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Optimization of lead time through genetic algorithm: A case study of equipment manufacturing industry

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ABSTRACT

This study aims at optimizing lead time through effective management of resources in an equipment manufacturing industry to ensure timely completion of the projects. The concept of “project crashing” was implemented to identify potential activities at production line of conventional two-roller machines. The developed model is optimized using modified Genetic Algorithm (GA). The results showed that the proposed model enabled to deliver products as per schedule without increasing planned cost. Sensitivity analyses were also conducted to find out the impact of various process parameters. From the analyses, it was found that the proposed model facilitates the manufacturer in delivering the products at specified time with increasing the planned cost.

Keywords: Lead time; Project Management; Optimization; Genetic algorithm.

1. INTRODUCTION

Processing time and cost are two significant parameters for successful completion of projects in manufacturing industries (Zheng et al., 2004). Delay in completion of the projects leads to penalties, earned value, and negative market reputation. In this situation, the project managers increase resources through “project crashing” to avoid delays (Ke, 2014).

Project crashing is performed to reduce total project time by analyzing cost of additional resources. The main aim of project crashing is to determine optimum scheduling (Parveen and Saha, 2012). As cost is directly proportional to project duration, it can be cut down to an extent through crashing (Shr and Chen, 2006, Sprecher et al., 1997). Optimized schedule means completion of project in minimum cost within given time frame (Sahu and Sahu, 2014). The crashing of project activities is accomplished by increasing capacity (working time, work force, and machines) (Kanahalli and Hutti, 2013). The project managers seek most cost effective route of completing a project which is termed as time-cost or lead time optimization (Davis, 1973). Because of randomized probability in machine breakdowns, quality, and transportation, there exist uncertainty in lead-time which needs to be minimized to fulfil project targets (Hnaien et al., 2008).

This study focused on production of roller machines used for extraction of juice from sugar cane. There are several types of machines comprising 2, 3, or 5 rollers (Feng et al., 1997). Two-rollers are an emerging technology with most efficient design enabling efficient processing and enhanced profitability (Li and Love, 1997).

Genetic algorithm (GA) is a technique based on natural selection for solving optimization problems (Ke et al., 2009). The algorithm repetitively transforms a population of discrete solutions through iterations. At each phase, the genetic algorithm arbitrarily selects individuals from existing population and customizes them as parents to produce off-springs for next generation through reproduction, crossover and mutation operations. Keeping in view the time constraint, we modified mutation process with upper limit for the value of objective function. Genetic algorithm can also solve problems that are not highly suitable for standard optimization algorithms, including challenges, in which the objective function is highly nonlinear, discontinuous, stochastic, or non-differentiable. Genetic Algorithm is exploited here to optimize the production plan (Ahuja et al., 1994).

This paper addresses lead time optimization issues faced in manufacturing of two-roller machines at Heavy Mechanical Complex (HMC). HMC has no competitor in local market in terms of product quality; however, the performance is not up to the mark in fulfilling product delivery deadlines, which may disrupt market reputation and ultimately, loss of customers.

Lead time optimization through crashing has been discussed for various construction, manufacturing, supply chain, and production management projects (Saraswat, 2016). Most of the studies discussed lead time optimization for construction and supply chain management projects. Considering this gap, we discussed lead time optimization for manufacturing of two-roller machines used in sugar industry. Like other industries, HMC is using conventional methods of manufacturing industrial equipment with few latest scheduling and optimization techniques. Hence, there exist issues of late deliveries as a result of which company bear a huge financial loss. Hence, this paper focuses on implementation of Genetic Algorithm for lead time optimization of two-roller machines.

The organization of this paper is as follows. The details of the mathematical model are given in Section 2. The results and analysis using Genetic Algorithm are presented in Section 3. Conclusions and recommendations for future research work are given in Section 4.

2. METHODOLOGY

The activities involved in manufacturing process of two-roller machines are presented in Table 1. The manufacturing process is divided into two sections. First section is Forge and Foundry works which includes processes of technology making, pattern making, hydraulic presses, heat treatment and fettling. In this section, steel and cast-iron casting are mainly done, and ingot is prepared for further processing in section 2, that is, mechanical works. This section includes processes of fabrication, machining, assembly and dispatch of finished products.

Whenever an enquiry arrives, the sales and marketing team forward it to design department which estimates material requirements. Meanwhile, project management department estimates for site erection and installation. Once the order is finalized by sales and marketing department, the design department issue manufacturing drawings along with Bill of Quantity (BOQ). Based on BOQ, production planning and control team forward requisitions for issuance of materials from the stores. If required material is not available in the stores, indents are forwarded for procurement. The material is issued to the respective shops and after completion of manufacturing cycle, and the product is dispatched for installation.

