Acta Tecnología - International Scientific Journal about Technologies
Volume: 9 2023 Issue: 2 Pages: 59-71 ISSN 2453-675X

https://doi.org/10.22306/atec.v9i2.171 *Received: 05 June 2023; Revised: 12 June 2023; Accepted: 23 June 2023*

Review on PCB assembly line balancing – glance

Panneerselvam Sivasankaran
Department of Mechanical Engineering, Manakula Vinayagar Institute of Technology, Pondicherry – 605 107, India,
sivasankaranmech@mvit.edu.in

Keywords: assembly line balancing, workstation and PCB manufacturing, precedence constraints and balancing efficiency, algorithm, mathematical model and simulation.

Abstract: The industrial technique known as assembly line balancing is used to increase the efficiency of balancing in production lines. By increasing line efficiency, the assembly line balance problem reduces the number of workstations. The assembly line balancing technique improves line production by utilizing the priority limits for task assignment in the workstation. By distributing the tasks among the workstations according to priority constraints, assembly line balancing improves the efficiency of the line. Line balance issues are observed to fall under the category of sequence-dependent issues while deciding which part numbers to allocate in the workstation. When choosing which part numbers to allocate in the workstation, line balancing concerns are seen to fall under the category of sequence-dependent issues. Mathematical models, algorithms, and simulation software are just a few of the techniques that have been used in the past to handle assembly line balancing concerns. In order to decrease workstation loads and boost assembly line productivity, an effort has been made to review the PCB manufacturing assembly line balancing problem in the current research study. The goal of the study is to cut down on the workloads and waiting times for each task on a manufacturing line. In order to reduce job waiting times and maximize station workloads, U Type Assembly Line is preferred in this study.

1 Introduction

In order to balance the workload across the workstations within the constraints of the cycle time, a procedure known as "line balancing" is used. The fundamental difficulty in an assembly line is assigning a set of duties to each workstation without going against the order of assembly. By increasing line efficiency, a good assembly line will attempt to balance all workloads. Line balancing is a flow-oriented manufacturing approach for boosting productivity and cost-effectiveness in mass production processes. A certain amount of time is allotted for the production of a particular product. Tasks are then evenly distributed across staff and workstations to ensure that every activity in the queue is finished within the allowed time limit.

Production line balancing is the process of simply allocating the correct quantity of workers and machinery to each area of the assembly line. This helps to achieve production rate targets by cutting down on idle time.

1.1 Why production line balancing is beneficial?

In order to increase production process efficiency, production line balancing is a great model to use. Here are a few of its advantages:

- Reduces the amount of idle time at workstations.
- Helps the production process to flow more efficiently.
- It aids in establishing the ideal assortment of workstations and the quantity of tasks to be performed at each one.
- By streamlining processes, one may increase teamwork and staff morale.
- enhances both the output quality and pace of manufacturing of the generated goods.
- Increases production capacity and labor utilization cuts down on waste.

1.2 Guidelines for line balancing:

To take advantage of the aforementioned benefits, your production line must be configured in a way that makes it easy for materials and components to move freely from one workstation to another.

A workstation is any place in the assembly line where employees execute a task on the final product. The cycle time is the length of time required to complete each workstation task. Production is at its peak when every product is made within the allotted time frame. The vast majority of specialists concur that achieving optimal scheduling is practically unattainable. Manual calculations can frequently be challenging and time-consuming. Each task at each workstation ought to be processed in an equal amount of time.

1.3 Assembly line balancing procedures

A. Create a precedence chart and outline the order of your workstations.

The entire production process is divided into a series of steps in this method. The task at a specific workstation must be finished before a product can go on to the next section.

A precedence diagram is a table-based depiction of the tasks that must be completed during a production project. The project can be displayed as a whole or in part using general or partial precedence diagrams. Your diagram should include information on the activities involved in production as well as their interdependencies.

B. Determine how much cycle time is required at each workstation.

You must conduct time studies to find out how long it takes to complete each task on the production line. The maximum amount of time a task can conceivably take to complete at each workstation is known as the cycle time.

You can determine the precise amount by dividing the quantity of the intended product by the number of manufacturing hours in a day. The time between each workstation and the workforce at the current machine pace will then be known to you.

The daily production volume of one line is used when determining cycle time. When the same product is produced on several lines, composite cycle time estimations using digital line balancing equipment would be necessary for accuracy.

C. Determine the estimated number of workstations you'll require.

This computation, which is based on cycle times, will help distribute the workloads across the workstations fairly. You can figure out how many workstations you need by dividing the overall task times by the desired actual times.

D. Assign work to the workstations and continue doing so until the process times are equal.

Continue to reorganize the duties to lessen overproduction and production bottlenecks. This entails moving a certain number of employees from stations with light workloads to stations with heavy workloads. This method aids in shortening wait times in overcrowded stations.To maximize machine utilization; make an effort to intelligently distribute the workload among the operators in a queue. For synchronicity, it is intended for each activity to take the same amount of time. Be aware that Takt time calculations will be necessary to guide your job distribution if you want to efficiently satisfy consumer demand. The Takt time is a measurement of how long a skilled individual or an automated system needs to complete a task. You incur the danger of overproduction and waste if you undertake keg line balancing until production exceeds takt time.

1.4 Assembly line significant importance

The process of making items or products is time-consuming since various tiny elements must be put together. The finished product is formed by connecting or assembling smaller elements in a specific order of phases. The use of an assembly line guarantees that the manufacturing process is divided into several steps, with smaller parts being attached at each level.

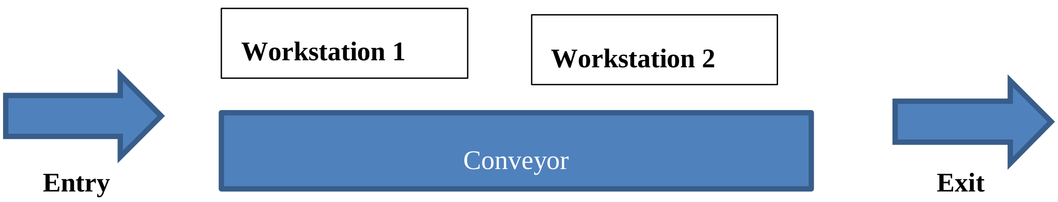

Figure 1 Assembly line systems in production

Workers can work side by side at their various phases of a streamlined manufacturing process, and the utilization of a conveyor belt or line guarantees that the product is sent to each stage after it for the assembly of the next smaller item. A key strategy for increasing productivity and maximizing the effectiveness of the product being created is assembly line production.

