A Review on Methods to Improve and Balance the Assembly Line

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Abstract. Assembly line is well known as an important part in manufacturing process. It consists of several workstations that linked together to create a complete product. Each of workstation is doing their own tasks. However, during the process of item moving from workstation to another workstation to become a finished product, the unbalance of workload among workstation will create a bottleneck effect. This problem will cause the performance of assembly line is not optimal. Therefore, to improve the performance of assembly line, many methods are applied and used to solve assembly line balancing problem. In this paper, different methods which can be used to improve and balance the assembly line are discussed.

1. Introduction
The assembly lines have a big influence on industrialization. It was first introducing by Henry Ford in 1913 to manufacture a new Ford T model. The mass automobile production was using assembly line and it able to reduce the processing time to build a car.

In assembly line, the complete product will be divided into several different parts and each part is assigned to the workstation. However, which part to process first must follow the precedence flow strictly. The part that should process first must not process second and so on because the item from previous process is needed to begin the next process. These parts are added together until the finished product is produced. Each workstation is linked together but their tasks are different and they are doing their tasks.

Even though the assembly line able to reduce the time it took to complete a product, the bottleneck effect was happened during the process of manufacturing. It happens because of unbalance distribution of workload among workstations and time each workstation required to do their task are different. Therefore, the assembly line is not in best condition and its performance is not optimal.

The term of assembly line balancing (ALB) is normally utilized to represent a procedure of allocating the tasks which their aim is to allocate the tasks into suitable workstations so that each workstation has approximately equal processing time to complete their tasks and precedence constraint is respected. The tasks are operations which required converting raw material into finished product.

There are some reviews and surveys on assembly line which can be found in current literature. They are presented in the paper whose first were studied by Baybars [1] and publish in year 1986, followed by Ghosh and Gagnon [2] in year 1989, Erel and Sarin [3] in year 1998, Rekiek, Delchambre,
Dolgui and Bratcu [4] in year 2002, Becker and Scholl [5] in year 2006, Boysen, Fliedner and Scholl [6] and Kriengkorakot and Pianthong [7] in year 2007, Rashid, Hutabarat and Tiwari in year 2012 [8], Kumar and Mahto [9] and Battaia and Dolgui in year 2013 [10], Saif, Guan, Wang, Mirza and Huang [11], Pachghare and Dulu [12] and Sivashankaran and Shahabudeen in year 2014 [13], Jusop and Ab Rashid [14], Rane, Sunnapwar, Sudhakar and Rane [15] and Hazir, Delorme and Dolgui [16] in year 2015, Dolgui and Gafarov [17] in year 2017, Mohammed, Ramli and Zakaria [18] and Bakar, Ramli, Sin and Masran [19] in year 2019.

This paper is especially focused on methods that can be applied to improve and balance the assembly line. Numerous methods to optimize the assembly line can be found used in many available research papers. Their aims mainly to solve different kind of problems related to the assembly line and improve its performance. A few methods to improve ALB like heuristic, meta-heuristic, simulation approach and queuing concept are going to be discussed later.

2. Methods to improve the Assembly Line

Nowadays several methods have been used to tackle the assembly line balancing problem (ALBP) and improving the performance of the assembly line. The ALBP can be categorised as the NP-hard problem because of its nature. However, a few exact procedures have been proposed to tackle and find it optimum solution. Even though by using those methods guaranteeing an optimal solution, the size of tasks become it limitation. Its unable to achieve an optimal solution for problem of a large number of tasks.

Therefore, new methods have been proposed and developed to discover the best solution to a problem with such limitation and thus, able to obtain optimum result which is closely to an optimal solution. That was how approximate methods such as heuristic and meta-heuristic methods come to exist. Besides that, the simulation approach is quite popular among researcher and also be able to measure, evaluate and improve the assembly line. Queuing concept is also one of the methods that can be used to analyze the assembly line.