2.1 Process Diagram

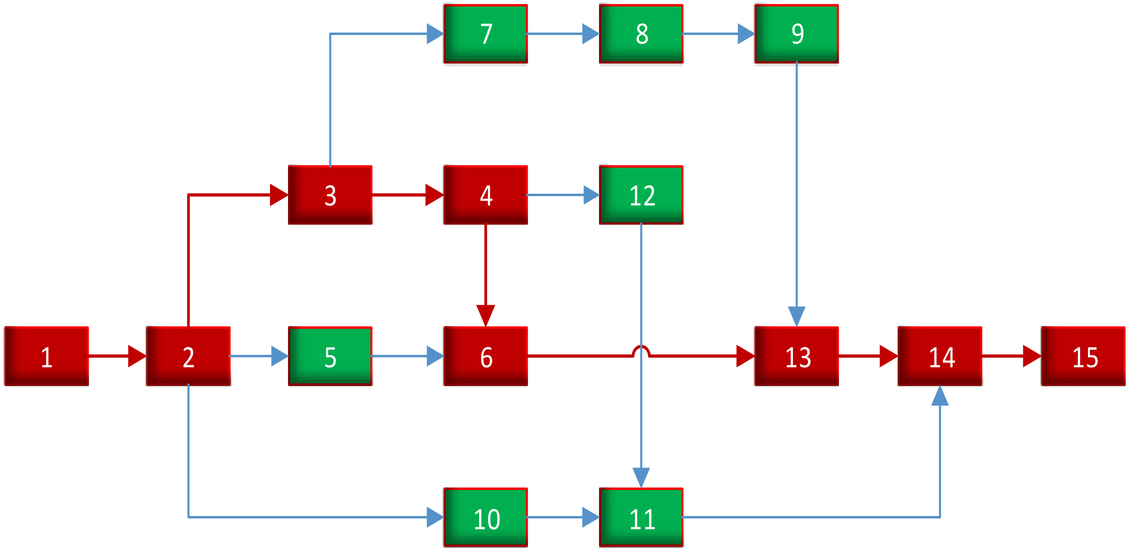

Figure 1. Process diagram.

The details of the events presented in Figure 1 are given as follows:

(1) Preparation of Manufacturing Drawings
(2) Material Procurement and Issuance
(3) Casting of Foundation Nuts and Bolts
(4) Machining of Foundation Nuts and Bolts
(5) Casting of Mill Cheeks
(6) Machining of Mill Cheeks
(7) Casting/Forging of Brass Bearings
(8) Fabrication of Brass Bearings
(9) Machining of Brass Bearings
(10) Casting of Rollers
(11) Machining of Rollers
(12) Fabrication of Plumber Block
(13) Fabrication of Pressure Chutes
(14) Assembling
(15) Sand blasting and painting.

2.2 Model Implementation

Scheduling through MS Project revealed that the project is going to be completed in 135 days with existing facilities. However, we need to complete it in 120 days with minimum possible cost. For this, there is a need to identify crash-able activities on critical path to minimize completion time.

The 'Normal time' of an activity is time to complete that activity with minimum or normal cost. 'Crash Time' is minimum time to complete an activity and the corresponding cost incurred is called "Crash Cost" (Lin, 2006).

The model assumed linear relationship between cost and time taken. The time and cost at any point on the line are called intermediate time and cost.

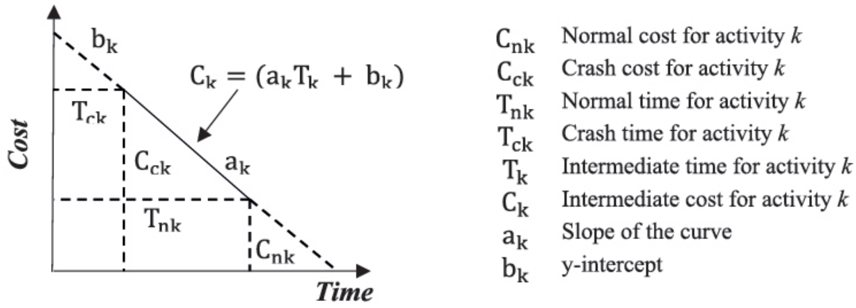

Figure 2. Time and cost relationship (activity k)

The objective of time-cost optimization problem is to minimize total cost by crashing activities to shorten total duration to a targeted limit. The total cost function is given in (A).

