A review on mixed assembly line balancing, sequencing and scheduling in an industry

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Abstract. Assembly line in a production unit is a line of workers and machines. In a manufacturing unit the production of components are done on assembly line. The product moves along this line while it is being processed. The assembly lines changed with time from single models straight lines to the mixed, multi-model lines in a flexible manufacturing system and also lines with parallel work stations, U-shaped lines. The main objective of assembly line design for a system is balancing the assembly line according to the desired production volume per shift and minimizing the number of workstations. In this paper, different assembly line balancing problems (ALBP) have been reviewed and discussed. For solving the assembly line balancing and sequencing problems, the development of mathematical model may be quite helpful for the researchers.

Key Words: U-shaped lines; ALBP; workstations

1. Introduction
Assembly line is the method where the product goes through a number of workstations for being processed. The whole work in the system is divided between each station in order to complete the total work.

1.1 Types of assembly lines
The categorisation of assembly line is based on the product variety; single model line, mixed-model line and multi-model line.

For manufacturing of product with no variants, the assembly which is used is single model line. The work is same for all stations for all the work-pieces.

The mixed-model line has different product variants. In this, the operations are similar for different variants but the operation time is different for different product varieties.

When the productions of different product varieties are done in batches, the class of assembly line is multi-model lines. This type of assembly line requires a setup for tools or equipment change as there are different operations for different product variants. So, the production is done in batches so that the setup time, cost or change over cost can be reduced.

1.2 Assembly line balancing
Line balancing is a procedure in which the tasks are evenly distributed to each workstation in a line so that equal amount of work is assigned to all the workstation. The main objective for line balancing is to maintain workload balance among the operators at every workstation and reduce the operator idle time i.e. decreasing the unused idle station capacity.
A balanced line has various advantages such as reduced wastes, worker idleness, and need of changing operator, faulty product and stocks. By decreasing the production cost per unit reduces the product price.

2. Available studies
Manavizadeh et al. [1] used make-to-order (MTO) environment to solve the sequencing problem. Their main three objectives to solve the problem were constant production rate variation, total utility work, and to minimize the tardiness and earliness cost. Their main contribution is the advance available to promise (ATP) mechanism for a mixed assembly line sequencing problems. Cemalettin et al. [2] proposed models considering both the balancing and sequencing at a station with the best possible schedule of tasks. They used constraint programming approach and mixed integration programming approach for the proposed model by taking into account the precedence diagrams. It was found that the Constraint programming approach performs better than the mixed integration programming approach and decomposition schemes.

Boysen et al. [3] reduced the setup operations so that the various models having the same base product could be manufactured. They discussed three approaches and provided a hierarchy of classification so that the academic effect and efforts can be recorded systematically for the deduction of the future research issues. The approaches they discussed were mixed model sequencing, level scheduling and car sequencing.

Miltenburg [4] developed a theoretical and presented some new scheduling algorithms and heuristics. At desired times the required quantities of the products which are necessary are produced by just-in-time system. The objective in the line is that the usage of parts is at constant rate. Andres et al. [5] studied the classical simple assembly line balancing problem (SALBP) and an effort was made so that the difference between the theoretical results and reality of the industry can be reduced. In this paper setup time had to be added when the next task was assigned at the same workstation for the computation of the global workstation time. When the mathematical model of the problem was made, there was a high combinatorial nature of problem. For such problem the GRASP algorithm was designed and tested having eight different heuristic rules. A genetic algorithm was introduced by Özcan [6] for the mixed model, U-shaped line balancing and sequencing problem by considering the stochastic task time. Ramalingam [7] used randomized method for calculating the objective function, for up to 15 sequences. When compared with Miltenburg's algorithm, the simulated annealing approach was favourable and competitive. Cao et al. [8] used the eM-Power software of a digital factory for mixed-model assembly line balancing and sequencing problem. Using this method, the virtual model simulation and control logic of transmission is done and the results were found feasible. Pastor and Andres [9] considered a company producing four different product models. They used an integrated approach for the scheduling and line balancing problem based on four heuristics and using a tabu search algorithm. Shahamaghi et al. [10] found optimal assignment and schedule for the tasks for a traditional SALBP. They also proposed a mathematical model for the problem. Borregoero et al. [11] enhanced the line balancing and scheduling for the aeronautical industry in airbus. The unique DMU stored both design and industrial information. It included process ordering information within an assembly station and their constraints. They selected the heuristic approach to solve the scheduling problem by them. Ranky et al. [12] focused on the dynamically scheduling, lean balancing problems and reconfigure the disassembly cells and lines. To solve the problem, they used COMSOAL algorithm. Sebrina and Diawati [13] did an impact of learning on assembly line capacity with an Indonesia car factory. A learning curve was a method describing the learning capabilities of an organization. They generated a learning curve for a factory having a mixed model assembly line system, and studied its effect on the assembly line capacity.

