Abstract- Assembly lines are widely used in all kind of industries where mass production is done. But there always arises an Assembly Line Balancing Problem (ALBP) i.e. improper assignment of tasks to the work stations. In this paper different techniques to solve this ALBP are reviewed. Overall development and trends of solving ALBP is studied and presented in this paper.

Index Terms- Assembly line, workstations, line balancing, cycle time, sequencing, algorithm.

1. INTRODUCTION

Assembly lines are flow-line production systems, where a series of workstations, on which interchangeable parts are added to a product. The product is moved from one workstation to other through the line, and is complete when it leaves the last workstation. The productivity level of an assembly line generally depends on balancing performance.

Line Balancing is a classic Operations Research optimization technique which has significant industrial importance in lean system. The concept of mass production essentially involves the Line Balancing in assembly of identical or interchangeable parts or components into the final product in various stages at different workstations.

- Definitions of Related Terms:-

1) Assembly line:
An Assembly is made up of a number of workstations, arranged serially. These stations are linked together by a transportation system that aims to supply materials and move the production item from one station to next one.

2) Line Balancing:
Line Balancing is leveling the workload across all processes in a cell or value stream to remove bottlenecks and excess capacity. A constraint slows the process down and results if waiting for downstream operations and excess capacity results in waiting and absorption of fixed cost.

3) Cycle Time:
Cycle time is the Maximum amount of time allowed at each station. This can be found by dividing required units to production time available per day.

\[
\text{Cycle Time} = \frac{\text{Production Time per day}}{\text{Units produce per day}}
\]

4) Lead Time:
Summation of production times along the assembly line or Total time required to manufacture an item or it is the time that elapses between when a process starts and when it is completed.

5) Idle Time:
Idle time is the time specified as period when system is not in use but is fully functional at desired parameters.

6) Bottleneck:
Delay in transmission that slow down the production rate. This can be overcome by balancing the line.

7) Precedence:
The product can’t be move to the next station if it doesn’t complete at the previous station. The products flow from one station to the other station. In assembly line the products have to obey this rule. It can be represented by nodes or graph.

1) Smoothness Index:
This is the index to indicate the relative smoothness of a given assembly line.
balance. A smoothness indeed is zero indicates perfect balance.

\[ SI = \sqrt{\sum_{i=1}^{n} (ST_{max} - ST_{i})^2} \]

Where,

- \( ST_{max} \) - maximum station time (in most cases cycle time),
- \( ST_{i} \) - station time of station i.

2. **ASSEMBLY LINE BALANCING**

Mixed-model assembly line with both closed and open stations has been modeled using max-plus algebra to compare given sequence of demand mix over a range of processing times of assembly task as well as analyze different line performance measures considering one of the line parameter as variable. [1] The presented analysis would allow designers to see which stations are most sensitive in assembly time and whether it will affect the line length or the idle time. Also the analysis can be used for redesigning of existing line where the length of line is a fixed constraint but the line capacity can be adjusted by changing launching rate. But in this paper only closed and open station with fixed launching rate have been considered.

To improve the manufacturing quality, this paper evaluates the potential to adapt the Failure Process Matrix (FPM) to assembly lines with small quantities.[2] The adapted FPM proved efficient to analyze potential to further improvement in assembly quality of both assembly lines BR2000 and BR4000. The assembly errors at the early station of the assembly line cause high rework costs because, at the end, these parts are in the center of the engine. This makes these failures particularly difficult to undo. The improved usability, the new calculation formulas and the automated graphical analyses proved efficient during the case study.

A real life two-sided ALBP with additional assignment restrictions was considered by the author. [3] They took into account operating sides of tasks in addition to precedence and cycle time constraints, when the allocation of the tasks to an ordered sequence of workstations was determined. Objective function was to minimize number of workstations and to ensure a smooth distribution of workload between workstations. They used Teaching–Learning Based Optimization Algorithm to obtain high quality solutions in a very short computational time. In this solution, current line was balanced with fewer workstations in the new configuration with lower smoothness index. A considerably improvement in the distribution of workloads between the workstations, and significant reduction in total number of operators for the assembly system is achieved by using TLBO.

