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A Heuristic Approach for U-Shaped Assembly Line Balancing to Improve Labor Productivity

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Abstract- The assembly line balancing problem is a non-deterministic polynomial type planning problem for mass production. Layout design changes constitute a major decision that yields investment for assembly operations and numerous heuristics have been reported in the literature for solving the line balancing problems. U-shaped assembly layout offers several benefits over traditional straight-line layout in implementation of lean manufacturing and Just-In-Time technology. In the paper an attempt has been made to evaluate labor productivity in U-shaped line system and straight line system. A Critical Path Method (CPM) based approach for U-shaped assembly line has been applied for assigning the task to the work stations for assembly line layout. Results show that the CPM based U-shaped approach performs better and improve the labor productivity of assembly line layout.

Keywords- Assembly Line Balancing, Critical path method, Heuristics, Labour Productivity, U-shaped line.
Abstract- The assembly line balancing problem is a non deterministic polynomial type planning problem for mass production. Layout design changes constitute a major decision that yields investment for assembly operations and numerous heuristics have been reported in the literature for solving the line balancing problems. U-shaped assembly layout offers several benefits over traditional straight-line layout in implementation of lean manufacturing and Just-In-Time technology. In the paper an attempt has been made to evaluate labor productivity in U-shaped line system and straight line system. A Critical Path Method (CPM) based approach for U-shaped assembly line has been applied for assigning the task to the work stations for assembly line layout. Results show that the CPM based U-shaped approach performs better and improve the labor productivity of assembly line layout.

Keywords- Assembly line balancing (ALB), Critical path method (CPM), Heuristics, Labour productivity, U-shaped assembly line.

1. Introduction

An assembly line is generally used for mass production and has been a matter of concern of researchers for a long time. A straight line balancing may be defined as processes of assigning tasks to the workstations in such a manner that all workstations have approximately the equal amount of work assigned to them. During assignment of the tasks to the workstations precedence relations among these tasks should not be violated. Many heuristics have been reported for the assembly line balancing (ALB) (Chiang and Urban, 2006).

In recent years, many manufactures have adopted Just-in-Time (JIT) approach for manufacturing, as it is capable to improve productivity, profits and product quality. JIT is beneficial for companies that are engaged in job shop, repetitive types of jobs and process manufacturing. An important change resulting from JIT implementations is the replacement of the traditional straight lines with U-shaped production lines (Aase et al. 2004).

The U-shaped assembly line has become an amicable alternative for assembly production system since operator may perform more than one task located to different places of assembly line. Moreover, the U-type line disposition allows for more possibilities on how to assign the tasks to the workstations therefore the number of workstations needed for a U-shaped line layout is never more than the number of workstations needed for the traditional straight assembly line. In the traditional ALB, for a given cycle time (the time interval between two successive outputs), the set of possible assignable tasks is confirmed by those tasks whose predecessors have already been assigned to workstations, whereas in the U-type line balancing problems, the sets of assignable tasks is determined by all those tasks whose predecessors and successors have already been assigned (Liu et al., 2003).

One of the important characteristics that make U-shaped assembly lines different from straight assembly lines is that the entrance and the exit of these lines are at the same position (Monden 1993). Products enter the U-shaped assembly line at the front-side and exit from the back-side of the line. The lengths of front-side and back-side of the U-shaped assembly line are equal and operators work inside of the U-shaped assembly line. Studies on U-shaped assembly lines provide evidence for their potential to improve visibility and communication skills between operators, reduce operator requirements, increase quality, reduce work-in-process inventory, and facilitate problem-solving and efforts to adjust to changes in the external environment of the firm.
(Miltenburg 1998, 2001, Aase et al. 2004; Kara et al. 2011). Cheng et al. (2000) have listed the following factors that enhanced the wider acceptance of U-shaped lines:

I. **Volume flexibility:** - The production rate of a line in a JIT environment changes frequently. In such an environment, a U-shaped is preferred to a straight line because of its volume flexibility. By increasing or decreasing the number of operators on the line, a company can adjust the production rate as required. This level of volume flexibility is harder to obtain with a straight line.

