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Application of Game Theory to Resource Optimization for Concreting Operations

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Abstract: The production of concrete is a common operation on thousands of construction sites in the world. The construction method to be employed in the production of concrete on construction sites is one of the most important decisions that construction project managers have to make. Any decision on the utilization of scarce construction resources must be well-informed and should not be based upon expert judgement. The ideal of optimization of the utilization of construction materials is all about optimizing the available resources, but this cannot be achieved without available information required to devise the best way to optimize and without a formal model of decision-making. This study aims to apply Game Theory, a formal model of decision-making, to resource optimization for concreting operations by using a concreting operation extract from a priced Bill of Quantities. The study revealed that Game Theory can be effectively applied to maximize the utilization of construction resources and recommended its use for construction managers in their functions of managing construction projects.

Keywords: Game Theory, Resource Optimization, Concreting Operations, Optimization models.

1. Introduction

Construction projects utilize enormous quantity of resources, especially concrete. The production of concrete is a common operation on thousands of construction sites in the world (Dunlop and Smith, 2000). Concrete is an important material in construction, mostly because it uses the most expensive and important raw materials of construction – cement. It is composed of cement, sand, aggregate and water with or without admixtures; when mixed in the designed proportion, concrete is a stable and versatile building material which can be used in a variety of applications ranging from roads, dams, bridges and buildings. Singh (2004) described concreting operations as the operations which are followed in actual practice in the making of concrete and in improving and maintaining the quality of concrete such as batching of materials, mixing of constituents, transportation of concrete mix, placing of concrete, compaction of concrete, finishing of concrete surface and curing of concrete. The construction method to be employed in the production of concrete on construction sites is one of the most important decisions that construction project managers have to make.

Gong, Tang, & Liu, (2017) noted that production should be planned based on demand, and should have principal-agent as its focus so as to be able to deal with contract relations challenges. Sabau (2009) observed that it is the responsibility of the manager of a project to decide on the strategy for optimizing the resources required in production. Phillips and Bana (2005) opined that the difficult task of allocating and optimizing resources is continually facing construction managers. They are challenged to continuously make decisions throughout the development of a project in their attempts to minimize the overall cost of completing that particular project and meet a pre-established deadline. These time-cost trade off decisions are made even more complex when resources constraints are added to the problems (Perez and Kuhl, 2014). Any decision taken by the manager of a construction project impacts multiple entities that interact with or within that project because decision-making process is a crucial element of any construction projects. Besides the importance of decision-making process, the competitiveness in the construction industry makes it imperative for construction managers to make decisions more quickly and accurately.

Construction activities require resources which are scarce in the market (Kim et. al, 2006). Any decision on the utilization of scarce construction resources must be well-informed and should not be based upon expert judgement. Optimization of resources is complex and difficult because many options are present, benefits and risks are rarely expressed as single objectives, multiple stakeholders with different agendas compete for limited resources, individually optimal resource allocations to organizational units are rarely collectively optimal, and those dissatisfied with the decisions taken may resist implementation (Phillips and Bana, 2005). Resource optimization should take all constraints such as resource availability, activity calendars, and relationships between projects information consideration (Bodea and Sabau, 2009). Senouci, and Al-Derham (2008) noted that it is important to incorporate activity costs as decision variables in the optimization process. (Actenum, 2005) concluded that the key to achieving operational excellence is in the effective and flexible management of resources, and this means optimizing and scheduling people, processes, vehicles, equipment, and materials so that utilization is maximized while business goals are met. Resource optimization is crucial to the success of a construction project; acquiring resources for construction projects without planning for their effective utilization is not a good strategy (Kim et al, 2006). The ideal of optimization is all about optimizing the available resources, but this cannot be achieved without available information required to devise the best way to optimize. Bodea and Sabau (2009) argued that there is no standard approach of optimizing resources. Therefore, this study aims to apply Game Theory to resource optimization of concreting operation. Game Theory has been applied majorly to economics (Eatwell et al, 1987). As a decision technique, game Theory makes use of available information to devise the best plan to achieve one's objective. Interdependent decisions are everywhere, especially in construction processes. the Construction Industry is competitive for construction firms, the decisions of one firm can impact the decisions of other firms, therefore the application of Game Theory to bidding decisions or strategies of a firm can be helpful in choosing the optimal decisions. Erhun and Keskinocak (2003) observed that Game Theory improves strategic decision-making by providing valuable insights into the interactions of multiple self-interested agents and therefore it is increasingly being applied in business and economics. According to Theodore and Bernard (2003) the concepts of Game Theory provide a language to formulate, structure, analyze and understand strategic scenarios. The theory is useful for modelling situations, improving strategic decision making and allocating resources more efficiently and optimally than traditional practices. The internal consistency and mathematical foundations of game Theory make it a prime tool for modelling and designing automated decision-making processes in interactive environments. As a mathematical tool for the decision-maker the strength of Game Theory is the methodology it provides for structuring and analyzing problems of strategic choice. Game Theory is a mathematical technique that is both flexible and robust and can be used for resource optimization. The objective of the game is to win and this can be done by identifying the optimal strategy. Although, the principles are simple, the applications are far-reaching (Dixit and Barry, 1991).