A Pareto biogeography-based optimization (BBO) approach to mixed-model sequencing problems on a two-sided assembly line where a learning effect was also taken into consideration, was presented.[4] Three objectives which typically conflict with each other were optimized simultaneously comprising minimizing the variance of production rate, minimizing the total utility work and minimizing the total sequence-dependent setup time. To compare the performance of A-BBO against the well-known algorithms, i.e. NSGA II, DPSO, PSONK and BBO, four comparison metrics were used including convergence, RNDS, spread metrics and computational time. The results indicate clearly that, apart from high computation time which may be considered as a trivial concern, A-BBO outperforms all other competitive algorithms in terms of solution quality. The success of A-BBO is due to the trade-off between the exploration ability of the underlying BBO and the exploitation ability of the local search embedded in an adaptive mechanism being utilized in an effective manner.

First, a mathematical programming model was presented to formally describe the problem.[5] Then, an ant colony optimization algorithm was proposed to solve the problem. 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. The main goal was to minimize the number of workstations of the line, but additional goals were
also envisaged. The good performance of the algorithm was proved by computational experiments with a set of single model benchmark problems but the development of an approach under a multi-objective perspective may be useful to address the different nature of goals of the problem. The procedure uses a non-delay rule for ants while available tasks exist, however this may discard optimal solutions since it may be best to wait a brief time for the opposite ant and then perform a mated-task.

A Genetic Algorithm (GA) was developed to solve the two-sided assembly line balancing problem.[6] The developed GA specifies a new method for generating the initial population. It applies a hybrid crossover and a modified scramble mutation operators. A proposed station oriented procedure was adopted for assigning tasks to mated-stations. In order to assess the effectiveness of the developed GA, a set of test problems were solved. The Genetic Algorithm and Direct Search Toolbox in Matlab7.6.0 was used to test developed GA on the different benchmark problems. The developed GA obtained the best solution for more than 90% of the test problems. The results showed that the developed side assignment rules were efficient specially in large scale problems. The techniques applied in the developed Genetic Algorithm were able to find optimum and near optimum solutions within a limited number of iterations. This proofs that applying the proposed method of generating the initial population and the hybrid crossover technique are efficient in solving the TALBP.

The researchers suggest a generic approach for designing of an assembly line where, with a given number of workstations, one can efficiently arrive at the desired solution under different methods of search like simulation, heuristic etc. [7] Thus, the main aim of this paper was to redefine the objective of the Assembly Line Balancing Problem and sequentially handle Balancing Loss and System Loss. The balancing problems studied were oriented towards minimization of balancing loss and can be best used in transfer lines where work elements are preferably performed by machines/ robots. From the solution set generated by simulation search, final choice was made based on optimum number of workstations and minimum variance.

Researcher has proposed new multi objective constructive approaches to tackle the TSALBP.[8] The performance of two solution procedures based on the Multiple Ant Colony System (MACS) and Multi-Objective Random Search Genetic Algorithm(MORGA) with different design configurations has been presented and analyzed. Good performance was shown after applying every algorithm to 10 well-known problems. In addition, those algorithms which have provided the best results has been employed to tackle a real-world problem at the Nissan plant, located in Spain. From the obtained results they had concluded that the best yield to solve the problem globally corresponds to the MACS algorithm.

A mathematical model and an adaptation of the Strength Pareto Evolutionary Algorithm II (SPEA2) for the Mixed-Model Assembly Line balancing and equipment selection problem was explained.[9] The choice of the SPEA2 was based on the study of Zitzler et. al., in which they compared the behavior of various evolutionary approaches based on test functions. The study shows that SPEA2 and NSGA-II displayed the best performance among the algorithms. This optimization method aimed to find a set of non-dominated solutions that minimize the idle time of various models among an assembly line and minimize the equipment costs. This approach, which is independent from the size of the problem, was enriched with a task and an equipment reassignment procedure.

A mathematical model and a genetic algorithm for two-sided assembly line balancing were presented by Kim [10]. A two-sided assembly line is a type of production line where tasks are performed in parallel at both sides of the line. The line is often found in producing large products such as trucks and buses. In this they presented a mathematical model and a genetic algorithm (GA) for two-sided assembly line balancing. The mathematical model can be used as a foundation for further practical development in the design of two sided assembly lines.

Validation of Line Balancing by Simulation of Workforce Flexibility by Markus Propster
To stay competitive and reach a high productivity, mixed model assembly lines need to handle variations in capacity requirements induced by the different variants manufactured. Therefore workforce flexibility is required, i.e. drifting, which allows workers to leave their stations to fulfill high equipped variants, and the allocation of jumpers. These support if drifting is not sufficient. This paper presents a simulation tool which simulates these aspects of worker flexibility according to the produced variants and their sequence.

