Developing a Time-Cost & Storage Optimization Model for Construction project

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Abstract

Project managers in the construction industry confront challenges in managing inventories and executing projects within the scheduled time frame. In this research, a mathematical model is given for applying the Lagrange method and linear programming to tackle the time-cost and storage-related difficulties that arise in the construction project. The study's objectives are to minimize total cost escalation and ascertain the ideal order quantity for the building project while considering non-negative, start, crash, and floor space limits into account. The ideal order quantity is determined using MS Excel, and LINDO software determines the crashing duration. Program analysis produced a workable solution. The model maintains the analysis's accuracy and the outcomes' correctness. By increasing the project's cost, the linear programming approach predicts when each task will take less time to complete. The EOQ model was proposed to determine the optimal order quantity of building supplies. Adopting this technology can yield instant benefits for any real-time construction job.

Keywords:

Linear Programming Method; Lagrange method; Time-cost; Storage; Construction project; LINDO Software

1 Introduction

Project management is a study that involves the application of skills, tools, and techniques to meet the project requirements. Whenever the project gets delayed and runs behind schedules, the overall indirect cost increases. Usually, project duration can be reduced by crashing activities and assigning more resources. Construction of a project with a normal duration will ensure specific resources and direct costs. In contrast, the same project is constructed under the crashing method, decreasing project duration and escalating the cost to the allowable percentage. A study developed an optimum solution for time and cost using ant colony optimization without dominating either function. Zhang presented a time-cost optimization problem using the ant colony method. To deal with the multi-objective problem, a modified weight approach was implemented to combine time and cost as a single objective[1]. Mondal proposed an intuitionistic fuzzy geometric programming to solve the deterministic single objective problem[2]. This study was conducted in an apartment consisting of 9 floors located in Bangalore. This paper proposes a mathematical model to solve the time-cost and storage-related problems in the construction project using linear programming and the Lagrange method, respectively[3]. The study aims to optimize the overall cost escalation and determine the construction project's optimum order quantity under start time, crash time, non-negative, and floor space constraints. To determine the crash duration and optimum order quantity, LINDO Software and MS Excel are used, respectively.

2 Background

The time and cost optimization technique decreases the total float available for non-critical activities and decreases the flexibility of the schedule. There is always a need to establish a new method for time and cost such that it can provide optimum time and cost value. The author has attempted nonlinear integer programming using the best solver technique, which can be applied to a real-time project[4]. Whenever there is a trade-off between time and cost, the duration of the project will decrease, and the cost will increase. The results obtained proved the model is significant. It helps the project manager execute different trade-offs between time and cost[5]. A study proposed an intuitionistic fuzzy geometric programming to solve the deterministic single objective problem. Intuitionistic fuzzy geometric programming can also solve economic order quantity with a deterministic single objective model with floor space constraint. Any variable such as limited production cost, time-dependent and independent holding cost can be considered. Intuitionistic fuzzy geometric programming can be extended by existing fuzzy geometric programming to solve nonlinear and linear optimization problems. This method can minimize the total average cost of the EOQ model by applying intuitionistic fuzzy geometric programming. Intuitionistic fuzzy geometric programming is more feasible and preferable than crisp and fuzzy geometric programming[2]. The cost factor has to lie within a permissible range. The company will face huge losses if the cost exceeds the permissible range. Table 1 shows the percentage cost escalation from literature using different methods. It shows that, the average permissible cost escalation can be 1.0% - 1.3%.

Table 1. The percentage cost escalation

Author	Method	% Cost Escalation
Uroš Klansek [6]	Nonlinear Programming	1.16
Mohammed Woyeso Geda[7]	Linear Programming	1.11
Omar M. Elmabrouk [8]	Linear Programming	1.09
Michael J. Risbeck [9]	Mixed-Integer Linear Programming	1.12
Athanasios P et al [10]	Approximation method	1.96
Michael J. Risbeck at al [11]	Mixed-Integer Linear Programming	2.09
Ehsan Eshtehardian at al [12]	GA and fuzzy sets theory	1.4
Rana A. Al Haj et al [5]	Nonlinear-Integer Programming	0.99
Mohammed Nooruldeen Azeez et al [13]	Ant Colony Optimization	1.05
Yanshuai Zhang et al [1]	Ant Colony Optimization	0.75

3 Methodology

In this research, the following methodology is framed in Figure 1 to achieve the study's objectives, which are to minimize total cost escalation and ascertain the ideal order quantity for the building project while taking non-negative, start, crash, and floor space limits into account.