2.1. Exact Methods

Usually, to aid decision makers and designer to have a clear understanding of assembly system, assembly line balancing problem is described by using integer linear programming model. However, by considering the real world scaled problems, most often the standard solvers were not efficient and cannot produce the optimal solution. Hence, the exact procedures to solve ALBP that can be found in literature is based on 1) dynamic programming (DP) and 2) branch-and-bound (B&B) procedures.

1) DP procedure is a method that breaks the problem into small sub-problems and changes it into a multi-stage decision process. The small sub-problems are solved to find it optimal solution and then in order to build the optimum solutions of the real problem, the optimal solution of sub-problem is used.

2) B&B procedure is an enumeration method, where the aim was to determine the optimum solution by discovering the possible solution subsets. A branching process is process of branch the solution space to create the Sub-regions. For a bounding process, by using different searching strategies, it is used to find lower or upper bounds of the optimum result within each sub-region.

2.2. Heuristic Methods

A heuristic method normally used to solve ALB is the greedy approach. The solution is selected on the basis of a given requirement until a final solution is produced at each step of the procedure. The simplest procedure will randomly produce the solutions, analyzes every of them and retains the best possible solution. Fundamentally, constructive methods are based on priority rules where certain element must be considering such as the number of predecessor’s number, the successors number and the task processing time. The Ranked Positional Weight (RPW) was the first proposed heuristic
method to solve ALBP. By arranging the tasks in descending order of the positional weight, where the positional weight is summation of the task processing time and all its successors processing times. The biggest values of positional weight will be ranked at top whereas the smallest value at the bottom. Then, the process of allocating the tasks into their specific workstation can be done. However, the precedence flow must be strictly followed.

Besides that, there are several other heuristic methods based on priority rules such as large candidate rule, Kilbridge and Wester’s method, longest processing time of task, maximum total successors number, minimum earliest and latest workstation and Gray-Kidd algorithm or known also as minimum slack. By combining several priority rules some other heuristics are created. The method based on priority rule generates the assignable tasks rank list. If the summation of task time and the current time of workstation less or equal to the cycle time and all of its predecessors have already been assigned to workstation then that task is assignable. The process of select and assign the tasks to the workstations was done by following one of the two strategies.

The first strategy is Station-oriented. This strategy is started with one workstation at a time, and then others are sequentially considered one by one. From the ranked list obtained from each iteration process, tasks are picked and allocated to the current workstation. After completely loaded the current workstation, start to open a new workstation to assign the remaining tasks and so on.

The second strategy is task-oriented. The task with the highest priority, which is the first task in the rank list is chosen and allocated to the earliest workstation that can be assigned the task to it. This procedure is further separated into immediate-update-first-fit and general-first-fit procedures. These two procedures can be distinguished based on whether the rank list of tasks available is updated instantly after allocating a task or after allocating all the tasks currently available in the rank list, respectively.

2.3. Meta-heuristic Methods
The main advantage of classical heuristic methods is dropping in a local optimum. In opposition to this, meta-heuristics have been developed in the past years to overwhelm such a limitation. Glover (1986) is the first person that has introduced the term of meta-heuristic. Generally, the procedures in heuristic methods are based on constructive methods where an initial solution (a population of initial solutions) is needed to be found and local search algorithms is required to move to an improved neighbour solution. In contrast to local search approaches, meta-heuristics do not stop when no improving neighbour solutions can be found. Furthermore, the movement to worsening solutions is allowed in the meta-heuristic system as to avoid premature convergence to a local optimum solution. Various concepts derived from artificial intelligence and evolutionary algorithms inspired by mechanisms of natural evolution are used in meta-heuristics.

GRASP (Greedy Randomized Adaptive Search Procedure) is an iterative process in which each iteration contains of two stages. The first one is the construction stage where an initial solution is produced. The initial solution is generated by probabilistically selecting the next element to be incorporated in a partial solution from a restricted candidate list (RCL). Secondly, is the improving stage. In this stage, a local optimization procedure is used in finding a local optimum.