2. Background

Resource optimization is the maximization of the sum of the benefits of all investments subject to the constraint that the budget cannot be exceeded. It is about making better, efficient and effective decisions in an economic sense that allows businesses to accommodate customer and workers' preferences while taking into consideration a much wider set of requirements. Resource optimization is required for better management of resources and it focuses on calculating the best possible utilization of resources that are needed to achieve a result, such as minimizing cost or time [Phillips and Bana, 2005; Actenum, 2005)]. In any real-world situation, resource optimization is not possible without the use of sophisticated techniques and cannot be achieved in a poorly defined decision-making environment. Models to be adopted for resource optimization should be based on the optimization objective, decision variables and constraints (Actenum, 2005; Goren et al, 2008). (Goren et al, 2008) further argued that optimization models should design a system or process to be as good possible in some defined sense and that a typical optimization model (as shown in Figure 1.0) should analyze all possible decisions or actions based on given data, objectives and constraints. Phillips and Bana (2005) observed that for resource optimization models to be useful to decision-makers, the models should be able to accommodate financial and non-financial benefit criteria, risk and uncertainty, data and judgement, and be transparent, while providing an audit trail. In an attempt to develop a resource optimization model for concreting operations, Dunlop and Smith (2000) treated concrete placing operations as a Stochastic System and developed a Stochastic model for the production of concrete with a view to maximizing the productivity of concrete placing operations. In another study, Perez and Kuhl (2014) presented a simulation-based optimization approach applied to the construction time-cost trade off problem encountered in stochastic resource constrained project management problems. A genetic algorithm-based multi-objective model was developed by (Senouci, and Al-Derham, 2008; Kim et al, 2008) to provide planners and decision-makers in construction projects with an optimization model that is capable of generating optimal resource utilization plans that optimize construction time and cost and visualizing the trade-offs among project time and cost in order to support decision-makers in evaluating the impact of various resource utilization plans on project performance. Cao et al (2004) applied operations simulation modelling and genetic algorithms optimization to resource planning and production planning of a ready-mixed concrete plant in order to achieve better plant-site coordination and meet the daily demand of sites for concrete. Also, Leu et al, (2000) proposed a genetic algorithm-based optimization for construction resources. A metaheuristic technique for hard discrete optimization problems termed ‘ant colony optimization algorithms’ was proposed by (Garmsiri and Abassi, 2002) for modelling construction resources optimization. Liu and Wang (2008) proposed resource-constrained construction project scheduling model for profit maximization considering cashflow by adopting constraint programming techniques. The optimization model integrates resource constraints and cash flow management issues, and maximizes net cash flow to optimize project profit from the contractors’ perspective. Liu and Wang (2012) introduced another optimization model for linear construction projects with multi-skilled crews to minimize the project duration, and considered the concept of multi-skilling for improving work efficiency in construction. As an established decision-making technique, Game Theory has not been applied to optimize resources for construction operations, especially an important operation like concrete production. The application of game Theory to the economics of construction operations is therefore considered in this study.