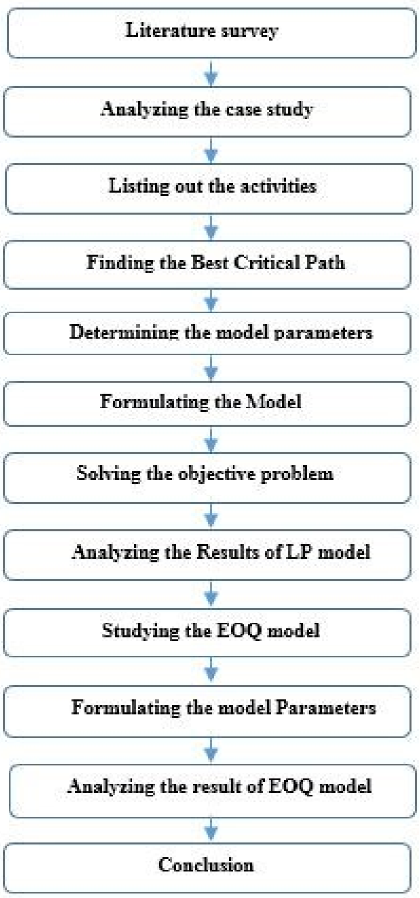

Figure 1. Methodology chart

Technical specifications in the research included:

i. Activity on Node used to determine the network logic for the project schedule.

ii. The cost slope is the slope of the direct cost curve, approximated as a straight line. It is defined as follows.

$$C_s = \frac{C_c - C_n}{t_n - t_c} = \frac{\Delta C}{\Delta t} \qquad (1)$$

Where:

C_s Cost slope

C_c Crash Cost

C_n Normal Cost

t_n Normal Time

t_c Crash Time

ΔC Change in cost

Δt Change in time

iii. Linear programming is a technique used in mathematics to optimize processes under limitations. Maximizing or minimizing the target function is the aim of linear programming. The optimization is done using the LINDO program, which has a high degree of ease in solving complex functions.

4 PROPOSED EOQ MODEL

The best order amount a business or organization should buy to reduce inventory expenses, including holding costs, shortfall costs, and order costs, is the economic order quantity, or EOQ. Finding the ideal quantity of product units to order is the goal of the economic order quantity. If successful, a business can reduce the price of purchasing, shipping, and storing units. Production levels and order intervals are also determined using the economic order quantity model to maintain the ideal inventory level. The software can coordinate supply chain networks and logistics with the economic order quantity model. In cash flow analysis, the model is equally crucial. The approach can assist a business in managing the cash flow related to its inventory. In the EOQ model as shown in figure 2, the reorder point is defined as the point at which the inventory is about to fall. Economic order quantity is responsible for reordering, the cost incurred while placing an order, and storing the materials.

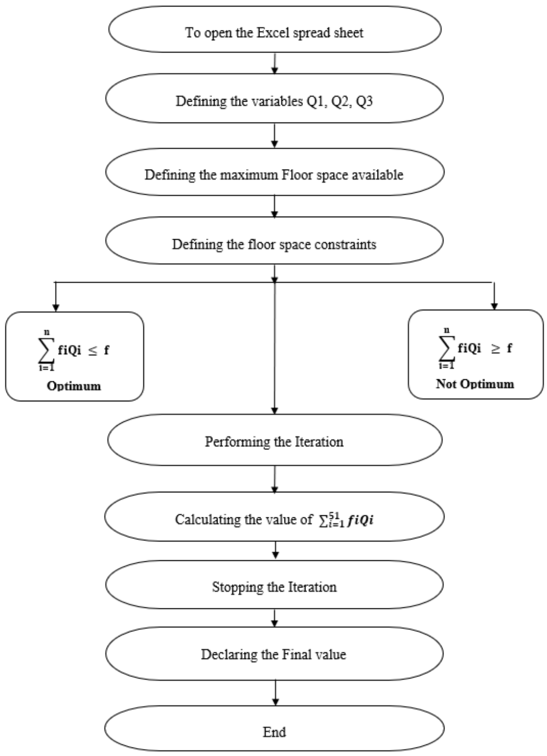

Figure 2. Algorithm To Solve the EOQ Model

In the construction industry, projects face high inventory costs because of the need for more floor space to keep the materials. To minimize the total costs of inventory, an Economic order quantity model with floor space constraints is developed using the Lagrangian function. The concept of EOQ is to determine the optimum order quantity of each material for the available floor space. This model can help construction engineers manage and control the inventory and facilitate ease of construction. The project has limited warehouse capacity, and the items compete for floor space. The available floor space in the construction project is 376 sq. m. To construct the model, the following assumptions are made: Production or supply is instantaneous with no lead time. Demand is uniform and deterministic. Shortages are not allowed. Suppose there are N-items to be stored in an inventory system; then -

