Abstract— Genetic Algorithm (GA) is an invaluable tool for solving optimization problems due to its robustness. It does not break even if the inputs are changed slightly or in the presence of a reasonable noise. GA offers a significant benefit over other optimization techniques in searching a large state space or n-dimensional surface. In this paper we have made an attempt to study the effect of population size cross over and mutation on the performance and convergence of GA. The criteria for adopting the proper selection method is also studied. There is lot of literature on application of GA in various domains but best to our knowledge there exist very few papers which discuss the distribution of population, criteria for choosing selection method. Finally, we use the results for optimizing the non-value added cost component of a cycle time of constrained resources for productivity improvement. The problem is for medium scale manufacturing plant and is solved using GA toolbox of MATLAB. The results are used in redesigning the assembly line to overcome the limitations offered by constrained resources.

Keywords – Genetic Algorithm, MATLAB, Cycle Time, Constraint Resource, Production Line, Non-linear Optimization.

I. INTRODUCTION

Genetic algorithms (GA) are adaptive heuristic search algorithms based on the evolutionary ideas of natural selection and genetics. As such they represent an intelligent exploitation of a random search used to solve optimization problems [1]. Although randomized, GAs are inherently not random instead they exploit historical information to direct the search into the region of better performance within the search space. A space of all feasible solutions is referred to as search space. Each and every point in the search space represents one possible solution. Each possible solution can be marked by its fitness value and GA looks for a best solution among a number of possible solutions represented by one point in the search space. Keeping in memory more than a single solution at each iteration offers lot of advantages. The algorithm can span larger search space for better solutions [2]. It can recombine better solutions to get still better ones. In optimization a few random changes can be a good way of exploiting a search space quickly. The distribution of population over search space together with mutation prevents the algorithm to be trapped in a local minimum [3]. GAs are something worth trying when everything else fails or when we know absolutely nothing of the search space [4,5].

Production lines are flow line production systems which are of great importance in the industrial production of high quantity standardized products and more recently even gained importance in low volume production of customized products. Small and Medium Scale Enterprises (SME) have lack of knowledge to manage the company resources especially in the production line [6]. The challenge is to reduce the cycle time, thus reducing the lead time of production. Cost reduction and inventory reduction have become more important for survival of an enterprise. Theory of Constraints (TOC) is one such technique for productivity improvement which focuses on improving system performance [7]. TOC tries to identify constraints in the system and exploit and elevate them to improve the overall output of the system. However, there is a practical limitation on the value up to which a cycle time can be reduced. If the line balancing is not achieved within this practical limit alternative methods such as buffer stocks, shifting some of the operations to a new machine are to be considered [8].
The five focusing steps of TOC provide a simple and effective approach to continuous improvement in cases where the constraint is fairly clearly identifiable [9,10].

**Step 1 : Identify the systems constraint or bottleneck.**
Identify the operation that is limiting the productivity of the system. This may be a physical or policy constraint.

**Step 2 : Decide how to exploit the bottlenecks.**
Achieve the best possible output from the constraint. Remove limitations that constrain the flow and reduce non-productive time, so that the constraint is used in the most effective way possible.

**Step 3 : Subordinate everything else to the above decision.**
Link the output of other operations to suit the constraint. Smoothen work flow and avoid build up of work-in-process inventory. Avoid making the constrained wait for operation.

**Step 4 : Elevate the system’s bottlenecks.**
In situations where the system constraint still does not have sufficient output invest in new equipment or increase staff to increase output.

**Step 5 : If in the previous step a bottleneck has been broken go back to step 1.**
Assess to see if another operation or policy has become a system constraint.

The following analysis reveals the formulation of optimization problem for one constrained resource. In real situation, the proper line balancing would require the simultaneous balancing of n such constrained resources.