Minimize $C_t = \sum C_k = \sum (a_k T_k + b_k)$ (A)

Subject to

$\sum T_i = T_t$ (1)

where

$a_k = \frac{Cn_k - Cc_k}{Tn_k - Tc_k}$ (a)

$b_k = \frac{(Cc_k * Tn_k) - (Cn_k * n\, c_k)}{Tn_k - Tc_k}$ (b)

$Tn_k \leq T_k \leq Tc_k$

where $k \in A$ = subset of crash-able activities on the critical path, and

C_t and T_t represent total cost and total time (after crashing), respectively.

From Figure 2, there exist linear (inverse) relationship between processing time (duration) and cost. A duration with minimum cost of an activity is called normal time while minimum time to complete an activity (at high cost) is called crash time. The linear relationship between cost and time infers that any intermediate point can also be selected it may represent the optimal time-cost relationship.

The slope of the line joining normal and crash point is called cost slope of the activity. The slope can be calculated using formula Cost-Slope = [Crash Cost-Normal Cost] / [Normal duration – Crash duration] as shown by equation (a). The objective function is a slope-intercept, where (a) is slope and (b) is the intercept as mentioned in figure 2. The two extremes of slope indicate relation between normal and crash parameters. To find optimum value of time and cost, there is an intermediate point on the slope, which is the target point.

Table1 gives us the details of normal and crashed cost and time for activities on critical path:

Table 1. Detail of Normal and Crashed Time for Crash-able Activities.

Activity #	Activity	Normal Time	Normal Time Cost Rs. (Thousands)	Crash Time	Crash Time Cost Rs. (Thousand)
1	Manufacturing Drawings	10	80	8	100
2	Material Procurement & Issuance	30	1300	25	1560
3	Casting of Foundation Nuts & Bolts	20	1000	15	1333
4	Machining of Foundation Nuts & Bolts	15	1300	12	1625
6	Machining of Mill Cheeks	25	1000	20	1250
13	Fabrication of Pressure Chutes	15	200	11	273
14	Assembling	15	800	10	1200
15	Sand Blasting & Painting	5	500	3	833

GA is a solution method based on natural selection of population genetics. The stepwise GA to solve above problem are given below.

Step 1: Initialize: Randomized generation of initial population.
Step 2: Evaluation and Selection of Parents: Evaluate each chromosome (solution) and choose best.
Step 3: Crossover and mutation: Apply multi-point crossover and mutation.
Step 4: Re-evaluation: Evaluate off-springs.
Step 5: Diversification: If diversity is not up to the mark, apply mutation, until required diversification achieved.
Step 6: Termination: Repeat iterative process until stopping criteria achieved.

Initially, feasible solutions (Ti values) are randomly generated and encoded as strings. These initial solutions are evaluated for selection of parents. Crossover of parents to generate off-springs is performed. After crossover, the best offspring is selected and duplicated to replace the poor offspring. Further, bit flip mutation was applied for further exploration for optimal solution. The procedure was repeated several times until the function generated lowest value.

3. RESULTS AND DISCUSSION

As we crashed project to complete in 120 days (instead of normal 135 days) to ensure on-time delivery, the estimated cost increased to PKR 6,707 (Thousands), which was then optimized and reduced to PKR 6,367 (Thousands), as shown in Figure 3.

