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Optimization of Construction Logistics Planning Cost in Egypt Using Genetic Algorithms

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Abstract

The effective and efficient management of construction resources is the core of success for any construction project. Traditionally, researchers and industry professionals identify the five main construction resources to include, time, capital, labor, equipment and material. Although, one of the important project resources that have been overlooked during the planning phases of most construction projects is site space. The contractors in Egypt impose serious challenges to plan for material procurement and site logistics due to the insufficiency of construction site space. The aim of this research is to optimize the construction logistics planning cost in Egypt. A literature review is performed on an adapted construction logistics planning model, whereas, implementing and verifying the automated construction logistics planning model using genetic algorithms, applying and validating a case study to the automated construction logistics planning model to the Egyptian industry which is expected to help contractors in Egypt to develop more optimized site layout plans and procurement plans to avoid material shortage and unorganized site layouts that could led to cost overruns.

Keywords: Optimization; Material procurement; Site logistics; Adapted

List of Abbreviations

CLC: Construction Logistics Costs;

OC: Ordering Cost;

FC: Financing Cost;

SC: Stock-out Cost;

LC: Layout Cost;

T: Number of project stages;

M: Number of project materials;

NOR_m^t: Number of Orders of Material (m) in stage (t);

Q_n: Quantity of Order n;

$PCR_m^t(Q_n)$: Purchase Cost Rate of Material (m) in stage (t) with Q_n order quantity;

$DLC_m^t(Q_n)$: Delivery Cost of Material (m) in stage (t) with Q_n order quantity;

NCD: Number of project days;

CS_d^m: Cumulative Supply of material (m) in day (d);

CD_d^m: Cumulative Demand of material (m) in day (d);

PCR_m^{avg}: Average Purchase Cost Rate of material (m);

DIR: Project Delay Interest Rate;

MRPD: Materials Related Project Delay;

EFi: Early Finish of activity (i) in the base line project schedule;

EF_i : Expected Early Finish of activity (i) after considering late delivery of materials;

LQD: Liquidated Damage Cost;

TDIC: Time Dependent Indirect Cost;

MHC: Material Handling Cost;

RTC: Resource Traveling Cost;

SRC: Site Reorganization Cost;

NF_t: Number of Temporary Facilities used in stage (t);

NB_t: Number of Buildings under construction in stage (t);

$C_{m,f}^t$: Travel cost rate of material (m) to facility (f) in stage (t);

$D_{m,f}^t$: Euclidian distance of material (m) to facility (f) in stage (t);

$q_{m.f}^r$: Estimated quantity of material (m) required in facility (f) in stage (t);

$q_{m.f}^r$: Handling capacity of handling crew (r) handling material (m) to facility (f);

HCR_r: Hourly Cost Rate of handling crew (r) (\$/hr.);

v_r: Speed of handling crew (r) (m/hr.);

$C_{f,g}^t$: Travel cost rate of resources between facilities (f, g) in stage (t);

$D_{f,g}^t$: Euclidian distance between facilities (f, g) in stage (t);

E_f: Existence factor {1 if movebale facility exists in stage t-1};

RC_f: Relocation Cost of moveable facility (f);

IF {condition}: A conditional function that returns 1 if the inside condition is satisfied, 0 otherwise;

θ_f^t : Orientation angle of facility (f) in stage (t);

θ_f^t : Orientation angle between facilities (f's) positions in stages (t, t-1);

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θ_f^t : Euclidian distance between facilities (f's) positions in stages (t, t-1);

$PDCR_m^t(Q_n)$: Purchase and delivery cost rate of material (m) in stage (t) with Q_n order quantity;

$PDCR_m^{avg}$: Average purchase and delivery cost rate of material (m);

IF {condition}: A conditional function that returns 1 if the inside condition is satisfied, 0 otherwise;

θ_f^t : Orientation angle of facility (f) in stage (t)

Introduction

Adapted construction logistics planning cost model

An adapted construction logistics planning model was designed to outfit the Egyptian building construction industry. The adapted model aims to optimize the construction logistics cost, which is divided into four main parts: (1) ordering cost; (2) financing cost; (3) stock-out cost and (4) layout cost [1]. The objective function used to minimize the construction logistics costs is shown in Equation 1 and each component is discussed in the following subsections.

$$CLC = OC + FC + SC + LC \quad (1)$$

Ordering cost (OC)

The ordering cost (OC) according to the Egyptian building construction market is the summation of the cost of purchasing and the cost of transporting them to the construction site as an ordering cost rate for the material [2]. Based on the procurement decisions the number of material orders and their quantities are determined which directly affects the construction material ordering cost, as shown in Equation 2.

$$OC = [\textstyle\sum_{t=1}^{T} \sum_{m=1}^{M} \sum_{n=1}^{NOR_m^T} \left(Q_n \times PDCR_m^t\left(Q_n\right)\right)] \quad (2)$$

Financing cost (FC)

In the adapted model the financing cost is calculated as the accumulation of the sum of the daily interest rate defined by the planner paid on the monetary value of the daily inventory of each material over the project duration as shown in Equation 3. It should be noted that as the abovementioned procurement decision variables (FOPm,t) where longer, it leads to larger materials inventories which in turn affects the cumulative supply [3].

$$\left[\sum_{d=1}^{NCD}\left(\sum_{m=1}^{M}\left(CS_d^m - CD_d^m\right) \times PDCR_m^{avg} \times DIR\right)\right] \quad (3)$$

Stock-out cost (SC)

Stock-out cost (SC) represents project delay costs is any cost to the contractor that occurs due to the shortage of material as a result of delayed materials delivery and depleted materials inventory when needed, which comprehends project delay penalties and labor waiting costs. The material-related delay of critical construction activities may cause costly penalties as stated in liquidated damages section of the project contract.

$$MRPD = \max_i\left(\overline{EF_1}\right) - \max_i\left(EF_i\right) \quad (4)$$

Then the stock-out cost (SC) is calculated as shown in Equation 5 using the previously estimated materials related project delay (MRPD), the project liquidated damage (LQD) and/or time-dependent indirect costs (TDIC).

$$SC = [\left(MRPD\right) \times \left(LQD + TDIC\right)] \quad (5)$$

Layout cost (LC)

The adapted model divides the layout cost (LC) as shown in Equation 6, into two main cost components: materials handling cost (MHC), and site reorganization cost (SRC).

LC = MHC + SRC

Materials handling cost (MHC)

The materials handling cost (MHC) for the adapted model is shown in Equations 7 and 8.

$$\textstyle\sum_{t=1}^{T} \sum_{m=1}^{M} \sum_{f=1}^{NF_t} C_{m.f}^t \times D_{m.f}^t + \sum_{t=1}^{T} \sum_{m=1}^{M} \sum_{f=1}^{NB_t} C_{m.f}^t \times D_{m.f}^t \quad (6)$$

$$C_{m.f}^t = \frac{\left(2 \times \left(Q_{m.f}^t / q_{m,t}^r\right) \times HCR_r\right)}{V_r} \quad (7)$$

Site reorganization cost (SRC)

Equation 9 shows that the extra cost paid by the contractor to change site layout at the beginning of each construction stage by relocating some or all moveable facilities conducts the site reorganization cost (SRC) according to the adapted model.

$$\textstyle\sum_{t=1}^{T} \sum_{f=1}^{NF_t^M} E_f \times RC_f \times IF\left\{D_f^{t,t-1} > 0 \text{ or } \theta_f^t \neq \theta_f^{t-1}\right\} \quad (8)$$

Model Automation

The automated model is developed using the Matrix Laboratory (MATLAB R2013a), a software package developed for performing calculations using matrixes and vectors. The automated model is an interactive computer program [4] that helps its users address the integration between the critical procurement decisions and dynamic layout planning task [5,6]. The model is designed to optimize the construction logistics cost using the aforementioned equation 1 which is divided into four main parts: (1) ordering cost; (2) financing cost; (3) stock-out cost and (4) layout cost. Therefore the developed automated model was divided into four modules, each calculating one of the abovementioned costs and a main module to calculate the total construction logistics cost.