II. **Operator Flexibility:** - Since walking distance is shorter in a U-shaped than on a straight line, it is easier for an operator to oversee on several work stations.

III. **Number of Workstations:** - The number of workstations required for a U-shaped is never more than, that required on a straight line. There are more possibilities for grouping tasks into workstations on a U-line.

IV. **Material Handling:** - A U-line eliminates the need for special material-handling equipment such as conveyors and other special material-handling operators those are necessary in straight line. Instead, production operators move products from machine to machine.

V. **Visibility and Teamwork:** - In a straight line layout operators are spread out along a long line and may be separated by walls of inventory. The compact size of a U-line improves visibility and communication. This enhances teamwork, gives a sense of belonging, and increases responsibility and ownership compared to a straight line.

VI. **Rework:** - In a U-line, the distance to return the defective product is short. It is easier to correct a quality problem quickly by returning a defective product to the station where product was produced. This is in contrast to the traditional policy of sending the defective product to a separate rework area.

In this paper an analysis of labor productivity for U-shaped line and traditional straight has been carried out using bi-directional assignments and with a CPM based approach. In section II, the relevant literature has reviewed, while Section III depicts precise description of the U-shaped and traditional straight-line layout. In section IV, the applied approach has been described and in section V a practical example and computational results have been shown with the conclusion in Section VI.

2. **Literature review**

Assembly line balancing problem has become a matter of concern for academicians and researchers for a long time. Many heuristics, exact algorithms and optimization techniques have been deployed for the assignment of the tasks to workstations. However, majority of the past studies has been focused on the traditional straight assembly line layouts.

Baybarst (1986) has developed a single pass heuristic for single-model deterministic line balancing, for different priority rules. Askin and Zhou (1997) have proposed a nonlinear integer program as a model for mixed model line balancing problems with parallel workstations. Fleaser and Hindi (2003) have proposed a bidirectional heuristic for assembly line balancing problem with a reduction technique. Liu et al. (2003) have proposed two heuristics for solving the assembly line balancing. The proposed algorithm first generates an initial solution by a bi-directional assignment
procedure, thereafter improves the solution by swapping tasks among workstations. Liu et al. (2005) have proposed a bi-directional heuristic to solve the single-model stochastic assembly line balancing problem and then smoothed the workload by swapping tasks among workstations. Dolgui et al. (2006) have presented a solution for a special case of transfer lines balancing by graph approach. Becker and Scholl (2006) presented a survey on problems and methods for generalized assembly line balancing. Yeh and Kao (2009) have proposed a bi-directional heuristic based on critical path method. Bautista and Pereira (2009) have proposed a dynamic programming based heuristic for the assembly line balancing problems. Guschinskaya and Dolgui (2009), described transfer line balancing problems with an objective to group the operations into blocks and to assign the blocks to machines in order to minimize the total amount of the required equipment. They also presented a comparison of exact and heuristic methods for a transfer line balancing problems. Battaia and Dolgui (2012) have presented a survey with an objective to analyze research on balancing flow lines within different industrial contexts in order to classify and compare the means for input data modeling, constraints and objective functions used.

Nakase et al. (2002) have proposed a management design approach for stochastic task time and have evaluated the cost and lead time under demand fluctuation. Khan et al. (2002) have proposed a knowledge based design methodology to optimize the mixed model assembly line for real life problem with stochastic task times. Kumar et al. (2003) presented an Expert Enhanced Coloured Stochastic Petri Net and its application in assembly/disassembly with the focus on facilitates. The process planning activities of assembly/disassembly are also analysed. Simaria and Vilarinho (2004) have used genetic algorithm to minimize the cycle time for mixed model problem with parallel workstations. Killincci and Bayhan (2006) have proposed an algorithm based on Petri-Net approach for minimization of number of workstations. Bautista and Pereira (2006) have proposed an Ant algorithm for time and space constrained assembly line balancing.

