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Management of Construction Resources by Using Integer and Dynamic Programming

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ABSTRACT: This project aims at management of construction resources by using integer and dynamic programming. In many construction companies are still established to derive financial profit. In this regard the main aim of such establishments is to maximize the profit and allocated the limited resources. The dynamic programming interrelates the alternative feasible decisions on the basis of total system cost. In dynamic model, the multistage graph problem is to determine shortest path from source to destination. This can be solved by using either forward or backward approach. In linear programming, all variables whose optimal solution must be non-negative integer values known as integer programming problem. The cutting plane method is to derive the maximum profit from the resource management of construction project. The LINGO software helps to solve linear, non-linear and integer optimization models. Finally, the integer programming problems were formulated and optimum results derived using manual and LINGO software program and the two results are compared.

KEYWORDS: Integer programming, Dynamic programming, Optimization, LINGO.

I. INTRODUCTION

In organizational studies, resource management is the efficient and effective development of an organization's resources when they are needed. Such resources may include financial resources, inventory, human skills, production resources, or information technology (IT). The process of using a company's resources in the most efficient way possible. These resources can include tangible resources such as goods and equipment, financial resources, and labor resources such as employees. Resource management can include ideas such as making sure one has enough physical resources for one's business, but not an overabundance so that products won't get used, or making sure that people are assigned to tasks that will keep them busy and not have too much downtime. Resource planning and management is one of the most important ingredients for competitiveness and profitability in today's construction industry. In order to control costs, equipment and labor should be utilized in the most efficient way possible. This can be achieved by minimizing the total cost of leased resources under the constraint of maximum and most efficient use of owned equipment and contracted labor force.. Based on the Critical Path Method time analysis, the model derives the schedule for equipment rentals and transient resources, as well as the utilization scheme for owned equipment and other available resources. The model can be used as an estimating tool for multi-project resource planning and sharing, and as a means to implement the most efficient utilization of resources throughout the duration of the whole project. The Integer and Dynamic Programming is used in business to find maximum profit or minimum cost. The all resources in construction like labour charge, machine, material cost and its availability to known while starting work. So as to manage all construction activity within the time period.

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1.1 Operation research

Operational Research (OR) is the use of advanced analytical techniques to improve decision making. It is sometimes known as operations research, management science or industrial engineering. Operations Research tools are not from any one discipline. Operations Research takes tools from different discipline such as mathematics, statistics, economics, psychology, engineering etc. and combines these tools to make a new set of knowledge for decision making. Today, Operations Research became a professional discipline which deals with the application of scientific methods for making decision, and especially to the allocation of scarce resources. The main purpose of O.R. is to provide a rational basis for decisions making in the absence of complete information, because the systems composed of human, machine, and procedures may do not have complete information.

1.1.1 Different operation research problem

- 1) Integer programming (IP)
- 2) Dynamic programming (DP)
- 3) Linear programming (LP)
- 4) Game theory
- 5) Transportation model
- 6) Assignment model

1.2 Dynamic programming

Dynamic programming is a useful mathematical technique for making a sequence of interrelated decisions. It provides a systematic procedure for determining the optimal combination of decisions. In contrast to linear programming, there does not exist a standard mathematical formulation of dynamic programming problem. Rather, dynamic programming is a general type of approach to problem solving, and the particular equations used must be developed to fit each situation. Therefore, a certain degree of ingenuity and insight into the general structure of dynamic programming problems is required to recognize when and how a problem can be solved by dynamic programming procedures. These abilities can best be developed by an exposure to a wide variety of dynamic programming applications and a study of the characteristics that are common to all these situations. A large number of illustrative examples are presented for this purpose.

1.2.1 Multistage graph problem

A multistage graph is a directed graph in which the nodes can be divided into a set of stages such that all edges are from a stage to next stage only (In other words there is no edge between vertices of same stage and from a vertex of current stage to previous stage). We are give a multistage graph, a source and a destination, we need to find shortest path from source to destination. By convention, we consider source at stage 1 and destination as last stage.