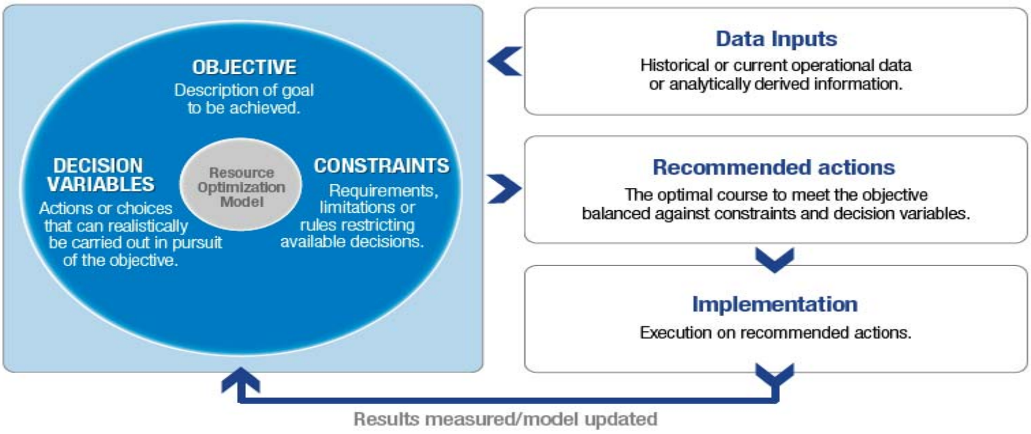

Figure 1： Resource optimization model (Source: Goren et al., 2008)

3. Game Theory

The word ‘game’ is a formal description of a strategic situation or environment while the player is an agent who makes decision in a game. Therefore, a formal study of decision-making in a strategic situation is known as Game Theory (Theodore and Bernard, 2003). Eatwell et al (1987) defined Game Theory as an interactive decision theory and a rational analysis of a strategic situation. Kartik (2009)described it as a formal methodology and a set of techniques to study the interaction of rational agents in strategic settings. Game Theory has also been defined as a branch of decision theory concerned with interdependent decisions (Dixit and Barry, 1991). Carmichael (2005) defined Game Theory as a technique that can be used to analyze strategic problems in diverse settings. According to(Hutton,2006), Game Theory is an intellectual framework for examining what various parties to a decision should do given their possession of inadequate information and different objectives. Game Theory is a technique that can be used to analyze situations where for two or more individuals or institutions, the outcome of an action by one of them depends not only on the particular action taken by that individual but also on the actions taken by the other (or others) (Carmichael, 2005). The plan of actions or available decisions are the strategies of the player. The player of the game is the strategist who is trying to make decisions by identifying the optimal strategy.