Miltenburg and Wijngaad (1994) have introduced U-line balancing to overcome the limitations of the traditional straight line balancing. They used a dynamic programming formulation to solve small problem instances. Sparling and Miltenburg (1998) studied the mixed model U-lines (MMULs) and developed a procedure for line balancing. Urban (1998) presented an integer linear programming formulation to solve small to medium size U-line balancing problems via standard mathematical programming software. School and Klein (1999) have developed a branch and bound procedure to solve, problems with 297 tasks. Ajenbit and Wainwright (1998) have developed a genetic algorithm for assembly line balancing. Miltenburg (2002) has solved the dual problem of balancing and scheduling using a genetic algorithm. Cheng et al. (2000) have analyzed the effect of the straight line layout and U-shaped line layout on the product quality. Eral et al. (2001) have proposed simulated annealing as solution methodology for large U-lines. A study containing the analysis of procedures followed for the balancing of U-line was carried out by Aase et al. (2003) which detailed various design elements that should be included into the solution methodologies for solving the U-shaped assembly line balancing problem. Later Aase et al. (2004) found the impact of U-shaped assembly line layout on the labor productivity. Some hypothesis and variable on which the labor productivity depends have been described. Hadi et al. (2005) have proposed a new model based on the finding the shortest route in a directed network for simple U-
shaped assembly line balancing problems. Kim et al. (2006) have proposed an evolutionary algorithm for the mixed-model U-line balancing and scheduling that utilized the endosymbiotic principles of evolution. Chiang and Urban (2006) have proposed a heuristic based on the first-fit assignment approach and the priority based approach with stochastic task time. Nakade and Nishiwaki (2008) have presented an optimization problem for finding an allocation of workers to the line that minimizes the overall cycle time under the minimum number of workers satisfying the demand. Toksari et al. (2008) have proposed an algorithm for simple and U-shaped assembly line with learning effect for minimization of number of workstations. Agarwal and Tiwari (2008) have presented a mixed-model U-shaped disassembly line with stochastic task time problems and have proposed Collaborative Ant Colony Optimization (CACO) for line balancing and model sequencing problems simultaneously. Kara et al. (2011) have proposed a new integer programming formulation for Resource dependent assembly line balancing problems in U-shaped lines and examined the percent improvement in total cost when the line layout is switched into the U-shaped from the straight line shape. Prakash et al. (2012) have proposed a Constraint-Based Simulated Annealing (CBSA) approach to solve the disassembly scheduling problem. Hamzadayi and Yildiz (2012) have proposed a genetic algorithm based approach for balancing and sequencing of mixed-model U-lines simultaneously with parallel workstations and zoning constraints.

The benefits of the U-line as compared to a straight line include reduction in the wasted movement of operator, work-in-process inventory, and improved productivity (Hirani, 1988), easier implementation of zero-defects comparing, higher flexibility in workforce planning in the face of changing demand (Monden, 1983), and improvement in material handling (Sekine, 1992). Several authors, including Sekine (1992) have provided an explanation of U-shaped production lines and the way they operate, as well as the benefits realized by their implementation (Chiang and Urban, 2006).