Tabu search (TS) is a meta-heuristic that focused on memory structures which prevent solution from returning and keeping trap in a local optimum solution. It is allowed to move from a local optimum to worse solutions to escape and obtained a better solution. To prevent the solution from moving back to recently visited solutions, a tabu list is used. The size of the set and main parameters can determine the number of iterations during which a given solution to reoccurring can be avoided. The procedure stops when several search movements have been carried out and no further progress has been achieved.
Ant colonies algorithms (ACO) is a model inspired by looking at the behavior of ants. For example, in the process of finding the food, the ants connect two different locations by searching for an optimal path. The path selection is stochastic. It is affected by both the quantity of pheromone that other ants have placed on a path and the local objective function values that can be determined if the path is chosen.

A method inspired by an analogy with the physical annealing of solids is called Simulated Annealing (SA). It models how at high temperatures disorder the molecular structure of metals, and at low temperatures, the molecular structure of metals is ordered and crystalline. To formulate a problem instance, developed it in such a way that it resembles disordered material. Gradually, the temperature is reduced in such a manner that the ordered states correspond to good problem solutions. By allowing uphill moves based on a model of the annealing process in the physical world, SA technique able to prevent getting trap in a local optimum and lead to a much better solution.

Genetic algorithms (GA) are related to imitating biological evolution as they map programs and data into structures similar to DNA and convey some fitness notion. GA method uses a set of initial solutions, i.e. individuals, each point in the search space represents one feasible solution to a particular problem. A certain number of people conform to a population of feasible solutions. By applying crossover and mutation operators along with an objective function (i.e. the function of fitness) that determines how likely individuals are to be reproduced, the population is evolved.

2.4. Simulation Approach
The simulation concept has adapted by many enterprises for improving the system of production. The possibility of the simulation causes enterprises to evaluate the outcomes for different alternatives. Hence, unnecessary errors and costs can be reduced. Besides, numerical and logical models based on real-world problems are also generated through simulation, and different scenarios using computers are imitated to find solutions for problems. An effective tool provided by computer simulation technology help in planning for solving, analysing and evaluating different alternatives especially for complex problems with high risks or impossible for real-world testing.

The continuous improvement and updating of computer hardware and software cause computer software simulation to be demanded by the people due to high computation efficiency and accuracy. Simulation can observe the different operational patterns quickly and choose the appropriate plan to solve problems. Commonly, a set of techniques for computers to imitate, or simulate the operations of various kinds of real-world facilities or processes is known as simulation. A real phenomenon is imitated in this process using a set of mathematical formulas. The numerical model of reality is generated using a computer for the determination of describing complex interaction among components of a system. Furthermore, other functions of the simulation are to see the behaviour of the process under different conditions and to test new theories. After creating a theory of causal relationships, the theorist can codify the relationships in the form of a computer program. If the program then behaves in the same way as the real process, there is a good chance that the proposed relationships are correct. Nevertheless, the simulation result cannot solve the problem but may display the problem clearly.

A modelling technique where only changes in states of a system are defined as Discrete Event Simulation (DES). Basically, a queue of events is created via DES has affected the system state. The arrangement of these events is based on their timings. The simulation then moves via these events and the changes on the system is applied without modelling the time between any two events. The arrival of a part, the initial and end of cycle times on machines and the occurrence of breakdowns are examples of such events in a typical manufacturing system. Therefore, it is a dynamic simulation technique where changes in the system are represented over time. The reader is referred to look for
more details on DES as it has been applied successfully in a wide range of business and manufacturing applications. In fact, it is the most popular technique to model manufacturing systems.

The modelling variability in statistical or empirical distributions and rapid modelling by providing built-in modules that accelerate the modelling process are the main features including in typical DES software. Moreover, a visual interactive simulation where changes in the system are animated and users can interact during the simulation are enabled in typical DES software. Last but not least, a better understanding of the model can be gained from a visual interactive simulation by visualizing, interactive experimentation, improved communications to all stakeholders and the facilitation of model verification.

2.5. Queuing Concept
The assembly line consists of workstation that linked together and they are performed their own tasks with aim at the end of the production to produce a finished product. Raw materials are moving from one workstation to another workstation. The combination of a few queuing systems is also recognised as the assembly line.