To this end, CLPC takes as input a sequence of activities (including durations and precedencies), facilities associated with activities and their dimensions, purchase and delivery cost rates of construction materials and their storage dimensions, material assignments and quantities to different activities, site and building geometric data and time frames (project phases) over which to create layouts. For each such time frame, CLPC provides 2-dimensional templates of the facilities present in it, as shown in Figure 1. Facilities with known positions are automatically displayed at their positions by CLPC. The advantage that CLPC has to offer, over manually creating these layouts that change over time, is that it tracks facilities positions over time and maintains consistency between layouts, taking into consideration the critical procurement decisions.

Modeling Assumptions

The developed CLC automated model was exposed to some modeling assumptions, such as: (1) a discrete representation is used to model time. CLC can slice the project duration into time intervals of any length and create a layout to cover each time interval. By convention, a layout can depict each facility in one and only one position, i.e., it is

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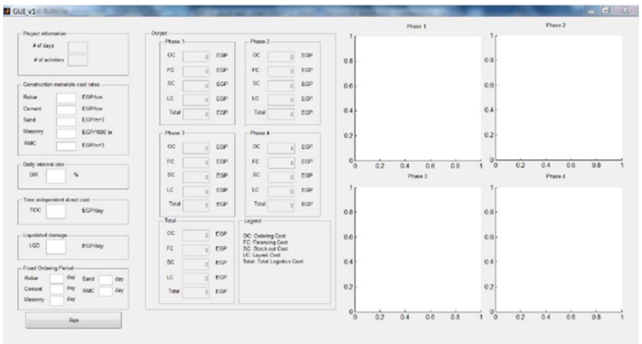

Figure 1: Construction logistics planning cost (CLC) automated model.

assumed that the facility is stationary for the duration o f a single layout; (2) an activity can use zero, one, or multiple construction material. A construction material can belong to one or multiple activities. There is no limit to the number of concurrent activities that can use single construction material; (3) facilities, including the project site, the fixed facilities, and the temporary facilities, are modeled as 2 dimensional templates with one of two shapes: rectangles, squares; (4) all facilities have predefined and fixed dimensions, i.e., the length and width of each temporary facility are specified by the user before any layout is constructed and cannot be changed after the first layout has been saved. However, a set of fixed dimensions are assigned to each construction material storage area according to a set of predefined quantities, which allows the size of the storage area to vary from one construction phase (interval) to another, but fixed throughout the existence in the same time interval; (5) the angle of orientation of facilities is limited to 0 or 90 Degrees only; (6) the distance between facilities is calculated based on the Manhattan method; (7) construction materials fixed ordering period is constant throughout the construction phase and only allowed to change between one phase and the other, based on the following periods 1, 7, 14 and 21 days; (8) the study is limited to five construction materials which are rebar, cement, sand, masonry and ready mix concrete; and (9) the purchase and delivery cost rate of material is constant along the project duration.

Main module: total construction logistics planning cost

Inputs: The main CLC module uses the fixed ordering period for each construction material (m) and construction phase (t), (FOPm,t) as an input by the user and the purchase and delivery cost rate of each construction material (m), (PDCRm) as an input by the user, as shown in Figure 2.

Computations: The main module calls all other four modules. A function is developed to sum all outputs from the four modules. First a summation for all modules for each construction phase (t). Second a function is created to calculate the total construction logistics planning cost.

Output: The main module gives an output of all the four modules. Moreover, the value of the construction logistics cost for each phase and the value of the total construction logistics planning cost. An output of the site layout plan with all facilities placed for each phase is generated in a plotted chart as shown in Figure 3.

First module: ordering cost

Inputs: The ordering cost module uses the construction materials quantities for each phase (rebar, cement, sand, masonry and ready mix concrete) from an external ASCII file and the purchase and delivery cost

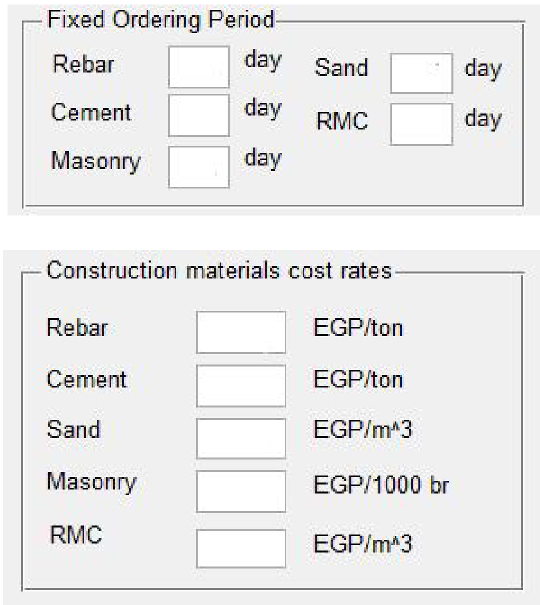

Figure 2: Fixed ordering period, purchase and delivery cost rate of each construction material user input screen.

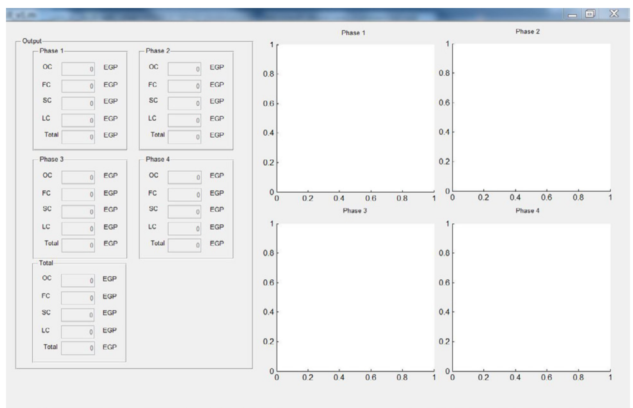

Figure 3: A screen that displays the logistics cost output and the generated site layout plan for each construction phase.

rate of each construction material (m), (PDCRm) from the main module.

Computations: The ordering cost module calculates the ordering cost based on equation 2 by taking the quantity of each construction material in each phase and multiplies it by the purchase and delivery cost rate of the material. This computation is repeated for each construction phase.

Output: The ordering cost module provides an ordering cost output for each construction material in each construction phase, followed by the ordering cost of all construction materials in each phase, then a total ordering cost of materials for the whole project as shown in Figure 4.

Second module: financing cost

Inputs: The financing cost module uses the number of project phases (t), daily interest rate percentage (DIR), as an input by the user shown in Figure 5, daily demand (quantities) of each construction material (m) in each construction phase (t) which is read from an

Figure 4: An output screen that displays the ordering cost (OC), financing cost (FC), Stock-out cost (SC) and layout cost (LC) for each construction phase and the total ordering cost of materials for the whole project.

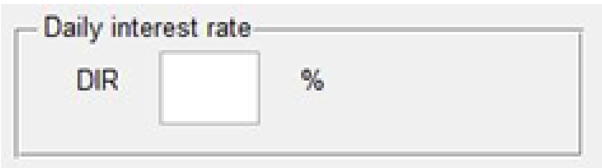

Figure 5: Daily interest rate (DIR) user input screen.

external ASCII file and the purchase and delivery cost rate of each construction material (m), (PDCRm) from the main module.

