (q_{11}+q_{12})$ (15)

$h_{41} = 0.003 \times (q_{11}+q_{12})$ (16)

$h_{51} = 0.05 \times (q_{11}+q_{12})$ (17)

$h_{61} = 10 \times (q_{11}+q_{12})$ (18)

3. Demand constraint: to ensure the quantity of raw materials procured are enough to meet the assumed demand. Demand was assumed for the application of the model in this study, the assumed demand for each steel product is shown in Table 1.

Table 1: Assumed demand for semi-finished/finished steel products

luct (tonnes)	**ımed demand**
l billets to be sold (q_{11})	%
e rod (r_{11})	%
al angles (r_{12})	%
orofile (r_{13})	%
ofile (r_{14})	%
are bar (r_{15})	%
nd bar (r_{16})	%

i. Casting:

$q_{11} = 0.134 \times (q_{11}+q_{12})$ (19)
$q_{12}= 0.866 \times (q_{11}+q_{12})$ (20)

ii. Rolling:

$r_{11} = 0.2771 \times q_{12}$ (21)
$r_{12} = 0.2113 \times q_{12}$ (22)
$r_{13} = 0.1097 \times q_{12}$ (23)
$r_{14} = 0.1270 \times q_{12}$ (24)
$r_{15} = 0.1109 \times q_{12}$ (25)
$r_{16} = 0.164 \times q_{12}$ (26)

4. Non-negativity constraint: to ensure all variable have a value greater than zero.
$g_{ij}, h_{ij}, q_{ij}, r_{ij} > 0 \ \forall\ i, j$ (27)

2.3.6 Model summary

This is the construction of the model after all the equations above have been used to construct the model.
The Linear programming model:

$$\text{Min } z = (85{,}580g_{11} + 100{,}230g_{21} + 7000g_{31}) + (h_{11} + 115{,}000h_{21} + 85{,}910h_{31} + 40{,}370h_{41} + 7000h_{51} + h_{61}) - (380{,}200q_{11} + 456{,}100r_{11} + 418{,}000r_{12} + 450{,}000r_{13} + 432{,}000r_{14} + 415{,}000r_{15} + 475{,}000r_{16}) \quad (28)$$

Subject to:

$h_{11} - 83{,}335 \leq 0$ (29)
$q_{11} + q_{12} - 83{,}333 \leq 0$ (30)
$q_{11} + q_{12} - 76{,}167 \leq 0$ (31)
$r_{11} + r_{12} + r_{13} + r_{14} + r_{15} + r_{16} - 25{,}000 \leq 0$ (32)
$g_{11} = 1.7 \times h_{11}$ (33)
$g_{21} = 0.7 \times h_{11}$ (34)
$g_{31} = 0.05 \times h_{11}$ (35)
$h_{11} = 0.4 \times (q_{11}+q_{12})$ (36)
$h_{21} = 0.5 \times (q_{11}+q_{12})$ (37)
$h_{31} = 0.002 \times (q_{11}+q_{12})$ (38)
$h_{41} = 0.003 \times (q_{11}+q_{12})$ (39)
$h_{51} = 0.05 \times (q_{11}+q_{12})$ (40)
$h_{61} = 10 \times (q_{11}+q_{12})$ (41)
$q_{11} = 0.134 \times (q_{11} + q_{12})$ (42)
$q_{12} = 0.866 \times (q_{11} + q_{12})$ (43)
$r_{11} = 0.2771 \times q_{12}$ (44)
$r_{12} = 0.2113 \times q_{12}$ (45)
$r_{13} = 0.1097 \times q_{12}$ (46)
$r_{14} = 0.1270 \times q_{12}$ (47)
$r_{15} = 0.1109 \times q_{12}$ (48)
$r_{16} = 0.164 \times q_{12}$ (49)
$g_{ij}, h_{ij}, q_{ij}, r_{ij} > 0 \ \forall\ i, j$ (50)

2.4 Determination of the Optimum Strategy for Resource Allocation Using Lingo 18.0

The resource allocation model abovewas translated into Lingo 18.0 for computation, to determine the optimum strategy for resource allocation in the selected steel manufacturing plant. Lingo 18.0 was also used to produce the sensitivity analysis of the developed model.The result of the model translation to Lingo 18.0:

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!Objective function;
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Min = (85580*g11 + 100230*g21 + 7000*g31) + (115000*h21 + 85910*h31 + 40370*h41 + 7000*h51) - (380200*q11 + 456100*r11 + 418000*r12 + 450000*r13 + 432000*r14 + 415000*r15 + 475000*r16);

!Capacity constraint;
!Direct reduction of iron ore;
h11 - 83335 <= 0;