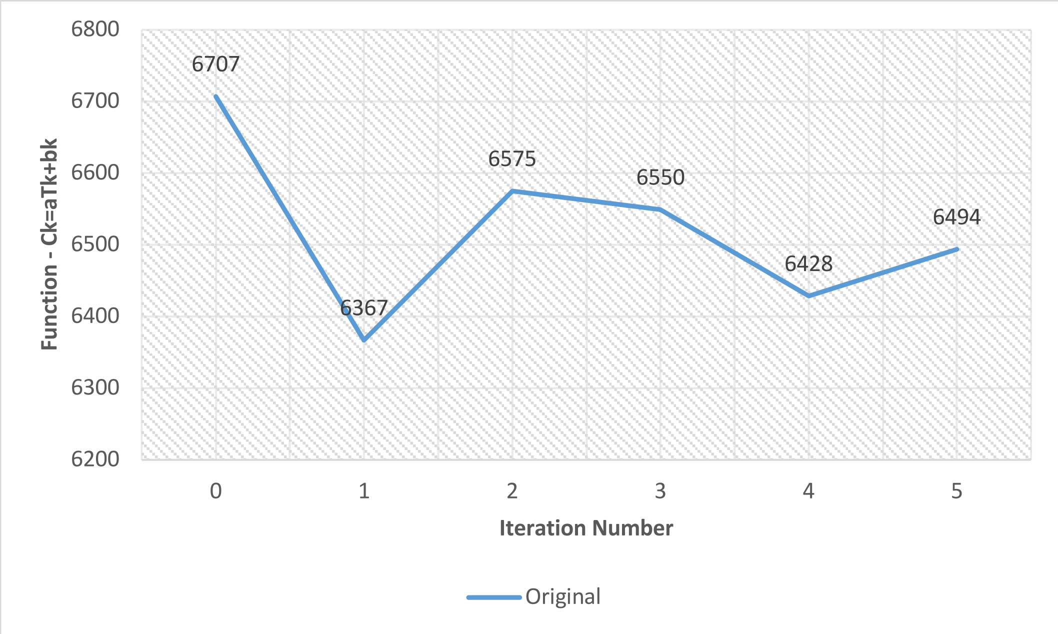

Figure 3. Crashed cost of the project in iterative process.

From Figure 3, the cost of the project within required duration (120 days) is optimized through GA. As the values of Tn and Cn were fixed, sensitivity analyses are conducted to find out the impact of normal time and cost for first four activities.

3.1 Changing Tn value of Activity 1

Table 2 shows the impact of Tn value for activity 1 on crashed cost. There exists an inverse relation between crashed time and cost; that is, the higher the reduction in time, the higher the crashed cost of the activity.

Figure 4 shows the impact of Tn value for activity 1 on total cost of the crashed project.
The value of total cost increases by increasing Tn value of activity 1.

Table 2. Normal and crashed time with different Tn values for activity 1.

Activity #	Activity	Normal Time	Normal Time Cost Rs. (Thousands)	Crash Time	Crash Time Cost Rs. (Thousand)
1	Manufacturing Drawings	**10**	80	**8**	**100**
		12	80	**8**	**120**
		14	80	**8**	**140**
		16	80	**8**	**160**
2	Material Procurement & Issuance	30	1300	25	1560
3	Casting of Foundation Nuts & Bolts	20	1000	15	1333
4	Machining of Foundation Nuts & Bolts	15	1300	12	1625
6	Machining of Mill Cheeks	25	1000	20	1250
13	Fabrication of Pressure Chutes	15	200	11	273
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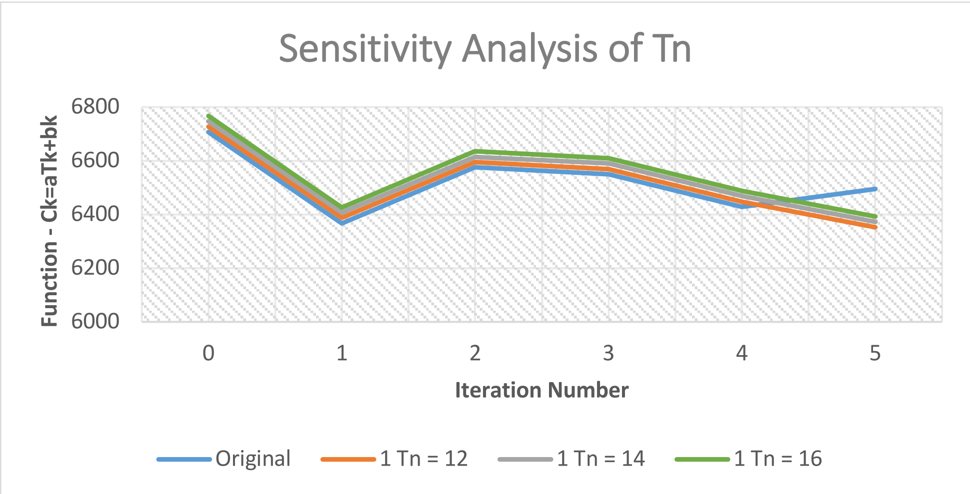

Figure 4. Total cost at different Tn values of activity 1.

3.2 Changing Cn value of Activity 1

From table 3, an increase in normal cost increases crashed cost for activity 1. Similarly, total cost of the crashed project increases by increasing normal cost of activity 1 (Figure 5).

Table 3. Normal and Crashed Time with different *Cn* values for activity 1.