Multi-objective Evolutionary Algorithm with Strong Convergence of Multi-area for Assembly Line Balancing Problem with Worker Capability presented by Wenqiang Zhang (2013) [12] suggested that, according to different work capability, the skill level of a worker in a given task differs greatly among workers, i.e., the task times depend on the worker since they have different skill and capability. Furthermore, operating the line causes short-term operating costs such as wages, material, set-up, inventory and incompletion costs, especially, the labor cost or worker cost is the main cost in most manufacturing companies. Therefore, the manufacturing company managers have hired more non-regular employees to reduce the permanent worker cost and assign them to increase line efficiency.

N. Papakostas (2014) suggested in multi-criteria assembly line design under demand uncertainty [13]. The manufacturing industries include production environments where materials are processed and individual parts are made along the facilities where they are joined together in subassembly or final product the objective of process design is maximization of the ratio between throughput and required cost. The customer demands specific quantity at a certain time and specific characteristics depending on his needs. A change in demand, in assembly lines that are set to produce mixed products in a given sequence would cause change in actual operation times of required process. This causes uncertainty and re-designing of process is required.

A. Al-Zuheri (2012) suggested in this paper that effects of sources of randomness in validation of a mathematical model for a dynamic type of assembly systems called walking worker assembly line WWAL [14]. The main objective of this current research work is to inform of a decision making process with the aid of modeling and simulation and to provide feedback in assisting the design of a walking worker assembly line in the early design stage. This process also includes a comparison of the dynamic performance based on simulation results that were obtained from simulation models with predicated results of the mathematical model which modeled the randomness of the same assembly line under different design scenarios.

Chutima and Chimklai (2012) [15] works on multi-objective two-sided mixed-model assembly line balancing using particle swarm optimization with negative knowledge. Particle swarm optimization (PSO) is an evolutionary metaheuristic inspired by the swarming behavior observed in flocks of birds. A PSO algorithm was presented with negative knowledge (PSONK) to solve multiobjective two-sided mixedmodel assembly line balancing problems. Instead of modeling the positions of particles in an absolute manner as in traditional PSO, PSONK employed the knowledge of the relative positions of different particles in generating new solutions.

A mathematical programming model for Cost-oriented Multi-manned Assembly Line Balancing Problem by Abdolreza Roshani and Davide Giglio (2015) suggested that a Multi-manned assembly line balancing problems usually occur in plants producing large-sized high-volume products such as automobiles and trucks. In this paper, a cost-oriented objective function was presented for a multi-manned assembly line balancing problem. This kind of objective function may be used to balance final assembly lines of products in which manufacturing process is very labor intensive.

A mixed-integer mathematical programming model was proposed to solve the problem optimally. The proposed formulation has been used to solve some small size problems by considering both time-oriented and cost-oriented objective functions. It was shown experimentally that with a same cycle time, two different optimal solutions can be actually found.
When switching from time-oriented to cost-oriented objective functions, and vice versa.

[17] Assembly line balancing with ergonomics paradigms: two alternative methods by D. Battin et al. (2015). In this paper, the assembly line balancing problem when ergonomics principles are taken into account is considered. Two different approaches were presented and discussed with a numerical example to provide new insights on the field and to illustrate their use on a didactic example. The first one applies a multi-objective model based on the energy expenditure, used to estimate the ergonomics level. The second one transforms the energy expenditure rate in a rest time in order to reduce the multi-objective problem to a single objective one.

In many industrial sectors, the production of high value and customized products is even today only feasible with a large involvement of a highly skilled workforce. A poor ergonomic design of assembly and manufacturing systems can generate a large amount of sick leaves due to musculo-skeletal disorders (MSDs). Thus, it is even more necessary to design efficient assembly systems and enhance work related satisfaction of human operators.

In this paper the authors adapted a traditional SALBP-2 model in order to include ergonomics paradigms into the assembly system balancing problem.

[18] Disassembly Line Balancing and Sequencing under Uncertainty by Mohand Bentaha et. al. deals with the problem of stochastic disassembly line balancing and sequencing in the presence of hazardous parts of the End of Life (EOL) product. The case of partial disassembly process was considered. The objective was to design a production line with a maximum profit under uncertainty of task times which were assumed to be random variables with known probability distributions. Tasks of the best selected disassembly alternative were to be assigned to a sequence of workstations while satisfying precedence and cycle time constraints. To cope with uncertainties, an exact solution method based on integer programming and Monte Carlo sampling was developed. Results of experiments on problem instances were presented.

