CHAPTER 2

RELATED THEORY & LITERATURE REVIEW

2.1 Assembly Line Balancing

The line balancing problem is to arrange the individual processing and assembly tasks at the work stations so that the total time required at each work station is approximately the same.

If the work elements can be grouped so that all the station times are exactly equal, we have perfect balance on the line and we can expect the production to flow smoothly. In most of the practical situation, it is very difficult to achieve perfect balance when the workstation times are unequal. The slowest station determines the overall production rate of the line.

Operator: An individual who does specific, assigned work upon the units of a product, during progressive assembly, as they are conveyed past through hid assigned work station.

Work Station: A work station is an assigned location where a given amount of work is performed. Assembly line work station is generally manned by one operator. And on lines of large products work station is frequently manned by several operators.

Work Element: It can be defines as the smallest rational division of the total work content in an assembly process.

Cycle Time: The time available at each station for the performance of the work is known as cycle time.

Precedence Diagram: It is a graphic description of any order or sequence in which work elements must be performed in achieving the total assembly of the product. There are 4 precedence conditions:

- Must precede: One work element must be performed before another can be performed.
- Must follow: One work element must not be performed until another has been performed.
- No relationship: One work element can be performed either before or after another.
- Not together: One work element must be performed at the same work station as another because of technological limitation.

Balance delay or Idle time: The amount of idle time on the line due to the imperfect division of work between stations. Since it seems to be seldom possible to divide the work evenly between all operators on the line, those operators having shorter assignments will have some idle time. This idle time is a measure of the imbalance of the line.

The degree or percent of imbalance, simply called "balance delay" is the ratio between idle time at the stations and the maximum operation time. Stated otherwise, balance delay is the ratio between the total idle time and the total time spent by the product in moving from the beginning to the end of the line.

Objectives

Generally, assembly line balancing techniques are based upon two related optimization problems.

I - To find out minimum number of stations for an assembly line, subject to its cycle time not exceeding a given required cycle time and no violation of precedence.

II - To find a assembly line with minimum total balance delay, i.e., minimum cycle time, subject to that the number of stations are not exceeding a given required number of stations.

2.1.1 Assembly Line Balancing Problem

There are, generally, three types of assembly lines according to the variety of the products and the nature of production. These are the single model assembly line devoted to the production of a single model or item, the multi-model assembly line on which two or more similar types of item are produced separately in batches, and the mixed-model assembly line on which two or more similar items are produced simultaneously.

A lot of research has been done on assembly line balancing through several decades. A brief overview on the line balancing problem solution is given below.

SALVESON (1955) presented the first article, well accepted, published on assembly line balancing. He introduced an approach to the problem in which the cycle time was fixed and the number of stations as variables. Salveson defined the problem as following: ... selecting a permutation of the tasks into stations such that:

1. The selected combinations of elements satisfy the technological precedence requirement.
2. The station time is equal to or less than the cycle time.
3. The sum of the idle times over the line is a minimum.

He defines the cycle time as a function of the production volume:

C = Production time / Production volume

Salveson also defines the minimum number of stations for an assembly line as the smallest positive integer out of n integers where n is greater than or equal to the sum of the elemental times divided by the cycle time:

$Kmin = Min (Integer\ n|n > \Sigma Ei / C)$

Where: Kmin = Minimum number of stations;

E = Elemental time;

C = Cycle time

Salveson suggested the use of precedence diagrams to represent ordering relations among work elements and also a linear programming type model encompassing all feasible combinations of work elements that may be assigned to a work station. Combinations with the smallest amount of idle time are selected first, and combinations having work elements also represented in the selected combinations are then deleted. The procedure is repeated until results from this assignment exceeds the cycle time, reducing the number of work stations is to be made. First group of work stations whose cumulative idle time exceeds the cycle time are selected, then recombine work elements in these work stations to obtain a new solution. This procedure is continues until an optimal solution is achieved or until no further improvement is possible.

HELGESON and BIRNIE (1961) proposed a **"Rank Position Weight "** Technique. Each work element is given a weight equal to its time plus the sum of the times of all elements which must follow it.

$Pw_i = Wt_i + (PMAT_{ij}) \times WT_j)), j = 1,2,.....n$

Where Pw_i = positional weight of work element i;

Wt_i = work element of work element i;

WT_j = work element time of work element j;

$PMAT_{ij}$ = dependent coefficient

= 0 if work element j does not need to follow work element i, and i=j.

= 1 if work element j must follow work element i;

n = number of work station

The work elements are then listed in descending order of weight, and an attempt is made to assign them in that order to the assembly stations, starting with the first station and proceeding, station by station, along the line.

