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A Review Article of Balancing Assembly Line Using Particle Swarm Optimization Algorithm

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Abstract **– This review article presents the application of particle swarm optimization (PSO) algorithm for the simple assembly line balancing problem, SALBP-I. A new indirect encoding method for the solution of SALBP-I is developed to keep the feasibility of operation sequence. The particle that represents a feasible operation sequence is based on a smallest position value rule. Given the defined by a particle, the optimal assignment of the operations to the workstations is identified by an optimum seeking procedure with polynomial-time complexity. Then PSO is employed to find the optimum efficiently in the search space comprising the optimal assignments associated. The PSO algorithm is tested on a set of problems taken from the literature and compared with other approaches. The computation results show the effectiveness of the algorithm.**

Keywords**- Simple Assembly Line Balancing, Particle Swarm Optimization, Operation Sequence, Smallest Position Value**

I. INTRODUCTION

Now a days, the majority of production processes in our country and all over the world are carried through assembly operations. Therefore, assembly lines form the basis of the manufacturing systems where production is performed in a flow-line production system; it is called as a “mass production”. In these lines, raw materials or semi-finished goods enter from one point and they pass a number of operations, then they leave from manufacturing process as finished products.

First, in 1913, Henry Ford started out with the idea of mass production and he designed an assembly line to manufacture the automobiles. Since then, Assembly Line (AL) concept has been pervaded, as it has widely proven its effectiveness to produce well-qualified, low-cost standardized similar products. A classic assembly line is composed of serial stages, in which workpieces (jobs) are flowed down the line and transferred from one workstation to the other through workforce or material handling equipment.

At each stage, definite assembly operations are completed repeatedly in order to obtain finished products. The tasks are allocated to workstations considering some restrictions including precedence constraints, number of workstations, cycle time and incompatibility relations between tasks.

The problem of assigning jobs to consecutive workstations that one or more goals are optimized based on the required tasks, processing times and some particular constraints are named the Assembly Line Balancing Problem (ALBP).

The process of balancing is a crucial task in designing highly efficient and cost effective assembly lines. The establishment or re-arrangement of a line is quite an expensive investment so effective regulations of lines are essential at the beginning of process.

Lines need to be balanced in the design stage; otherwise unbalanced lines cause inefficiency in production, increased cost, and a lot of casualties such as waste of labor or equipment, Kucukkoc et al.[1].A product, according to Askin et al. [2] is any item that is designed, manufactured and delivered with the intention of making a profit for the producer by enhancing the quality of life of the customer.

Most products are made up of various parts, where a part can be described as a single unit of a product that are brought together with others to form the finished product. Assembly, therefore, can be explained as the operation of bringing parts together, either manually by operators or automatically by robots, to form a finished product.

Fixing of more complex parts that have more than one component before being assembled to the work-piece as a single unit is called a sub-assembly. A work-piece is an unfinished product whose assembly is in progress.

In order to establish a comprehensive understandingof the dynamics of assembly, it is essential to be familiar with the stages and various elements involved in the assembly process. Figure 1provides a brief overview of a typical assembly process by highlighting the major constituents of an assembly line.

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II.ASSEMBLY LINE

An assembly line (AL) is a production process which is composed of different operations. Workpieces are successively combined on a product at each station to manufacture a final product. ALs are the mostly used technique in mass production, as they enable the assembly of complicated products by workers with restricted training and devoted robots and/or machines.

Assembly lines consist of workstations arranged by a conveyor belt or a similar material handling system. The parts are flowed towards end of the line and transferred among the workstations, Gocken, et al. [3]. At every station, specific operations are performed continually in connection with cycle time. When tasks are completed at each station, finished product is obtained.