Cheng et al. (2000) and Gokcen et al. (2005) have described some salient features of U-shaped line over straight line. These features includes: operator flexibility, number of workstations, material handling, visibility and team work etc. A U-line arranges machines around a U-shaped production line. Operators work inside the U-line. The space at the center of the U is a shared area where operators can supervises both the entrance and the exit of the line, communicate to other operator, help one another, and learn one another’s skills. Wantuck (1989) describes better communication as one of the benefits of a U-line in a plant in Tennessee. These advantages of U-shaped line over straight lines make an operator more flexible to work at any workstation. The U-shaped line disposition allows for more possibilities on how to assign the tasks to workstations therefore the number of workstations needed for a U-shaped assembly line layout is never more than that for the straight line layout. The numbers of material-handling equipments used and total material-handling distance in U-shaped lines are less as compared to straight line. It is due to the fact that the straight lines can be oriented in two directions, horizontally or vertically, and that U-shaped lines can be oriented in four ways, horizontal with the opening to the left or right and vertical with the opening to the top or bottom. As machines are closed to each other, it results in better visibility (Wantuck, 1989; Maskell, 1991; Hall, 1992), especially when operators walk back and forth between machines on opposite sides of the U-line. Operators on a U-shaped line with at
least one crossover station can visualize one another’s work, examine a higher number of completed tasks than operators on a straight line, develop a better understanding of the whole production process, and can help one another. Operators are trained to be multi-skilled, and are rotated through jobs on the U-shaped line. The average distance between pairs of stations on U-lines is less than it is on straight lines. The operators are closer on U-lines, it is easier for them to work together as a team to identify and solve chronic quality problems.

Suzaki (1987) has reported that the visibility of U-line as compared to traditional straight production line may be explained by the example of an U.S. Company. The company used a traditional straight line that featured a conveyor to ease material handling. However, material flow was still complicated, in-process inventory was high, and quality problems went uncorrected. The company decided to rearrange the straight line into a U-shaped. The conveyor was removed, machines were placed closer together, and operations were synchronized. In-process inventory dropped by 99% and quality problems fell by 72% (Cheng et al., 2000).

### 3. U-shaped and traditional straight-line layout

Manufacturing of a product needs the completion of a set of tasks. Each task has a processing time and a distance that is the amount of space the task occupies on the line. The order in which tasks may be completed is constrained by a set of precedence relations that reflect technological requirements for production of a product. The work content in a station is the total time an operator requires travelling to the locations of the tasks and processing them. The maximum work content of a station is denoted, and is called the cycle time (Cheng et al., 2000).

Insert Fig. 1(a) & 1(b)

The traditional straight line layout allows organizing the tasks sequentially in one direction to form stations. A U-line, however, permits tasks located on both side of the line to form stations (Balakrishnan et al., 2009). Fig. 1 (a, b) illustrate the fundamental difference between the straight line and U-line layouts. When using a straight line layout, operators perform one or more tasks on a continuous portion of the line whereas in a U-shaped layout, operators are allowed to work across both legs of the line. By allowing operators to work across both legs of the line, the U-shaped layout in Fig. 1 requires fewer workstations then the straight line layout (Aase et al., 2004). Stations on a U-shaped line are of two types, crossover and regular. A crossover station contains tasks on both sides of the line, and the operator must cross from one side of the line to the other to complete all of the tasks in the station. Examples of crossover stations are stations 1 and 3 in Fig. 1(b). Tasks in a regular station are located one after the other, and the operator is not required to cross from one side of the line to the other to complete them. Examples of regular stations are all stations in Fig. 1(a) and stations 2 in Fig. 1(b) (Cheng et al., 2000).

The U-line balancing problem is to assign tasks to stations arranged in a U-shaped production line (Aase et al., 2004). The U-shaped assembly line balancing problem may be define as the assignments of all the tasks on the U-line to form a minimal number of work stations while the work contents in each station should not be greater than the given cycle time (Balakrishnan et al., 2009).
U-lines are described as the production lines that fabricate a product, assemble a product, or fabricate and assemble simultaneously (Cheng et al., 2000).

4. Proposed Heuristic

The proposed heuristic is a modification of the heuristic that was proposed by Yeh and Kao (2009). In case of heuristic proposed by Yeh and Kao (2009), the tasks can be assigned to different workstation from both ends of the assembly line on different workstations and these tasks cannot be assigned to same workstation from both ends of the line and precedence graph. In case of proposed U-shaped assembly line the tasks can be assigned to same workstation from both ends of the line and precedence graph. The U-shape of the line and type of task assignment procedure makes it differ from the heuristic proposed by Yeh and Kao (2009) and it improves the performance of the heuristic in terms of minimum number of required workstations and labor productivity.