1.5 Types of assembly line

There are various assembly line manufacturing procedures, depending on the set up, design, stages, production needs, etc. Among them are:

1. A modular approach

In this method, numerous smaller goods are produced simultaneously on parallel assembly lines.

All lines or smaller items are combined to create the finished product at the end of each assembly line.

2. Manufacturing of cells

Instead of using separate stages for each step that needs to be completed, this assembly line method uses machines that can complete numerous tasks at once.

Acta Tecnología - International Scientific Journal about Technologies
Volume: 9 2023 Issue: 2 Pages: 59-71 ISSN 2453-675X

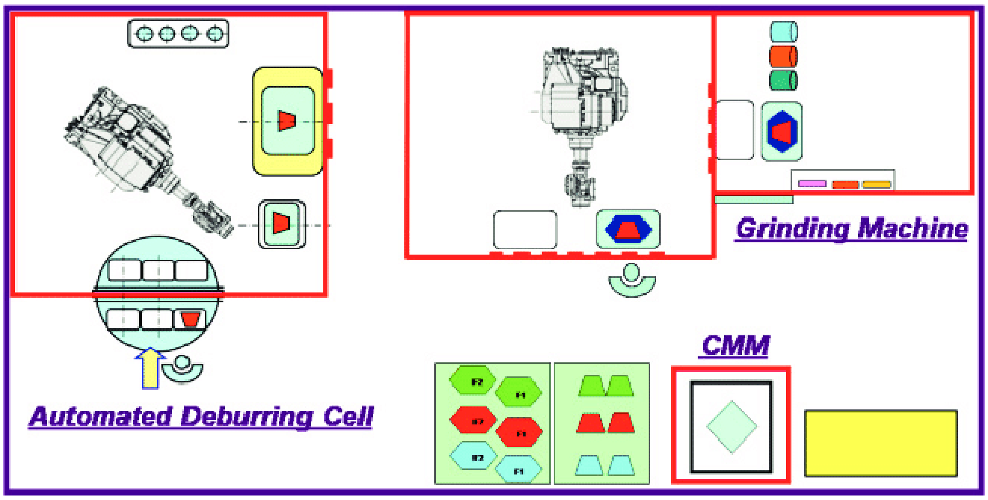

Figure 2 Manufacturing cells

3. Group effort

Teams had to participate in each stage and the final quality check in order for the technique to guarantee a high-quality final output. The several teams each have their own set of tasks to complete inside a stage, which they then turn over to the following team.

4. U-shaped assembly line

Workers in this method stand between the curves of a U-shaped or curved production line, which replaces the traditional straight production line. Better communication between related production phases is ensured as a result.

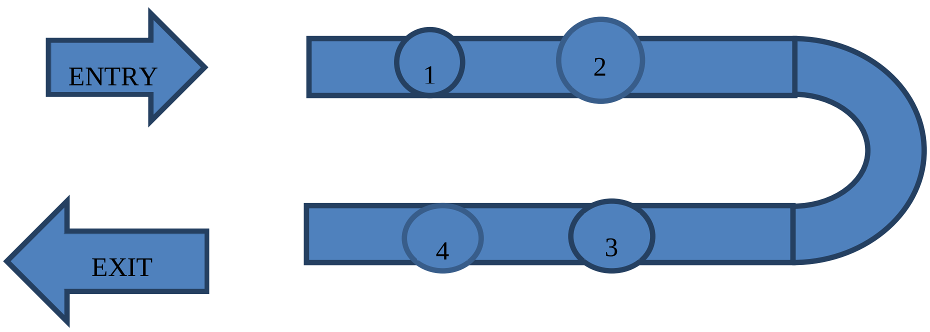

Figure 3 U type assembly line

2 Literature on asssembly line for PCB manufacturing

Assembly line balancing for PCB manufacturing is the subject of a thorough analysis of the literature in this part, which is listed below.

Classification of Assembly line balancing after 2007, 2013 and beyond 2015:

Onc¨u Hazır & Alexandre Dolgui [2019] This article reviews the difficulties, solutions, models, and algorithms associated with resilient assembly line balancing problems and offers potential attractive future research directions. Applications for single- and multi-criteria optimisation issues include precise and heuristic solution methods. Included are decision support systems (DSS), cutting-edge modelling techniques, simulation models, and their application to business decision-making and product life cycle management. Finding unresolved problems and research areas with immediate industrial relevance may be made easier with the help of the analysis and debate.

Naveen Kumar & Dalgobind Mahto [2013] Achieving the stated goal on an assembly line requires understanding how to balance tasks among workstations. The most frequent goals are to reduce the number of workstations and boost output. This paper reviews a number of works in the area of assembly line balancing in an effort to lower the cost of all the equipment and the number of workstations. Additionally, it looks for current market trends and technological advancements.

Nils Boysena, Philipp Schulze & Armin Scholl [2021] Mass-producers in many industrial branches have prioritized flow-oriented assembly processes, in which work parts are moved from workstation to workstation on an assembly line, since the time of Henry Ford up until the industry 4.0 period. One of the most fundamental optimization challenges in this situation is the assembly line balancing problem, which determines how to distribute labor throughout an assembly line's stations. This study examines the body of scholarly literature that has been produced since the most recent substantial review publications on assembly line balancing, which were published in 2006 and 2007, respectively.

Kheirabad M., Keivanpour S., Chinniah. Y & Frayret, J.M. [2022] The problems with assembly line balancing have been studied for a long time. The integration of collaborative robots into assembly processes and recent advancements in Industry 4.0 technology have created problems with task distribution, workload balance, and scheduling. This essay contrasts the salient features of the collaborative assembly line balancing issues that have been discussed in the literature to date and offers some suggestions for further study.

Mohamed Abdelkhak, Shady Salama & Amr B. Eltawil [2018] Discrete event simulation was utilized in this study to better understand the behavior of a TV PCB production line in one of the leading companies in the Middle East and Africa. The outcome of the simulation demonstrates an imbalance in workload between workstations that precludes any opportunity for improvement. In order to break up bottlenecks and enhance resource utilization, a range of scenarios for resource rearranging were presented. These scenarios involved transferring technicians from idle to active workstations. Throughput and workload balancing over the entire line have been considerably improved by the suggested configurations, demonstrating their superiority. Finally, a cost analysis was performed to assess the return on investment of each scenario separately in order to confirm the validity of these recommendations.