1.2.2 Multistage graph procedure

1. The multistage graph problem is to find a minimum cost from a source to a sink.
2. A multistage graph is a directed graph having a number of multiple stages, where stages element should be connected consecutively.
3. In this multiple stage graph, there is a vertex whose in degree is 0 that is known as the source. And the vertex with only one out degree is 0 is known as the destination vertex.
4. The one end of the multiple stage graphs is at i thus the other reaching end is on $i+1$ stage.

If we denote a graph $G = (V, E)$ in which the vertices are partitioned into $K \geq 2$ disjoint sets, $V_i, 1 \leq i \leq K$. So that, if there is an edge $\langle u, v \rangle$ from u to v in E , the $u \in V_i$ and $v \in V_{i+1}$, for some $i, 1 \leq i \leq K$. And sets V_1 and V_k are such that $|V_1| = |V_k| = 1$.

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$$\text{Cost}(i, j) = \min \{ c(j, l) + \text{cost}(i+1, l) \}$$

$$l \in V_{i+1}$$

Where,

cost(i, j) = cost(level, no. of nodes at that level)

‘c’ is a weight assigned on each edge

‘k’ is the no. of stages

Each set V_i is called a stage in the graph.

1.2.3 Shortest path in a multi-stage graph

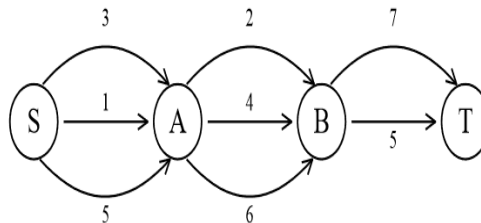


Fig. 1.2.3 Shortest path in a multi-stage graph

Apply the greedy method for finding the shortest path from S to T : $1 + 2 + 5 = 8$ and its minimum durations are also calculated. The minimum cost of s to t path is indicated by a dashed line. This method can be used for solving many problems such as allocating some resources to given number of projects with the intent to find the maximum profit.

1.3 Integer programming

The integer programming problem (IP) is an LP in which some or all of the variables are required to be non-negative integers. Unfortunately, we will also see that IPs is usually much harder to solve than LPs. It also discusses how to solve IPs on the computer with UNDO, LINGO, and Excel Solver. An IP in which all variables are required to be integers is called a pure integer programming problem. An IP in which only some of the variables are required to be integers is called a mixed integer programming problem.

1.3.1 Cutting plane method

In mathematical optimization, the cutting-plane method is an umbrella term for optimization methods which iteratively refine a feasible set or objective function by means of linear inequalities, termed cuts. Such procedures are popularly used to find integer solutions to mixed integer linear programming (MILP) problems, as well as to solve general, not necessarily differentiable convex optimization problems. The use of cutting planes to solve MILP was introduced by Ralph E. Gomory. Cutting planes were proposed by Ralph Gomory in the 1950s as a method for solving integer programming and mixed-integer programming problems. However most experts, including Gomory himself, considered them to be impractical due to numerical instability, as well as ineffective because many rounds of cuts were needed to make progress towards the solution.

1.3.2 Cutting plane procedure

An iterative procedure for the solution of an all integer linear programming problem by Gomory's fractional cut method (or cutting plane method) may be summarized in the following steps:

Step 1: Express the given linear programming problem into its standard form and determine an optimum solution by using simplex method ignoring the integer value restriction.

Step 2: Test the integrality of the optimum solution.

- 1) If the optimum solution admits all-integer values, an optimum basic feasible solution is attained.
- 2) If the optimum solution does not include all-integer values, then move on to next step.

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Step 3: Choose the largest fractional value of the basic variables. Let it be f_{k_0} .

Step 4: Express each of the negative fractions, if any, in the k th row of the optimum simplex table as the sum of a negative integer and a non-negative fraction.

Step 5: Generate the Gomorian constraint (fractional cut) in the form

$$G_1 = -f_{k_0} + f_{k_1}x_1 + f_{k_2}x_2 + \dots + f_{k_n}x_n$$

Where, $0 \leq f_{k_j} \leq 1$ and $0 < f_{k_0} < 1$.

Step 6: Add the Gomorian constraint generated in step 5 at the bottom of the optimum simplex table. Use dual simplex method to find an improved optimum solution.

Step 7: Go to step 2 and repeat the procedure until an optimum basic feasible all-integer solution is obtained.

