CHAPTER 1

INTRODUCTION

1.1 Production and Productivity

Basically, production is concerned with the conversion or transformation of inputs into outputs. The inputs may be in the form of raw materials or semi-finished products. The efficiency of this transformation process can be increased by selecting the proper layout like process layout (or) product layout according to the nature of operation involved, like batch production or mass production respectively to get finished product in desired quantity.

Productivity is the watchword for any organization because “Drops of productivity add to ocean of profits”. Assembly Line Balancing (ALB) is very important for improving the productivity of mass production systems.

1.2 Assembly Line Balancing Problem

1.2.1 Description of Assembly Line

The components and characteristics of an assembly line are described in this section.

The manufacture of certain products is accomplished by using a series of workstations or an assembly line. The basic components of such an assembly line are number of indivisible elemental operations, precedence relations and processing times. The processing times are independent of the sequence in which the operations are performed. The precedence relations require certain operations to be completed before others are started. An assembly line is designed by aggregating elemental operations at workstations in such a way that the constraints like precedence relations are satisfied for a given volume of production.
Assembly line may also be described in the following way:

Assembly line is the best example of product layout, which consists of number of work elements/tasks, each having an operation processing time and a set of precedence relationships, which specify the permissible ordering of tasks. A detailed specification of how the assembly of a product flows from one element to another element is indicated by a precedence relationship. These work elements are usually divided into a set of workstations. While forming the work stations, care should be taken such that the sum of the processing times of the assigned work elements in each station is not more than cycle time and also all the immediate predecessors of the work elements which are assigned to that station are already assigned to some other earlier station(s)/that station (current station) or they don’t have any predecessor(s).

The standard practice of assembling a product in the flow production shop is to use a conveyorized line. Operators are placed along the line on which the chassis or frame of the product being assembled is moved. The total assembly of the product is broken into elements of work and assigned to various stations on the line. When the product moves along the line, each operator adds to it his share of the work.

In a mass production system, it is essential to design assembly line in a better way by taking the production volume per shift and the effective time available per shift as inputs. Based on these two quantities, Cycle Time (CT) is computed. The cycle time is the ratio of production volume per shift and the effective time available per shift.

**1.2.2 Line Balancing Problem**

The structure of line-balancing problem is presented here.

In a line-balancing problem, one is given a finite set of work elements, each having a fixed processing time, and a set of precedence relations among them,
which specifies the permissible ordering of the elements. The problem is to assign the elements to an ordered sequence of stations such that the precedence relations are satisfied and that some measure of performance is optimized. The most common objective is to minimize the sum of the idle times of the stations.

Formally, given a finite set B, a partial order p defined on B, a positive real valued function t defined on B, and a number c, find a collection of subsets of B, \((A_1, \ldots, A_n)\) satisfying the following five conditions:

1. \(\bigcup_{i=1}^{n} A_i = B\)
2. \(A_i \cap A_j = \emptyset\) (the empty set), \(i \neq j\)
3. \(t(A_i) = \sum_{x \in A_i} t(x) \leq c, i = 1, \ldots, n\)
4. If \(xpy\) (x proceeds y) and \(x \in A_i, y \in A_j,\) then \(i \leq j\)
5. \(\sum_{i=1}^{n} [c - t(A_i)]\) is minimized.

In the above discussion, the set B consists of the work elements \((x, y, \ldots)\) or if \(xpy\) (x proceeds y) and \(x \in A_i, y \in A_j,\) then \(i \leq j\) and the partial order p corresponds to the precedence relations. The function t assigns processing times to the work elements and c is the cycle time. Sets \(A_i\) satisfying conditions from 1 to 4 are feasible assignments and those satisfying all five conditions result with an assignment of elements to \(n\) stations which minimizes the total idle time. The minimization of the total idle time will automatically minimize \(n\).

Each individual assembly line presents a unique problem for the operation manager. In balancing a line, a large number of interrelated variables like number of operators, number of workstations, duration and the precedence relationships among various operations of the product to be manufactured must be planned and controlled.