## II. PROBLEM FORMULATION

Cycle time of a manufacturing process comprises of two components

i) Value added component which is an actual processing time known as machine time which remains more or less same for all components.

ii) Non valued added component which gives a major scope for reducing the cycle time. It includes loading/unloading time of a component, machine setup time which are mainly dependent on the skills of a personnel.

\[
\text{Cycle Time} = \text{Value Added Component} + \text{Non-value Added Component}
\]

Let \(C_T_{\text{original}}\) denote original cycle time in the presence of constrained resources. Hence

\[
C_T_{\text{original}} = V + N \tag{1}
\]

Where, \(N\) and \(V\) represent Value Added and Non Value Added components, respectively.

Led \(C\) and \(D\) denote available capacity i.e. available machine hours per day and demand per day, respectively. Hence,
Required Units = \( \frac{D}{CT_{\text{original}}} \)  

Actual Units Produced = \( \frac{C}{CT_{\text{original}}} \)  

In the case of limited constraints

Required Units > Actual Units Produced.

However, the condition required for line balancing is

Required Units = Actual Units Produced.  

Hence there is a need to reduce a cycle time. If the non-value added component of a cycle time is reduced by a factor of \( x \), the revised cycle time is given by,

\[ CT_{\text{Revised}} = V + (N - x) \]  

Hence the condition for line balancing becomes

\( \frac{D}{CT_{\text{original}}} = \frac{C}{CT_{\text{Revised}}} \)  

OR

\( \frac{D}{V+N} = \frac{C}{V+N-x} \)  

The factor \( N-x \) represents new non-valued added cycle time.

Solving equ (6) we get,

\[ x = (1 - \frac{C}{D}) \times CT_{\text{original}} \]  

subject to the constraints

\[ C \leq c \text{ and } D \geq d \]

Where, \( c \) and \( d \) are actual capacity available and demand per day, respectively.

Generalizing the above equation to \( n \) constrained resources, the optimization problem becomes,

\[
\text{Minimize } y = (1 - \frac{x_1}{x_2}) CT_{\text{original}}^1 + (1 - \frac{x_3}{x_4}) CT_{\text{original}}^2 + \ldots + (1 - \frac{x_{2n-1}}{x_{2n}}) CT_{\text{original}}^n
\]

For \( n \) constrained resources, subject to the constraints,

\[ x_i \geq c_i \text{ for } i = 1,3,5,\ldots,(2n-1) \text{ and } \]

\[ x_i \geq d_{i/2} \text{ for } i = 2,4,6,\ldots,(2n) \]  

where \( c_i \) and \( d_i \) are capacity and demand constraints on \( i^{th} \) machine. The optimization problem as formulated above is non-linear and hence requires a heuristic method where the entire search space is examined for better solution.

III. CASE STUDY
The theoretical model developed above is applied to the line balancing problem of Jadhav Industries, MIDC, Kolhapur. From the previous demand data analysis it was found that the selected component for the study has maximum demand from customers. Also, during manufacturing of selected housing part the company is facing bottlenecks in the production line. Layout of housing production line is shown in figure 1.

![Figure 1: Layout of Housing Production Line before Implementation](image)

The major problems faced by the company during manufacturing of selected housing products are,

1. Problems associated with dispatches
2. Problems associated with work in process inventory
3. Problems associated with Raw material inventory.

The available capacity and demand placed on each resource was carried out using time study method. The comparison between available capacity and the required capacity (demand) is very useful to identification of constraint resources (CR). The resource having available capacity more than required capacity (demand) is identified as non constraint resource (NCR). When the available capacity matches with demand those resources are identified as capacity constraint resource (CCR).

<table>
<thead>
<tr>
<th>Machine Resource</th>
<th>Available Capacity (minutes)</th>
<th>Demand per Day (minutes)</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turret Lathe 1</td>
<td>1260</td>
<td>1080</td>
<td>NCR</td>
</tr>
<tr>
<td>Turret Lathe 2</td>
<td>1260</td>
<td>1080</td>
<td>NCR</td>
</tr>
<tr>
<td>VMC 4</td>
<td>1260</td>
<td>1200</td>
<td>NCR</td>
</tr>
<tr>
<td>VTL 2</td>
<td>1260</td>
<td>1380</td>
<td>CR</td>
</tr>
<tr>
<td>HMC 2</td>
<td>1260</td>
<td>1500</td>
<td>CR</td>
</tr>
<tr>
<td>VMC 1</td>
<td>1260</td>
<td>960</td>
<td>NCR</td>
</tr>
<tr>
<td>Chamfering and Debarring</td>
<td>1260</td>
<td>540</td>
<td>NCR</td>
</tr>
</tbody>
</table>

Table 1: Comparison between available capacity and demand for resources.