The total unit cost for all the items is given by:

$$\mathrm{TC} = \sum_{\mathrm{i=1}}^{\mathrm{n}} \left(0.5 \, * P_{ci} * I_{ci} * Q_i + \frac{R_{ci} \, * D_i}{Q_i} \right) \tag{2}$$

Where,

Di – Demand rate for ith item
P_{ci} – Purchase cost of i_{th} item
R_{ci} – Replenishment cost for i_{th} item
I_{ci} – Inventory carrying cost fraction per unit per annum for i_{th} item
Q_i – Order quantity for i_{th} item

4.1 Application of LP Model

The case study is conducted in prestige pine wood apartments in Bangalore. Due to the extreme weather conditions, the project faced a delay in its completion. All the activities from the project have been grouped under 16 significant activities. To model, it is essential to determine the ES-EF and LS-LF in terms of starting and ending events. It is observed that the total duration for completion of the project is 2598 days based on the critical path. The list of essential activities under the critical path are: Earthwork excavation, Soil nailing, Retaining wall, Grade slab, Pedestal and column construction, Backfilling, Stitch slab, Reinforcement works, Concrete works, Brickworks, Water supply and sanitation works, Electrical works, Plastering works, Flooring works, Painting works, Wooden works.

There were seven possible ways to reach the final activity. The normal time (NT) and the crash time (CT) are calculated individually for all seven possible paths. The path with the maximum normal and full crash time is chosen for crashing. The maximum time the project can take to complete is 2511 days, and the maximum crashing time allowable is 2288 days.

2511 days >= X_i >= 2288 days

Where $\boldsymbol{X_i}$ = Amount of time that each activity *i* will be crashed

Y_i = Start time of activity *i*

U_i = Change in cost by change in time for activity *i*

Table 2 shows the cost slope for all activities. The value of $\boldsymbol{U_i}$ can be written as shown in Table 3.

Table 2. Determining the cost slope

Activity ID	Normal Time (days)	Crash Time (days)	Normal Cost (Rs)	Crash Cost (Rs)	Cost Slope (C_s)
1	56	37	1,16,61,840	13032640	72147.36
2	37.5	30	735000	750750	2100
3	15	13	1056873	1064873	4000
4	51	46	18297190	18312190	3000
5	34	34	1470547	1470547	0
6	11.5	6	1711304	1743804	5909.09
7	50	45	18297190	18312190	3000
8	417	371	14064681	14170481	2300
9	365	332	222709837	222815437	3200
10	292	271	4,57,26,135	4,57,66,135	1904.76
11	80	80	88,41,000	88,41,000	0
12	73	73	88,41,000	88,41,000	0
13	486	459	24823281	24875281	1925.92
14	331	303	19663020	19758220	3400
15	226	201	27180189	27230189	2000
16	73	73	29982541.38	29982541.4	0

Table 3. Determining the U_i value

U_1	U_2	U_3	U_4
72147.3	2100	4000	3000
U_5	U_6	U_7	U_8
0	5909.09	3000	2300
U_9	U_{10}	U_{11}	U_{12}
3200	1904.76	0	0
U_{13}	U_{14}	U_{15}	U_{16}
1925.92	3400	2000	0

To Determine the Objective Function and Constraints of the LP Model:

Minimize Z = 72147.3 X1 + 2100 X2 + 4000 X3 + 3000 X4 + 0 X5 + 5909 X6 + 3000 X7 + 2300 X8 + 3200 X9 + 1904.7 X10+ 0 X11 + 0 X12 + 1925 X13 + 3400 X14 + 2000 X15 + 0 X16

Subject to the conditions mentioned in Table 4, all the activities' crash time constraints are shown.

Table 4. Determining Crash Time Constraints

Crash Time Constraints			
X_1<=19	X_5<=0	X_9<=33	X_{13}<=27
X_2<=7.5	X_6<=5.5	X_{10}<=21	X_{14}<=28
X_3<=2	X_4<=5	X_{11}<=0	X_{15}<=25
X_4<=5	X_8<=46	X_{12}<=0	X_{16}<=0

Table 5 shows the Start time constraints of all the activities.