Activity #	Activity	Normal Time	Normal Time Cost Rs. (Thousands)	Crash Time	Crash Time Cost Rs. (Thousand)
1	Manufacturing Drawings	10	**80**	8	**100**
		10	**90**	8	**113**
		10	**100**	8	**125**
		10	**110**	8	**138**
2	Material Procurement & Issuance	30	1300	25	1560
3	Casting of Foundation Nuts & Bolts	20	1000	15	1333
4	Machining of Foundation Nuts & Bolts	15	1300	12	1625
6	Machining of Mill Cheeks	25	1000	20	1250
13	Fabrication of Pressure Chutes	15	200	11	273
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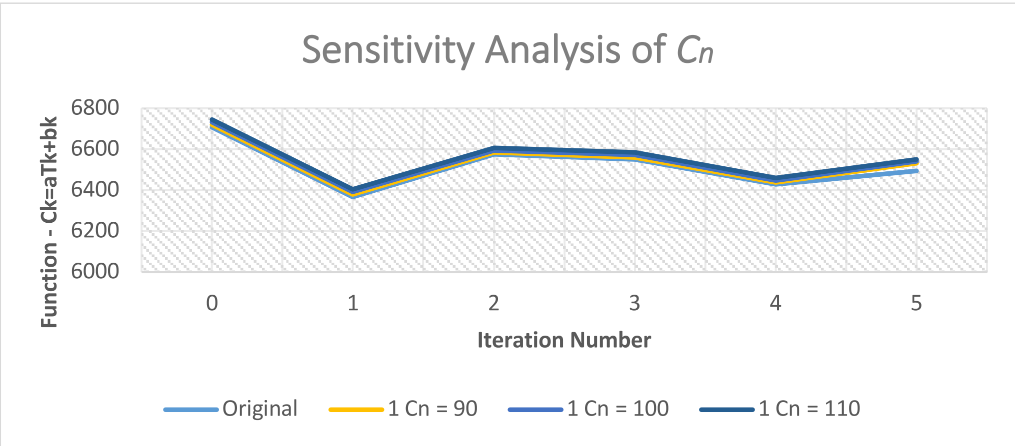

Figure 5. Total cost at different values of Cn for Activity 1.

3.3 Changing Tn for Activity 2

From table 4, an increase in normal time for activity 2 increases crashed cost. The result of this increase on total cost is depicted in Figure 6. The increasing trend in total cost is similar to activity 1.

Table 4. Normal and crashed time with different Tn values for activity 2.

Activity #	Activity	Normal Time	Normal Time Cost Rs. (Thousands)	Crash Time	Crash Time Cost Rs. (Thousand)
1	Manufacturing Drawings	10	80	8	100
2	Material Procurement & Issuance	**30**	1300	25	**1560**
		33	1300	25	**1716**
		36	1300	25	**1872**
		38	1300	25	**1976**
3	Casting of Foundation Nuts & Bolts	20	1000	15	1333
4	Machining of Foundation Nuts & Bolts	15	1300	12	1625
6	Machining of Mill Cheeks	25	1000	20	1250
13	Fabrication of Pressure Chutes	15	200	11	273
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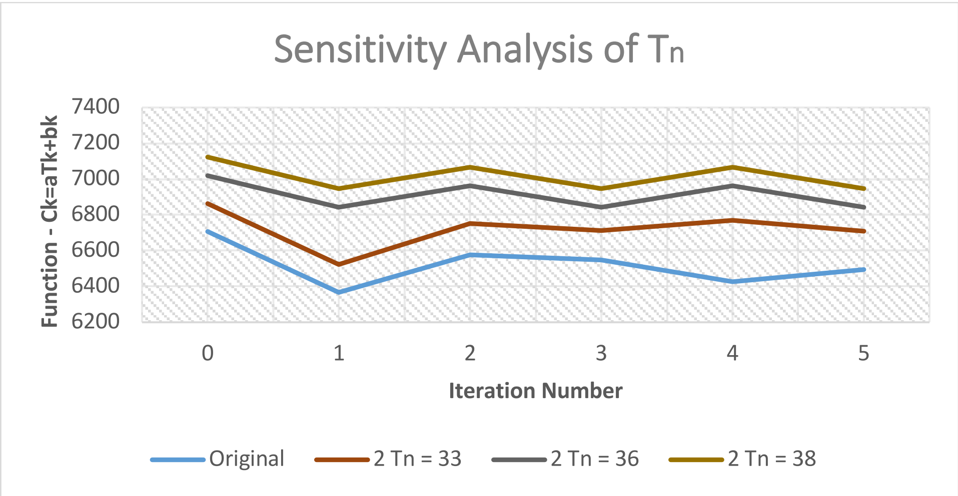

Figure 6. Total cost at different Tn values of activity 2.

3.4 Changing Cn for Activity 2

The impact of change in normal cost for activity 2 on crashed cost (activity 2) and total cost of the project is similar to activity 1, as shown in table 5 and figure 7, respectively.