Table 1 indicates the available capacity of resources for Turret Lathe 1, Turret Lathe 2, VMC 4, Chamfering and Debarring is more than demand. Hence these resources are identified as non constraint resources (NCR). But available capacity of resources VTL 2 and HMC 2 is less than required capacity (demand), hence VTL2 and HMC 2 are identified as constraint resources (CR).

Analysis of WIP inventory of selected housing product manufacturing on housing production line was carried out; and observed that WIP inventory associated with HMC 2 machine and VTL 2 machine is huge amount.

Available capacity of each resource in the selected production line is 1230 minutes per day (3 shifts). The demand of HMC 2 machine is 1500 minutes per day. This means that the capacity of HMC 2 machine is less than demand placed on it and maximum amount of WIP inventory is accumulated in front of HMC 2 machine. Hence
HMC 2 machine is identified as constraint resource. For achieving the production target 40 parts are required from each resource in selected housing production line per shift, but because of limited capacity HMC 2 machine is only able to produce about 32 parts per shift. Hence there is a shortage of about 8 parts per shift.

Hence to meet the required production rate and achieve the line balancing our study focused on locating constrained resources and applying optimization to minimize non value added component of the cycle time of constrained resources to achieve the synchronous manufacturing state, thus maintaining a uniform flow rate of components through different work stations and achieving optimum production by reducing the lead time of production. Non-linear optimization problem is solved using GA toolbox of MATLAB.

IV. RESULTS AND ANALYSIS

The above optimization problem was solved using GA toolbox of MATLAB. The following options were adopted.

<table>
<thead>
<tr>
<th>Population Type</th>
<th>Double Vector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creation Function</td>
<td>Uniform</td>
</tr>
<tr>
<td>Fitness Scaling Function</td>
<td>Rank</td>
</tr>
<tr>
<td>Initial Population Size</td>
<td>100</td>
</tr>
<tr>
<td>Selection Function</td>
<td>Roulette</td>
</tr>
<tr>
<td>Cross Over frequency</td>
<td>0.8</td>
</tr>
<tr>
<td>Mutation Function</td>
<td>Gaussian</td>
</tr>
<tr>
<td>Crossover Function</td>
<td>Scattered</td>
</tr>
</tbody>
</table>

For the problem under consideration, the individual reduction in non-value added component of cycle time of constrained resources were found to be 30.0 min and 20.0 min, respectively. The former reduction is not practically achievable. Hence alternate measures were recommended. However, the reduction in the non-value added component of cycle time of VTL2 machine is practically achievable by the proper assigned skilled employees and reducing set up time, which automatically balances the production line without requirement of any buffer or shirting some operations to other machines.

Solved HMC 2 Constraint Resource

HMC 2 machine utilized side milling, side drilling, tapping and countering operations on selected housing product. For these operations, cycle time required on HMC 2 machine is 12.5 minutes. To overcome this problem it was suggested to introduce tap fast (TLM1) machine to shift tapping and chamfering operations on HMC 2 on tap fast 1 machine. Therefore, HMC 2 machine is utilized only for side milling and side drilling operations. Layout of the housing production line after implementation of TOC is shown in figure 2.

![Figure 2: Layout of Housing Production Line after Implementation](image-url)
The following figures 3a) and 3b) depict the reduction in cycle time of HMC2 machine and VTL2 machine after the application of TOC using Genetic Algorithm.

Figure 3a: Reduction in Cycle Time of HMC2 Machine

Figure 3b: Reduction in Cycle Time of VTL2 Machine
REFERENCES