Amardeep et al. [14], for single model assembly line the proposed method reduced the non value added activities, cycle time and workload distribution at each workstation to improve the overall efficiency. Elia and Choudhary [15] optimized a mixed multi model assembly line. The four models are considered having different quantities of production for the assembly line optimization. For allocation of tasks to stations, the task times of all the models are computed. Using the iterative algorithm the idle time of each station was reduced by incrementing the quantity. Aydogan et al. [20] proposed particle swarm optimization method to improve the quality and productivity of U-line. This
method performs better when compared to the other existing methods. They used this method for U-line assembly, this method can also be used in different assembly lines such as parallel or mixed-model assembly line.

Hua et al. [21], used the combination of ant colony algorithm and beam search. 96.54% optimal solutions for 269 benchmark problems. Defersha et al. [22], proposed a method to solve the mixed-model assembly problems. They proposed the multi-phased linear programming with using the genetic algorithm to solve the sequencing and balancing problems simultaneously. On comparing the proposed method with the branch and bound method, it has solutions near to the optimal solutions.

3. Classification of assembly line problems of balancing and sequencing
While designing the assembly lines, the designers need to consider the present factory layout. The ALB problems were classified from the literature review conducted. The assembly line balancing problem classification is based on objective functions and problem structure.

3.1 Objective Function Dependent Problems:
The problems are classified the type F, 1, 2, E, 3, 4 and 5. The Type F is the problems regarding the feasibility of the line balancing problems. The minimizing the number of stations with known cycle time is the Type-1. Type-2 is the reverse problem of type-1. Type-E is the generalized problems of minimizing the cycle time and number of station to maximize the efficiency. Type 3, 4 and 5 maximizes the workload smoothness, work relatedness and also to achieve multiple objectives.

3.2 Problem Structure Dependent Problems:
Becker and Scholl [18] divided the problem structure in three parts SMALB, MuMALBP and MMALBP. SMALBP is a single model ALB problem where only one product will be produced. MuMALBP is the multi model ALB problem. In this type, the production is done for more than one product mainly in batches. The third type of problem structure is MMALBP which is mixed model ALB problem where on the line, various products models are produced in an intermixed situation.

Baybor [19] also categorised the type to problem structure dependent problems in two types SALBP and GALBP. SALBP is the Simple ALB balancing problems. For a fixed number of workstations cycle time is minimized and vice versa. GALBP have the problems which come under general ALB problem but not included in the SALBP. Seven phase approach is depicted to design of assembly lines.

The first phase approach linked to the line evolution is the tendencies and orientation of ALs. The line orientation varies according to the production floor layout. Designers need to identify the line orientation whether its straight, U-Shaped or Parallel lines are generally applied. All the contributing constraints should be considered while designing the assembly line.

Model stage is the combination of assembly line design model and solution methodology. There are different heuristic method to solve the ALB problems such as Kilbridge and Wester heuristic, branch and bound search, positional weight method. Hoffman precedence matrix, IUFF- Immediate Update First-Fit, or Moodie-Young method are also some the heuristic methods used. There are also some meta-heuristic strategies to find solution of ALB problems- Tabu search, genetic algorithm, simulated annealing or Ant Colony optimization can be used in industrial and research level.

4. Solving the sequencing and balancing problems for a Mixed Model Assembly
The balancing of the assembly lines is achieved in two stages [16].

4.1 Single model balancing
At this stage, the objective is that with a specific number of station find a minimum cycle time. The fixed cycle time, $CT_{\text{min}}$ is increased by 1sec per iteration to find the desired station numbers. Cycle time ($CT_{\text{min}}$):

$$CT_{\text{min}} = \max \left\{ \frac{1}{S} \sum_{i=1}^{n} t_i, \max t_i \right\}$$

$t_i$ is the $i^{th}$ task time and $S$ is the number of stations.
Since the whole system is a mixed model assembly line, so, the different models’ tasks would be considered as an equivalent single model. The optimized feasible solution from stage 1 is the input for stage 2 and hence, the solutions are stored.

Step by step algorithm is given below.