[19] A bibliographic review of production line design and balancing under uncertainty by Mohand Lounes Bentaha et al. (2015) reviews the solution methods developed for the design and balancing problems of production lines such as assembly and disassembly lines. The line design problem aims in determining the number of workstations along with the corresponding assignment of tasks to each workstation, while the line balancing problem seeks an assignment of tasks, to the existing workstations of the line, which ensures that the workloads are as equal as possible among the workstations. These two optimization problems can be also integrated and treated as a multi-objective optimization problem. This review considers both deterministic and stochastic formulations for disassembly lines and was limited to assembly line design and balancing under uncertainty. This bibliography covers more than 90 papers since 1970 for assembly and 1999 for disassembly.

[20] The Assembly Line Balancing Problem with Task Splitting: A Case Study by W. Grzechca and L. R. Foulds. In this paper different types of assembly line structures were discussed in brief including their advantages. It puts forth that the assembly line balancing problem (ALBP) involves distributing the tasks needed to manufacture any unit of the products to be assembled among the work stations along a manufacturing line. It was usually assumed that the required tasks cannot be split, that is, each must each be performed at a single station. However, this is not always the case in practice where task splitting can sometimes lead to improved line balancing. A case study was used to explain task splitting among more than one station in a Polish factory. It was shown how the precedence graph can be modified to allow for task splitting and discussed the application of some existing ALBP heuristics that lead to improved line time for the reported case study.

Finally it was concluded that task splitting, where appropriate, has the potential to significantly improve assembly line performance.

[21] Lagrangian Relaxation for Stochastic Disassembly Line Balancing Problem by Mohand Bentaha, Olga Battaia and Alexandre Dolgui. This study deals with the problem of profit oriented disassembly line balancing considering partial disassembly, presence of hazardous parts and uncertainty of task times. The objective of this paper was to design a serial line that obtains the maximum profit under uncertainty. Tasks of the best selected disassembly alternative are to be assigned to a sequence of workstations while respecting precedence and cycle time constraints. The line profit was computed as the difference between the positive revenue generated by the retrieved parts of the End of Life (EOL) product and the line operation cost. It also includes the workstation operation costs and additional costs for handling hazardous parts. Task times were assumed to be random variables with known probability distributions. An AND/OR graph was used to model the disassembly alternatives and
the precedence relationships among tasks and subassemblies. To cope with uncertainties, a solution method based on Lagrangian relaxation and Monte Carlo sampling technique was developed. To show the relevance and applicability of the proposed method, it was evaluated on a set of problem instances from the literature.

[22] Hybrid Multiobjective Evolutionary Algorithm for Assembly Line Balancing Problem with Stochastic Processing Time by Wenqiang Zhang et al. suggested that an assembly line (AL) is a typical manufacturing process consisting of various tasks in which interchangeable parts are added to a product in a sequential manner at a station to produce a final product. Most of the work related to the ALs concentrate on the assembly line balancing (ALB) which deals with the allocation of the tasks among stations so that the precedence relations among them are not violated and a given objective function is optimized. From the view point of the real ALB systems, multiobjective ALB with stochastic processing time (S-moALB) is an important and practical topic from traditional ALB problem involving conflicting criteria such as the cycle time, variation of workload, and/or the processing cost under uncertain manufacturing environment. This paper proposes a hybrid multiobjective evolutionary algorithm (hMOEA) to deal with such S-moALB problem with stochastic processing time considering minimization of the cycle time and the processing cost, given a fixed number of stations available.

[23] Production line balancing with discrete event simulation: A case study by Zupan and H. Herakovic. In this paper a case study was presented for the optimization of the production line by using the balancing and discrete event simulation approach. First the basic theory and steps for the production line balancing were presented. For the real production process, consisting of two production lines and an assembly workplace the simulation model was built and the initial results obtained. After balancing of the production process and improvement of its performance some further steps of the process optimization by using the improved simulation model were performed. The results of the combination of the line balancing and further process optimization raise the production rate of the process enormously.

[24] Simple and U-type assembly line balancing problems with a learning effect by M. Duran Toksari et al. In this paper, researchers introduced learning effect into assembly line balancing problems. It was shown that polynomial solutions can be obtained for both simple assembly line balancing problem (SALBP) and U-type line balancing problem (ULBP) with learning effect. It was also put forth that the simple assembly line balancing problem and U-type line balancing problem with the consideration of learning effects remains polynomially solvable. More computational effort than the effort required for solving the original problems is required to solve line balancing problems with a learning effect. Assembly line balancing with a learning effect are clearly interesting and significant topics for future research on assignment problems.