Computations: The financing cost module calculates the cumulative daily demand of each construction material (m) in each construction phase (t) based on the daily demand inputs. Also based on the inputs of the FOPm,t the number of orders is determined for each material in each phase by which the supply of each materials is determined, which is then used to generate daily cumulative supply for each construction material. A function is created then to subtract the daily cumulative demand from the daily cumulative supply of each construction material which is then multiplied by the purchase and delivery cost rate of this material, and multiplied by the daily interest rate (DIR), this function is repeated by the number of construction phases (t). Another function is created to make a summation of the financing cost generated by all construction phases.

Output: The financing cost modules gives an output for the financing cost of each material (m) in each construction phase (t), the financing cost of all materials in each construction phase and the total financing cost of all construction stages as shown in Figure 4.

Third module: stock-out cost

Input: The stock-out cost uses the following inputs for its computations. The daily time-depended indirect cost (TDIC), the daily project liquidated damage (LQD), number of project activities,

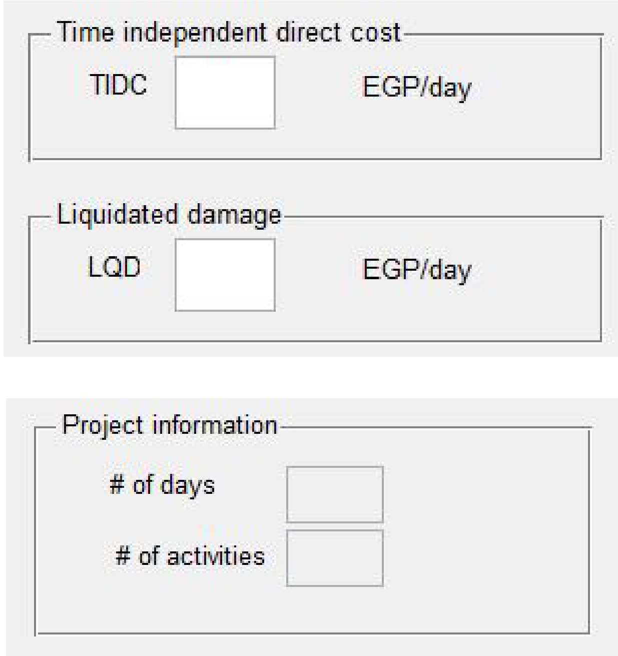

Figure 6: The daily time-depended indirect cost (TDIC), daily project liquidated damage (LQD) and the Project information (Number of project working days and number of project activities) user input screen.

Number of project working days, as an input by the user shown in Figure 6. The duration and relations of each activity (predecessors and successors) which are read from an external ASCII file, number of construction materials, Delivery Average Delay of each material (m) (DADm), Fixed Ordering Period (FOPm,t) read from the main module, Materials Delivery Schedule of each construction material (m) in each construction phase (t) based on the abovementioned (FOPm,t) and Construction materials assignments to each activity which are read from an external ASCII file.

Computations: The computation of the stock-out cost is based on a three loops calculation. Before the loops start, the module computes the planned project schedule (start and finish times of each activity) based on the developed scheduling code using the critical path method. Then the first loop starts iterating the number pf project days, while the second loop iterates each material for all activities in the third loop. The second and third loop iterates all materials for all activities to all project days in the first loop. The loops start by checking the first material into day one by all activities, the loop checks that the activity is in progress by checking day (d) to be greater than the start time and smaller than the finish time of activity (i), a check if the material (m) is assigned to activity (i) based on the input of the materials assignment schedule, a check for the material (m) delivery on that day is present or not based on the previous input of the fixed ordering period of each material and check if the delay of activity (i) is smaller than the delivery average delay of material (m). If all four conditions are satisfied, then the module will store the delay of activity (i) to be equal to the delivery average delay of material (m), and then it iterates for all activities (i). After finishing all activities (i) in day (d) the second loop starts with the second material and repeat all conditions for all activities (i) in day (d). After all materials (m) iterates to all activities (m) the module will store the values of delay (i) and update the schedule. Then the loop will iterate for the following day (d+1) by the same computations. At the end of the project days the updated project finish time is stored. Finally, a function is created according to Equation 4 to calculate the Materials Related Project Delay (MRPD) by subtracting the planned project duration from the updated project duration, followed by a function based on Equation 5 which calculates the stock-out cost by multiplying the MRPD by the summation of the daily time-depended indirect cost (TDIC) and the daily project liquidated damage (LQD).

Output: The stock-out cost gives an output for the value of the material related project delay and the stock-out cost of each phase, followed by a total stock-out cost of the whole project as shown in Figure 4.

Fourth module: layout cost

Input: The Layout cost takes inputs such as the construction site, building and site gate dimensions, locations and orientations. The relocation cost of storage areas and temporary facilities (RC) which are read from an external ASCII file. The Hourly Cost Rate (HCRr), handling rate (qr) and velocity (vr) of each handling crew (r) which are read from an external ASCII file. The existence factor of each storage area and temporary facility in each construction stage (t).

Computations: The layout cost module is divided into two main functions. The first is based on Equation 6 to calculate the Materials Handling Cost (MHC) and the second is based on Equation 8 to calculate the Site Relocation Cost (SRC). The MHC is calculated by multiplying the travel cost rate calculated by equation 7 by the distance between the facilities under study using the Manhattan calculation method. While the SRC is calculated by multiplying the Relocation cost of each facility by the existence factor given as an input (0 or 1) which shows if this facility is present in this phase it gives a value of 1, otherwise 0. Which is then multiplied by the IF which is a calculated value under an If condition which gives a value of 1 if the condition is satisfied and 0 otherwise. The conditions are if there is a change in the facility's location or orientation from the previous construction phase. Finally, a function is developed to calculate the summation of both the MHC and SRC to find the layout cost, which is then repeated for each construction phase.

Output: The layout cost module gives an output for the Layout cost of each material (m) in each construction phase (t), the layout cost of all materials in each construction phase and the total layout cost of all construction stages as shown in Figure 4.

Model Verification

The automated model was then verified based on the Model-Based Design and Verification technique which allows verifying each module separately throughout the model development lifecycle, since doing testing at the end of the effort does not help prevent defects from being injected at the beginning of the requirements or design phases. The verification was performed separately using a manually solved example for the whole. The output of the manually solved example is then compared to the output of the CLC automated model.

Verification example input assumptions

The developed example was for a project which consists of four phases consisting of six activities. The project takes twenty six working days to be accomplished. The layout consists of a main building under construction, five materials storage areas and four temporary facilities. The construction site dimensions are 36 × 41 m. The daily interest rate (DIR) is assumed to be 0.03%, time independent direct cost (TIDC) is set to be 3000 EGP/day and the liquidated damage cost (LQD) equals to 2000 EGP/day. All other assumed data are as shown in Table 1.

Verification example manual solution

According to the abovementioned data, manual calculations have been performed to get the optimal total construction logistics cost. Calculations were executed using the aforementioned modified construction logistics planning cost model equations. On the basis of manual calculations, ordering cost, financing cost, stock-out cost and layout cost for each phase which in turn used for conducting the optimal total construction logistics cost for each phase and the project as a whole.