4. Elements of Game Theory

The features of Game Theory include: acts, utilities, events, optimal events, outcomes, payoff matrix, decision tree and backward or regressive induction. According to Carmichael (2005), acts in Game Theory are the possible moves or actions. They are the strategies of the game and represent the decision rule or decision node or complete contingent plan specifying how the decision-maker will 'act' at every information set. The decision-maker using Game Theory will get to decision points or nodes where he would have to act; the set of actions or choice being considered by the decision-maker at each decision node are referred to as 'acts' in game Theory(Kartik,2009). In game Theory, 'events' are occurrences taking place outside the control of the decision-maker; while the 'optimal events' is the optimal strategy or decision to be adopted by the player based on the decision criteria or objective of the player. The 'optimal event; is expected to give the highest pay-off in order to be the optimal strategy. The optimal strategy or decision to measure and maximize the pay-offs is referred to as 'utilities'. It is a unit of measuring pay-offs and must be assigned to the pay-offs in a way that makes sense from the player's perspective or that is closer to the reality; because the reliability of the optimal strategy supplied by Game Theory depends on the closeness of the utilities to the reality(Dixit and Barry, 1991; Carmichael, 2005). The 'game table' of game Theory is 'pay-off matrix'. It simplifies decisions and solves the decision problem for the decision-maker (Dixit and Barry, 1991). Pay-offs are negative or positive values placed on the occurrences by the decision-maker to describe how well off he is with the outcomes. Theodore and Bernard (2003) opined that pay-off is a number that reflects the desirability of an events. But when the outcome is random, pay-offs are usually weighted with their probabilities. Pay-offs may be measured in terms of units of money or time or anything that might be relevant to the strategic situation (Carmichael, 2005). Rather than using the 'pay-off matrix' to select the 'optimal event', the decisions that could be taken after the consideration of all relevant information could be modeled using the 'decision tree'. The 'decision tree' is a 'decision analysis' that maps out all of the possibilities in form of a decision structure and makes it easier to assess the pay-offs and make optimal decisions (Erhun and Keskinocak, 2003; Dixit and Barry, 1991).A game that evolves over time is better represented by a decision tree than using the pay-offs matrix. The pay-offs matrix only contains redundancies but decision tree reflects the temporal aspect and formally describe the game with a specification of the sequence of decisions, available information and the pay-offs (Eatwell et al, 1987; Theodore and Bernard, 2003) A technique to solve a game of perfect information is referred to as 'regressive induction'. It is required to determine the best move or the optimal strategy in each decision structure. The idea is to proceed backwards in time until the beginning of the game is reached by solving for optimal 'act' at each decision node, starting at the 'end' of the 'decision tree' and working back up the 'decision tree' in order to determine optimal decision earlier in the game(Theodore and Bernard, 2003; Kartik, 2009).

5. Method

The objective of this study is to apply game theory to resource optimization for concreting operations. In order to achieve the objective, a typical example of concrete production activity was extracted from an existing priced Bill of Quantities as shown in Table 1.0 in order to illustrate the application of game theory to decision-making for that activity.

Table 1: concreting operation

item	description	quantity	unit	rate	price (₦)
A. B. C.	Reinforced in-situ concrete (1:2:4 – 20mm aggregate) filled into formwork and well packed around reinforcement (Formwork and reinforcement measured separately) Ground beams 200mm ground floor slab Steps	50 100 2	M^3 M^3 M^3	26,500 26,500 26,500	1,325,000.00 2,650,000.00 53,000.00
		152			4,028,000.00

ACTS: the ‘acts’ of any construction operation are based on the available construction methods. In this study, two construction methods are considered;

Act 1: Machine – based method (Mechanical mixing method)

Act 2: Labour – based method (Hand mixing method)

EVENTS: the ‘events’ are the required resources for the acts.

Event 1: there will be need for a mixer if ‘act 1’ is taken.

Event 2: there will be need for mixing crew if ‘act 2’ is taken.

PAY-OFFS: the pay-offs of the ‘acts’ are measured as shown in Table 2.0 below

Table 2: pay-off measurement for the construction method options

ACTS	EVENTS	ALTERNATIVES	OUTCOMES
Machine – based method	There will be need for a mixer	A1: hire a mixer	Cost of hiring mixer, delivery and setting up mixer; consumables cost; fueling cost; cost of plant operator; cost of unloading and stacking of cement; cost of labour for loading concrete; cost of labour for transporting concrete; cost of labour for placing concrete.
		B1: use own mixer	Cost of capital; repair and maintenance; fueling cost; consumables cost(oil and grease); interest rate on capital; cost of insurance; cost of plant operator; cost of unloading and stacking of cement; cost of labour for loading concrete; cost of labour for transporting concrete; cost of labour for placing concrete.
Labour – based method	There will be need for mixing crew	A2: use mixing crew and separate crew for loading concrete.	Cost of mixing concrete; cost of loading concrete; cost of transporting concrete; cost of unloading and stacking of cement; cost of placing concrete.
		B2: use mixing crew for loading concrete as well.	Cost of mixing concrete; cost of transporting concrete; cost of unloading and stacking of cement; cost of placing concrete.