II. METHODOLOGY

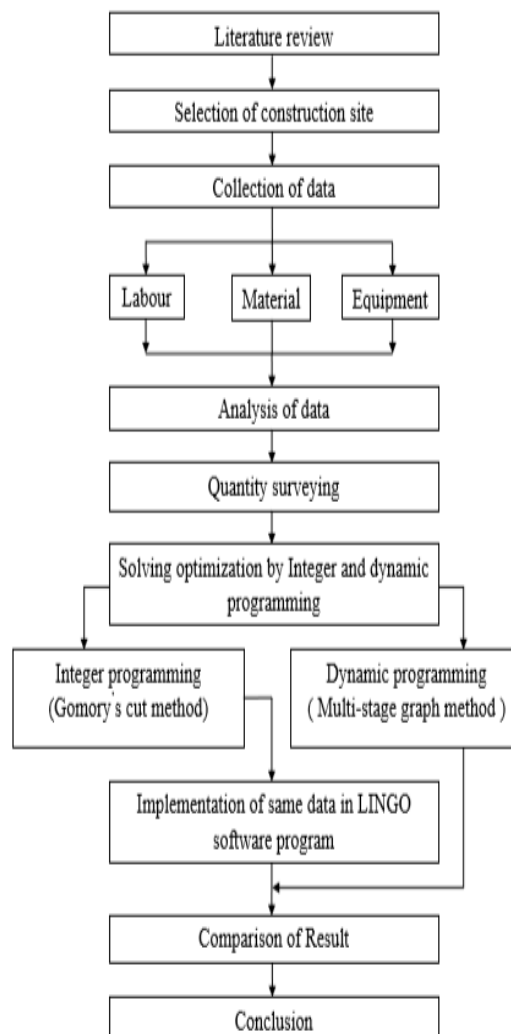


Fig. 2.1 Methodology for resource management in construction

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III. DATA COLLECTION

The following data was describing the raw material needed for residential building brick work construction. The building has ground plus two storey's and the area of the building was 1,175 sq. feet. The building estimated cost is Rs. 55,70,000.

3.1 Data collection for integer programming

Data 1 : Super structure

Raw material needed for brick structure	Quantity available for whole structure
Manpower (no s)	148
Cement (50 kg bag)	130
Sand (cft)	305
Brick (no s)	16,037

Table 3.1.1 Quantity of resources available for brick structure

Resources Floor	Ground floor (per day)	First floor (per day)	Second floor (per day)
Manpower (no s)	12	10	8
Cement(50 kg bag)	10	8.5	7
Sand (cft)	76	64	51
Brick (no s)	2778	2315	1852

Table 3.1.2 Quantity of resources required for each floor in brick structure

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FLOOR	PROFIT (Rs.)
Ground floor	3700
First floor	3000
Second floor	2400

3.2 Construction scheduling data for dynamic programming

Activity I.D.	Activity	Predecessors	Duration
1	Earthwork excavation.	-	10
2	Foundation concrete.	1	5
3	Random rubble masonry work in foundation.	1	15
4	Earthfilling	1	3
5	Brick work structure.	1	10
6	R.C.C work.	2, 3	10
7	Cement plastering.	2, 3, 5	6
8	Ceiling plastering.	5, 4, 2	3
9	Supplying and fixing of doors and window with primer and enamel paint on wood work area.	6, 7	7
	Floor finishing		

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10	with granite.	6, 7, 8	6
11	Laying of tiles.	8	3
12	White washing and colour washing with two coats.	9, 10, 11	10

Table 3.2.1 Scheduling data for ground floor residential building

IV. DATA IMPLEMENTED IN INTEGER AND DYNAMIC PROGRAMMING ALSO IN LINGO SOFTWARE PROGRAM

Table 3.1.3 Average profit for 3 floors

4.1 Data implemented in mixed integer programming

Gomory's Cut Method

$$\text{MAX } Z = 3700X_1 + 3000X_2 + 2400X_3$$

$$\text{Subjected to } 12X_1 + 10X_2 + 8X_3 \leq 148$$

$$10X_1 + 8.5X_2 + 7X_3 \leq 130$$

$$76X_1 + 64X_2 + 51X_3 \leq 305$$

$$2778X_1 + 2315X_2 + 1852X_3 \leq 16037$$

STEP 1: Convert the inequality constraint into equality constraint.