The following notations are used in the proposed heuristic:

Notations

\[
\begin{align*}
C & \quad \text{the cycle time} \\
WS & \quad \text{workstation} \\
i & \quad \text{index of workstation} \\
j & \quad \text{number of virtual workstation (1,2,\ldots,n)} \\
S & \quad \text{the set of tasks in the assembly to be assigned to workstations} \\
Sa & \quad \text{the set of tasks assigned to workstations} \\
Su & \quad \text{the set of tasks unassigned to workstations} \\
S_{cp} & \quad \text{the set of tasks on critical path} \\
S_{cp}' & \quad \text{the set tasks not on critical path} \\
T(WSij) & \quad \text{total processing time of tasks assigned to the virtual workstation } j \text{ at index } i
\end{align*}
\]

The assignment of the tasks has been carried out in four steps:

i. The first step is to find out the critical path of the precedence graph of given problem. Thereafter the tasks on critical path and not on critical path must be separated. A set of critical tasks \( S_{cp} \), are evaluated using CPM that have higher priority in tasks assignment and set of \( S_{cp}' \) represents those tasks which are not on critical path.

ii. The second step is creation of new virtual workstations. In U-shaped line, tasks are allowed to be assigned to the same workstations from both end of the precedence graph. Therefore, each time the assignment of tasks begins to new workstations. Some temporary workstations are created and assigned the eligible tasks to the workstations. The tasks can be assigned to workstation from both ends of precedence graph. A task is eligible to be assigned to a workstation from start end if all predecessors of the task have been already assigned or at finish end of its precedence graph, if all successors of the task have been already assigned, and the assignment of the task does not violate the cycle time requirements.

iii. The third step is to assign the eligible tasks to the virtual workstations. First of all assign the tasks to virtual workstation from \( S_{cp} \) with no predecessors or with no successors, and tasks in \( S_{cp}' \) are assigned necessarily only if the assignment of tasks in \( S_{cp} \) violate precedence...
relationship. In case of ties, any reasonable priority rule (such as maximum task time, number of followers, rank positional weight etc.) can be used for tie breaking. Task assignment continues until no more eligible tasks can be assigned.

iv. The forth step is to convert the virtual workstation to the real workstation. After assigning the task to the workstations, we select one workstation and make it permanent. The selection of permanent workstation depends on slack time of workstation, since slack time is the deviation of workstation workload from the cycle time; it is intuitive that smaller deviation tends to reduce the number of required workstation. Thus, the workstation having the smaller slack time is selected and made permanent with the tasks those are assigned to it, and the procedure terminates when all the tasks have been assigned to permanent workstations otherwise go to step 2. Flowchart of the above procedure is as shown in Fig. 2.

Insert Fig. 2 here

5. Example and computational results

In this section the procedure of the proposed heuristic has been illustrated by an example and the productivity has been calculated for both U-shaped line and straight line. Fig. 3 shows the precedence diagram of the selected problem having 7 tasks. The nodes represent the task and the arrow represents the direction of process. The number within the nodes represents tasks number or name and the arrow connecting the nodes specifies the precedence relations. The number over the nodes represents task processing time. The cycle time of this problem has been assumed as 10 units and the total processing time is 27 units. The given problem has been solved by proposed heuristic for both the U-shaped line and straight assembly line.

Insert Fig. 3 here

5.1. Illustration of computational procedure using proposed heuristic:

*Initialization:*

1. Step 1. \( Su = S = \{1,2,3,4,5,6,7\} \) and \( i = 1 \), apply CPM and have \( Scp = \{1,2,5,7\} \) and \( Scp^r = \{2,4,6\} \)

*Iteration 1:*

1. Step 2. Create temporary station for task assignment.
2. Step 3. \( Scp = \{1,2,5,7\} \) and \( Scp^r = \{2,4,6\} \) and workstations are \( \{1,7\} \) and \( \{1,2\} \).
3. Step 4. Since \( T(WS11) = 10 \) and \( T(WS12) = 10 \), and \( T(WS11) = T(WS12) \), workstation \( WS11 \) is made permanent therefore \( Sa = \{1,7\} \) and \( Su = \{2,3,4,5,6\} \), and let \( i = 2 \). Now go to step 2.