!Electric arc furnace;
q11 + q12 - 83333 <= 0;

!Continuous casting;
q11 + q12 - 76167 <= 0;

!Hot rolling;
r11 + r12 + r13 + r14 + r15 + r16 - 25000 <= 0;

!Proportion constraint;
g11 = 1.7*h11;
g21 = 0.7*h11;
g31 = 0.05*h11;
h11 = 0.4*(q11+q12);
h21 = 0.5*(q11+q12);
h31 = 0.002*(q11+q12);
h41 = 0.003*(q11+q12);
h51 = 0.05*(q11+q12);
h61 = 10*(q11+q12);

!Demand constraint;
q11 = 0.134*(q11+q12);
q12 = 0.866*(q11+q12);
r11 = 0.2771*(q12);
r12 = 0.2113*(q12);
r13 = 0.1097*(q12);
r14 = 0.1270*(q12);
r15 = 0.1109*(q12);
r16 = 0.164*(q12);

!Non-negativity constraint;
g11> 0;
g21> 0;
g31> 0;
h11> 0;
h21> 0;
h31> 0;
h41> 0;
h51> 0;
h61> 0;
q11> 0;
q12> 0;
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r11> 0;
r12> 0;
r13> 0;
r14> 0;
r15> 0;
r16> 0;
End

3. RESULTS AND DISCUSSION

3.1 Research Questions

i. The key factors influencing resource allocation as identified include the layout of the manufacturing system, market demand and the flow of resources within different sections of the plant.
ii. A linear programming model was developed using cost prices of raw materials and selling prices of products.
iii. Implementation results and sensitivity analysis highlighted the optimal decision variables flexibility of the model.

3.2 Key Factors that Affect Resource Allocation in the Selected Steel Manufacturing Plant

The findings from the interviews and data collection regarding a particular steel manufacturing plant are as follows:

1. Plant Description: The steel manufacturing plant is an integrated plant consisting of various facilities such as a pelletizing plant, steel melting shop, casting plant, and warehouse. The manufacturing system follows a single line layout.
2. Direct Reduction Plant: This section utilizes several resources:
    a. Iron ore: Beneficiated in the pelletizing plant to meet the requirement of 60-65% pure iron. Approximately 1.7 tonnes of iron ore is used to produce one tonne of pig iron.
    b. Coke: Produced from metallurgical coal through coking. About 0.7 tonnes of coke is used in the direct reduction of iron ore.
    c. Limestone: Used as a flux in the direct reduction furnace. It combines with impurities to form slag. Approximately 50kg of limestone is used in this process.
    d. Capacity: The direct reduction plant has a monthly capacity of 83,335 tonnes.
3. Steel Melting Shop (Electric Arc Furnace - EAF): This section utilizes various resources:
    a. Pig iron: Product of the direct reduction furnace. It contains excess carbon and impurities. About 0.4 tonnes of pig iron is added to the EAF to produce one tonne of molten steel.
    b. Scrap steel: Melted scrap steel with a composition of 90% pure iron is used in the EAF to enhance efficiency and reduce energy consumption. Approximately 0.5 tonnes of scrap steel is used per tonne of molten steel.
    c. Alloy materials: Added to the EAF to give specific properties to the final product.
    d. Limestone: Used as flux for melting and impurity removal. The amount of limestone used depends on the composition of the scrap steel and desired properties.

   e. Oxygen: Blown into the EAF to facilitate combustion and melting of scrap steel.
   f. Capacity: The EAF has a monthly capacity of 83,333 tonnes.
4. Continuous Casting Machine (CCM): Produces semi-finished products called billets from molten steel. The process involves directional solidification to achieve a uniform microstructure. The CCM has a capacity of approximately 79,167 tonnes per month.
5. Hot Rolling Machine: Processes the steel billets from the CCM into various products such as wire rods, equal angles, ipn profiles, u profiles, square bars, and round bars. The hot rolling machine has a capacity of 25,000 tonnes.
6. Resource Allocation: Resource allocation in the plant is currently done manually based on past experience and expected demand. This approach has proven to be inefficient, resulting in occasional profit loss and insufficient production quantities. Unexpected demand and higher raw material costs contribute to these issues.
7. Market Demand: The demand for rolled steel products is influenced by seasonal changes, with higher demand during the dry season due to increased construction activities.
8. Proposed Model: The study proposes a model that offers a more effective technique of resource allocation to maximize profit, considering changing industry conditions and market demand.