Table 5. Normal and crashed time with different *Cn* values for activity 2.

Activity #	Activity	Normal Time	Normal Time Cost Rs. (Thousands)	Crash Time	Crash Time Cost Rs. (Thousand)
1	Manufacturing Drawings	10	80	8	100
2	Material Procurement & Issuance	30	**1300**	25	**1560**
		30	**1500**	25	**1800**
		30	**1700**	25	**2040**
		30	**1900**	25	**2280**
3	Casting of Foundation Nuts & Bolts	20	1000	15	1333
4	Machining of Foundation Nuts & Bolts	15	1300	12	1625
6	Machining of Mill Cheeks	25	1000	20	1250
13	Fabrication of Pressure Chutes	15	200	11	273
14	Assembling	15	800	10	1200
15	Sand Blasting & Painting	5	500	3	833

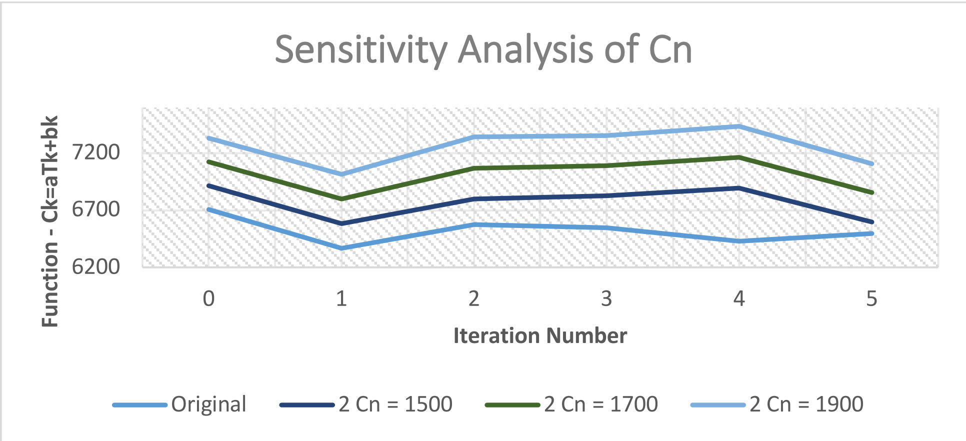

Figure 7. Total cost at different *Cn* values of activity 2.

3.5 Changing Tn Value for Activity 3

From table 6 and figure 8, the trend of change in crashed cost (activity 3) and total cost of the project by changing normal time of activity 3 is similar to activities 1 and 2.

Table 6. Normal and crashed time with different *Tn* values for activity 3.

Activity #	Activity	Normal Time	Normal Time Cost Rs. (Thousands)	Crash Time	Crash Time Cost Rs. (Thousand)
1	Manufacturing Drawings	10	80	8	100
2	Material Procurement & Issuance	30	1300	25	1560
3	Casting of foundation Nuts & Bolts	**20**	1000	15	**1333**
		24	1000	15	**1600**
		26	1000	15	**1733**
		28	1000	15	**1867**
4	Machining of Foundation Nuts & Bolts	15	1300	12	1625
6	Machining of Mill Cheeks	25	1000	20	1250
13	Fabrication of Pressure Chutes	15	200	11	273
14	Assembling	15	800	10	1200
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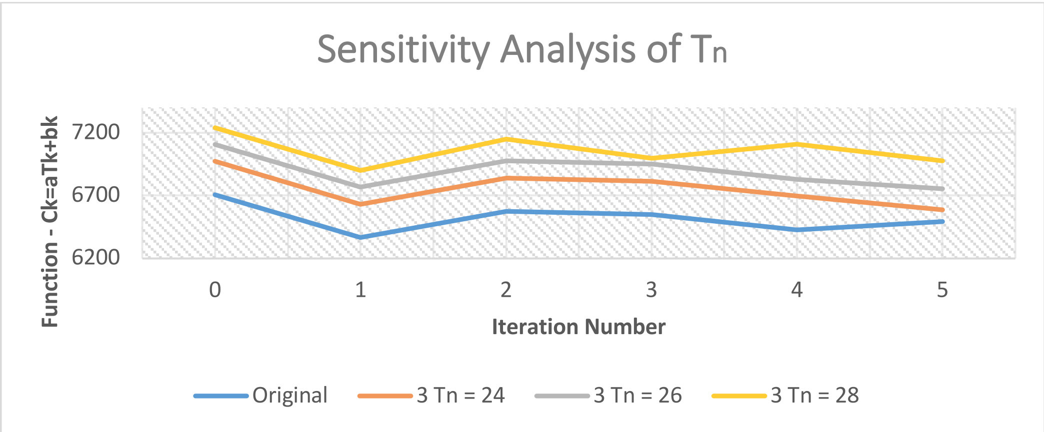

Figure 8. Total cost at different values of Tn for activity 3.