To model the assembly line with the principles of queuing theory, first we must adapt the production system components to the components of a queuing system. Regarding to this modelling, products of assembly line are considered as customers of queuing systems and workstations are assumed as servers in the queuing system.

This method can be used to solve ALB however there are so few researchers who’s interested in this method. Hence lead to lack of literature.

3. Research gaps
According to the thorough literature survey, it is concluded that no buffer, no breakdown, no material shortage, fixed demand and many more are the assumptions that most of the papers referred on. However, these cases do happen in a real-world situation. The difficulties in the collection of data are the effect of the limitation in using the statistical tools, as the real-world does not permit data collection due to competition and confidentiality.

Cost restriction has been paid very little attention due to confidentiality. Trends and shifts are needed to develop and advance algorithms such as GA, ACO and SA are required to be compared. To the best of our knowledge, there is a lack of attention on the combinatorial effect of feeder lines, automation, failure, worker’s skill and number, absenteeism and material shortage (delay and rejection).

There are lack of literature related to queuing system for assembly line balancing compared with other methods. Many researcher tendencies to choose other method than queuing concept even though this method can improve the assembly line just same as other method and can be much better for certain cases.

4. Suggestion and future research
Various categories of ALBPs and state-of-the-art research in each category can be understood through the ALBP review. Several number of the researchers have developed many meta-heuristics, namely a genetic algorithm, simulated annealing algorithm, tabu search algorithm, ant calonies algorithm, greedy randomized adaptive search procedure and many more for multi-modelling of ALBPs.

Different crossover methods may be proposed by the researchers are compared in terms of their effectiveness in the accuracy of the solution during the development of a genetic algorithm. Similarly, for the development of a SA algorithm, an efficient seed generation algorithm is required in designing in its first stage, which will result in a greater effect on the solution accuracy in the second stage of the SA algorithm. Moreover, the hybrid development method is encouraged to approach as, two or more
basic heuristic(s) or meta-heuristic(s) are to be combined to bring a synergetic effect on the solution accuracy. On the other hand, the researchers may research finding the best combination of the basic heuristic(s) or meta-heuristic(s) in terms of greater solution accuracy for a selected problem to serve as a hybrid algorithm.

Besides that, a specific crossover method is used by the researchers in genetic algorithm. Alternatively, a crossover method may be selected randomly by them for each pair of chromosomes from a pool of crossover methods, while performing the crossover operation in each of the iterations. Consequently, this will result in an opportunity to form offspring with improved fitness function values.

In most of the meta-heuristics, such as SA algorithm, GA algorithm, ACO algorithm, and many more, the parameters are either fixed through trial-and-error method using an experiment or based on past published works, which may not guarantee the best performance. Hence, the parameter of these algorithms should be optimized by the researchers using Taguchi’s method before executing each of these algorithms. As a result, the accuracy of the solution of the problems that are solved using that algorithm can be enhanced.

In all the categories, statistical comparisons of the performance of new approaches with that of existing approaches are not comprehensive in terms of applying design of experiment to test the effects of the factors or parameters of the problems on the response variable(s). So, the comparison of the algorithms must be done using a complete factorial experiment by considering relevant factors with interaction effects, in which “Algorithm” is a factor to check the superiority of the proposed algorithm. It is observed that very less work is done on multi-model ALB categories and the categories with U-type ALBPs.

To sum up, the development of meta-heuristics with single or multi-objective can be carried out in these categories for future studies. Also, it is found that less work is carried out on the SALB-2 problem. Meanwhile, it is also considered as a significant problem in ALB and more research efforts should be made on this problem.

5. Conclusion
Many kinds of literature included the past and recent research papers have been mentioned on the numerous balancing methods of the assembly line. The exact method, Heuristic method and Meta-heuristic method are such examples. These methods are used to obtain an optimal solution and improve the assembly line. However, there are still some gaps in research that can be thinking about and explore. By doing so will provide some help to other researchers to develop a new idea and contribute to existing knowledge.

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