3.3 Development of the Linear Programming Model for Resource Allocation of the Selected Steel Manufacturing Plant

The tables below display the key data used in the developed model (equation 2.1 – 2.23), including the cost prices of raw materials and the selling prices of semi-finished and finished products. Table 2 provides the cost prices of the raw materials used in the direct reduction of iron ore. The raw materials considered in the model include iron ore (g_{11}), coke (g_{21}), and limestone (g_{31}). The cost prices per tonne for each material are presented in Naira (₦). The cost prices play a crucial role in determining the overall cost of production and, consequently, the resource allocation decisions within the steel manufacturing plant.

Table 2: Cost prices of raw materials used in direct reduction of iron ore

Raw material (tonnes)	**Cost price**
Iron ore (g_{11})	₦85,580
Coke (g_{21})	₦100,230
Limestone (g_{31})	₦7,000

Table 3 presents the cost prices of raw materials used in the Electric arc furnace. The raw materials considered in this stage include scrap steel (h_{21}), sulphur (h_{31}), silicon (h_{41}), and limestone (h_{51}). Each raw material's cost price per tonne is shown in Naira (₦). Pig iron (h_{11}) and oxygen (h_{61}) costs are not included here, as they are produced within the plant.

Table 3: Cost prices of raw materials used in electric arc furnace

Raw material (tonnes)	**Cost price**
Scrap steel (h_{21})	₦115,000
Sulphur (h_{31})	₦85,910
Silicon (h_{41})	₦40,370
Limestone (h_{51})	₦7,000

Table 4 displays the selling prices of semi-finished products of continuous casting. The primary product considered in this category is steel billets to be sold (q_{11}), and its selling price per tonne is provided in Naira (₦). The selling price is a crucial factor in determining the revenue generated from the sale of semi-finished products and impacts the allocation of resources within the steel manufacturing plant.

Table 4: Selling prices of semi-finished products of continuous casting

Product (tonnes)	**Selling price**
Steel billets to be sold (q_{11})	₦380,200

Table 5 presents the selling prices of finished products of hot rolling. The finished products considered in the model include wire rod (r_{11}), equal angles (r_{12}), ipn profile (r_{13}), u profile (r_{14}), square bar (r_{15}), and round bar (r_{16}). The selling price per tonne for each finished product is displayed in Naira (₦).

Table 5: Selling prices of finished products of hot rolling

Product (tonnes)	**Selling price**
Wire rod (r_{11})	₦456,100
Equal angles (r_{12})	₦418,000
Ipn profile (r_{13})	₦450,000
U profile (r_{14})	₦432,000
Square bar (r_{15})	₦415,000
Round bar (r_{16})	₦475,000

These tables provide essential data inputs for the developed linear programming model. The model utilizes these values, along with the defined constraints and objectives, to optimize the resource allocation within the steel manufacturing plant. The model considers resource allocation on a monthly basis, in practice these parameters can be modified to fit the market state at any point in time, so that the model produces the optimum values for resource allocation given the updated parameters.

3.4 Results of Application of the Linear ProgrammingModel to Determine Optimum Resource Allocation Strategy

This section presents the findings and analysis of the resource allocation model. The tables below provide an overview of the results of applying the developed model and the accompanying sensitivity analysis. Table 6 shows the result of minimising cost and maximising profit using the linear programming model. The objective value obtained from the model is ₦8,369,598,000. The objective value represents the value of
the objective function when all the optimal values of
The decision variables are taken into account. In this case, the model has minimized the cost and maximized the profit to achieve this objective value.

Table 6: Result of the minimisation of cost and maximization of profit

Objective value	₦8,369,598,000

Table 7 presents the results of the optimal decision variables. The decision variables represent the values determined by the model to achieve the optimal resource allocation. The values obtained for each variable are shown, along with their reduced costs. The reduced cost represents the amount that the objective coefficient of the variable would have to be improved by for it to become profitable to assign the corresponding variable a positive value in the optimal solution. In this case, all the decision variables have a reduced cost of zero, indicating they are all essential or profitable. It is important to note that the objective value is not the profit of the steel manufacturing plant, as other production costs (labour, maintenance, electricity, etc.) would be deducted from this value to arrive at the profit.