*Iteration 2*

1. Step 2. Create temporary stations for task assignment.
2. Step 3. \( Scp = \{3,5\} \) and \( Scp^r = \{2,4,6\} \) and workstations are \( \{3\} \) and \( \{2,4\} \).
3. Step 4. Since $T(WS21) = 8$ and $T(WS22) = 8$, and $T(WS21) = T(WS22)$, so workstations WS21 is made permanent and let $i = 3$, $Sa = \{3\}$, $Su = \{2,4,5,6\}$, go to step 2.

**Iteration 3**

1. Step 2. Create temporary stations for task assignment.
2. Step 3. $Scp = \{5\}$, $Scp^- = \{2,4,6\}$ and workstations are $\{2,4\}$ and $\{2,6\}$.
3. Step 4. Since $T(WS31) = 8$, $T(WS32) = 9$, and $T(WS31) < T(WS32)$, so workstations WS32 is made permanent and let $i = 4$, $Sa = \{2,6\}$, $Su = \{4,5\}$, go to step 2.

**Iteration 4**

1. Step 2. Create temporary stations for task assignment.
2. Step 3. $Scp = \{5\}$, $Scp^- = \{4\}$ and the only workstations is $\{4,5\}$.
3. Step 4. Since only one workstation is available, so workstations WS4 is made permanent and let $i = 5$, $Sa = \{4,5\}$, $Su = \{NULL\}$, now terminate the process.

The procedure is terminated when all tasks have been assigned, and the result of the above iteration and task assignment by the proposed heuristic has been summarized in Table 1 and Table 2. It is noticed that four workstations are needed by the proposed heuristics which are less than the workstation required for the traditional straight line layout.

**Insert Table. 1 here**

**Insert Table. 2 here**

It can be seen (Table 1 and Table 2, Fig. 4 and Fig. 5) that the number of workstation required by the traditional straight assembly line layout are 5 and the number of workstations required for the U-shaped assembly line layout are 4. Therefore the number of workstations has been reduced by one in U-shaped line layout.

**Insert Fig. 4 here**

**Insert Fig.5 here**

5.2. Impact on labor productivity on assembly lines:

The labor productivity of an assembly line depends upon a number of factors. The three main factors used by the Aase et al. (2004) are reduction in number of workstations, level of labor productivity and percentage improvement in labor productivity. These factors are described in the following sub sections.

5.2.1. Reduction in number of workstations:

The reduction in number of workstations can be calculated by following expression:

\[
\text{Reduction in number of workstations} = M_{SALB} - M_{SULB},
\]

where $M_{SALB}$ is the optimal number of workstations for straight assembly line layout and $M_{SULB}$ is the optimal number of workstation for U-shaped assembly line layout.
5.2.2. Level of labor productivity:

The labor productivity for the problem can be calculated by using following expression:

\[ P_j = \frac{1}{(CT \times M_j)} \]  

(2)

where \( P \) is the labor productivity level; \( j \) is the shape of layout that may be U-shaped or straight line; \( M \) is the number of work station; \( CT \) is the cycle time of the workstation that can be calculated with the help of the required production rate. The \( CT \) has fixed for both types of layouts so the level of labor productivity is inversely proportional to the number of workstations.

5.2.3. Percentage improvement in labor productivity:

The percentage improvement in labor productivity that can be got by using U-shaped assembly layout over traditional straight line layout has calculated as follows:

\[ \Delta P = \frac{(M_{SALB} - M_{SULB})}{M_{SULB}} \]  

(3)

where \( \Delta P \) = percentage improvement in labor productivity.