Fansuri, A.F.H, Rose, A.N.M, Ab Rashid, M.F.F, Nik Mohamed, N.M.Z, Ahmad, H [2018] Discrete event simulation was utilized in this study to better understand the behaviour of a TV PCB production line in one of the leading companies in the Middle East and Africa. The outcome of the simulation demonstrates an imbalance in workload between workstations that precludes any opportunity for improvement. In order to break up bottlenecks and enhance resource utilization, a range of scenarios for resource rearranging were presented. These scenarios involved transferring technicians from idle to active workstations. Throughput and workload balancing over the entire line have been considerably improved by the suggested configurations, demonstrating their superiority. Finally, a cost analysis was performed to assess the return on investment of each scenario separately in order to confirm the validity of these recommendations.

Yiyo Kuo, Taho Yang & Tzu-Lin Huang [2022] This paper suggests applying two restrictions to address the U-shaped production line balance problem. First, tasks can be performed in different places as long as they respect the order of priority between any two activities. Second, every piece of work is intended to be finished in a particular setting. When an operator is given two or more jobs, the cycle time must account for the time spent walking between the tasks' locations. The proposed problem is first presented using an integer programming formulation and is then resolved by commercial software named LINGO in order to decrease the cycle time and performance of the U-shaped production line. The empirical results show that U-shaped manufacturing lines function more effectively than traditional straight production lines.

Marcello Fera, Alessandro Greco, Mario Caterino, Salvatore Gerbino, Francesco Caputo, Roberto Macchiaroli & Egidio D'Amato [2019] The optimization of production processes, which strives to increase productivity while reducing associated costs, has historically been one of the foundations of manufacturing businesses. Thanks to Industry 4.0, some cutting-edge technologies that were believed to be out of reach just a few years ago are now available to everyone. The widespread use of these technologies in manufacturing facilities enables the interconnection of the resources (people and machines) and the control of the entire production chain through the collection and analysis of real-time production data to support decision-making. In order to examine production line performance metrics, this article will give a methodological framework that supports the analysis of both experimental and numerical data.

R. Gupta [2023] The goal of this study is to identify the essential components that will maximize printed circuit board (PCB) performance by increasing manufacturing process efficiency. A low scrap rate and optimised PCB design leads are the results of using the Failure Modes and Effects Analysis (FMEA) technique to reduce the percentage of finished goods that are discovered to be defective during the manufacturing process and final inspection. The entire quality process to obtain excellent performance in PCB design is introduced in this article. The study is set in the electronics manufacturing sector, where printed circuit boards are first accepted as raw materials and fed into the stamping and assembly processes using surface mount technology (SMT).

A.G. Gudsoorkar [2015] The study examines the procedures employed in a sizable electronics industry for the manufacture and assembly of electronic components and gadgets. The initial introduction to the industry details its goals as well as the rapid developments it has made in the 17 years since its founding in the fields of consumer electronics, computers, communications, and control systems. It also discusses the rise in sales turnover over the previous five years.

Carlos Alexandre X. Silva, Les Foulds & Humberto J. Longo [2019] In a common variation of the Simple Assembly Line Balancing Problem (SALBP-1), tasks are assigned to stations along an assembly line with a predetermined cycle period in order to decrease the required number of stations. It has long been held that the total quantity of labour necessary to produce each product unit is broken down into discrete tasks that are economically unassignable. However, it is often feasible to divide particular jobs in a certain way at a time penalty cost. Despite the consequences, task division occasionally reduces the required minimum of stations when it is feasible. The task division assembly line balancing issue, or TDALBP for short, is created when deciding which permissible jobs to split. We offer a precise solution method, a mathematical model of the TDALBP, and encouraging computational findings for the adaption of various traditional SALBP examples from the research literature. The outcomes show that the TDALBP sometimes has the ability to dramatically raise assembly line productivity.

Sivasankaran P. & P. Shahabudeen [2014] The productivity of an organisation depends on the architecture of its mass production system. Production lines that assemble goods and those that machine components are the two different kinds of mass production systems. The system of assembling products on an assembly line, also referred to as a production line, is the subject of this study. In this method, balancing the assembly line to get the right amount of production per shift is challenging. Reduce the number of workstations for a given cycle time (type 1), reduce the time for a given number of workstations operating at maximum capacity (type 2), and so forth are the main objectives of the assembly line design.

Sivasankaran P. & P. Shahabudeen [2016] The intensifying global competitions force organisations to use a number of productivity growth strategies. By assisting in the design of the assembly line to maximise balancing efficiency, assembly line balancing helps a company achieve this. When more than one model is assembled on the same line, the aim of the mixed model assembly line balancing problem is to maximise the average balancing efficiency of the models. By maximising the average balancing effectiveness of the models and minimising the makes pan of the sequencing models, a multi-objective function is created. The intensifying global competition forces organisations to use a number of productivity improvement strategies.

Sivasankaran P. & P. Shahabudeen [2017] This study contrasts assembly line balancing problem type 1 solutions with and without the use of a mixed model. To maximise the assembly line's ability to balance workloads, the ALB problem type 1 aims to distribute the jobs among the fewest number of workstations for a given cycle length. In contrast to the single model assembly line balancing, which involves only one model being assembled, the mixed model assembly line balancing involves numerous models being assembled on the same assembly line. A company must use mixed-model assembly line balancing in order to respond to the needs of its clients.

Jabir Mumtaz, Zailin Guan, Lei Yue, Zhengya Wang, Saif Ullah & Mudassar Rauf [2019] Printed circuit board (PCB) assembly lines are crucial for producing a variety of electrical devices. The PCB manufacturing industries tend to develop towards automated and complex manufacturing processes as a result of an increase in consumer demand for increasingly sophisticated products. The PCB assembly process is impacted by many planning and scheduling problems. Therefore, the current study looks at multiple levels of planning and scheduling for PCB assembly lines, including line assignment to PCB models, component allocation to machines, and component placement sequencing by machines on PCB boards.