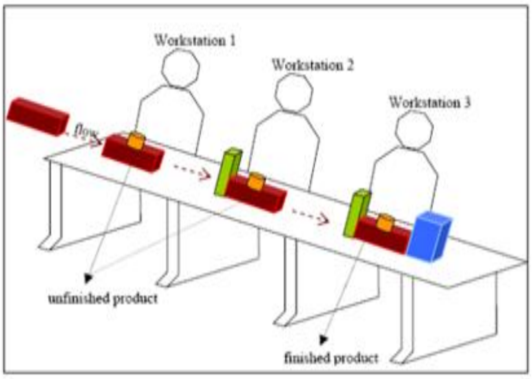

Fig.1. Concept of assembly line (Ozmehmet T., 2007)

Assembly lines are flow-oriented production systems where the units of production performing the operations are aligned in a serial manner, referred to as *stations*. Workers and/or robots perform certain operations on the product at the stations in order to exploit a high specialization of labour and the associated learning effects, Manavizadeh et al. [5].

The smallest individual and indivisible operations are called *tasks*. The necessary time for a task to be performed is called the *task time* or *the processingtime*. Every product follows the stations along the assembly line until the raw materials turn into a finalproduct. The operations assigned to stations are carried out on the product at each station within a specified time.

III.CLASSIFICATIONOF ASSEMBLY LINE

Assembly lines can be divided into two different groups based on product characteristics and some technical requirements: (i) one-sided as asembly lines, and (ii) two-side assembly lines. While only one restricted side (either left (L) or right (R) side) is used in one sided assembly lines, both left and right sides are used in two-sided assembly lines.

Two-sided assembly lines are usually constructed to produce large-sized high volume products such as buses, trucks, automobiles, and some domestic products. Two directly facing work stations called mated station are allocated at each working position, Chutima et al. [6]
In terms of the various numbers of product models assembled on the line, assembly lines can also be classified as single-model assembly lines and mixed-model assembly lines, Kara et al.

The production lines in which more than one product model is assembled [7] on the same line without any setup requirement between models and/or tasks are called as mixed model assembly line, Battini et al. [8]. Mixed model assembly lines offer several advantages over single-model assembly lines, include in gavoidance of constructing several lines, satisfied differentcustomer demands, and minimized workforce need.

Constructing parallel assembly lines is another type of lineconfiguration which was proposed by Gokcen et al. [9] toincrease the efficiency when demand is high enough. Parallelassembly lines have some advantages like minimised idletimes, reduced operator requirements, enhancedcommunication between operators, and improved resource utilization, Ozcan et al. [10]

Depending on production tactics and different conditions in practice, assembly line systems show a large diversity; therefore they can be classified in various ways. Figure 1.2 illustrates six main classifications of ALs in terms of number of models, line control, frequency, level of automation, and line layout.

Assembly lines are distinguished in terms of the number and variety of finished products in the line:

1.Single model: when producing high volume of a product, single-model assembly lines are mostly used to carry out a single homogenous product. In addition, if more than one product is produced on the same line, but neither setups nor distinct differences in processing times occur, the assembly system is also called as a single model line, such as case in the production of CDs or drinking cans.

2. Multi model: in this type of lines, several products are assembled in batches. The batch production line is used in the case of multiple different products, or family of products, which presents significant differences in the production processes. Using batch production leads to scheduling and lot-sizing problems.

3. Mixed model: this type of lines includes different models of the same base product, which have identical

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production

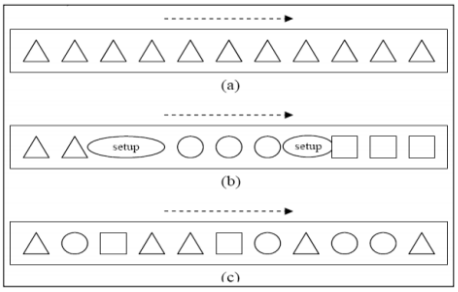

Fig.2 Assembly lines for single model (a), multi model (b), mixed model products (c).

IV. OBJECTIVES OF THE PRESENT STUDY

Through analysis of operations at the pre-assembly line and processes at the corresponding workstations, the objectives of this study are,

- To investigate the balance losses in the current pre-assembly line and maximise line efficiency,
- To achieve a lean assembly line by eliminating wastes in current production system and performing necessary revisions with the current station setup,
- To evaluate different layout possibilities for the new station setup,
- To perform these tasks with minimum costs.
- To minimize the number of work stations for a given cycle time.
- To minimize the cycle time for a given number of workstations.
- To minimize the number of incomplete jobs or dropped orders.
- To minimize the expected total costs.
- To maximize the productivity.