Ordering cost manual calculations

In the light of the given project schedule data, construction materials quantities in Table 1, the ordering cost of materials PDCRm (EGP/unit) and fixed ordering period. Ordering cost for each phase is calculated using Equation 2 for each construction material (m) in each phase (T) and the ordering cost values.

Financing cost manual calculations

According to the given project schedule data, construction materials quantities in Table 1 and fixed ordering period, the daily materials demand and supply schedule was conducted for each phase (T). By using the assumed daily interest rate the financing cost for each phase is calculated using Equation 3 for each construction material (m) in each phase (t) and the conducted financing cost values.

Stock-out cost manual calculations

By the means of calculating the material related project delay (MRPD) based on the assumed project schedule data, construction materials quantities and materials assignment in Table 1, the fixed ordering period and the delivery average delay of materials (DADm). And the use of the assumed time independent direct cost (TIDC) and the liquidated damage cost (LQD). The stock-out cost is manually calculated using Equation 4.

Layout cost manual calculations

The layout cost for each phase (T) is manually calculated based on Equation 6 according to the optimal temporary facilities and storage areas location and orientation on site. Equation 6 is subdivided into material handling cost (MHC) and site reorganization cost (SRC). First material handling cost is calculated using Equations 7and 8, based on the assumed construction materials in Table 1 and materials handling data. Second the site reorganization cost is manually calculated using Equation 8, according to the assumed relocation cost of facilities on site at each phase (T). On the basis of the above mentioned layout organization for each phase, the layout cost is manually calculated

Total construction logistics cost manual calculations

Finally, the logistics cost of each phase is calculated throughout the summation of the ordering cost, financing cost, stock-out cost and the layout cost of the phase. The construction logistics cost of the project is then calculated by summing the logistics cost of each phase equals to 62652.49 EGP, as shown in the following Table 2.

Genetic algorithms implementation

A study on the effect of genetic parameters is carried out in order to tune the optimum value of the parameters in genetic algorithms to determine the optimal site layout that minimize the construction site logistics cost. The testing of this technique has been carried out on a standard problem to show the choice of parameters in genetic algorithms [7]. As for any genetic algorithm, one of the problems is

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Activity	Planned Duration (days)	Predecessor	Relation	Activity Lag (days)	Construction Materials Quantity				
					Rebar (ton)	Cement (ton)	Sand (m^3)	Masonry (1000 br.)	RMC (m^3)
A	6	-	Finish to Start	-	17	-	-	-	100
B	3	A	Finish to Start	-	5	-	-	-	30
C	6	B	Finish to Start	-	10	-	-	-	60
D	5	C	Finish to Start	6	-	11	33	7.5	-
E	3	D	Start to Start	2	-	9	30	-	-
F	2	C	Finish to Start	6	2.5	-	-	-	15

Table 1: Project scheduling and construction materials data.

Construction Logistics Cost	Construction Phase (T)				Total (EGP)
	T_1	T_2	T_3	T_4	
Ordering Cost (EGP)	14850	13365	3152	939	32306
Financing Cost (EGP)	2.80	2.10	0.35	0.14	5.39
Stock-out Cost (EGP)	10000	20000	0	0	30000
Layout Cost (EGP)	74	66	112	89	341
Construction Logistics Cost (EGP)	24926.3	33433.1	3264.55	1028.54	62652.49

Table 2: Summary of manual calculations of the construction logistics cost of each phase and the total construction logistics cost of the project.

its convergence behavior which is affected by many factors including the genetic parameters. The selection of these genetic parameters is generally quite ad hoc. However, we find in this research that proper parameter selection is critical because they significantly affect the convergence and optimality of the solution obtained.

Tuning of GA parameters

To illustrate the effect of each parameter on the performance of the genetic algorithms, a lot of changes had been done to the previous parameters with a model run for each change to achieve the best parameters to conduct the optimal solution and these changes are listed in Table 3.

Parameter Domain	Trial Range	Trial Step	Recommended
Population type	Double Vector	Double Vector	Double Vector
Population size	50-400	50	200
Generations	50-250	50	150
Crossover function	Two Point	Two Point	Two Point
Crossover fraction	0.6-0.9	0.05	0.75

Table 3: The GA parameter domains for the optimal solution.

Verification example CLC model solution

The construction logistics planning cost (CLC) model was also used to solve the verification example using the aforementioned project data in Table 1 to generate an integrated optimal material procurement and a site layout plan. Figure 7 shows the CLC model input data for the verification example. Project information, construction materials cost rates, daily interest rate, time independent direct cost, liquidated damage and fixed ordering period are entered by the user [8].

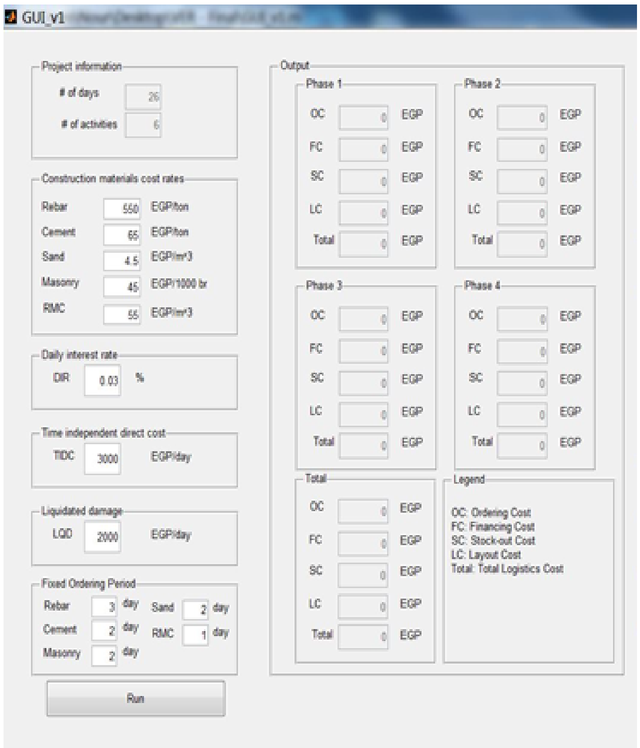

Figure 7: CLPC model data input for the verification example.

Using a Genetic Algorithm population size of 200, the present model generated an optimal layout integrated plan with a total construction logistics cost of 62651.5646 EGP, which was compared to the manual solution total construction logistics cost of 62652.49 EGP, to find approximately equal values that shows that the model is verified. The model was used to evaluate the fitness (construction logistics planning cost) [9,10] by executing the following steps for each solution examined by the GA optimization tool in order to calculate: (1) the order quantities of each material during every stage based on the generated FOP and the material's demand in that stage; (2) the ordering costs listed in Table 2; (3) the financing cost using Equation 3 based on the cumulative materials demand and the cumulative supply which is dependent on the FOP values; (4) the stock-out cost using Equation 5 throughout calculating the material-related project delay (MRPD); (6) the storage space needs and dimensions for each material in every stage based on the planner-defined footprint schedules and the value of the FOP; and (7) the layout costs using Equations 6 through 9 considering the values of layout decision variables (locations and orientations) for all storage areas and temporary facilities [11,12].

The final results of the CLC model for each construction phase are shown in Figure 8. In the light of comparing the aforementioned optimal cost results and site layout plan of the verification example manual solution and construction logistics plan model throughout the four construction phases. It has revealed a verified model that has similar outputs with only approximation errors from the manual output [13]. These results also showed a difference in the location of the (others) temporary facility from the manual solution, which does not affect the construction logistics cost of the third phase, since it's material handling cost was not included in the study. However, in the fourth phase it showed a difference in the location from the manual solution but with keeping the same location as the third phase with no change to achieve the optimal layout cost, since it has a relocation cost which affects the reorganization cost.