1.2.3 **Definition of Assembly Line Balancing (ALB)**

There are number of ways by which Assembly Line Balancing may be defined. Various ways of defining ALB are discussed in this section.
Assembly Line Balancing may be defined as assigning number of work elements to various workstations so as to maximize Balancing Efficiency (BE) or to minimize Number of workstations (N) or to accomplish any other given objective function for a given volume of output without violating the precedence relationship.

Another way of defining ALB is assigning the tasks to a minimum number of workstations for a given cycle time and / or to reduce the probability of line stoppage in a production line.

Panneerselvam and Oudaya Sankar, (1993) have defined ALB as assigning work elements to various work stations in such a way that the sum of the assigned cycle time is maximized or the sum of unassigned cycle time (Sum of the idle time of the stations) is minimized for a given volume of line output.

The processing times of the tasks or work elements can be constant or probabilistic. When the task times are constant, the ALB problems may be called as deterministic problems and when they are probabilistic the ALB problems are called as stochastic problems.

1.3 History of Assembly Line Balancing

A brief history about the development of Assembly Line Balancing problem is presented in this section.

Salveson (1955) was the first one to present a mathematical formulation of Assembly Line Balancing problem, in the form of a linear program. Since then, several research papers in the area of line balancing have appeared. ALB problems are NP hard (Gutjahr and Nemhauser, 1974). This has made it difficult to develop exact algorithms to obtain optimal solution. The need for designing efficient heuristics with polynomial time complexity function has motivated the researchers to develop computer efficient approximation algorithms or heuristics to solve large-scale ALB problems (Hoffman 1963, Arcus 1966, Magad 1972,

Also it is well known that the heuristics for solving line-balancing problems end up in a local optimum. Enumerative methods which give global optimum solutions are computationally very expensive when the problem size is very large. So random search techniques like Simulated Annealing (SA) or Genetic Algorithms or other new algorithms are preferred over optimal methods as they give consistently near optimal solutions, which are better than those provided by other heuristic methods. In this research, a new heuristic for assembly line balancing problem is proposed.

1.4 Classification of Assembly Line Balancing problems

Different types of Assembly Line Balancing problems are presented in this section. Classification of Assembly Line Balancing problems is shown in figure 1.1.

![Figure 1.1 Classification of ALB problems](image)

1.4.1 Single Model Deterministic (SMD) problems

This category is the simplest form of ALB problems in which single product type is assembled in an assembly line. Here the task times are known deterministically. This will hold for shops with a high level of automation.
1.4.2 Single Model Stochastic (SMS) problems

In this model also, a single product type is assembled in an assembly line. But the processing times of different tasks are assumed to be probabilistic in this category. This is more realistic for manual assembly lines, where operators task times are seldom constant.

1.4.3 Multi / Mixed Model Deterministic (MMD) problems

In this category the task times are assumed to be deterministic but multiple products are assembled in the same assembly line. Multi – model lines assemble two or more products in batches, whereas in mixed – model lines, different models of the same product are assembled. But the above two types of problems are analyzed under the same class of problems.

1.4.4 Multi / Mixed Model Stochastic (MMS) problems

It differs from MMD only in terms of stochasticity in task times. In this category, multiple products are assembled in the same assembly line as in MMD problem. The concept of multi-model lines and mixed –model lines of MMD problems hold good for this MMS problems also. But the task times are stochastic in nature.

1.5 Assembly Line Balancing Terminologies

The important terminologies involved in Assembly Line Balancing are explained in this section.

**Workstation**

It is an assigned location where a given amount of work is performed. Normally a workstation is manned by one operator only. Sometimes, workstations are manned by several operators, e.g. aircraft production line.

**Minimum rational work element**

It is an indivisible element of work, or natural minimum work unit, beyond which assembly work cannot be divided rationally.
In an automobile assembly, fixing fuel pump, fuel tank, wheel drum etc., are some of the examples of minimum rational work element.