V.ISSUE OF OLD ARTICLE

1. Classification of assembly line balancing problem

Many types of ALB problems are derived and studied in the literature. Among the ALB problems, the most well-known and well-studied is certainly the simple assembly line balancing (SALB) problem.

It uses many assumptions to simplify the problem without ignoring its main aspects; hence, it is regarded as the core problem of ALB. Set of assumptions used for SALB problems are listed below (Scholl and Becker, 2006) [1].

- Mass-production of one homogeneous product is carried out.
- All tasks are processed in a predetermined mode, i.e. no alternatives for the processes exist.
- The assembly line is a paced line with a fixed cycle time for all stations.
- The assembly line is a serial line.
- The processing sequence of the tasks should not violate the precedence relations.
- The task times are deterministic.
- There are no restrictions for the assignment of tasks except for precedence constraints.
- A task is indivisible. Hence, it needs to be completed in a single station.
- All stations are identical with respect to workforce, technology, etc.

A feasible line balance for a SALB problem is an assignment that does not violate the precedence relations (Boysen, Fliednerand and Scholl, 2007) [2].SALB further assumes that the cycle times of all stations are equal to each other.

Assembly lines satisfying this assumption arecalled *paced*. However, it is possible, inevitable in most cases, that some stations will have a sum of processing times smaller than the cycle time of the assembly line. The unproductive period of time at a station is called *idle time*. A good assembly line balance should have as few idle times as possible.

According to the objective function considered, SALB problems are further categorized in four types (Scholl and Becker, 2006), [1]

- SALBP-I (Type-I): Minimizing the length of the assembly line for a given cycle time.This objective is equivalent to minimizing the idle times of opened stations.
- SALBP-II (Type-II): Minimizing the cycle time for a given number of stations opened.
- SALBP-E: Maximizing the line efficiency, E. This objective both considers number of stations and cycle time as a variable. The line efficiency is the productive fraction of the line’s total operating time:

$$E = \frac{t_{sum}}{N \times CT} \qquad (2.1)$$

Where t_{sum} is the sum of processing times of all tasks, N is the number of stations and CT is the cycle time.

- SALBP-F: This is the feasibility problem which is to establish whether or not a feasible line balance exists for a given cycle time and line length.

In the literature, the assumptions of SALB problem are relaxed and various model extensions are considered. Also, variations with respect to the objective are studied. A detailed classification of ALB problems was presented by the work of Boysen, Fliedner and Scholl (2007) [2]. The most common variations are explained below:

1.1.Mixed-Model Line: Different models of a product are produced in an arbitrarily intermixed sequence. The task time may differ between models. Producing each model of the product requires the completion of its own set of tasks. In other words, each model has its own precedence graph.

1.2.Multi-Model Line: Multi-model line produces a sequence of batches of one model with intermediate setup operations. Hence, the ALB problem is not only a sequencing problem but also a lot sizing problem.

1.3.U-Shaped Line: Instead of a straight line, the stations are arranged along a narrow "U", where both legs are closely together. This configuration allows *crossover stations*. Work pieces mayrevisit the same station at a later stage in the production process. This can result in better balances for cases with large number of tasks and stations.

1.4. Parallel Stations: In cases when the processing times of some tasks are greater than the aimed cycle time, *parallelism* should be considered. Parallelism is the duplication of a station task group. The tasks are performed on different stations on different products simultaneously. In these problems, number of parallel stations is another decision variable to be considered.

1.5.Two-Sided Line (2SALB): These lines are necessary when assembling physically large products, such as buses and trucks. In these lines, both left and right sides of the assembly line may be used. At a time different tasks may be carried out at the sides of the stations.