1) Cycle time at station $S_1$, $C = \frac{CT_{\text{min}}}{923/919/24}$
2) Tasks without predecessor are determined, $s = \{i,j...n\}$
3) In station $S_1$, from $s$, tasks are randomly assigned.
4) In the precedence graph, as the tasks are assigned they are removed and the cycle time, $C = \frac{CT_{\text{min}}}{923/919/24} - t_1$, the station time is updated.
5) Without the predecessor tasks sets are updated. $s = \{j,k...n\}$
6) Tasks are randomly assigned from $s$ to $S_1$ until positive station time, $C$, are positive and also keep on updating station time and tasks for each time.
7) For randomly assigned tasks, when station time, $C$, is negative or zero, then go and check for the next tasks in $s$ that can be fitted in $S_1$.
8) For all the tasks, when station time becomes negative or zero, then go to the next station $S_2$ and cycle time $C = CT_{\text{min}}$.
9) To assign all the tasks repeat steps 1 to 8.
10) All feasible solutions are found.
11) Check the feasibility of the solutions of predefined station numbers. In case the solution found in the first iteration are not feasible than the above steps would be repeated with increasing the cycle time by 1 sec i.e. $C = CT_{\text{min}} + 1$ and the steps are repeated till the required number of stations are met.
12) On achieving the feasible solutions, the final updated cycle times are stored.

4.2 Mixed modal balancing

At this stage, feasible solution found for the mixed model problems are achieved from first stage i.e. single model balancing, iterations with the results, which would be as input for stage 2. The solutions from the stage 1 iterations are considered as input for stage 2, given as below:

1. $N$, Number of workstations is the highest value of the solution. The length of the solution in a precedence graph is the number of tasks $K$.
2. In workstations, the tasks assignment is done.
3. MMALB-2, the number of models produced $M$, $N_m$ demand for each model production and $T_{km}$ task times for each model is the input for the objective function.

4.3 Objective function formulation

The total number of products to be produced, where;
$$\text{Total number of products to be produced} = \sum_{m=1}^{M} N_m$$

For all the models, the total time required to complete the production:
$$E_k = \sum_{m=1}^{M} N_m \times T_{km}$$

$Q_{sm}$ is the operation time. It is the amount of time per unit of model $m$ at station $s$. At station $s$, the total time assigned to it in period $T$:
$$T_s = \sum_{m=1}^{M} N_m \times Q_{sm}$$

Total work of all the tasks of all models assigned to $s$ station
$$p_{sm} = N_m \times Q_{sm}$$

The desired amount of work from the total work of model $m$ at each station for all units
$$p_m = N_m \times \sum_{s=1}^{S} \sum_{m=1}^{M} t_{km}$$

Over all the workstations the total work load can be equalised for each model, minimize the value of $(P_m - p_{sm})$. So, the objective function $X$, is to minimize the following function
$$X = \min \sum_{s=1}^{S} \sum_{m=1}^{M} [P_m - p_{sm}]$$

4.4 Sequencing of Mixed-model line

Task time of task $k$:
$$t_k = \sum_{m=1}^{M} q_{m} t_{km}$$
$q_m$ is the amount which is produced of each model $m$. The greatest common denominator is $r$ of all $q_m$ and so, the cycle is repeatedly comprised of $N_m = \frac{q_m}{r}$ units that should suffice. To satisfy the demand the cycle would be repeated $r$ times. In such a case items produced in each cycle is $N_m = \sum_{m=1}^{M} N_m - C_s$ is the relative workload of station $s$, its workload can be defined as:

$$C_s = \sum_{k} S_k t_k$$

The station having maximum or equivalent workload per cycle is bottleneck station $S_s$. Hence,

$$S^b = \arg\max S_i C_i$$

Let the value of $X_{mn}$ equals to 1, if at the $n$th position the model $m$ is placed and 0 otherwise. In the assembly sequence, when a model is placed it is indicated by $m(n)$ where $n$ is its position in the assembly sequence. So, the $n$th model is selected.

In two consecutive steps, the sequencing is done:

**Step 1:** List named $A$ consists of products that are assigned during the cycle.

**Step 2:** From list $A$, a list named $B$ is made for $n = 1$ to $N$ without violating any constraints, the product types that could be assigned. Product type ‘$m’$ is selected from list $B$ to minimize the objective equation 13. At the $n$th the $m’$ model is added. From list $A$, the product type $m’$ is removed. If $n < N$, than go to step 2.