GUTJAHR and NEMHAUSER (1964) presented an algorithm that generated the states of a partially ordered set, determine the arcs through a network with nodes consisting if the generated states, find the path with minimum number of arcs, and use these arcs to establish the stations for a production line. A "state" is a collection of work elements that can be performed in any order consistent with the specified ordering relations without the prior completion of any other work elements. A method is used to generate the states of a partially ordered set in such a way that no subsets are duplicated, all generated subsets are states, and every states is generated. Th states are then identified as nodes in a network which are used for any required cycle time. Nodes are connected by arcs if: (i) the subset or work elements is another, and (ii) the difference between the sum of the work element times in each of these nodes is equal to or less than the cycle time.

HUNG (1975) have been considered a number of existing methods in assembly line balancing to obtain solutions of production line problems, Methods involved in the study are *Integer-Linear Programming, Mixed-Integer Linear Programming, One-Phase Heuristic method,* and *Two-Phase Heuristic method.* Computer programs for these methods were written in FORTAIN IV. The output efficiency attained for a specified cycle time is used as the measure of effectiveness and the computing time required to make line balancing calculation for a specified output rate is used as the measure of cost. Comparison between linear programming approach and heuristic approach showed that the latter appears to dominate the former in terms of both efficiency and cost.

AKAGI, OSAKI and **KIKUCHI** (1983) proposed the PAM (Parallel Assignment Method) because the typical assembly line is serial with no paralleling of work elements and work station allowed. This series assumption restricts the least cycle time to be the maximum work element time, thus limiting the production rate. An alternative way to increase the production rate (hence lowering the cycle time) is by assigning multiple workers to one work station. Therefore, PAM is proposed for achieving a higher production rate.

In the first phase of PAM the work elements are assigned to work stations under the multi-stage upper time limits. But as two or more workers are assigned to one station, the operation time of each worker is longer in proportion to the number of workers at the station.

In the second phase of PAM work elements are assigned to the workers in each stations so that each of the workers may perform shorter work elements where the work element is a minimum rational indivisible work item.

SHTUB and DAR-EL (1990) reported the use of precedence diagrams and estimates of task times, as the only source of engineering information for assembly line balancing (ALB) which is concern the most ALB technique developed to date. This journal presents a model which incorporates the information carried by an assembly chart (or a Gozinto chart) into the ALB problem in an attempt to consider engineering objectives such as improving work methods and work enrichment in the design of assembly lines. A multi-objective approach is developed which integrates the tradition objective of minimizing the idle time of the line with the objective that a minimum number of subassemblies should be handled at each workstation.

KABIR (1992) has developed a multiattribute-based approach to determine the number of workstations. At first, a set of feasible number of workstations which are balanced changeover time for each configuration (number of workstation), and finally, a multiattribute evaluation model is developed to select the number of workstations considering *Production rate, Variety, Minimum distance moved, Division of labor* and *Quality* using the Analytic Hierarchy Process and simulation. The methodology is then applied to a real life batch-model assembly line for printing calculators.

2.1.2 Optimization Approach to Assembly Line Balancing Problems

ROSENBLATT and CARLSON (1985) developed a mathematical model for an assembly line to get a relationship between profitability and efficiency of the line. A four-step solution procedure was developed which would determine the optimal number of workstation by maximizing a profit function. The objective function was as:

$$Max.\ x(n) = \frac{f_1}{c} - \sum_{k=1}^{k=n} f_2(k)$$

Where: $x(n)$ = profit per unit of time where n stations are used

f_i = 'contribution' per unit of product

$f_2(k)$ = fixed cost per unit of time for using the kth work station

c = cycle time

n = number of stations

DAS (1987) suggested an improvement to the Jackson's step by step enumeration method of simple single product line balancing problem. The suggestion for improvement of the solution is a selective search technique in a narrow region for obtaining the optimal or near-optimal solution. But so far only optimal solutions have been found.

The step-by-step enumeration technique of Jackson is simple but the solution derived is most often away from optimality but with a little modification of the Jackson's technique the solution of balancing problems can be further improved towards optimality. Generally balance delay and smoothness index are the two criteria for choosing the best line balance. It is obvious that for a given cycle time as the number of station decreases, balance delay decreases too.