OBJECTIVES: Optimization objectives of every construction project is to deliver the work within the acceptable time, cost and quality. These have always been the criteria for measuring construction project performance.

UTILITIES: The estimated cost of outcomes of 'events' and their alternatives (see Appendix B).

Estimated cost of alternative A1, CA1= ₦ 4, 189, 440.00

Estimated cost of alternative B1, CB2= ₦ 4, 071, 028.00

Estimated cost of alternative A2, CA2= ₦ 4, 192, 800.00

Estimated cost of alternative B2, CB2= ₦ 4, 116, 800.00

PAY – OFFS MATRIX: The decision problem of the optimal strategy is tabulated as shown in Table 3.0 and 4.0 below.

Table 3: The outline of the pay – offs matrix.

Labour-based method (L-B-M)	Machine-based method (M-B-M)				
		A1	B1	A2	B2
	A1	CA1, CA1	CA1, CB1	CA1, CA2	CA1, CB2
	B1	CB1, CA1	CB1, CB1	CB1, CA2	CB1, CB2
	A2	CA2, CA1	CA2, CB1	CA2, CA2	CA2, CB2
	B2	CB2, CA1	CB2, CB1	CB2, CA2	CB2, CB2

Table 4: Pay – offs matrix with the estimated cost of alternatives (₦000, 000)

Labour-based method (L-B-M)	Machine-based method (M-B-M)				
		A1	B1	A2	B2
	A1	4.19, 4.19	4.19, 4.07	4.19, 4.19	4.19, 4.12
	B1	4.07, 4.19	4.07, 4.07	4.07, 4.19	4.07, 4.12
	A2	4.19, 4.19	4.19, 4.07	4.19, 4.19	4.19, 4.12
	B2	4.12, 4.19	4.12, 4.07	4.12, 4.19	4.12, 4.12

DECISION TREE AND REGRESSIVE INDUCTION: The alternatives are mapped out on the 'decision tree' and solution is found for 'optimal strategy' at each decision node (Figure 2.0).