Attila Tótha, Timo Knuutilaband Olli S. Nevalainen [2018] A typical gantry-type placement machine is made up of numerous connected, independently operating component placement modules. The machine was designed to allow for the use of several types of interchangeable placement heads and vacuum nozzles in the modules. Many interconnected, independently functioning component placement modules make up a conventional gantry-type placement machine. In order to accommodate several types of interchangeable placement heads and vacuum nozzles in the modules, the machine was constructed. A typical gantry-type placement machine is made up of numerous interconnected, independently operating component placement modules. The machine was built to be able to fit several types of interchangeable placement heads and vacuum nozzles in the modules**.**

M. Duran Toksar, Selcuk K., Isleyen, Ertan Guner, Omer Faruk Baykoc [2008] In this work, the learning impact of assembly line balancing problems was taken into consideration. By performing the same or similar activities repeatedly in multiple realistic contexts, the produced worker(s) (or machine(s)) evolve. As a result, processing a product later speeds up the production process. We show that for both the simple assembly line balancing problem

(SALBP) and the U-type line balancing problem (ULBP), polynomial solutions may be discovered with the help of learning.

Yu-ling Jiao, Han-qi Jin & Xin-ran Liu [2021] Due to the constant update of the manufacturing system, the research of the assembly line balance issue (ALBP) is continuously deeper in application theory and solution approaches. To determine the research topic and stage of assembly line balancing development, 89 papers are studied and reviewed. We classify ALBPs utilising vertical thinking and horizontal classification to create the research network structure.

Parames Chutima, Panuwat Olanviwatchai [2010] It is practically challenging to solve real-world problems using deterministic algorithms due to the documented NP-hardness of mixed-model U-shaped assembly line balancing problems (MMUALBP). This study uses a just-in-time production system and the combinatorial optimisation with coincidence algorithm (COIN) to solve Type I MMUALBP problems. All three criteria are taken into account at once: the least amount of workstations, the least amount of work-relatedness, and the least amount of workload smoothness.

Amir Nourmohammadia, Hamidreza Eskandarib, Masood Fathic & Mehdi Ranjbar Bouranid [2018] The line balancing and parts feeding (PF) challenges related to assembly line design are examined in this study using supermarkets. These problems occur in actual assembly lines (ALs), when decision-makers try to reduce total installation costs for ALs, which include line balancing and PF costs, by figuring out the appropriate number of stations and stores at the same time. To do this, an integrated mathematical model is proposed, and its performance is assessed by resolving a variety of benchmark problems and a real-world case from industry.

Parames Chutima [2020] The findings of a review of studies on assembly line balance issues (ALBPs) that were released between 2014 and 2018 are presented in this study. Before beginning a detailed literature analysis, the inefficiency of the previous ALBP categorization structures is investigated. A new classification system based on assembly line layout configurations is then offered. The research trend in each manufacturing line architecture is depicted graphically. Additionally emphasised as a technological path for upcoming research studies are the challenges with ALBPs.

Yuchen Li, Xiaofeng Hu, Xiaowen Tang & Ibrahim Kucukkoc [2019] In the written word. The vagueness of the task may lead to overcrowded workstations. Aspects of unpredictable task time were investigated using probability theory's frameworks. In terms of the best answers, we arrive to a few useful theorems. We also develop an algorithm based on the branch and bind remember method to address the proposed issue. To illustrate our model, numerical studies are then performed.

Yuri N. Sotskov [2023] Conventionally, assembly lines (conveyors) are used for large- and mass-scale production. The assembly process can be made more efficient by setting up and establishing an assembly line for the same or similar types of final products. The issue at hand is the layout of the assembly line and how the full burden for creating each unit of the fixed product to be assembled is distributed among the assigned workstations along the established assembly line. The assembly line balancing study focuses on simple assembly line balancing problems, which are limited by a number of elements that make a particular assembly line interesting for investigation.

Nuchsara Kriengkorakot and Nalin Pianthong [2007] The classic line balancing problem, commonly referred to as the straight line assembly line balancing problem, considers a production line with stations arranged in a line sequentially. A balance is produced by dividing work into stations and moving through a precedence diagram. However, the just-in-time (JIT) manufacturing approach has demonstrated that the U-line configuration of the stations has a number of advantages over the traditional setup. This paper introduces the U-line assembly line balance challenge. It is more challenging than the balance problem for a straight assembly line since tasks can be given by moving ahead, backward, or simultaneously in both directions through the precedence diagram.

Mustafa Fatih Yegul, Kursad Agpak & Mustafa Yavuz [2010] This study provides a new hybrid design for a certain type of assembly line and suggests a multi-pass random assignment method to identify the bare minimum number of stations required. The given tasks' timetable and sequence are also decided by the algorithm. The new design mixes U-shaped and two-sided lines, gaining the advantages of both at once. One side of the line is configured in a U form to accommodate stations with crossings, while the other side is balanced like a typical straight flow. Depending on the orientation of the product, the line's left or right side may be shaped like a U. The method was applied to fix both small and significant two-sided assembly line test-bed issues.

Ronnachai Sirovetnukul and Parames Chutima [2010] In most cases, the one-piece flow production line is set up as a U-shaped assembly configuration for both standard and customized goods. The properties of a single U-line are discussed and modelled in this paper. The job assignment into a U-line and assigning tasks to workers in order are both hierarchically important aspects of the worker allocation problem. Seven-task to 297-task challenges that require the assembly of several products are completed in a particular cycle time. Finding the effects of walking time on symmetrical and rectangular U-shaped assembly layouts is the main goal. Comparing the number of workers between two fixed layouts is the minor goal.

Zixiang Li, Mukund Janardhanan, Qiuhua Tang & Zikai Zhang [2022] Due to the development in robotic technology and the rise in labour expenses, collaborative robots (cobots) are being used more and more in many sectors. The cobots in the assembly line can be used to finish the jobs autonomously or with the help of the people. The U-shaped assembly line balancing problem involving cobots is examined in this study. Several cobots with various purchasing costs are chosen in accordance with the budgetary restrictions. To reduce cycle time, three mixed-integer programming models are developed, and the resulting models are effective in finding the best solutions for small-scale problems.

Krit Chantarasamai [2021] For the purpose of resolving Type 2 U-shaped Assembly Line Balancing Problems (UALBP-2), we outline a Differential Evolution (DE) algorithm. By creating solution techniques and conducting testing on 15 problem sets (101 occurrences), it was possible to determine the minimal cycle time in a just-in-time production line for producing a single product with a specific number of workstations. Ten sets of medium-scale issues (50 instances each) and five sets of large difficulties (51 instances each) were created from the problems. The DE method could produce 14 better solutions (28%) in the medium-scale problems and 3 better solutions (approximately 6%) in the large-scale problems when compared to the results of the rule-based heuristic; three rules and two rules.