A two-sided assembly line is illustrated in Figure 2 A mated-station consists of right and left stations directly facing each other. The nature of the physically large products imposes side restrictions on the tasks.In other words, some tasks may only be performed on the left of the assembly line (L-tasks) and some tasks may only be performed on the right (R-tasks), while some tasks, without side restrictions, may be assigned to either side of the line (E-tasks).Both sides of the mated-stations are identical to each other and they are subject to the same cycle time.

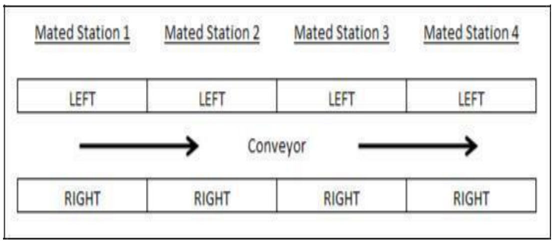

Fig.3 Two-Sided Assembly Line

VI. LITERATURE ON TWO-SIDED ASSEMBLY LINE BALANCING (2SALB)

Bartholdi (1993) [3] was first to address 2SALB problem and developed an interactive algorithm for balancing one-sided and two-sided assembly lines. The program uses a modified First Fit Rule (FFR).

The set of schedulable tasks is created at each step. The sequence of the tasks in the set is the same as the sequence they are introduced to the program. The first task of the set is assigned. The user interaction allows modifying the sequence of the tasks in the set.

Kim et al. [4] used PSO (GA) techniques to solve type-II 2SALB problems. The steps of the GA are presented with an encoding and decoding procedure of a possible solution to the problem. The overall framework of the GA procedure is as follows:

Step 1: Initial population is generated
Step 2: Each individual is evaluated.
Step 3: More fit individuals are selected with respect to the evaluation function value in order to pass on their good characteristics to offspring.
Step 4: A new crossover operator, called *structured one-point crossover (SOX)*, is developed. Using this operator, offspring is generated.
Step 5:A mutation operator is used to produces an offspring by introducing small changes in order to avoid a premature convergence to a local optima.
Step 6: Genetic crossover and mutation operations are followed by an adaptation procedure in order to complete the missing positions of the resulting offspring.

Lee et al. (2001) [5] introduced two new performance measures: *work relatedness* and *work slackness*. Work relatedness measures the interrelation of the tasks assigned to the same station. Two tasks are interrelated if one is reachable from the other on the precedence graph. Assigning interrelated tasks to a station is preferable according to this measure.

Work slackness (WS) is a measure to quantify the tightness of task sequences. Use of this measure tends to put some room between two related tasks that are assigned to companion stations. In case the preceding task delays, the succeeding task will not be affected if there is sufficient slack time.

This can be achieved by modifying the task sequence within a station. That is, the sequence of the tasks that do not have precedence relations may be flexibly adjusted and work slackness may be improved. The authors propose a heuristic approach using these performance measures. The heuristic approach is based on grouping the tasks.

Wu et al. (2008) [6] proposed a branch-and-bound algorithm (B&B) to solve the balancing problem optimally. Also a non-linear mathematical model for type-I problem is introduced. Since the size of 2SALB enumeration tree is very large owing to the existence of E tasks, task assignment rules are developed and applied in order to reduce the size of the tree. Developed rules are:

Step 1: the tasks will be ranked according to its start time in the current position, the earlier it starts, the earlier it will be branched.
Step 2: ties broken, tasks with original L or R operation direction are assigned first.
Step 3:ties broken, tasks with the maximal ranked positional weight are assigned first.
Step 4: ties broken, tasks with the maximal operation time are.
Step 5: ties broken, assigned randomly.

Baykasoglu and Dereli (2008) [7] also used ant-colony optimization (ACO) technique for 2SALB problem. The objective is to minimize the number of workstations for a given cycle time. Also a secondary objective of maximizing work relatedness measured by Agrawal formulation is used. The proposed algorithm can handle zoning constraints.