3.6 Changing Cn for Activity 3

From table 7 and figure 9, the trend of change in crashed cost (activity 3) and total cost of the project by changing normal cost of activity 3 is similar to that of activities 1 and 2.

Table 7. Normal and crashed time with different values of Cn for activity 3.

Activity #	Activity	Normal Time	Normal Time Cost Rs. (Thousands)	Crash Time	Crash Time Cost Rs. (Thousand)
1	Manufacturing Drawings	10	80	8	100
2	Material Procurement & Issuance	30	1300	25	1560
3	Casting of Foundation Nuts & Bolts	20	**1000**	15	**1333**
		20	**1250**	15	**1667**
		20	**1450**	15	**1933**
		20	**1600**	15	**2133**
4	Machining of Foundation Nuts & Bolts	15	1300	12	1625
6	Machining of Mill Cheeks	25	1000	20	1250
13	Fabrication of Pressure Chutes	15	200	11	273
14	Assembling	15	800	10	1200
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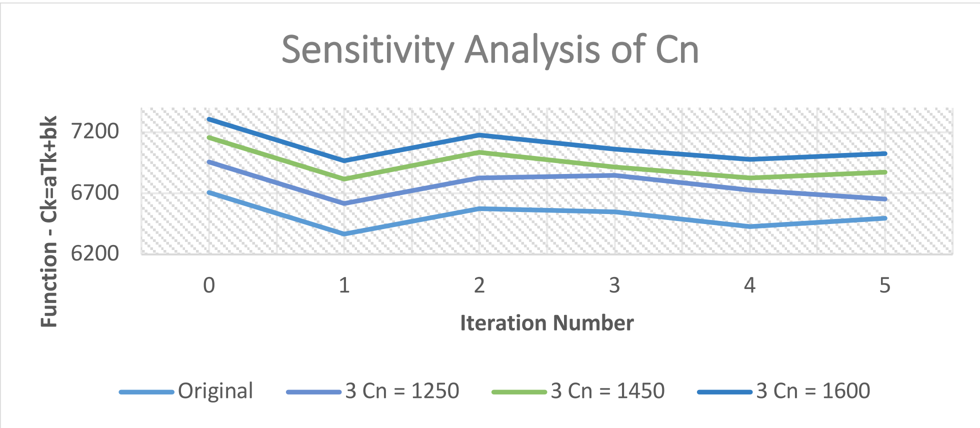

Figure 9. Total cost at different values of Cn for activity 3.

3.7 Changing Tn for Activity 4

From table 8 and figure 10, the trend of change in crashed cost (activity 4) and total cost of the project by changing normal time of activity 4 is similar to activities 1, 2 and 3 except a slight change in iteration 5, which can be because of mutation.

Table 8. Normal and crashed time with different *Tn* values for activity 4.

Activity #	Activity	Normal Time	Normal Time Cost Rs. (Thousands)	Crash Time	Crash Time Cost Rs. (Thousand)
1	Manufacturing Drawings Material	10	80	8	100
2	Procurement & Issuance	30	1300	25	1560
3	Casting of foundation Nuts & Bolts	20	1000	15	1333
4	Machining of Foundation Nuts & Bolts	**15**	1300	12	**1625**
		17	1300	12	**1842**
		19	1300	12	**2058**
		21	1300	12	**2275**
6	Machining of Mill Cheeks	25	1000	20	1250
13	Fabrication of Pressure Chutes	15	200	11	273
14	Assembling	15	800	10	1200
15	Sand Blasting & Painting	5	500	3	833