Yuling Jiao, Xue Deng, Mingjuan Li, Xiaocui Xing, and Binjie Xu [2022] A parallel U-shaped assembly line system balancing approach is developed with the goal of increasing assembly line flexibility and efficiency. It is possible to get the bidirectional priority value formula from the improved product priority diagram. Workstation definition follows the z-q partitioning of assembly lines. The parallel U-shaped assembly line balance problem is then given a mathematical formulation. Explanatory examples and test examples are resolved using a heuristic process based on bidirectional priority values. The heuristic algorithm is suitable for big balancing problems, as can be seen from the outcomes and effect indicators of the assembly line balancing problem.

Mohammad Zakaraia, Hegazy Zaher [2021] A parallel U-shaped assembly line system balancing approach is developed with the goal of increasing assembly line flexibility and efficiency. It is possible to get the bidirectional priority value formula from the improved product priority diagram. Workstation definition follows the z-q partitioning of assembly lines. The parallel U-shaped assembly line balance problem is then given a mathematical formulation. Explanatory examples and test examples are resolved using a heuristic process based on bidirectional priority values. The heuristic algorithm is suitable for big balancing problems, as can be seen from the outcomes and effect indicators of the assembly line balancing problem. The suggested approach provides a faster calculation time and greater calculation accuracy.

Ihsan Sabuncuoglu, Erdal Erel & Arda Alp [2009] A production line where items move continually through a series of stations is called an assembly line. The assignment of work to an ordered series of stations subject to priority restrictions with the aim of optimizing a performance metric is known as the "assembly line balancing problem." In this study, we suggest ant colony algorithms to address the issue of balancing a single-model U-type manufacturing line. We carry out a thorough experimental research in which the performance of the suggested algorithm is evaluated in comparison to best-known algorithms described in the literature. The outcomes show that the proposed algorithms outperform them in a very competitive manner.

Adarsh Adeppa, M. S. Uppin [2018] Balancing in the assembly line is one of the often employed production methods. Assembly line balancing involves reducing the number of workstations, reducing cycle time, and increasing the smoothness of the workload. an increase in work-relatedness It is utilized to quickly assemble huge quantities of a consistent product. Assembly lines were initially created for the mass manufacturing of standardized products at a low cost in order to take advantage of the high specialization of labor and the resulting learning effects.

Aadarsh Adeppa [2015] One of the most common production methods is the assembly line. Assembly line balancing involves reducing the number of workstations, reducing cycle time, and increasing the smoothness of the workload. an increase in work-relatedness It is utilized to quickly assemble huge quantities of a consistent product. Assembly lines were initially created for the mass manufacturing of standardized products at a low cost in order to take advantage of the high specialization of manpower and the resulting learning effects.

Guangyue Jia, Honghui Zhan and Yunfang Peng [2023] Just-in-time manufacturing is frequently implemented using U-shaped assembly lines. To increase production, the U-shaped assembly line balancing problem must be solved. The majority of research disregard variables like operating times. In order to solve the type-II U-shaped assembly line balancing issue (UALBP-2) under uncertainty, this work employs robust optimisation techniques. A genetic algorithm is created to handle a mathematical programming model that has interval task operation timings. The most frequent option that falls within a predetermined percentage of the ideal solution for several sets of scenarios is referred to as a robust solution. To confirm the viability and efficacy of the robust approach, the experimental findings are compared with the anticipated outcome.

Mohammad Zakaraia The U-shaped assembly line balancing problem with stochastic processing time is covered in this article. Chance-constrained programming is utilized to formulate the issue, and the greedy randomized adaptive search method is employed to resolve it. 71 issues from well-known benchmarks are solved and compared with the theoretical lower bound in order to demonstrate the effectiveness of the suggested algorithm. Of these, 13 were compared with beam search, another method that was employed to tackle the identical problem in a different work. The findings reveal that 59 issues match the theoretical aspiration lower bound. In addition, 11 out of 13 issues' outcomes compared to beam search are same, and two problems' results are superior to beam search.

Salah Eddine Ayoub El Ahmadi, Laila El Abbadi & Moulay Taib Belghiti [2019] A technique used in mass production, particularly in the automotive sector, is the assembly line. It comprises of numerous workstations arranged along a belt transport system or other handling equipment. The Assembly Line Balancing Problem (ALBP), which has a direct impact on the productivity of the entire production system, is a key issue. This study provides an up-to-date review of the subject and discusses the evolution of the classification of assembly line balancing issues (ALBP), as well as the procedures and algorithms that, in our particular example, suggest solutions to the ALBP.

Belassiria Imad, Mazouzi Mohamed, ELfezazi Said, Cherrafi Anass & ELMaskaoui Zakaria [2017] In order to solve the challenge of balancing an assembly line, we suggest a hybrid genetic algorithm in this study. We concurrently maximise assembly line productivity and reduce overall idle time in the optimization framework. The model can handle more realistic assembly line balancing situations, like zoning restrictions. By sequentially combining the well-known assignment rules heuristics with the genetic algorithm, we seek to give the genetic algorithm with the ability to explore the solution space effectively.

N.H. Kamarudin, M.F.F. Ab. Rashid [2017] This article presents a mathematical model for the Simple Assembly Line Problem Type 1 (SALBP-1) with constraints on both human and mechanical resources. The present SALBP-1 model assumes that each workstation has a similar capability, but in reality, due to technological and human skill limits, each workstation has a unique capability. The proposed model seeks to mathematically represent the SALBP-1 with resource constraints. Three objective functions are also provided with the intention of reducing the number of personnel, machines, and workstations. Different machine types are assumed to be needed in an assembly line to produce diverse items, while the workers are thought to have a variety of skills and aptitudes. The concept is then demonstrated and validated using a few instances.

M. Bagher & M. Zandieh & H. Farsijani [2011] In order to improve efficiency and flexibility, U-shaped assembly lines are increasingly being examined in the industry as a replacement for traditional straight assembly lines. Due to their complexity in terms of mathematics and computation, assembly line balance problems are known to be NP-hard in nature. Many meta-heuristics have been proposed in order to find the optimal solution to these problems. This research offers a new hybrid evolutionary algorithm to balance stochastic U-type assembly lines with the aim of lowering the number of workstations, idle time at each station, and non-completion probabilities of each station (probability of the station duration exceeding cycle time).