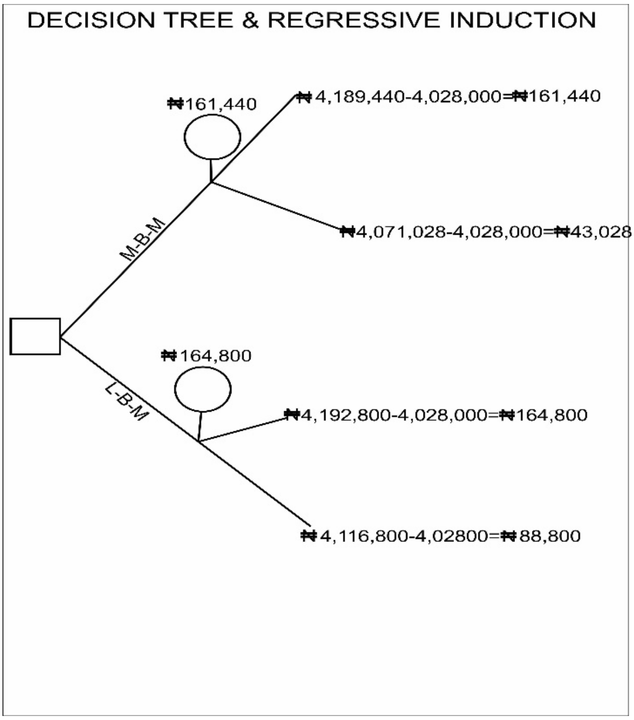

Figure 2： decision tree and regressive induction

6. DISCUSSION

Figure 2.0 presents a decision problem where four alternatives are available and only one optimal option is to be chosen. The first option is to use a machine-based construction method, where the mixer required would be hired; the second option is also a machine-based construction method but a mixer owned by the firm would be used. The third and fourth options are both labour-based construction method where hand-mixing method would be used to produce the required concrete. The difference between the third and fourth options is that the third option would use two sets of crew, one set as ‘mixing crew’ and the other as ‘loading crew’; while the fourth option would use one set of crew for mixing and loading concrete. The cost implications of these options as shown in Table 3.0 are mapped out on the decision tree. The outcome of each of the options was considered for optimal strategy by deducting the budgeted cost of ₦4, 028, 000.00 from the estimated cost of the alternatives respectively in order to determine the savings in cost provided by each of the alternatives. To make the final decision based on the savings in cost of each of the alternatives. Alternatives that provide higher savings in cost in comparison with the other ones had their values regressed to the nearest decision node on the decision tree. Since only two decision nodes are available on the decision tree, owing to the scope of the decision problem under consideration; The values of ₦161, 440.00 and ₦164, 800.00 representing the higher values of savings in cost from their respective sections on the decision tree would then be used to make the final and optimal decision. If machine-based construction method is considered, the savings in cost would be ₦161, 440.00 from using a hired mixer; and if labour-based construction method is considered, the savings in cost would be ₦164, 800.00 from using two sets of crew, one crew for mixing concrete and the other crew for loading concrete. Nevertheless, both 'events' provide savings in cost and the objective is to deliver the work within acceptable time of two days (see Appendix A), budgeted cost of ₦4, 028, 000.00 and to quality. Machine-based construction method seems to be the optimal strategy because it conforms with the performance requirement of operation, most especially because mixers are more reliable for the production of consistent, workable and quality concrete than manual method of mixing concrete.

7. CONCLUSION AND RECOMMENDATIONS

Meeting the goals of construction projects hinges on the maximization of the utilization of construction resources. Construction managers are relied upon to make decisions that would optimize the utilization of construction resources, maximize the profits of construction firms and deliver the requirements of construction clients. Obviously, optimal strategies cannot be wished for but can be planned for and the planning itself is beyond the scope of expert judgement. Planning for optimal utilization of resources requires an optimization that is based on the optimization objectives and decision variables because two construction operations and projects are never the same. The circumstances and objectives of each operations and projects are basically different. As a proven model for planning and strategizing, Game Theory has found applications in Economics and as studied in this research work, it can also be effectively applied as a technique for planning the economics of construction methods.

The essence of Game Theory is to win and this is in line with the desires of every construction managers and firms handling a construction project. Game Theory can be effectively applied to the decision problems encountered in the optimal utilization of construction resources and it is therefore recommended for construction managers as a planning technique for optimization of construction resources.

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Appendixes

Appendix A: Basic Assumptions

Time allocated for the operation	2 days
Target outputs for plants (concrete mixer)	10/7 portable concrete mixer of 20m^3 output per day
target outputs for unloading and stacking of cement	120 bags/man day
Target outputs for mixing concrete	1m^3/ man day
Target outputs for transporting concrete (not exceeding 100m haulage cycle)	6m^3/man day
Target outputs for placing concrete in beams/slabs	3m^3/man day
Rates for plant operator	₦1500.00k
Rates for skilled labour	₦2000.00k
Rates for unskilled labour	₦500.00k
Cost of materials	₦3,319,600.00k
Profits and overheads	₦604,200.00k

Appendix B: Estimation of Utilities

1: COST OF HIRING CONCRETE MIXER	
Cost of hiring mixer, delivery and setting up	Say, ₦1,250.00k/hour
Fuelling cost (Assume 1.8 litres @ ₦60.00)	₦108.00k/hour
Consumables (Assume 20% of cost of hiring and setting up)	₦250.00k/hour
TOTAL	₦1,608.00k

2: COST USING OWN CONCRETE MIXER	
Cost of capital/hour (Assume initial cost as ₦150,000.00; scrap value as ₦10,000.00 and life span of plant as 6 years @ 2000hours/year)	$\frac{\text{₦}150{,}000.00-\text{₦}10{,}000.00}{6\ X\ 2000}$ = ₦11.66/hour
Repair and maintenance (Assume 10% of capital cost)	₦1.17/hour
Fuelling cost (Assume 1.8litres @ ₦60.00k)	₦108.00k/hour
Oil and grease (Assume 20% of capital cost)	₦2.34/hour
Interest rate on capital (Assume 20% of capital cost)	₦2.34/hour
Cost of insurance (Assume 20% of capital cost)	₦2.34/hour
TOTAL	₦127.85/hour