**Cycle Time (CT)**

Cycle Time may be defined as the ratio between the effective time available per period and the production volume per period.

\[
\text{Effective time available per period} = (\text{Time per period}) \times (\%\text{Utilization of period})
\]

The cycle time may also be interpreted in the following ways:

- It is the time between consecutive releases of finished assemblies from the last station of the line.
- It is the time between consecutive releases of semi-finished products between any two adjacent stations.
- It is the maximum time allocated per station.

The relationship between Cycle Time and duration of different work elements is explained with help of the following expression:

\[
t_{\text{max}} \leq CT \leq \sum t_i
\]

where \( t_i \) = duration of \( i^{\text{th}} \) work element

\( t_{\text{max}} \) = maximum work element duration

From the above equation, we understand that cycle time (CT) must equal or exceed the maximum element time \( t_{\text{max}} \). But, it cannot exceed the total work content time, \( \sum t_i \).

**Total Idle Time (TIT)**

The difference between the time required by any station to complete its operations and the cycle time is called the idle time of that station. It is
conventional to treat the minimization of the sum of all stations’ idle time, namely Total Idle Time (TIT) as an objective while designing an assembly line.

1.6 Benefits of Assembly Line Balancing

The benefits of Assembly Line Balancing may be classified into two categories as represented here.

1.6.1 Technical benefits

(1) Minimizing the number of workstations for a given Cycle Time.
(2) Minimizing the Cycle Time for a given number of workstations.
(3) Minimizing the Balance Delay (or) Maximizing the Balancing Efficiency.
(4) Minimizing the total idle time.
(5) Minimizing the overall facility or line length.
(6) Minimizing the throughput time.

1.6.2. Economic benefits

(i) Minimizing the combined cost of labour, workstations, and product incompleteness.
(ii) Minimizing the labour cost per unit.
(iii) Minimizing the total penalty cost for a number of inefficiencies.
(iv) Minimizing the inventory, set up and idle time costs.
(v) Minimizing the total in process inventory costs.
(vi) Maximizing the net profit.
1.7 Methodologies to solve Assembly Line Balancing problems

The methodologies available to solve ALB problems can be classified into two categories namely Exact or Optimum methods and Heuristic methods as given below.

1.7.1. **Exact or Optimum methods**

They can be further classified as
- Linear programming approach
- Integer programming approach
- Dynamic programming approach
- Branch and bound approach
- Goal programming approach
- Shortest path technique

1.7.2 **Heuristic methods**

A heuristic or rule of thumb, is a shortcut solution procedure that searches for a near optimal solution, rather than optimal solution. Analogous to the human trial – and – error process, heuristics reach acceptable solutions to the problems for which optimal solutions are too difficult to find. Well-designed heuristics will produce near optimal solutions and sometimes the optimal solution itself.

They may be further classified as
- Priority Ranking Methods
- Tree search Methods
- Trade and Transfer Methods
- Random sampling Methods

1.8 **Need for the Current Research**

From the overall review of the current literature on Assembly Line Balancing (ALB), the following conclusions can be drawn:
1. Most of the Global Search Methods used for obtaining near optimal solution for ALB problem stop the procedure of obtaining near optimal solution when the stopping criterion is reached.

2. The above methods start with an inferior initial solution.

3. No suitable heuristic is available which gives different weightage to different priority rules used in line balancing. Since all the priority rules may not have equal impact on the solution, they have to be prioritized by giving suitable weights to them.

Thus there is a need to develop a new efficient heuristic to overcome the above deficiencies.

1.9 Research Problem

Assembly Line Balancing problem may be explained as given below.

When a certain commodity is to be manufactured by a production line, first the processing required to produce the commodity has to be broken down into least possible operations / work elements and the following data are to be obtained.

(i) The time required to perform each operation (work element) on one unit of the commodity.

(ii) The technological precedence relationships on the order in which the work elements can be performed to assemble each and every unit of the commodity.