Olcay Polat, Özcan Mutlu and Elif Özgormus [2018] One of the crucial components of production systems that affects the overall cost and efficiency is the assembly line. The effectiveness of assembly lines in actual use is directly impacted by the productivity of the human resource on the lines.

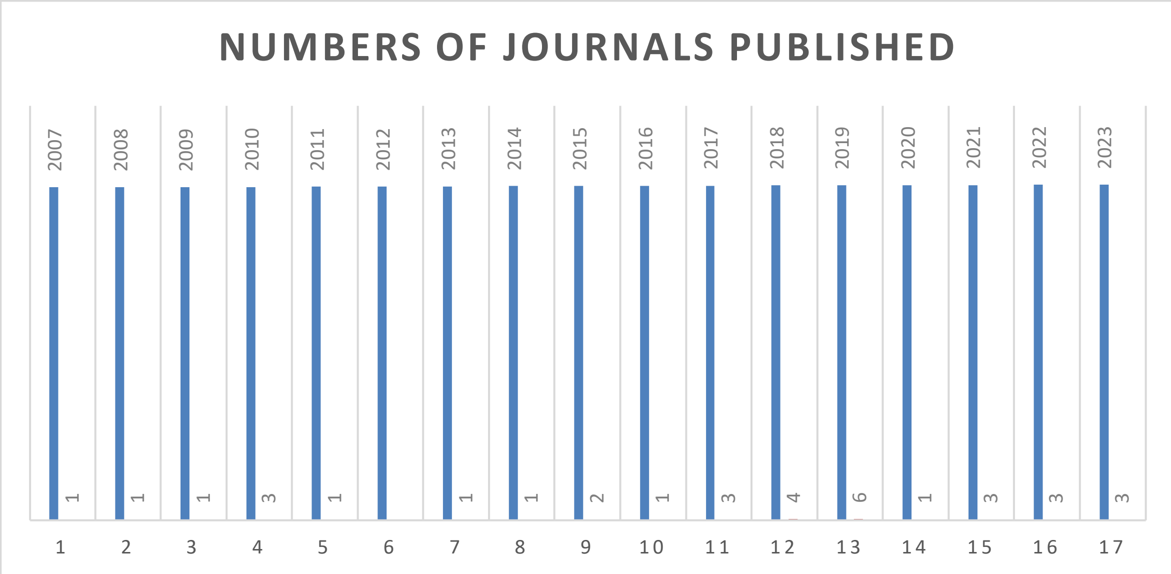

Figure 4 Nubers of journals published

From Figure 4, it is observed that number of journals published in 2019 is higher compared to other years in line balancing concepts. Line balancing is one of the modern concepts in operation management system. Hence attempt has been made to conduct survey on U type line balancing problem.

3 Methodology

In this section detailed methodology of solving assembly line balancing problems is illustrated here. Among various types of line layout, U Type Assembly line balancing is considered in this research. The general description of layout is given below in the following illustration (Figure 5).

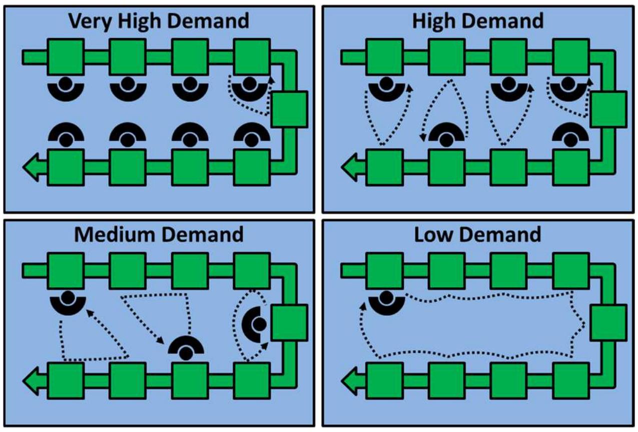

Figure 5 Different demands of U type Assembly line

For optimizing the Various station workloads U Type assembly line is most preferred one in common use.

3.1 Benefits of using U type line balancing in assembly process

- Product should always be moved anticlockwise in the same direction.
- To increase accountability, quality, and traceability, cross-train staff so they can handle all or the majority of the tasks within the cell.
- To reduce the distance between the start and finish of the process, if possible, use U-shaped assembly cells.
- Use First in First out (FIFO) to decrease errors, speed up lead times, and enhance order accuracy.
- Workstations should be placed as near together as feasible to reduce wasted space, but not too close that maintenance is hampered or workers are uncomfortable.
- Design a mechanism that will allow sub-parts to enter the system in the best possible way while taking ergonomic principles into account.
- Keep the cell's flow channel open and unobstructed.

3.2 Case study on U type assembly line balancing problem

In this section detailed case study on U type Assembly line balancing problem in PCB assembly line is discussed here in this phase of research. Consider Assembly line with seven workstations as illustrated below.

Acta Tecnología - International Scientific Journal about Technologies
Volume: 9 2023 Issue: 2 Pages: 59-71 ISSN 2453-675X

Table 1 Precedence relationship table

S.NO	Task	Description	Duration	Predecessors
1	1	Preparing the Box	3	-
2	2	PCB with Bluetooth module	6	1
3	3	PCB with amplifier	7	1
4	4	Battery	6	2
5	5	Connecting circuit	4	2
6	6	Connecting The PCB s	8	2,3
7	7	Integrated circuit of the speaker	9	3
8	8	Adjusting the Connections	11	6
9	9	Charging & Command Panel	2	4,5,8
10	10	Protective grid	13	8,11
11	11	Speaker	4	7
12	12	Closing the box	3	9,1

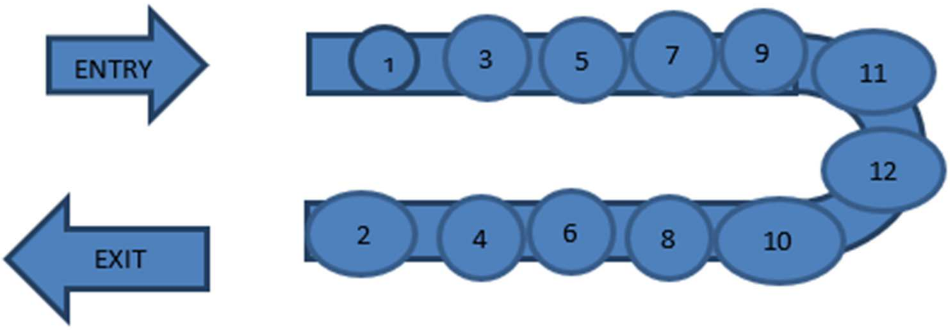

Figure 6 U type layout

From Figure 6 the various activities of PCB assembly line are arranged as per the precedence network constraints as illustrated above. In the precedence network tasks times also scheduled for each activity respectively as shown in Figure 6. The cycle time in the assembly is said to be 15 minutes.