3: MANPOWER DESIGN	
Volume of work	152m^3
No. of bags of cement(mix ratio 1:2:4)	$\frac{((1X152)\div 7)}{0.035}$=620 bags
No. of labour required for unloading and stacking of cement per day	$= \frac{620 bags}{120 bags\ per\ man\ day} = 5$
No. of labour required for mixing concrete manually	$= \frac{152 cubic\ metre}{1 cubic\ metre\ per\ man\ day} = 152$
No. of plants required for mixing concrete per day @ 80% efficiency	$= \frac{152\ cubic\ metre}{20 cubic\ metre\ output\ per\ day \times 0.80} = 10$
No. of labour required for transporting concrete per day	$= \frac{152 cubic\ metre}{6 cubic\ metre\ per\ man\ day} = 25$
No. of skilled labour required for placing concrete	$= \frac{152 cubic\ metre}{3 cubic\ metre\ per\ man\ day} = 51$

4:MACHINE-BASED METHOD	
A1: total cost of using a hired mixer	
Cost of concrete mixer per day	= ₦1,608.00/hour $\times 10 mixers \times 8 hours =$ ₦$128{,}640.00k$
Cost of plant operator	= ₦1500.00 X 10mixers = ₦15,000.00k
Cost of unloading and stacking of cements	= ₦500.00 X 5 = ₦2,500.00k
Cost of labour for loading concrete	= ₦500.00 X 10 = ₦5,000.00k
Cost of labour for transporting concrete	= ₦500.00 X 25 = ₦12,500.00k
Cost of labour for placing concrete	= ₦2,000.00 X 51 = ₦102,000.00k
Cost of materials	= ₦3,319,600.00k
Profits and overheads	= ₦604,200.00k
TOTAL (CA1)	= ₦4,189,440.00k

B1: total cost of using own mixer	
Cost of concrete mixers per day	= ₦127.85hours X 10 X 8 = ₦10,228.00k
Cost of plant operator	= ₦1,500.00 X 10 = ₦15,000.00k
Cost of unloading and stacking of cement	= ₦2,500.00k
Cost of labour for loading concrete	= ₦5,000.00k
Cost of labour for transporting concrete	= ₦12,500.00k
Cost of labour for placing concrete	= ₦102,000.00k
Cost of materials	= ₦3,319,600.00k
Profits and overheads	= ₦604,200.00k
TOTAL (CB1)	=₦4,071,028.00k

5: LABOUR-BASED METHOD	
A2: total cost of using mixing crew and separate crew for loading concrete	
Cost of mixing concrete	= ₦500.00 X 152 = ₦76,000.00k
Cost of loading concrete	= ₦500.00 X 152 = ₦76,000.00k
Cost of transporting concrete	= ₦500.00 X 25 = ₦12,500.00k
Cost of unloading and stacking of cements	= ₦500.00 X 5 = ₦2,500.00k
Cost of placing concrete	= ₦2,000.00 X 51 = ₦102,000.00k
Cost of materials	= ₦3,319,600.00k
Profits and overheads	= ₦604,200.00k
TOTAL (CA2)	= ₦4,192,800.00k

B2: total cost of using mixing crew for loading concrete as well	
Cost of mixing concrete (including loading)	= ₦500.00 X 152 = ₦76,000.00k
Cost of transporting concrete	= ₦12,500.00k
Cost of unloading and stacking of cement	= ₦2,500.00k
Cost of placing concrete	= ₦102,000.00k
Cost of materials	= ₦3,319,600.00k
Profits and overheads	= ₦604,200.00k
TOTAL (CB2)	= ₦4,116,800.00k