Table 5. Determining Start Time Constraints

Start time Constraints				
Y2-Y1+X1>=56	Y6-Y5+X5>=34	Y10-Y9+X9>=365	Y13-Y12+X12>=73	YF-Y16+X16>=73
Y3-Y1+X1>=56	Y7-Y6+X6>=11.5	Y11-Y10+X10>=292	Y14-Y13+X13>=486	YF<=2367
Y4-Y3+X3>=15	Y8-Y7+X7>=50	Y12-Y10+X10>=292	Y15-Y14+X14>=331	-
Y5-Y4+X4>=51	Y9-Y8+X8>=417	Y13-Y11+X11>=73	Y16-Y15+X15>=226	-

Table 6 shows the non-negative constraints of all the activities.

Table 6. Determining Non-Negative Constraints

Non-Negative Constraints							
X1>=0	X5>=0	X9>=0	X13>=0	Y1>=0	Y5>=0	Y9>=0	Y13>=0
X2>=0	X6>=0	X10>=0	X14>=0	Y2>=0	Y6>=0	Y10>=0	Y14>=0
X3>=0	X7>=0	X11>=0	X15>=0	Y3>=0	Y7>=0	Y11>=0	Y15>=0
X4>=0	X8>=0	X12>=0	X16>=0	Y4>=0	Y8>=0	Y12>=0	Y16>=0

4.2 Application of EOQ Model

The EOQ model is demonstrated using three different materials: Steel (Q1), Granite flooring (Q2), and Solid concrete block (Q3). The available floor space 'f" in the construction project is 376 sq.m. The project data is given in Table 7 below.

Table 7. Determining Material Parameters

Parameters	Q1	Q2	Q3
D_i	1900	2000	10000
P_{ci}	34	32	10
O_{ct}	100	150	180
f (sq. m)	12	11.9	1.2

The values of Q1, Q2, Q3 are determined by varying the lambda function. Solving the material Parameters:

Table 8 shows the value of $\sum_{i=1}^{51} fiQi$:- 375.98, where fi values is mentioned in table 7.

Table 8. Solving Material Parameters

λ	Q1	Q2	Q3	$\sum_{i=1}^{51} fiQi$
1	114.27	144.84	960.76	4247.81
2	84.59	42.73	79.30	1618.80
3	70.20	36.92	76.47	1373.57
4	61.30	32.97	73.92	1216.83
5	55.11	30.07	71.61	1105.21
6	50.48	27.82	69.50	1020.35
7	46.85	26.01	67.57	952.93
8	43.90	24.51	65.79	897.64
9	41.45	23.25	64.15	851.19
10	39.37	22.16	62.62	811.43
11	37.57	21.21	61.19	776.87
12	36.00	20.38	59.86	746.47
13	34.61	19.63	58.62	719.44
14	33.37	18.96	57.44	695.20
15	32.26	18.36	56.34	673.29
16	31.25	17.81	55.30	653.37
17	30.32	17.31	54.31	635.13
18	29.48	16.84	53.37	618.37
19	28.70	16.42	52.48	602.88
20	27.98	16.02	51.63	588.51
21	27.32	15.65	50.83	575.13
22	26.69	15.30	50.06	562.64
23	26.11	14.98	49.32	550.93
24	25.57	14.68	48.62	539.94
25	25.05	14.39	47.94	529.58
26	24.57	14.12	47.29	519.80
27	24.12	13.87	46.67	510.55
28	23.69	13.63	46.07	501.78
29	23.28	13.40	45.50	493.45
30	22.89	13.18	44.94	485.52
31	22.52	12.97	44.41	477.97
32	22.17	12.77	43.89	470.76
33	21.83	12.58	43.39	463.87
34	21.51	12.40	42.91	457.27
35	21.20	12.23	42.44	450.95
36	20.91	12.06	41.99	444.89
37	20.62	11.90	41.55	439.06
38	20.35	11.75	41.13	433.46
39	20.09	11.60	40.72	428.07
40	19.84	11.46	40.32	422.88
41	19.60	11.32	39.93	417.87
42	19.36	11.19	39.55	413.04
43	19.14	11.06	39.19	408.37
44	18.92	10.93	38.83	403.86
45	18.71	10.81	38.49	399.49
46	18.51	10.70	38.15	395.27
47	18.31	10.59	37.82	391.17
48	18.12	10.48	37.50	387.20
49	17.93	10.37	37.19	383.35
50	17.75	10.27	36.88	379.61
51	17.58	10.17	36.58	375.98

5 Discussions

The proposed models have been applied to a construction project to demonstrate their practicality. The main aim of this study is to mitigate the time-cost and storage-related problems occurring in the construction industry. The linear programming solution in Table 9, indicates the crashing activities to reduce the project duration to 2485 days from 2598 days, which increased the overall cost to Rs. 45,52,96,751 from Rs. 45,50,61,628.