Then, task is to assign the work elements to a sequence of workstations in such a way that:

1. All the tasks/ work elements should be assigned to workstations.

2. One task is assigned to one and only one workstation.

3. The sum of the times for work elements assigned to each and every station does not exceed a given cycle time.
4. Each and every work element is assigned to some station such that all its immediate predecessors are already assigned to some earlier stations or to the current station.

5. The sum of the idle times of the stations is minimized.

1.10 Objective of the Current Research

The most important objective of Assembly Line Balancing problem and the objective of this research work are explained in this section.

1.10.1 Objective of Assembly Line Balancing Problem

The most important objective of the Assembly Line Balancing problem is to design an assembly line with the maximum Balancing Efficiency (BE) or with the minimum Balance Delay (BD) which are explained here.

Balancing Efficiency (BE)

It indicates the percentage utilization of all the stations put together. The formula for calculating Balancing Efficiency in percentage is given below.

\[
BE(\%) = \left( \frac{SACT}{N \times CT} \right) \times 100
\]

Where

- \(CT\) = Cycle Time
- \(SACT\) = Sum of Assigned Cycle Time
- \(N\) = Number of stations.

Balance Delay (BD)

It indicates the idle time of all stations put together. The formula for calculating BD in percentage is given below.

\[
BD(\%) = \left( \frac{SUACT}{N \times CT} \right) \times 100 = 100\% - BE\%
\]
Where

\[ SUACT = \text{Sum of Un-assigned Cycle Time of the stations} \]

1.10.2 Objective of this Research

The objective of this research is to develop a New Efficient Heuristic (NEHU) for Assembly Line Balancing to overcome the difficulties in the previous researches as discussed in the section 1.8, carried out by Suresh and Sahu (1994) and Panneerselvam and Oudayasankar (1993) and also to get a better solution.

The New Efficient Heuristic (NEHU) comprises the following:

(i) Set of heuristics of Heuristics for Assembly Line-Balancing (HAL) – Panneerselvam and Oudayasankar (1993)

(ii) Composite Weight Factor (CWF) heuristic – Newly proposed

(iii) New Global Search Heuristic (NGSH) – Newly proposed

In this proposed heuristic, the best of the results of HAL and CWF heuristic is selected as the initial solution. Then, it is improved using NGSH. The performance of the proposed heuristic is compared with that of the existing set of heuristics namely, Heuristics for Assembly Line – Balancing (HAL).

Also, the power of this proposed heuristic has been proved by an extensive experimental design namely, ANOVA. Software in Visual Basic is developed for testing the sample problems developed in this work.

Apart from this, a case study is also conducted in a practical situation, manufacturing Turbo-chargers. The assembly line studied is balanced with the help of this proposed heuristic.

1.11 Phases of Research:

Figure 1.2 shows the phases of the research.
Figure 1.2 Phases of Research
This research consists of 4 Phases, which are as follows:

**Phase I : Objective:** To study the Assembly Line Balancing (ALB) Problem.

**Task 1:** Study the general concept of Assembly Line Balancing Problem, Classification of ALB problems and related terminologies.

**Phase II: Objective:** To confirm the need to develop a new heuristic.

**Task 2:** Reviewing literature on ALB problems.

**Phase III : Objective:** To develop a new heuristic for Deterministic ALB problem.

**Task 3:** Developing a heuristic for obtaining initial solution.

**Task 4:** Developing a Global Search Heuristic for obtaining optimal solution.

**Task 5:** Designing of the overall heuristic.

**Phase IV : Objective:** To experiment and compare the proposed heuristic, implement it in a case problem and to draw conclusions.

**Task 6:** Experimenting with the proposed heuristic.

**Task 7:** Comparing the proposed heuristic with an existing heuristic.

**Task 8:** Implementing the proposed heuristic in a real life situation.

1.12 Summary

The researcher has discussed the significance of Assembly Line Balancing, related terminologies involved and the methodologies available for solving line-balancing problems in the beginning of this chapter. Then he moves on to explain the need, objective and phases of the current research towards the end of this chapter.