3.3 Workstation formation

From Figure 7 Workstation design of assembly line is illustrated with various workstations say seven workstations in assembly line with cycle time as 15 minutes.

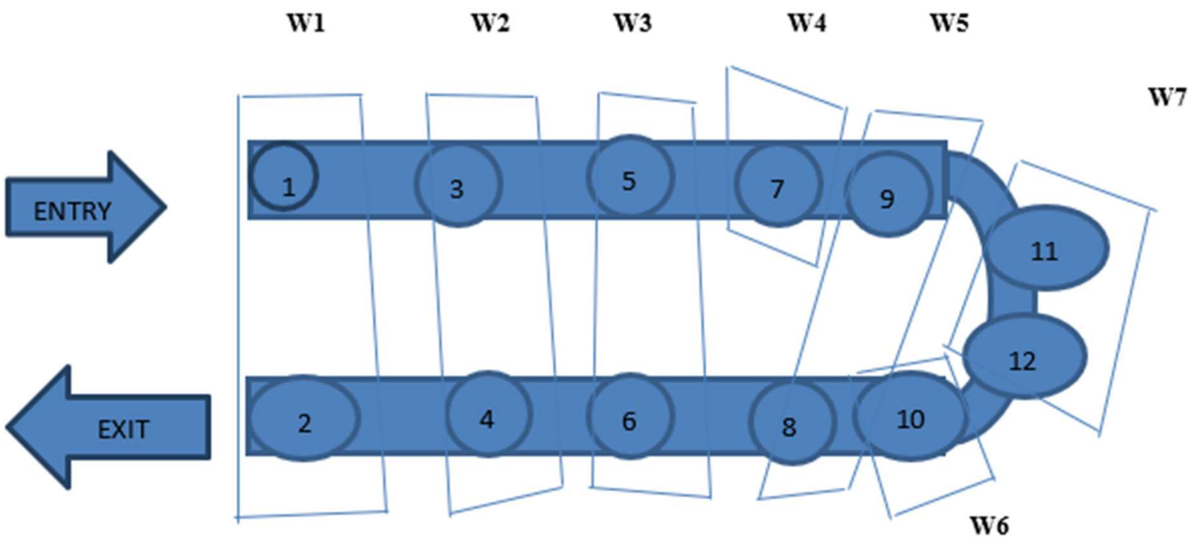

Figure 7 Workstation design of assembly line

In each stations the workload is assigned within the given cycle time constraints as listed below shown in the following table (Table 2).

Table 2 Computation of idle time for assembly station

Assembly Station	Tasks	Station Time (Minutes)	Idle time (Minutes)
1	1,2	09	06
2	3,4	13	02
3	5,6	12	03
4	7	09	06
5	8,9	13	02
6	10	13	02
7	11,12	07	08

From Table 2 station time and idle time are calculated by using the following expressions as listed below.

$$A = I + J \quad (1)$$

$$B = K - A \quad (2)$$

where:
A - station time,
B - idle time,
I - process time of activity,
J - process activity,
K - cycle time.

For task (1) and (2):
Station time A = 6 +3 = 09 minutes
Idle time B = 15-9 = 06 minutes

Computation of line efficiency (3):

$$L = M / (N{*}K) * 100 \ (\%) \quad (3)$$

where:
L - balancing efficiency (%),
M - sum of process times of all activities,
N - number of stations.

Balancing efficiency L = 76 / (7*15) * 100 = 72.38%

Thus, the balancing efficiency for U type assembly line is evaluated based on the number of workstations and cycle time respectively.

Outcome of case study:

In this case study attempt has been made to solve U type assembly line balancing for electronic PCB manufacturing system. The line efficiency was 72.38% which is considered to be average in nature. The maximum idle time in the assembly station occurs in the following station such as workstation 1, workstation 4 and workstation 7 respectively. Due to that line efficiency gives moderate percentage yield.

4 Conclusion

Line balancing is the production technique which is used to balance the workstation constraints for given cycle time. The main idea of line balancing concept is to adjust the station workloads as per cycle time constraints. Line balancing helps to maximize the line efficiency by assigning the workload in the assembly station. In this paper attempt has been made to solve line balancing problem under U Type model configuration for electronic manufacturing systems say PCB manufacturing Applications. Case study on U type line balancing problem is illustrated with precedence ray diagram with process time for various tasks elements.

In the case study description, the various workstation along with station time and idle time was discussed in the case study illustration shown in precedence graph. In addition to that balancing efficiency is computed as per cycle time constraints.

Future scope:

Mathematical model can be developed to solve line balancing problems then the solution is compared with algorithm in terms of solving time.

References

[1] HAZIR, Ö., DOLGUI, A.: A Review on Robust Assembly Line Balancing Approaches, *IFAC-PapersOnLine*, Vol. 52, No. 13, pp. 987-991, 2019. https://doi.org/10.1016/j.ifacol.2019.11.323
[2] KUMAR, N., MAHTO, D.: Assembly Line Balancing: A Review of Developments and Trends in Approach to Industrial Application, *Global Journal of Researches in Engineering Industrial Engineering*, Vol. 13, No. 2, pp. 29-50, 2013.
[3] BOYSEN, N., SCHULZE, P., SCHOLL, A.: Assembly line balancing: What happened in the last fifteen years?, *European Journal of Operational Research*, Vol. 301, No. 3, pp. 797-814, 2022. https://doi.org/10.1016/j.ejor.2021.11.043
[4] KHEIRABAD, M., KEIVANPOUR, S., CHINNIAH,Y.A., FRAYRET, J.M.: *A Review on Collaborative Robot Assembly line Balancing Problems*, 10th IFAC Triennial Conference on Manufacturing Modelling, Management and Control, 22.-24.06.2022, MIM 2022, pp. 2779-2784, 2022. https://doi.org/10.1016/j.ifacol.2022.10.151
[5] ABDELKHAK, M., SALAMA, S., ELTAWIL, A.B.: *Improving Efficiency of TV PCB Assembly Line Using a Discrete Event Simulation Approach: A Case Study*, ICCMS '18: Proceedings of the 10th International Conference on Computer Modeling and Simulation, pp. 211-215, 2018.
[6] FANSURI, A.F.H, ROSE, A.N.M, AB RASHID, M.F.F, NIK MOHAMED, N.M.Z, AHMAD, H.: *Productivity Improvement Through Line Balancing at Electronic Company – Case Study*, IOP Conference