$$\text{MAX } Z = 3700X_1 + 3000X_2 + 2400X_3 + 0S_1 + 0S_2 + 0S_3 + 0S_4$$

Subjected to

$$12X_1 + 10X_2 + 8X_3 + S_1 + 0S_2 + 0S_3 + 0S_4 \leq 148$$

$$10X_1 + 8.5X_2 + 7X_3 + 0S_1 + S_2 + 0S_3 + 0S_4 \leq 130$$

$$76X_1 + 64X_2 + 51X_3 + 0S_1 + 0S_2 + S_3 + 0S_4 \leq 305$$

$$2778X_1 + 2315X_2 + 1852X_3 + 0S_1 + 0S_2 + 0S_3 + S_4 \leq 16037$$

$$X_1, X_2, X_3, S_1, S_2, S_3, S_4 \geq 0$$

Where,

X_1 = Ground floor resource required for brick structure

X_2 = Second floor resource required for brick structure

X_3 = Third floor resource required for brick structure

STEP 2: The initial basic feasible solution.

Since there are 4 equations with 7 variables, the initial basic feasible solution is obtained by equating (7 - 4) = 3 variables to zero.

$$\text{Put } X_1 = 0, X_2 = 0, X_3 = 0$$

The initial basic feasible solution is $S_1 = 148, S_2 = 130, S_3 = 305, S_4 = 16,037$

STEP 3 : To draw initial Simplex tableau

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		C_j		3700	3000	2400	0	0	0	0	
C_B	Y_B	X_B	X_1	X_2	X_3	S_1	S_2	S_3	S_4	θ	
0	S_1	148	12	10	8	1	0	0	0	12.33	
0	S_2	130	10	8.5	7	0	1	0	0	13	
0	S_3	305	76	64	51	0	0	1	0	4.01	
0	S_4	16037	2778	2315	1852	0	0	0	1	5.77	
		$C_j - Z_j$	3700	3000	2400	0	0	0	0		

Step 4: To find the pivot element, entering and leaving variables.

Here some $C_j - Z_j \geq 0$, the current basic feasible solution is not optimal. Here X_1 as entering variable and S_3 as leaving variables.

New pivot equation = old pivot equation / pivot element

New equation = old equation - (corresponding column equation x New pivot equation)

Here the pivot element two intersecting variables of S_3 and X_1 .

STEP 5 : First iteration

		C_j		3700	3000	2400	0	0	0	0	
C_B	Y_B	X_B	X_1	X_2	X_3	S_1	S_2	S_3	S_4	θ	
0	S_1	99.84	0	-0.11	-0.05	1	0	-0.16	0	-632.36	
0	S_2	89.87	0	0.08	0.29	0	1	-0.13	0	683.06	
3700	X_1	305.76	1	0.84	0.671	0	0	0.013	0	304.99	
0	S_4	4888.89	0	-24.37	-12.04	0	0	-36.55	1	-135	
		$C_j - Z_j$	0	-115.79	-82.7	0	0	-48.68	0		

Here some $C_j - Z_j \leq 0$

Since the optimum solution is not integer valued, we consider only the fractional part of $X_{B1} = \frac{305}{76} = 4 + \frac{1}{76}$

Maximum $\{f_1, f_2\} = \text{maximum} \left\{ \frac{1}{76}, 0 \right\} = \frac{1}{76}$, let us choose f_1 .

Generate the Gomorian constraint (fractional cut) in the form,

$$G_1 = -f_{k0} + f_{k1}X_1 + f_{k2}X_2 + \dots + f_{kn}X_n$$

$$0.1053 X_2 + 0.052 X_3 + 0.158 S_3 + G_1 = -\frac{1}{76}$$

➤ Then introduce the G_1 value in iteration 1

		C_j		3700	3000	2400	0	0	0	0	
C_B	Y_B	X_B	X_1	X_2	X_3	S_1	S_2	S_3	S_4	G_1	
0	S_1	99.84	0	-0.11	-0.05	1	0	-0.16	0	0	
0	S_2	89.87	0	0.08	0.29	0	1	-0.13	0	0	
3700	X_1	8.013	1	0.84	0.671	0	0	0.013	0	0	
0	S_4	4888.89	0	-24.37	-	0	0	-36.55	1	1	
		9			12.04						
	G_1	-1/76	0	0.1053	0.052	0	0	0.158	0	1	
		$C_j - Z_j$	0	-115.79	-82.7	0	0	-48.68	0	0	

Step 6: To find the pivot element, entering and leaving variables.