Table 9. Determining the Crashed Duration and Crashed Cost

Variable	Value	Reduced Cost
X_1	0	69847
X_2	0	2100
X_3	0	1700
X_4	0	700
X_5	0	0
X_6	0	3609
X_7	0	700

X_8	40	0
X_9	0	900
X_{10}	21	0
X_{11}	0	0
X_{12}	0	0
X_{13}	27	0
X_{14}	0	1100
X_{15}	25	0
X_{16}	0	0

The objective found at the 40th iteration and its value is given by,

Minimum value of Z = Rs. 235123.7

Table 10. Comparing the Obtained result with the Standard value

Parameters	Permissible range	Obtained result
Cost Escalation	1.0% - 1.3%	1.0005%
Crash Duration	Between 2511 and 2285 days	2485 days

Table 10 shows that to crash the total construction time for 113 days, Rs 235123.7 crash cost is needed. Thus, an additional 235123.7 Rs is required to crash the total duration of the construction. From Table 9, it can be inferred that Activity 8,10, 13, and 15 have been hit to 40, 21, 27, and 25 days, respectively. For time-related problems, the CPM method is used to identify the critical path. The model indicates that about a 4.36% decrease in time can be achieved by increasing cost by 1.0005%, which is satisfactory, as shown in Table 10.

The Single objective EOQ model with limited floor space is solved for the floor space constraints using the lagrangian function. The Economic order quantity value was found at the 51st iteration; its values are given in Table 11.

Table 11. Determining the value of material parameters

Items	Optimum Value
Q1	18
Q2	10
Q3	36

The available floor space to accommodate the materials in the construction site is 376 sq. m. The $\sum_{i=1}^{51} fiQi$ value is 375.989 sq. m. Hence, the floor space constraints lie within the range. The optimum order quantity of steel, Granite, and Solid concrete blocks is 18, 10 and, 36 respectively, which can be accommodated in the area of 376 sq. m.

6 Conclusion

The linear programming model offers the best solution to time and cost constraints concerns. After optimization, it was discovered that the whole crash lasted 113 days. Therefore, the extra expense incurred due to the time reduction is Rs. 235123.70. According to the model, it is possible to obtain a sound time reduction of around 4.36% by raising the cost by 1.0005%. The model accurately analyses while maintaining the correctness of the outcomes. The linear programming methodology effectively ascertains a reduction in the length of every task. By using software techniques, the strategy may readily address complicated crashing situations and is very versatile. The approach works well for large-scale building projects with plenty of moving parts. It is challenging to cycle through many activities manually using the trial-and-error method. Therefore, using the linear programming method, the construction manager may quickly estimate the crash cost required to crash the complete project for a given set duration. The project manager can efficiently organize all activities thanks to the model's ease of use. It is limited to solving linear constraints and single-objective problems. Therefore, several techniques, such as fuzzy multi-objective linear programming, mixed integer linear programming, and particle swarm optimization, can also be utilized to handle multi-objective optimization problems.

Using the economic order quantity is an efficient approach to figuring out inventory control. The ideal order quantities for steel, Granite, and solid concrete blocks are 18, 10, and 36 lots respectively, and they may all fit within a 376-square-meter space. To maintain a good flow of production and prevent overinvestment in stocks, the model can keep an eye on the acquisition and storage of materials in the inventory. Any real-time project can directly benefit from the application of this technology. Regarding the building business, the model helps determine the order quantity at various process phases based on space constraints and demand. The model is easy to use and effective. Different programming techniques, including geometric, nonlinear, and Newton-Geometric programming, can be applied to determine the solution. Therefore, by employing this technique, the construction industry's inventory management quality can be raised. By introducing different uncertainties, additional research on the time-cost programming model, nonlinear discrete optimization of project schedules, and multi-project scheduling with resource constraints can be conducted. In the economic order quantity model, modified geometric programming in a neutrosophic environment can be used to accomplish multiple product optimization.

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