The results of calculation of improvement in labor productivity are shown in Table 3. Authors apply the proposed approach as well as CPM based traditional straight bi-directional by Yeh and Kao (2009), to solve the selected problems. The comparison of the results of these approaches to show the efficiency, effectiveness and their impact on labor productivity have been presented. The performance of proposed heuristic is compared with the heuristic proposed by Yeh and Kao (2009). It is noticed that proposed heuristic performs well and provides higher labor productivity with lesser number of workstations. The results are shown in Table 4.

6. Conclusion

Now a day, U-shaped layouts have been utilized in many assembly lines in place of the traditional straight line. This is just because of the use of just-in time principles in production industries. The U-shaped lines improve visibility and allow the worker to perform tasks on both sides of the line. As compared to straight assembly line, this unique feature of U-shaped line, combined with cross-trained workers and provide much more flexibility in designing of workstation.

The heuristic based on Critical Path Method has been proposed for the assignment of tasks to the workstations on U-shaped assembly line layout. The heuristic is capable to reduce the minimum number of required workstations for assignment of the tasks in U-shaped line layout as compared to traditional straight line layout. It also improves the productivity level of the labor. The results show improvements when using the proposed heuristic in terms of minimum number of required workstation and labor productivity.

This work also examined the statement made by JIT and lean manufacturing proponent that U-shaped assembly line layouts are more efficient than straight line layout by Khan and Day (2002). Results of experiments show that in most of the cases, U-shaped layouts are capable to improve labor productivity. Therefore it is proposed that managers may convert to a U-shaped layout while evaluating its viability of improvement in labor efficiency that in terns may save the
cost of assembling the product. The scope of future work may include modification of the proposed heuristic with stochastic task time. Further improvements for the effectiveness and extension of the proposed heuristic may be considered with other performance measures such as product quality, cost, speed, and flexibility.

References


Table 1. Solution by traditional straight assembly line layout

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<thead>
<tr>
<th>Workstation Number</th>
<th>Set of eligible tasks</th>
<th>Total task time</th>
<th>Idle time</th>
<th>Cumulative idle time</th>
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<td>1</td>
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<td>13</td>
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Table 2. Solution by U-shaped assembly line layout

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<th>Number of workstations</th>
<th>Set of eligible task</th>
<th>Total Task time</th>
<th>Idle time</th>
<th>Cumulative idle time</th>
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<tr>
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<td>9</td>
<td>1</td>
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Table 3. Improvement in labor productivity

<table>
<thead>
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<th>S. No.</th>
<th>Variables</th>
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<th>Proposed Heuristic</th>
<th>Improvement</th>
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<td>Labor productivity</td>
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<td>3</td>
<td>Percentage improvement in labor productivity</td>
<td></td>
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<td>25%</td>
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Table 4. Comparison of Proposed Heuristic with Bidirectional CPM Heuristic