Here some $C_j - Z_j \leq 0$, the current basic feasible solution is not optimal. Take X_2 as entering variable.

New pivot equation = old pivot equation / pivot element

New equation = old equation - (corresponding column equation x New pivot equation)

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Here the pivot element two intersecting variables of X_2 and G_1 also here X_2 is the entering variable and G_1 is the leaving variable.

Step 7: Final iteration

C_j			3700	3000	2400	0	0	0	0	
C_B	Y_B	X_B	X_1	X_2	X_3	S_1	S_2	S_3	S_4	G_1
0	S_1	99.83	0	0	-0.0004	1	0	0	0	1
0	S_2	89.88	1	0	0.25	0	1	-0.25	0	-0.75
3700	X_1	8.723	0	0	0.258	0	0	-1.25	0	-8
0	S_4	4885.72	0	0	-0.097	0	0	0.0026	1	231.5
3000	X_2	-0.13	0	1	0.49	0	0	1.5	0	9.5
	$C_j - Z_j$		3700	3000	-25.97	0	0	125	0	1100

Optimum solution in integers.

Here some $C_j - Z_j \geq 0$, therefore the optimum basic feasible integer solution has been obtained. Hence the optimum solution is,

$X_1 = 8.723$, $X_2 = 0.13$, and maximum $Z = 32,665$.

Step 7: RESULT

➤ Comparing Available Resource And Optimum Resource.

Resource required for ground floor brick structure	AVAILABLE RESOURCE	OPTIMUM RESOURCE
	Quantity	Quantity
Manpower (no.)	148	104
Cement (50 kg bag)	130	87
Sand (cft)	305	290
Brick (no.)	16,037	13,984

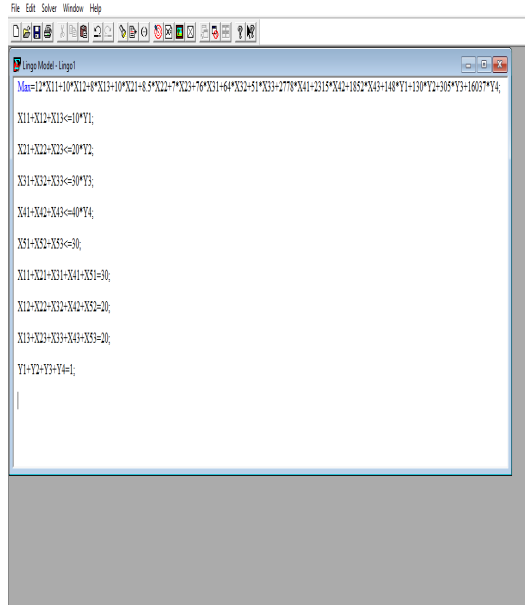
In integer programming method achieve the maximum profit Rs. 32,665.