Xiaofeng et al. (2008) [8] introduced a station-oriented enumerative algorithm depending on the concepts of earliest start time and latest start time. These values are used to develop a heuristics to assign tasks to stations as time within the cycle time of a station increases. Positions, mated stations, are considered one by one. The procedure may lead infeasible solutions violating the precedence relations. Hence, a backtracking mechanism is proposed to remove these infeasible solutions.

Kim et al. (2009) [9] proposed a mathematical model and a PSOfor 2SALB-II. This is the first mathematical model for type-II 2SALBP problem. The model uses binary station variables for each task-station-side (Xijk). The mathematical model is tested on small-sized literature problems with 12, 16 and 24 tasks. Optimal solutions to the problems are found andthe model is verified. However, due to time and memory requirements, MIP is not tested on large-sized problems. A neighbourhood PSO(n-GA) is developed for relatively large-sized problems.

The algorithm uses a localized evolution to promote population diversity and search efficiency. Member of the population is presented by a two-dimensional grid. A single member and its surrounding eight neighbours form the subject of the genetic algorithm. The fitness of the potential solutions is measured by an evaluation function. The algorithm creates better-fit generations based on the initial population of nine members and the genetic factors formulated

The results of the PSOare tested on large-sized problems with 65, 148 and 205 tasks. The solutions of the algorithm are compared with the results obtained by one another PSO proposed by Kim et al. (2009) [19] and the first fit rule (FFR) proposed by Bartholdi (1993) [10].

Ozcan and Toklu (2009) [11] proposed a mixed integer goal programming for 2SALB problem. The objective is to minimize the deviations from three specified target values in a lexicographic order:

- Number of mated-stations.
- Cycle time.
- Number of tasks assigned to a workstation.
-

In the second part of the paper, fuzziness is introduced into the problem. The objective is to maximize the weighted average of fuzzy goals with a membership function.

Ozcan and Toklu (2009) [12] introduced mathematical model and a simulated annealing algorithm for solving mixed model 2SALB problems. The proposed mathematical model aims to minimize the line length (number of mated-stations). The model also aims a secondary objective of minimizing the number of stations.

The model is designed for handling positive and negative zoning constraints, fixed location constraints and synchronous task constraints. In the second part of the paper, simulated annealing algorithm is introduced. The algorithm has two objectives: weighted line efficiency and weighted smoothness index. The objectives are used to maximize line efficiency and distribute the work load evenly among the stations. These objectives provide the minimization of the number of stations.

Ozcan and Toklu (2009) [13] proposed a tabu search algorithm for two-sided assembly line balancing. The line efficiency and the smoothness index are considered as the performance criteria. Proposed approach is tested on a set of test problems taken from literature and the computational results show that the algorithm performs well.

Simaria and Vilarinho (2009) [10] developed a mathematical model to formally describe the two-sided mixed-model assembly line balancing problem. The objective of the model is to minimize the line length.

However, the proposed model considers balancing the workloads between workstations and balancing the workloads within the workstations for different models as a secondary objective.

Furthermore, an ant-colony optimization algorithm to solve type-I 2SALB problems is proposed. In the proposed procedure two ants "work" simultaneously, one at each side of the line, to build a balancing solution which verifies the precedence, zoning, capacity, side and synchronism constraints of the assembly process.

VII.CONCLUSION

a particle swarm optimization (pso) algorithm for the simple assembly line balancing problem, salbp-i, is presented. a new indirect encoding method for the salbp-i is developed, which records the balance assembly line using a smallest position value (spv) method. given a balance assembly line represented by a particle, an optimum-seeking procedure with strong polynomial-time complexity is able to efficiently find the optimal solution associated with the balance assembly line. based on encoding method and position updating mechanism, the search space is narrowed to the optimal solution associated with all balance assembly line s. searching in the refined search space improves the efficiency of the pso and increases the possibility to find the global optimum. the computational results of the proposed algorithm for a set of problems taken from the literature and comparisons between pso algorithm and existing algorithms show that the proposed algorithm is effective and efficient. further study is needed to compare the performance of pso and other meta-heuristics such as ga and aco in details. multi-objective optimization for salbp-i needs to be further investigated using pso.

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