### 5. Analysis of Transfer Lines(AL)

In the analysis and design of assembly or production lines, there are three problem areas that must be considered (Book by Groover) [17]:

1. Line balancing
2. Processing technology
3. System reliability

The line balancing problem, the total processing work that is to be accomplished must be divided as evenly as possible among the workstations. Once the sequence of operations is established, the service time at a given station depends on how long it takes to accomplish the operation at the station. Process technology refers manufacturing processes used on the production line.

Third problem area is system reliability, failure of any one component in the system can stop the entire system. It is an important analysis that should be done. It is divided into two parts:

1. Analysis of AL with no internal parts storage
2. Analysis of AL with internal storage buffers.

#### 5.1 Analysis of AL with no internal parts storage

Following assumptions are made about the operation of system:

1. The workstation perform processing operations such as machining not assembly
2. Processing times at each station are constant, though not necessarily equal.
3. Work part is synchronous.
4. There are no internal storage buffers.

##### 5.1.1. Cycle time analysis

In the operation, parts first enter the workstation than are processed and finally transported to next stage at regular intervals to succeeding station. This interval defines the ideal time $T_e$ of the AL.

$$T_e = \text{Max}(T_a) + T_r$$

Average actual production time ($T_p$):

$$T_p = T_e + F T_d$$

$T_d$, is the downtime is the time taken by the repair crew to do the work. $FT_d$ is the averaged downtime on a per cycle basis.

The frequency of line to stop per cycle ($F$):

$$F = \sum_{i} p_i$$

where $p_1 = p_2 = \ldots = p_n = p$

##### 5.1.2 Performance measures

Actual average production rate, $pc/min$:
Ideal production rate, pc/min:
\[ R_p = \frac{1}{T_p} \]  
(15)

\[ R_c = \frac{1}{T_c} \]  
(16)

5.1.3 Line efficiency
Line efficiency is the proportion of uptime on the line. Line efficiency can be calculated as:
\[ E = \frac{T_s}{T_p} = \frac{T_c}{T_c + FT_d} \]  
(17)

Using the downtime performance of the line can also be measured, which is given by:
\[ D = \frac{FT_d}{T_p} = \frac{FT_d}{T_c + FT_d} \]  
(18)

So,
\[ E + D = 1.0 \]  
(19)

5.2 Analysis of AL with internal storage buffers.
In case of assembly line with no internal storage buffers, at the independent workstations, when there is starving or blocking the station breaks down and on the line all the other stations are also affected. The stations at upstream becomes blocked as the broken station will not accept the next part for processing from its upstream neighbour. So, the addition of one or more storage buffers between the workstations the downtime of a line can be reduced. Due to the storage buffers the line can be divided into stages which operate independently for a number of cycles.

There are n-1 storage buffers, for an n-stage line which excludes the raw parts inventory at front of the line or the finished parts inventory at the end of the line.

There are two cases for storage buffer effectiveness:
1. No buffer storage capacity at all.
2. Infinite capacity storage buffers.

5.2.1 No buffer storage capacity at all. In this case, as there is no buffer storage, so the line acts as one stage. The whole line stops when station breakdowns. The line efficiency (equation 17) is:
\[ E = \frac{T_c}{T_p} = \frac{T_c}{T_c + FT_d} \]

5.2.2 Infinite capacity storage buffers. No stages in a line will be blocked or starved due to breakdown at any stage because of the presence of infinite storage buffers.

For all transfer lines with storage buffers at the bottleneck stage, the overall line efficiency is limited. That is the slowest stage restricts the production on all stages. Cycle time \( (T_c) \) is assumed to be same for all stages, the efficiency of any stage \( k \):
\[ E_k = \frac{T_c}{T_c + F_k \cdot dt} \]  
(20)

The overall line efficiency is given:
\[ E_c = \text{Minimum}\{E_k\} \]  
(21)

for \( k = 1, 2, ..., K \)

The actual value of line efficiency for given buffer capacity \( b \) will be somewhere between these extreme because, buffer zones of infinite capacity is not possible.
\[ E_b < E_c < E_\infty \]  
(22)

6. Conclusion
The review shows the assembly line balancing and sequencing research work evolved from traditional simple problems (SALBP) for solving the generalized problems (GALBP). A lot of problems were designed and modelled to achieve higher efficiency by reducing the balance delay, with smooth production and have cost effectiveness and so for that to achieve the factory layout should be considered.

The research work has been carried over time on different approaches like heuristic algorithms, genetic algorithm, particle swarm optimization and other approaches to solve the assembly line
balancing and sequencing problems. The different optimization approaches can be introduced to improve the productivity, efficiency of the assembly lines.

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