The optimum number of work stations, K*, has to be settled with in the two limits as

$$Max\,[\,\text{Kmin, Kfeas}\,] \leq K^* \leq N$$

Where: Kmin = Minimum possible number of work stations

= Min [integer k|k$\leq$ p/c]

= (p/c)+1

Kfeas = Minimum feasible number of work stations

= [number of i|t_i > c/2]

N = number of work elements

p = total processing time

c= cycle time

t_i = processing time of ith work element

So effort must be made to try a balance with the number of work station of Kmin and then stepwise increase the number by unity.

2.1.3 Computerized Line balancing Methods

ARCUS (1966) developed a method called COMSOAL (Computer Method of Sequencing Operations for Assembly Lines). COMSOAL uses a digital computer to sample data and stimulate possible assembly line balances. It randomly generates a number of line balances (samples), allows for addition features such as two-man tasks at adjacent stations, parallel stations, task fixed at specific station, tool acquisition time, time for worker to change position, time to change the position of a unit, grouping task based on the criteria of different wage levels and movement of workers between unit. This can also accommodate mixed production of multiple models and stochastic task times.

IIT Research Institute developed CALB (Computer Assembly Line Balancing or Computer Aided Line Balancing), as referred by **Groover** (1992), in 1968. It can be used for both single-model and mixed model assembly lines. In single-model case, the data required to use the program include processing time T_e, the predecessors, cycle time T_c. the CALB program starts by sorting the elements according to their T_e and precedence requirements, then elements are assigned to stations.

2.2 Optimization Approach

When dealing with decision problems, the model is formulated to define the variables and quantify the relationships needed to describe system behaviour. After that, the analysis is taken to ultimately obtain the conclusions so that the decision can be made.

According to **WINSTON** (1991), A linear programming problem (LP) is an optimisation problem for which following:

1. It is to maximise (or minimise) a linear function of the decision variables. The function that is to be maximised or minimised is called the *objective function*.
2. The values of the decision variables must satisfy a set of *constraints*. Each constraint must be a linear equation or linear inequality.
3. A *sign restriction* is associated with each variable. The sign restriction specifies either nonnegative or unrestricted in signs.

For a maximisation problem, an optimal solution to an LP is a point in the feasible region with the largest objective function value. Similarly, for a minimisation problem, an optimal solution is a point in the feasible region with the smallest objective function value. The feasible region for an LP is the set of all points satisfying all the LP's constraints and all the LP's restrictions.

RARDIN (1998) defined the steps to formulate an optimisation model so that solution can be achieved. The first step in formulating any optimisation model is to identify the decision variables which represent the decisions to be taken. The next step is defining constraints that limits the decisions. Variable-type constraints specify the domain of definition for decision variables that the set of values for which the variables have meaning. Main constraints specify the restrictions and interactions, other than variable type, that limit decision variable values. Then, the objective function is solved by concerning on the constraints and restrictions.

The solution can be calculated by manual that may be take time to implement. Additionally, this method has some restrictions so it can solve the complex problems. Graph is one way to determining the feasible region to obtain the solution. It is plotted by introducing constraints one by one, keeping track of the region satisfying all at the same time. Another way to reach the solution is using *LINDO* (Linear Interactive and Discrete Optimiser). LINDO is a user-friendly computer package that can be used to solve linear, integer, and quadratic programming problems. It is easy to use and can solve the complex problem efficiently.

DOWNEY and LEONARD (1992) developed a methodology to design an assembly line where a fewer number of operators than stations were assigned to taken an advantage of flexible workforce. In this article, an innovative manufacturing techniques, called OFRO (Organisating Flexible, Rotating, Operators) method developed by Japanese, were considered where a fewer number of workers than number of workstations are employed. In such a situation, buffer level at each workstation was a major design factor. The first approach of this design was to balance the line then a cost function, as written below, was minimised.

Cost = Inventory cost + Production and idle time cost + Movement cost

In this work, only one criteria is optimised in designing an assembly line having less number of operator.

DECKRO (1989) developed zero-one model which simultaneously considered the minimisation of cycle time and number if workstations in an assembly line balancing problem. The Objective function included three cost components i.e., fixed cost associated with the addition of a workstation f_j, variable cost per unit of time for entire assembly line c and standard cost of assigning a task to a workstation t_{ij} and written as:

$$\text{Min}.Z = \sum_{j=1}^{j=M} f_j X_j + cC + \sum_{i=1}^{i=N} \sum_{j=E_i}^{j=L_i} t_{ij} X_{ij}$$

Where

X_j	=	A zero-one variable which equals 1 if workstation j is utilised, zero otherwise
X_{ij}	=	A zero-one variable which equals 1 if task i is assigned to station j
C	=	Cycle time
E_i	=	Earliest workstation task i can be assigned to given sequencing
M	=	Maximum number of workstations