Case Study and Validation

An application case study is used to evaluate and demonstrate the capabilities of the present CLC model in integrating and optimizing the critical planning decisions of material procurement and material storage on construction sites. The chosen case study is located in Alexandria, Egypt which lies north on the Mediterranean Sea.

The case study involves the construction of a new educational building (seventh educational building) in the University of the Arab Academy for Science, Technology and Maritime Transport (AASTMT), which is located in Abu Qir campus, Alexandria, Egypt [14].

The five floors building gone under construction on the sixteenth of February 2014, the project was planned to be accomplished in two hundred and eighteen working days. The building was built on one thousand footprint area in a construction site of five thousands seven hundred and sixty one footprint area. Figure 9 shows the site layout geometry and facilities location data [15].

For the purpose of illustration, five materials are considered in this case study, which include reinforcing steel (rebar), cement (used for plastering and masonry works only), sand (used for plastering and masonry works only), masonry and ready mix concrete (used in foundations and skeleton). Cost rates of materials and handling crews are derived based on the expert interviews. In this case study, the construction project requires the utilization of five temporary facilities such as office trailers and fabrication areas.

In this chapter, efforts are made to make a comparative analysis based on a real life case study. This is developed throughout several tasks: (1) introduce the case study input assumptions; (2) construction logistics cost manual calculation for the given case study actual data; (3) apply the present CLC model on to the case study which is based on real life data to generate the optimal procurement and layout decisions in order to minimize total logistics cost; (4) comparative analysis is made between the actual total logistics cost based on the actual procurement and layout decisions and the generated total logistics cost by the CLC model [16].

Case study input assumptions

As aforementioned the case study data was for an educational building that consists of four construction phases comprised of two hundred and sixty four activities. The project takes two hundred and eighteen working days to be accomplished. The construction site consists of a main building under construction, five materials storage areas and four temporary facilities [17,18]. The construction site dimensions are 50 × 20 m. The daily interest rate (DIR) is assumed to be 0.03%, time independent direct cost (TIDC) is set to be 30000 EGP/day and the liquidated damage cost (LQD) equals to 20000 EGP/day based on the expert interviews data. All other assumed data are as shown in Tables 4 and 5.

Case study actual logistics cost

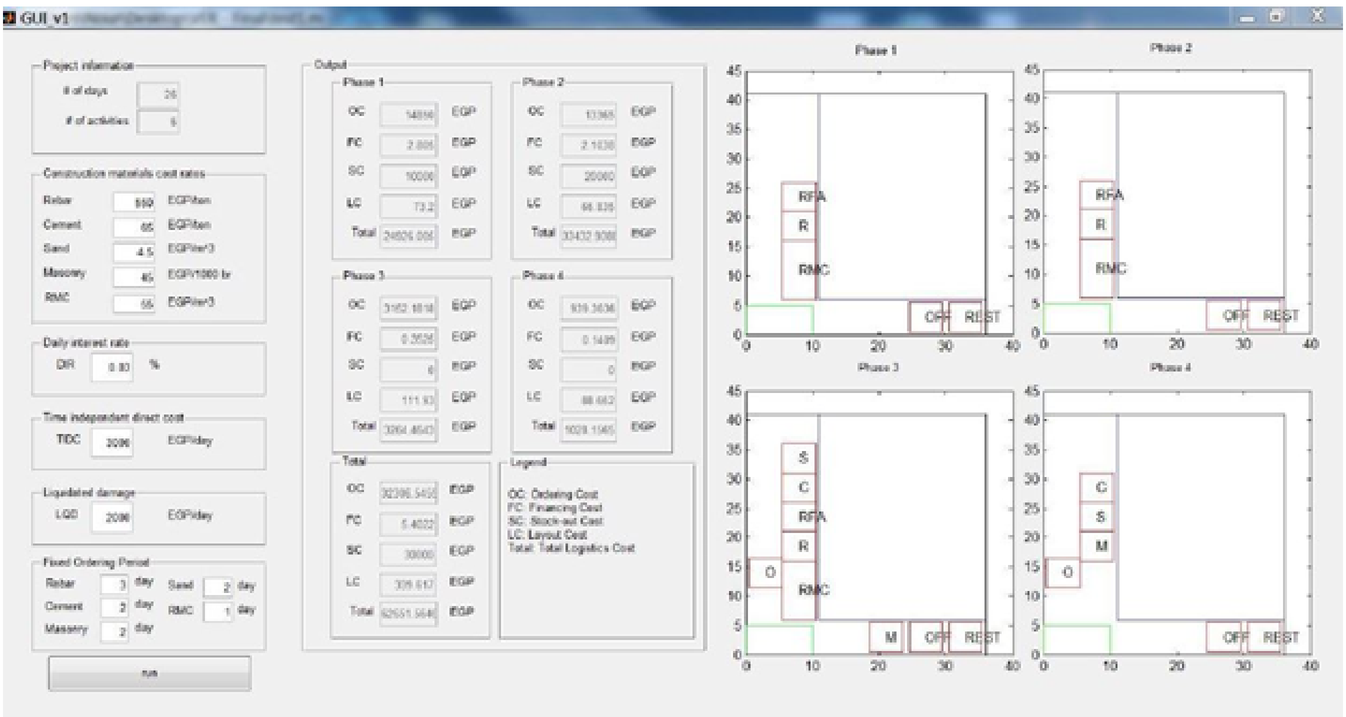

Figure 8: Results for the fourth construction phase layout and the logistics costs using CLC model.

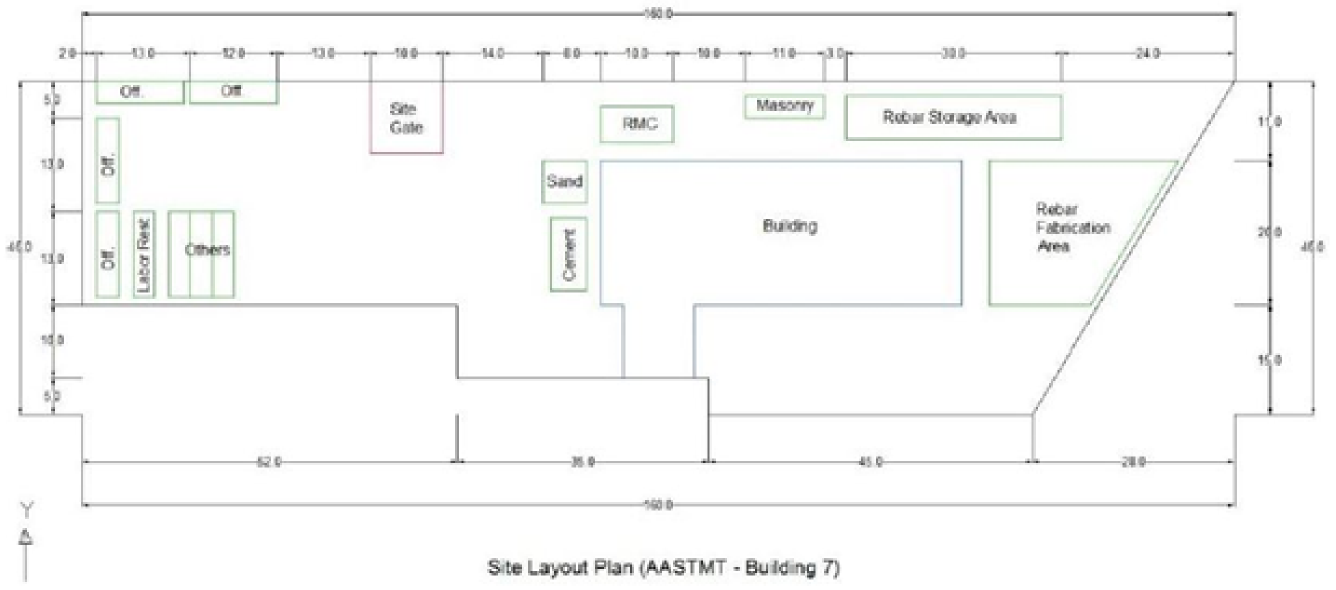

Figure 9: Site layout geometry and building location.