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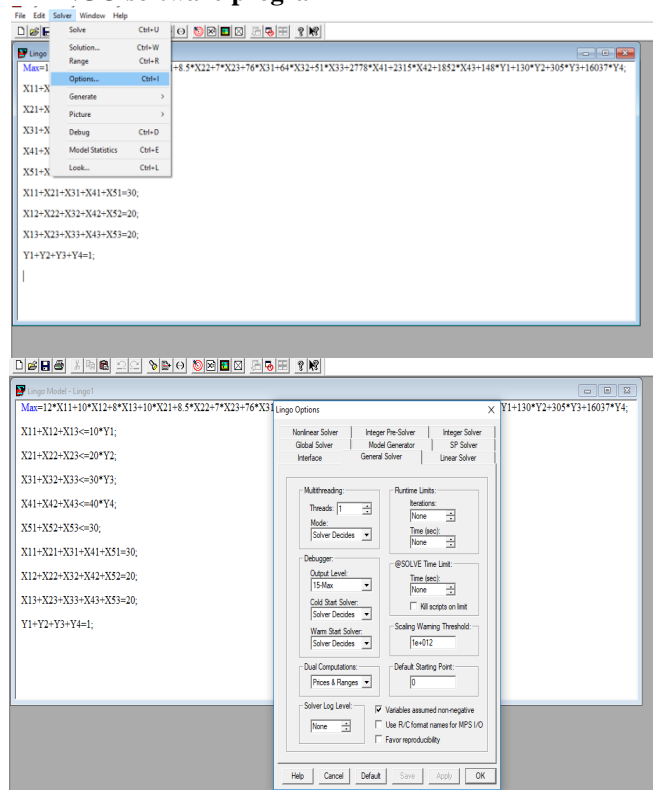
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4.2 Implementing the data in LINGO software program

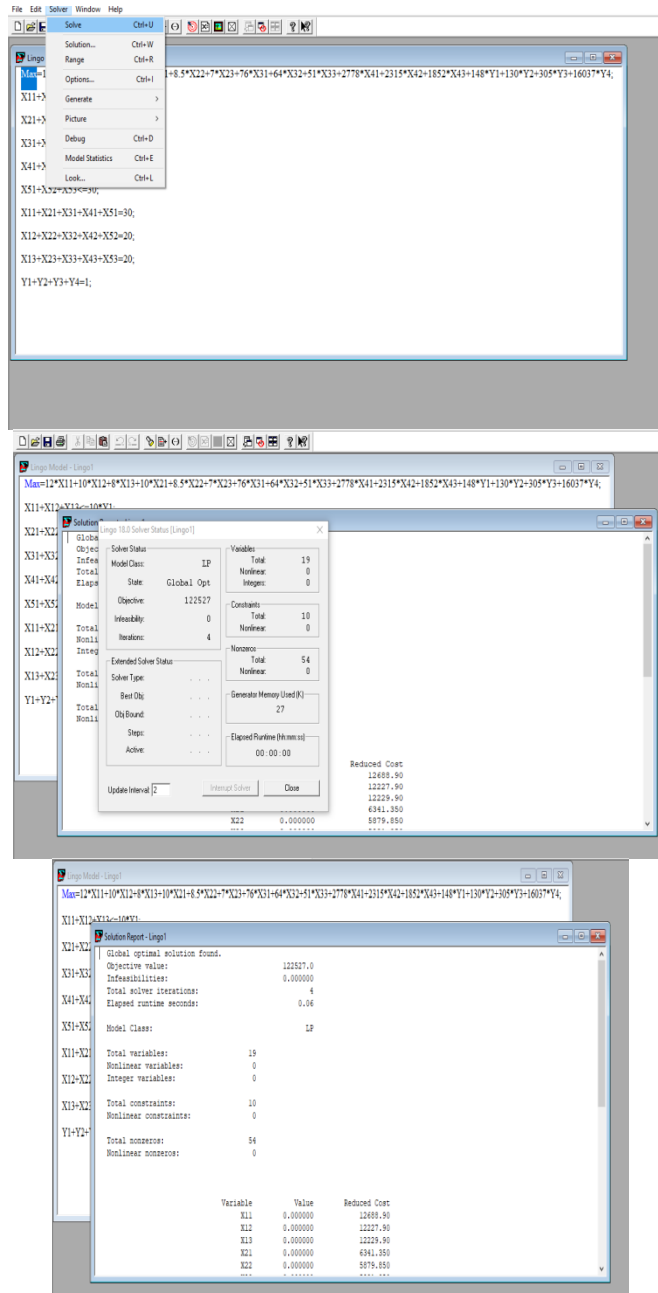


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The image displays three screenshots of the Lingo Solver interface. The top screenshot shows the 'Solve' menu and the model equations. The middle screenshot shows the 'Solution' dialog box with solver status and statistics. The bottom screenshot shows the 'Solution Report' with the optimal solution values and reduced costs.