Table 7: Results of optimal decision variables

Variable	Value	Reduced cost
Iron ore (g_{11})	19,630.480	0.000
Coke (g_{21})	8,083.141	0.000
Limestone (g_{31})	577.367	0.000
Pig iron (h_{11})	11,547.340	0.000
Scrap steel (h_{21})	14,434.180	0.000
Sulphur (h_{31})	57.737	0.000
Silicon (h_{41})	86.605	0.000
Limestone (h_{51})	1,443.418	0.000
Oxygen (h_{61})	288,683.600	0.000
Steel billets to be sold (q_{11})	3,868.360	0.000
Steel billets to be rolled (q_{12})	25,000.000	0.000
Wire rod (r_{11})	6,927.500	0.000
Equal angles (r_{12})	5,282.500	0.000
Ipn profile (r_{13})	2,742.500	0.000
U profile (r_{14})	3,175.000	0.000
Square bar (r_{15})	2,772.500	0.000
Round bar (r_{16})	4,100.000	0.000

Table 8 provides the results of the sensitivity analysis conducted on the model. The sensitivity analysis assesses the changes allowable in the objective coefficients of each variable (i.e. cost price or selling price) without inducing a change in the optimal values of the corresponding decision variable. The table displays the current coefficients of the variables, along with the allowable increase and allowable decrease for each coefficient. Infinity (∞) represents an unbounded range, indicating that there are no restrictions on the allowable increase or decrease for those coefficients.

Table 8: Results of sensitivity analysis

Variable	Current coefficient (₦)	Allowable increase (₦)	Allowable decrease (₦)
Iron ore (g_{11})	85,580	426,357	∞
Coke (g_{21})	100,230	1,035,439	∞
Limestone (g_{31})	7,000	14,496,140	∞
Pig iron (h_{11})	0	724,807	∞
Scrap steel (h_{21})	115,000	579,845	∞
Sulphur (h_{31})	85,910	14,4961,400	∞
Silicon (h_{41})	40,370	96,640,960	∞
Limestone (h_{51})	7,000	5,798,458	∞
Oxygen (h_{61})	0	28,992	∞
Steel billets to be sold (q_{11})	380,200	∞	2,163,604
Steel billets to be rolled (q_{12})	0	∞	334,784
Wire rod (r_{11})	456,100	∞	1,208,170
Equal angles (r_{12})	418,000	∞	1,584,401
Ipn profile (r_{13})	450,000	∞	3,051,813
U profile (r_{14})	432,000	∞	2,636,094

Square bar (r_{15})	415,000	∞	3,018,791
Round bar (r_{16})	475,000	∞	2,041,365

The results of the sensitivity analysis indicate the flexibility of the model.Information on the allowable increases and decreases on objective coefficients can be useful when there is a need to answer questions like, "How much more costly must this raw material be before we should be willing to utilize less of it?".For example, in the case of iron ore (g_{11}), the currentcost price (coefficient) is ₦85,580, and it can be increased up to ₦511,937 or decreased to an unlimited extent without affecting the optimal quantity of iron ore to be utilized. Similarly, for other variables such as coke (g_{21}), limestone (g_{31}), and pig iron (h_{11}), there are wide ranges of allowable increases or decreases, suggesting that these coefficients have a significant impact on the optimal solution. For the selling prices of the steel products (q_{11}, r_{11}, r_{12}, r_{13}, r_{14}, r_{15}, r_{16}), the sensitivity analysis shows that there are no bounds on the allowable increase, indicating that these prices can be increased indefinitely without affecting the optimality. However, there are specific limits on the allowable decrease, which could impact the optimal solution.

4. CONCLUSIONS

The study identified the principal factors influencing resource allocation in selected steel manufacturing plants. Through interviews and data collection, critical elements that shaped resource allocation decisions within the plant were revealed. These factors included using raw materials such as iron ore, coke, scrap steel, sulphur, and silicon and the cost and selling prices of these materials and the resulting products. The layout of the manufacturing system, the flow of resources within different plant sections, and the impact of seasonal changes on market demand were also influential factors. In addition, a linear programming model was developed to allocate resources specifically to a Nigerian steel manufacturing plant. The model incorporated the cost prices of raw materials, selling prices of semi-finished and finished products, and defined constraints and objectives. An optimal resource allocation strategy was determined by applying the model. The model considered iron ore, coke, limestone, pig iron, scrap steel, sulphur, silicon, limestone, oxygen, steel billets, and various finished products. The results of the model, objective value and optimal decision variables all provided valuable insights into the efficient allocation of resources to minimize costs and maximize profits.The application of the model yielded an objective value of ₦8,369,598,000, representing the minimized cost and maximized profit achieved through the optimal resource allocation. The decision variables obtained from the model and their reduced costs indicated the quantities or amounts of resources allocated. The sensitivity analysis conducted on the model further demonstrated its flexibility, allowing decision-makers to understand the allowable increases and decreases in objective coefficients without affecting the optimal solution. The developed model was useful for optimising operations, leading to improved efficiency, cost reduction, and ultimately, heightened profitability. These findings contribute to informed decision-making and potential improvements in production processes and profitability.

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