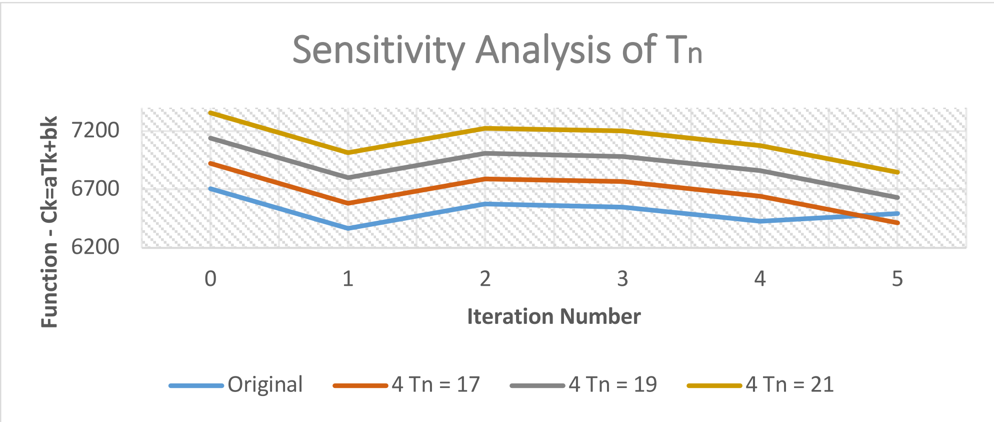

Figure 10: Total cost at different values of Tn for activity 4.

3.8 Changing Cn for Activity 4

From table 9, the impact of change in normal cost on crashed cost of activity 4 is similar to that of activities 1, 2, and 3.

Table 9. Normal and crashed time with different values of Cn for activity 4.

Activity #	Activity	Normal Time	Normal Time Cost Rs. (Thousands)	Crash Time	Crash Time Cost Rs. (Thousand)
1	Manufacturing Drawings	10	80	8	100
2	Material Procurement & Issuance	30	1300	25	1560
3	Casting of Foundation Nuts & Bolts	20	1000	15	1333
4	Machining of foundation Nuts & Bolts	15	**1300**	12	**1625**
		15	**1450**	12	**1813**
		15	**1600**	12	**2000**
		15	**1800**	12	**2250**
6	Machining of Mill Cheeks	25	1000	20	1250
13	Fabrication of Pressure Chutes	15	200	11	273
14	Assembling	15	800	10	1200
15	Sand Blasting & Painting	5	500	3	833

Figure 11 demonstrates the correlation between originally generated solution and newly generated solutions by changing the values of Cn at same value of Tn for activity 4 (Table 9). The graph indicates higher peaks for higher values of Cn with contradiction for iteration 5 indicating rise in graphical trend for original solution whereas decline for newly generated solutions. This graph also follows the same trend as shown in figure 10.

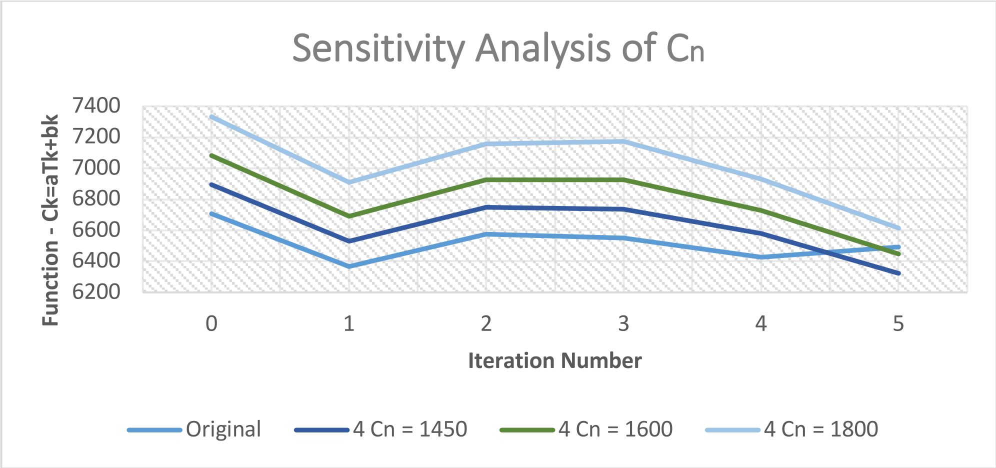

Figure 11. Objective Function values at different values of Cn.

The value of crashed cost and total cost of the project changed by changing values of *Tn* and *Cn,* showing a direct relation.

4. CONCLUSIONS AND RECOMMENDATIONS

Lead time optimization in heavy industries is challenging because of supply issues of the equipment/components within stipulated time. This paper gives an insight of a real time equipment manufacturing lead time optimization problem for sugar industry. The proposed time-cost problem is solved using GA. The results depict that optimized crashing of activities can facilitate fulfilling delivery deadlines. The results of this study are applicable for project managers to meet deadlines through crashing of activities. From sensitivity analysis, there exists an inverse linear relation between cost and completion time. The outcomes of this study are helpful in deciding crashing level as per available resources.

The research can be extended by considering nonlinearity in time-cost relationship and quality of crashed activities.

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