ID	Description	Dimensions (m)		Time on site				Fixed position	
		Lx	Ly	T1	T2	T3	T4	x	y
B1	Building (1)	50	20	√	√	√	√	72	15
G	Site Gate	10	1	√	√	√	√	40	45
Temporary Facilities ID	Description	Dimensions (m)		Time on site				Type *	Relocation Cost (EGP)
		Lx	Ly	T1	T2	T3	T4		
F1	6	24		√	√	√	√	M	3000
F2	15	15		√	√	√	√	M	300
F3	3	12		√	√	√	√	M	3000

Table 4: Geometry and time data of site facilities.

Construction Material	Unit	Quantity	Area (m²)	Lx (m)	Ly (m)	Remark
Rebar	Ton	0 - 20	48	4	12	
		20 - 40	72	6	12	
		40 - 60	96	8	12	
		60 - 80	120	10	12	
		80 - 100	144	12	12	
Cement	Ton	0-50	25	5	5	
		50-100	50	5	10	
Sand	m^3	0-20	36	6	6	
		20-40	49	7	7	
		40-60	64	8	8	
Masonry	1000 bricks	0-15	24	3	8	
		15-30	40	5	8	
		30-40	56	7	8	
Others	Caravan	4	144	6	24	

Site Offices	Caravan	4	144	6	24	
Labor rest area	Caravan	1	36	3	12	
Rebar fabrication area	-	-	225	15	15	

M = Moveable.

Table 5: Footprint area of materials storage and temporary facilities.

According to the abovementioned data, calculations have been performed to get the actual total construction logistics cost. Calculations were executed based on actual data collected from the contractor's company, by the help of collecting required documents and doing interviews with the company's owner and the project manager. On the basis of actual calculations, ordering cost, financing cost, stock-out cost and layout cost for each phase is calculated which in turn used for conducting the actual total construction logistics cost for each phase and the project as a whole to be compared to the CLC model output [19].

Ordering cost calculations

In the light of the collected actual project schedule data, construction materials ordering invoices, quantities of the materials are conducted in an ASCII format as shown in Figure 7, also the invoices were used to determine the actual ordering cost of materials PDCRm (EGP/unit) and the actual ordering periods of materials throughout each construction phase. Ordering cost for each phase is calculated for each construction material (m) in each phase (T).

Financing cost calculations

According to the abovementioned collected actual project schedule data, construction materials quantities and actual ordering period. The daily materials demand and supply schedule was conducted for each phase (T). By using the actual daily interest rate the financing cost for each phase is calculated for each construction material (m) in each phase (t). Table 6 shows the conducted financing cost values [20].

Stock-out cost calculations

By the means of calculating the material related project delay (MRPD) based on the contractor's actual updated project schedule data, construction materials actual quantities and materials assignment, the actual ordering period and the delivery actual delay of materials (DADm) in Table 6. And the use of the actual time independent direct cost (TIDC) which is equal to thirty thousand EGP per day and the liquidated damage cost (LQD) which is equal to twenty thousand EGP per day. The stock-out cost is calculated for each construction phase (T). The stock-out cost values are shown in Table 6.

Layout cost calculations

The layout cost for each phase (T) is calculated based on actual data according to the temporary facilities and storage areas location and orientation on site. The site layout was static throughout the project. The staff office trailers, labor rest area and other construction materials storage area, the ready mix concrete, rebar storage area and rebar fabrication area were fixed. The layout cost is based on the material handling cost (MHC), while there was no site reorganization cost (SRC) since the layout was stable along the project duration with no relocation. The material handling cost is calculated using the actual construction materials quantities, actual storage areas location on site as shown in Figure 9 and materials handling data given [20]. The layout cost for each construction phase (T) is shown in Table 6.

Total construction logistics cost calculations

Finally, the actual logistics cost of each phase is calculated throughout the summation of the ordering cost, financing cost, stock-out cost and the layout cost of the phase. The construction logistics cost of the project is then calculated by summing the logistics cost of each phase equals to 7,712,303 EGP, as shown in the following Table 6.

CLC Model Application

The present CLC model was used to analyze the aforementioned case study input data to generate an integrated optimal material procurement and layout plan for the application example. Using tuned GA parameters based on the verification example. The population size of 200, the present model generated an optimal plan. The model was used to evaluate the fitness (construction logistics cost) by performing the following steps for each solution examined by the GA optimization tool in order to calculate: (1) the order quantities of each material during every stage based on the generated FOP and the material's demand in that stage; (2) the ordering costs based on the order quantities identified in step 1 and the suppliers purchase and delivery costs; (3) the financing cost using Equation 3 based on the cumulative materials demand and the cumulative supply which is dependent on the FOP values; (4) the stock-out cost using Equation 6 throughout calculating the material-related project delay (MRPD); (6) the storage space needs and dimensions for each material in every stage based on the planner-defined footprint schedules and the value of the FOP; and (7) the layout costs using Equations 6 through 9 considering the values of layout decision variables (locations and orientations) for all storage areas and temporary facilities [21,22].

The present CLC model requires construction planners to provide the following input data for the available case study: (1) the construction site geometry including the dimensions and locations of buildings under construction and site boundaries; (2) the project stages and cumulative demand of each material over time as an ASCII file format; (3) the dimensions and relocation costs of each temporary facility as

Construction Logistics Cost	Construction Phase (T)				Total (EGP)
	T_1	T_2	T_3	T_4	
Ordering Cost (EGP)	2,100,000	2,000,000	2,887,200	95,100	7,082,300
Financing Cost (EGP)	3,701	4,023	5,966	297	13,987
Stock-out Cost (EGP)	150,000	200,000	200,000	50,000	600,000
Layout Cost (EGP)	3,108	3,108	8,500	1,300	16,016
Construction Logistics Cost (EGP)	2,256,809	2,207,131	3,101,666	146,697	7,712,303

Table 6: Summary of manual calculations of the construction logistics cost of each phase and the total construction logistics cost of the project.

Citation: Shamma MNEDA, Shawki KM, Bassioni HA (2017) Optimization of Construction Logistics Planning Cost in Egypt Using Genetic Algorithms. J Inform Tech Softw Eng 7: 205. doi: 10.4172/2165-7866.1000205

shown in Tables 1 and 5; (4) the purchase cost, delivery cost, and storage footprint data of each material; (5) on-site materials handling quantities and cost data; (6) the layout constraints imposed on temporary facilities and material storage areas; (7) layout grid pitch which is specified to be 0.5 m in this case study; (8) daily project interest rate (DIR) which is estimated to be 0.03%; (9) project liquidated damage (LQD) which is estimated to be 20,000 EGP/day; (10) time-depended indirect cost (TDIC) which is estimated to be 30,000 EGP/day; (11) possible values of fixed-ordering-period (FOP), which are 1, 7, 14, or 21 days; and (12) delivery average delay (DADm) of each material [23].