Model Equations:

$$\text{Max} = 12 \cdot X11 - 10 \cdot X12 + 8 \cdot X13 - 10 \cdot X21 - 8 \cdot 5 \cdot X22 - 7 \cdot X23 + 76 \cdot X31 + 64 \cdot X32 + 51 \cdot X33 + 2778 \cdot X41 + 2315 \cdot X42 + 1852 \cdot X43 + 148 \cdot Y1 + 130 \cdot Y2 + 305 \cdot Y3 + 1603 \cdot Y4;$$

$$X11 + X12 + X13 = 10 \cdot X1;$$

$$X11 + X21 + X31 + X41 + X51 = 30;$$

$$X12 + X22 + X32 + X42 + X52 = 20;$$

$$X13 + X23 + X33 + X43 + X53 = 20;$$

$$Y1 + Y2 + Y3 + Y4 = 1;$$

Solver Status:

Category	Total	Nonlinear	Integer
Variables	19	0	0
Constraints	10	0	0
Nonzeros	54	0	0

Objective Value: 122527.0

Global optimal solution found.

Optimal Solution Values:

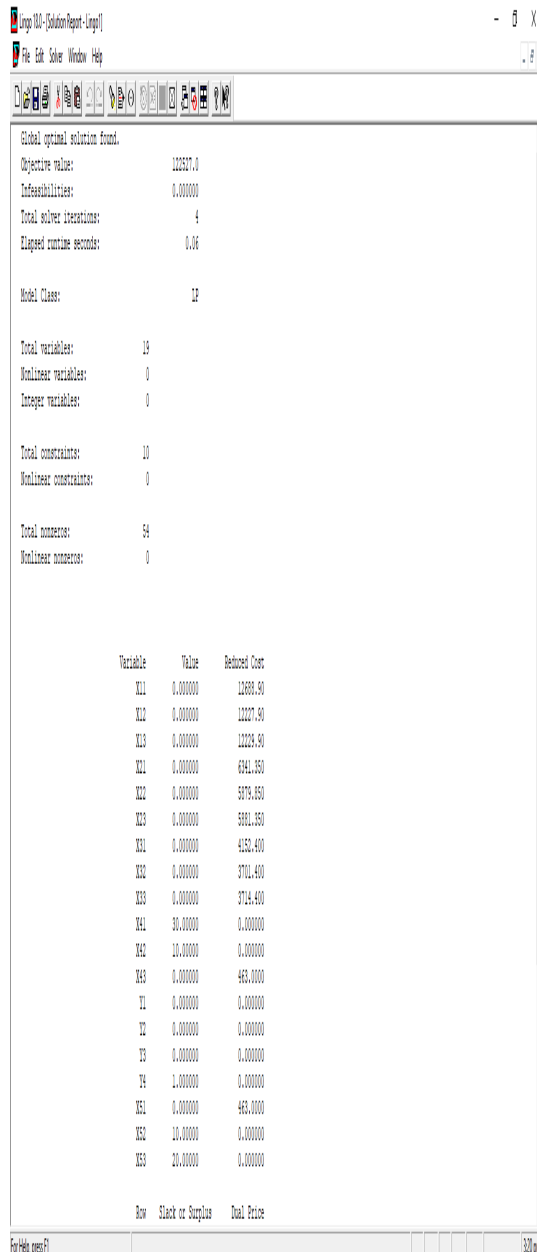
Variable	Value	Reduced Cost
X11	0.000000	12486.90
X12	0.000000	12227.90
X13	0.000000	12229.90
X21	0.000000	6341.350
X22	0.000000	5879.850

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Global optimal solution found.