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Variables</th>
<th>Bidirectional CPM Heuristic</th>
<th>Proposed Heuristic</th>
<th>Improvement</th>
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<tr>
<td></td>
<td>Number of required workstations</td>
<td>5</td>
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<tr>
<td></td>
<td>Labor productivity</td>
<td>0.0100</td>
<td>0.0125</td>
<td>Improved</td>
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<td>Percentage improvement in labor productivity</td>
<td>-</td>
<td>-</td>
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<tr>
<td>2.</td>
<td>Jacschke 9 tasks problem, CT=13</td>
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<td></td>
<td>Percentage improvement in labor productivity</td>
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<td>-</td>
<td>0%</td>
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<td>3.</td>
<td>School 12 tasks problem, 1999, CT =10</td>
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<tr>
<td></td>
<td>Labor productivity</td>
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<td>0.0167</td>
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</tr>
<tr>
<td></td>
<td>Percentage improvement in labor productivity</td>
<td>-</td>
<td>-</td>
<td>16.7%</td>
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<tr>
<td>4.</td>
<td>Stevenson 8 tasks problem, CT=16</td>
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<td>4</td>
<td>1 Reduced</td>
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<tr>
<td></td>
<td>Labor productivity</td>
<td>0.0125</td>
<td>0.0156</td>
<td>Improved</td>
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<tr>
<td></td>
<td>Percentage improvement in labor productivity</td>
<td>-</td>
<td>-</td>
<td>25%</td>
</tr>
<tr>
<td>5.</td>
<td>Stevenson 12 tasks problem, CT=17</td>
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</tr>
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<td></td>
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<td>0.0098</td>
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<tr>
<td></td>
<td>Percentage improvement in labor productivity</td>
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<td>6.</td>
<td>Hahn 53 tasks problem, CT=2004</td>
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<tr>
<td></td>
<td>Labor productivity</td>
<td>.0000554</td>
<td>.0000624</td>
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</tr>
<tr>
<td></td>
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<td>-</td>
<td>12.5%</td>
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<tr>
<td>7.</td>
<td>Hahn 53 tasks problem, CT=2338</td>
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<td>Labor productivity</td>
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<td>.0000611</td>
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<td>8.</td>
<td>Hahn 53 tasks problem, CT=2806</td>
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<td></td>
<td>Labor productivity</td>
<td>.0000509</td>
<td>.0000594</td>
<td>Improved</td>
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<td>16.67%</td>
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<td>9.</td>
<td>Rosenberg and Ziegler 25 tasks problem, CT=16</td>
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<tr>
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<td>Number of required workstations</td>
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<td>8</td>
<td>1 Reduced</td>
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<tr>
<td></td>
<td>Labor productivity</td>
<td>.00694</td>
<td>.00781</td>
<td>.00087 Improved</td>
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<tr>
<td></td>
<td>Percentage improvement in labor productivity</td>
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<td>12.5%</td>
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<tr>
<td>10.</td>
<td>Wee and Magazine 75 tasks problem, CT=52</td>
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<td>Number of required workstations</td>
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<td></td>
<td>Labor productivity</td>
<td>.00060</td>
<td>.00062</td>
<td>.00002 Improved</td>
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<td>Percentage improvement in labor productivity</td>
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<td>3.23%</td>
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<tr>
<td>11.</td>
<td>Wee and Magazine 75 tasks problem, CT=56</td>
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<td>Number of required workstations</td>
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<td></td>
<td>Labor productivity</td>
<td>.000576</td>
<td>.000595</td>
<td>.000019 Improved</td>
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<tr>
<td></td>
<td>Percentage improvement in labor productivity</td>
<td></td>
<td></td>
<td>3.33%</td>
</tr>
</tbody>
</table>
Fig. 2. Flow chart of proposed heuristic

Initialization:
Set $S_u = S$ and $i = 1$

Create new temporary workstations:

Task assignment:
Find $S_{cp}$ by the CPM
Assign eligible tasks in $S_{cp}$ to workstations
Tasks in $S_{cp}$ are assigned only necessarily.
Set $S_{cp}^- = S_u / S_{cp}$

Permanent workstation:
If $T(WS1) > T(WS2)$, make $WS1$ permanent
otherwise make $WS2$ to permanent
Let $S_u = S_u / S_a$, where $S_a$ is the set of tasks in permanent workstation.

All the tasks have been assigned?
Yes
Stop
No

Fig. 1.a. straight line layout

Fig. 1.b. U-shaped line layout
Fig. 3. Precedence diagram

Fig. 4. Solution by straight line layout

Fig. 5. Solution by U-shaped line layout
- We modify the CPM based heuristic and integrate it with U-shaped heuristic.
- We use this heuristic to improve labour productivity.
- We examine this heuristic over a large number of different size problems.
- This heuristic performs better than old CPM based heuristic.
- This heuristic also improves the productivity of labour.
- In some problems it improves the results up to significant level but in some problems it improves the results up to a very high level.