Figure 10 shows the CLC model input data for the case study project. Project information, construction materials cost rates, daily interest rate, time independent direct cost, liquidated damage and fixed ordering period are entered by the user. Using a Genetic Algorithm population size of 200, the present model generated an optimal layout integrated plan with a total construction logistics cost of 7,064,533 EGP. The final results of the CLC model for each construction phase are shown throughout Figure 10.

Comparative Analysis

In the light of comparing the aforementioned actual cost results and site layout plan of the case study project manual solution and the optimal results of the construction logistics plan model (CLC) throughout the four construction phases. It has revealed that the present CLC model considers and optimizes the tradeoffs among all logistics cost items (i.e., ordering, financing, and stock-out and layout costs) in identifying the optimal material procurement and site layout decisions, which gives a better solution [24]. Analyzing the generated optimal results reveals also that dynamic site layout decisions are affected by (1) procurement decisions and material storage space needs; and (2) site layout constraints. Similarly, the dynamic site layout decisions are affected by the distance and zone constraints (Figure 11).

The percentage of saving due to the optimal construction logistics cost values for each phase was analyzed in Tables 7-9. Finally, a total of 8.4% logistics cost saving for the whole project. Based on the aforementioned values of the actual and optimal construction logistics cost for each phase (T), it was conducted that the CLPC model gets lower cost values for each construction phase (T), as shown in Figure 11. In the first phase it was conducted that the CLPC model saved 4.6% of the ordering cost, 28.4% of the financing cost, 33.3% of the stock-out cost, 30.0% of the layout cost, leading to a total cost saving of 6.5%. In the second phase it was also conducted that the CLPC model saved 5.6% of the ordering cost, 34.5% of the financing cost, 50.0% of the stock-out cost, and 32.6% of the layout cost, which leads to a total cost saving of 9.7%. While in the third phase the CLPC model saved 2.5% of the ordering cost, 50.4% of the financing cost, 75.0% of the stock-out cost, 14.5% of the layout cost, leading to a total cost saving of 7.3% [25]. Finally the fourth phase had a total cost saving of 40.8% throughout saving 9.7% of the ordering cost, 76.8% of the financing cost, 100.0% of the stock-out cost and 28.2% of the layout cost.

According to the abovementioned cost saving percentages for cost items in each phase (T) shown in Table 6. First, it was conducted that the cost saving of the ordering cost is less than 10% throughout all phases, since the purchase and delivery cost rate changes are minimal for those construction materials and also the quantities of materials differs. Quantities in the CLPC model is calculated based on the fixed ordering period (FOP) of each material as required in the project baseline plan. While the quantity of materials for each phase in the case study were ordered based on the construction manager's rough calculations, with no fixed ordering periods which lead to possible ordering quantities more than needed in each phase [26].

Second, the cost savings of the financing cost is relatively high ranging from 28 to 77%, since the CLPC model calculations are based on the fixed ordering period of materials in each construction phase (T) which leads to the avoidance of unneeded inventory levels of materials on site at a specific time that in contrary happened in the case study.

Third, the stock-out cost savings are the highest throughout all construction phases reaching 100% savings. This is due to determining the materials procurement plan throughout setting the fixed ordering period in the CLPC model, which minimizes the risk of project time

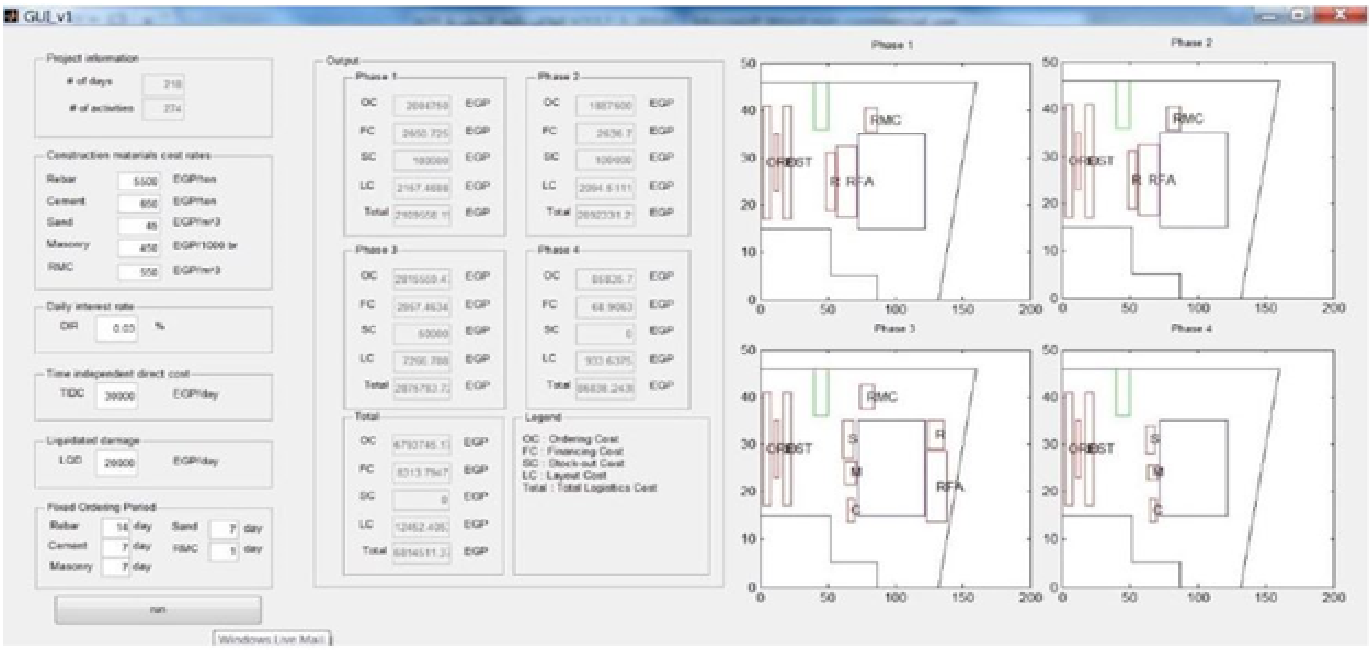

Figure 10: Results for the fourth construction phase layout and the total logistics costs using CLC model.

Citation: Shamma MNEDA, Shawki KM, Bassioni HA (2017) Optimization of Construction Logistics Planning Cost in Egypt Using Genetic Algorithms. J Inform Tech Softw Eng 7: 205. doi: 10.4172/2165-7866.1000205

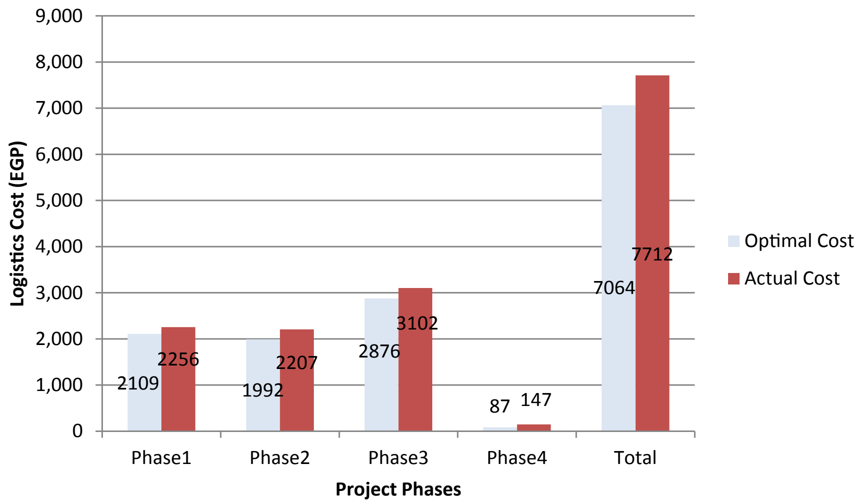

Figure 11: Actual versus optimal construction logistics cost for each construction phase.