Objective value: 122307.0
Infeasibilities: 0.000000
Total solver iterations: 4
Elapsed runtime seconds: 0.06

Model Class: LP

Total variables: 19
Nonlinear variables: 0
Integer variables: 0

Total constraints: 10
Nonlinear constraints: 0

Total nonzeros: 54
Nonlinear nonzeros: 0

Variable	Value	Reduced Cost
X11	0.000000	12683.89
X12	0.000000	12207.89
X13	0.000000	12229.89
X21	0.000000	6941.353
X22	0.000000	5876.353
X23	0.000000	5881.353
X31	0.000000	4150.400
X32	0.000000	3701.400
X33	0.000000	3719.400
X41	30.00000	0.000000
X42	10.00000	0.000000
X43	0.000000	463.0000
X5	0.000000	0.000000
X6	0.000000	0.000000
X7	0.000000	0.000000
X8	1.000000	0.000000
X51	0.000000	463.0000
X52	10.00000	0.000000
X53	20.00000	0.000000

Row Slack or Surplus Dual Price

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4.3 Data's implemented in dynamic programming Multi stage graph problem

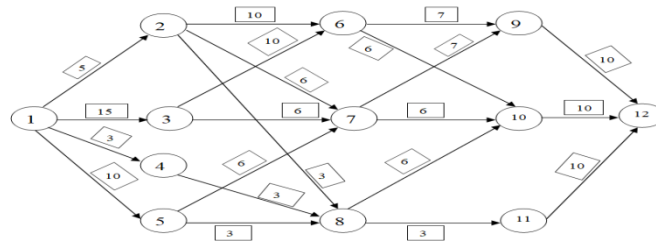


Fig. 4.3.1 Construction activity diagram for ground floor structure

❖ Shortest path in a multi-stage graph problem is calculated by

$$\text{Cost}(i, j) = \min \{ c(j,l) + \text{cost}(i+1, l) \mid l \in V_{i+1} \}$$

Where,

cost(i, j) = cost(level, no. of nodes at that level)

'c' is a weight assigned on each edge

'k' is the no. of stages

Each set V_i is called a stage in the graph.

❖ To find a shortest path in a multi-stage graph problem

- Cost (5, 12) = 0, Cost (4, 9) = 10,
- Cost (4, 10) = 10, Cost (4, 11) = 10,
- Cost (3, 6) = 16, Cost (3, 7) = 16,
- Cost (2, 5) = 16, Cost (1, 1) = 16,
- Cost (3, 8) = 13, Cost (2, 2) = 16,
- Cost (2, 3) = 22, Cost (2, 4) = 16,
- d (1, 1) = 4,
- d (2, 4) = 8,
- d (3, 8) = 11,
- d (4, 11) = 12

In forward method the shortest path of multi-stage graph problem is = 1 → 4 → 8 → 11 → 12 →

The construction activity minimum duration is = 3 + 3 + 3 + 10 = 19. Thus by dynamic programming multi-stage problem we can find out the shortest path and minimum duration of each construction project.

V. RESULT AND DISCUSSION

Project name	Maximum profit value (Rs)	
	Gomory's cut method (IPP)	LINGO software
Residential building brick construction for 3 storey's	32,665	40,500

Table 5.1.1 Result of comparing maximum profit value of Gomory's cut method and LINGO software

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In this project the maximum profit was calculated by using integer programming gomory's cut method and LINGO computer software. The profit values of this two way of calculation have some different but the calculation of manual gomory's cut method have some difficulty to comparing the LINGO software program. In my suggestion the profit was easily found by LINGO program and time was less to comparing the manual method. In forward method the shortest path of multi-stage graph problem is = $1 \rightarrow 4 \rightarrow 8 \rightarrow 11 \rightarrow 12$ in dynamic programming.

The construction activity minimum duration is = $3 + 3 + 3 + 10 = 19$. Thus by dynamic programming multi-stage problem we can find out the shortest path and minimum duration of each construction project.

VI. CONCLUSION

In this project, the building raw material data was collected in the construction company. The construction schedule data was solved by dynamic programming multi-stage graph method. The multi-stage graph problem which solve the shortest path and its minimum duration for an each construction activity. So as it helps the construction project each activity completed with in duration period. The resource data was solved by integer programming gomory's cut method and LINGO software program. The integer programming was important for the management to know how profit would be affected by an increase or decrease in the resource level and by a change in the cost of raw materials. In this type of changes analyzed and profit was calculated by using integer programming and LINGO software program. The result was compared and the each way of calculation was access. Finally, the profit was easily found by LINGO software programming.

ACKNOWLEDGEMENT

First and foremost we thank the almighty god for his wonderful presence with us throughout my project. I express heartiest thanks to our head of the department, project co-ordinator and guide for their support and ideas for completing the project.

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