Toksari tested proposed algorithm for large scale SALBP and ULBP with learning effect. Proposed algorithm obtained solutions equal and less than theoretical minimum numbers of workstations.

[25] After defining the mathematical model for the problem, a basic Branch and Bound approach with three possible search strategies and different parameters was presented. Also it proposed the use of a Branch and Bound-based heuristic for large problems and analyze the behaviour of both exact and heuristic methods through experimental studies. Finally the implementation of these procedures in a Sheltered Work center for Disabled—the real environment which has inspired this research was described. In these centres the adoption of assembly lines provide many advantages, since the traditional division of work in single tasks may become a perfect tool for making certain worker disabilities invisible. Efficiently applying this configuration helps these centres to achieve their primary aim: growth in order to provide more jobs for more disabled people, but always considering the specific limitations that the disabled workers have. In this sense this paper shows one of the possible real applications where Operations Research can help not only to get economic and productive benefits but also certain social aims.

[26] Efficient Multi-Objective Optimization Method for the Mixed-Model-Line Assembly Line Design Problem by Jonathan Oesterle and Lionel Amodeo. This paper presents a mathematical model and an adaptation of the Strength Pareto Evolutionary Algorithm II (SPEA2) for the Mixed-Model Assembly Line balancing and equipment selection problem. The SPEA2 was enriched with a task and equipment reassignment procedure and aims at supporting the planners to find better solutions in the earliest phases of a production system planning project. The researchers emphasizes on [1], the ability of a company to compete effectively is influenced to a
large extent by its capacity to produce an increased number of customer based products in a timely manner [2]. Shorter product life cycles; high flexible, dynamic and efficient production systems are required, engendering an increased complexity in all factory domains. To handle this complexity, methods of Operations Research are often used to support the decision maker to plan flexible and optimal assembly lines.

In this paper Assembly lines that allow a low cost production, reduced cycle times and accurate quality levels, has been classified into three variants: (i) the Single Model Line, designed to carry out a single product, (ii) the Mixed Model Line, designed to produce similar models of a product in sequence or batch and (iii) the Multi Model Line, designed to produce various similar or different models in large batches.

3. CONCLUSION

From the study of assembly line balancing it is found that assembly lines are flow-line production systems, where a series of workstations, on which interchangeable parts are added to a product. The product is moved from one workstation to other through the line, and is complete when it leaves the last workstation. Ultimately, we have to work for assigning the workstations so that predetermined goal is achieved. This can be done by minimization of the number of workstations and maximization of the production rate as studied in the literature survey. It has been also observed that equipment costs, cycle time, the correlation between task times and equipment costs and the flexibility ratio needs a great attention.

1. A heuristic procedure for solving larger size of problems can be designed.
2. Paralleling of workstations and tasks may be studied to improve the line efficiency.
3. To select a single equipment to perform each task from a specified equipment set.
4. Bee and ant colony algorithm to be adopted for finding number of workstations.
5. An ant colony optimization algorithm is proposed to solve the assembly problem in which 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.
6. Parallel assembly lines provide some opportunities in improving increasing system flexibility, reducing failure sensitivity, improving system balance and productivity when the capacity of production system is insufficient.

4. SUMMARY

<table>
<thead>
<tr>
<th>Reference No.</th>
<th>Author names</th>
<th>Algorithm used</th>
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<tbody>
<tr>
<td>1</td>
<td>A. Seleim And H. Elmaraghy(2014)</td>
<td>Max-plus algebra</td>
</tr>
<tr>
<td>2</td>
<td>Mark Hillmann Et. al. (2014)</td>
<td>Failure Process Matrix</td>
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<td>3</td>
<td>Gonca Tuncel And Dilek Aydin ()</td>
<td>Teaching–Learning Based Optimization Algorithm</td>
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<td>4</td>
<td>Parames Chutima And Wanwisa Naruemitwong (2014)</td>
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<td>Ana S. Simaria And Pedro M. Vilanho (2009)</td>
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<td>D. Roy And D. Khan (2010)</td>
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<td>Multiple Ant Colony System and Multi-Objective Random Search Genetic Algorithm</td>
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<td>13</td>
<td>N.Papakostas et. al (2014)</td>
<td>Multi-criteria assembly line Design</td>
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<td>14</td>
<td>A. Al-Zuheri, L. Luong And K. Xing (2012)</td>
<td>Mathematical model using Walking Worker Assembly</td>
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<td>15</td>
<td>Chutima and Chimklai (2012)</td>
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REFERENCES