First Phase (T1)					
Construction Logistics Cost	*Ordering Cost*	*Financing Cost*	*Stock-out Cost*	*Layout Cost*	*Total Cost*
Actual cost (EGP)	2,100,000	3,701	150,000	3,108	2,256,809
Optimal cost (EGP)	2,004,750	2,651	100,000	2,176	2,109,577
Cost Saving (EGP)	95,250	1,050	50,000	932	147,232
Percentage cost saving	4.6	28.4	33.3	30.0	6.5
Second Phase (T2)					
Construction Logistics Cost	*Ordering Cost*	*Financing Cost*	*Stock-out Cost*	*Layout Cost*	*Total Cost*
Actual cost (EGP)	2,000,000	4,023	200,000	3,108	2,207,131
Optimal cost (EGP)	1,887,600	2,637	100,000	2,095	1,992,332
Cost Saving (EGP)	112,400	1,386	100,000	1,013	214,799
Percentage cost saving	5.6	34.5	50.0	32.6	9.7
Third Phase (T3)					
Construction Logistics Cost	*Ordering Cost*	*Financing Cost*	*Stock-out Cost*	*Layout Cost*	*Total Cost*
Actual cost (EGP)	2,887,200	5,966	200,000	8,500	3,101,666
Optimal cost (EGP)	2,815,560	2,958	50,000	7,267	2,875,785
Cost Saving (EGP)	71,640	3,008	150,000	1233	225,881
Percentage cost saving	2.5	50.4	75.0	14.5	7.3
Fourth Phase (T4)					
Construction Logistics Cost	*Ordering Cost*	*Financing Cost*	*Stock-out Cost*	*Layout Cost*	*Total Cost*
Actual cost (EGP)	95,100	297	50,000	1,300	146,697
Optimal cost (EGP)	85,836	69	0	934	86,839
Cost Saving (EGP)	9,264	228	50,000	366	59,858
Percentage cost saving	9.7	76.8	100.0	28.2	40.8

Table 7: Actual versus optimal construction logistics cost items for each construction phase and percentage cost saving.

Project Logistics Cost					
Construction Logistics Cost	**Phase 1**	**Phase 2**	**Phase 3**	**Phase 4**	**Total Cost**
Actual cost (EGP)	2,256,809	2,207,131	3,101,666	146,697	7,712,303
Optimal cost (EGP)	2,109,577	1,992,332	2,875,785	86,839	7,064,533
Cost Saving (EGP)	147,232	214,799	225,881	59,858	647,770
Percentage cost saving	6.5	9.7	7.3	40.8	8.4

Table 8: Actual versus optimal project logistics cost for each construction phase and percentage cost saving.

Construction Logistics Cost	**OrderingCost**	**FinancingCost**	**Stock-outCost**	**LayoutCost**	**Total Cost**
Total Actual cost (EGP)	7,082,300	13,987	600,000	16,016	7,712,303
Total Cost Saving (EGP)	288,554	5,672	350,000	3,544	647,770
Percentage cost saving	4	41	58	22	8.4

Table 9: Construction logistics cost items savings.

delay due to the delay of delivery of the construction materials that may occur, which in turn lead to delay of ongoing activities that might cause delay of project duration and in return paying indirect costs and liquidated damages for that period, which was about an average of 50,000 EGP per day in the studied case [27,28].

Finally, the cost savings of the layout costs ranged from 14.5 to 33% savings, since the CLPC model optimized the allocation of temporary facilities and materials storage areas on site with smaller handling distances than the case study.

In accordance to the abovementioned cost saving analysis it was concluded that the highest cost saving percentages are for the stock-out cost item, which is then followed by the financing, layout and ordering cost items respectively as shown in Table 7. However, the effect of the stock-out and ordering cost items on the total value of cost savings is much higher than the other cost items as shown in Table 8, which is due to the large values of purchase cost rates of construction materials specially the rebar and ready mix concrete that highly affects the ordering costs in the first three phases of construction, and the high indirect and liquidated damage costs that reaches 50,000 EGP for each day of delay due to stock-out of materials [29].

Conclusions and Recommendations

The present research study focused on the optimization of site layout and material logistics planning during the construction projects. The new research developments of this study include an adapted material logistics planning model that considers existing interdependencies between material procurements and site storage decisions in the integration and simultaneous optimization of dynamic site layout and material procurement planning to be used in Egypt. First, a new adapted optimization model is developed that is capable of generating global optimal solutions of dynamic site layout planning in order to minimize resources travel costs and facilities relocation costs while complying with various site geometric constraints. The model is implemented using Genetic Algorithms. This model is designed to optimize facilities locations and orientations over a number of construction stages to minimize total layout costs, which include the travel cost of construction resources moving between site facilities and the cost of relocating temporary facilities between construction stages. Furthermore, the developed model consider four types of geometric constraints (boundary, overlap, distance, and zone constraints), which can be used to represent site space availability as well as any imposed construction operational and/or safety requirements. Second, the construction logistics planning cost (CLC) was developed to enable the integration and simultaneous optimization of critical planning decisions of material procurement and material storage layout on construction sites. Procurement decision variables are designed to identify the fixed-ordering-periods of each material in every construction stage, while dynamic layout decision variables are designed to identify the locations and orientations of material storage areas and other temporary facilities in each construction stage. The model utilizes Genetic Algorithms to generate optimal material procurement and layout decisions in order to minimize four types of construction logistics costs, including: material ordering, financing, stock-out, and layout costs which were able to minimize the total construction logistics cost by 8.4% for the whole project by saving 6.5, 9.7, 7.3 and 40.8% for each construction phase respectively. The highest costs saving percentages are for the stock-out cost item, which is then followed by the financing, layout and ordering cost items respectively. However, the effect of the stock-out and ordering cost items on the total value of cost savings is much higher than the other cost items.

Recommendations for construction industry in Egypt

The Egyptian contractors are recommended to use the adapted CLC model, as it showed the ability of considering the existing interdependencies between material procurements and site storage decisions in optimizing the dynamic site layout according to the Egyptian construction environment.

Contractors are recommended to use Material Resource Planning systems (MRP) to conduct a material procurement strategy that affects the fixed ordering period of different construction materials that helps in high savings among all logistics cost items.

Recommendations for future research

Although the present study was able to fully achieve its research objectives, a number of additional research thrusts have been identified during the course of this study, including:

1. Incorporating real time control and monitoring of construction logistics in order to continuously update and refine material procurement and site layout plans. Monitoring and controlling the performance of generated logistics plans is vital in detecting any variations in site conditions and updating previously generated plans. Construction sites are dynamic and changing environments that are difficult to predict during the planning phase. As a result, the planning input parameters and assumptions in this study can change over subsequent construction stages which affect the generated logistics plans.

2. Construct more advanced logistics cost models to suit any type of construction projects, more applications to other construction materials that are expected to highly affect the logistics cost savings and models that take into consideration other important parameters as safety, workflow and supervision on site.

3. Further research is required to make a risk analysis that measures the risk due to cost deviations of construction materials along the project duration and to incorporate the cost of materials inflation and fluctuations that might be high in some countries as Egypt. Which in turn affect the construction logistics cost items throughout construction project phases.

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