Series: Materials Science and Engineering, Vol. 409, pp. 1-6, 2018. https://doi.org/10.1088/1757-899X/409/1/012015

[7] KUO, Y., YANG, T., HUANG, T.L.: Optimizing U-Shaped Production Line Balancing Problem with Exchangeable Task Locations and Walking Times, *applied science*, Vol. 12, No. 7, pp. 1-15, 2022. https://doi.org/10.3390/app12073375

[8] FERA, M., GRECO, A., CATERINO, M., GERBINO, S., CAPUTO, F., MACCHIAROLI, R., D'AMATO, E.: Towards Digital Twin Implementation for Assessing Production Line Performance and Balancing, *sensors*, Vol. 20, No. 1, pp. 1-18, 2020. https://doi.org/10.3390/s20010097

[9] GUPTA, R.: Failure Mode and Effects Analysis of PCB for Quality Control Process, *MAPAN-Journal of Metrology Society of India*, Vol. 38, No. 2, pp. 547-556.

[10] GUDSOORKAR, A.G.: Production and Assembly of Electronic Equipments in a Large Electronics Industry: A Case Study, *IETE Technical Review*, Vol. 3, pp. 157-168, 1986.

[11] SILVA, C.A. X., FOULDS, L., LONGO, H.J.: Assembly Line Balancing With Task Division, *Computer Science, Artificial Intelligence*, Vol. 2019, No. June, pp. 1-15, 2019.

[12] SIVASANKARAN, P., SHAHABUDEEN, P.: Literature review of assembly line balancing problems, *The International Journal of Advanced Manufacturing Technology*, Vol. 73, pp. 1665-1694, 2014.

[13] SIVASANKARAN, P., SHAHABUDEEN, P.: Heuristics for Mixed Model Assembly Line Balancing Problem with Sequencing, *Intelligent Information Management*, Vol. 8, No. 3, pp. 41-65, 2016.

[14] SIVASANKARAN, P., SHAHABUDEEN, P.: Comparison of single model and multi-model assembly line balancing solutions, *International Journal of Computational Intelligence Research*, Vol. 13, No. 8, pp. 1829-1850, 2017.

[15] MUMTAZ, J., GUAN, Z., YUE, L., WANG, Z., ULLAH, S., RAUF, M.: Multi-Level Planning and Scheduling for Parallel PCB Assembly Lines Using Hybrid Spider Monkey Optimization Approach, *IEEE Transactions*, Vol. 7, pp. 18685-18700, 2019.

[16] TÓTH, A., KNUUTILA, T., NEVALAINEN, O.S.: Machine configuration and workload balancing of modular placement machines inmulti-product PCB assembly, *International Journal of Computer Integrated Manufacturing*, Vol. 31, No. 9, pp. 815-830, 2018.

[17] TOKSARI, M.D., ISLEYEN, S.K., GUNER, E., BAYKOC, O.F.: Simple and U-type assembly line balancing problems with a learning effect, *Applied Mathematical Modelling*, Vol. 32, No. 12, pp. 2954-2961, 2008.

[18] JIAO, Y.-L., JIN, H.-Q., LIU, X.-R.: Assembly line balance research methods, literature and development review, *Concurrent Engineering*, Vol 29, No. 2, pp. 183-194, 2021. https://doi.org/10.1177/1063293X20987910

[19] CHUTIMA, P., OLANVIWATCHAI, P.: Mixed-Model U-Shaped Assembly Line Balancing Problems with Coincidence Memetic Algorithm, *Journal of software Engineering and Applications*, Vol. 3, No. 4, pp. 347-363, 2010. https://doi.org/10.4236/jsea.2010.34040

[20] NOURMOHAMMADI, A., ESKANDARI, H., FATHI, M., BOURANI, M.R.: *An integrated model for cost-oriented assembly line balancing and parts feeding with supermarkets*, 51st CIRP Conference on Manufacturing Systems, Procedia CIRP 72, pp. 381-385, 2018.

[21] CHUTIMA, P.: Research Trends and Outlooks in Assembly Line Balancing Problems, *Engineering Journal*, Vol. 24, No. 5, pp. 94-134, 2020. https://doi.org/10.4186/ej.2020.24.5.93

[22] LI, Y., HU, X., TANG, X., KUCUKKOC, I.: Type-1 U-shaped Assembly Line Balancing under uncertain task time, *IFAC PapersOnLine* Vol. 52, No. 13, pp. 992-997, 2019. https://doi.org/10.1016/j.ifacol.2019.11.324

[23] SOTSKOV, Y.N.: Assembly and Production Line Designing, Balancing and Scheduling with Inaccurate Data: A Survey and Perspectives , *algorithms*, Vol. 16, No. 2, pp. 1-43, 2023. https://doi.org/10.3390/a16020100

[24] KRIENGKORAKOT, N., PIANTHONG, N.: The U-line Assembly Line Balancing Problem, *KKU Engineering Journal*, Vol. 34, No. 3, pp. 267-274, 2007.

[25] YEGUL, M.F., AGPAK, K., YAVUZ, M.: A New Algorithm For U-Shaped Two-Sided Assembly Line Balancing, *Transactions of the Canadian Society for Mechanical Engineering*, Vol. 34, No. 2, pp. 225-241, 2010. https://doi.org/10.1139/tcsme-2010-0014

[26] SIROVETNUKUL, R., CHUTIMA, P.: The Impact of Walking Time on U-Shaped Assembly Line Worker Allocation Problems, *Engineering Journal*, Vol. 14, No. 2, pp. 53-78, 2010. https://doi.org/10.4186/ej.2010.14.2.53

[27] LI, Z., JANARDHANAN, M., TANG, Q., ZHANG, Z.: Models and algorithms for U-shaped assembly line balancing problem with collaborative robots, *Soft Computing*, Vol. 27, pp. 9639-9659, 2023. https://doi.org/10.1007/s00500-023-08130-y

[28] CHANTARASAMAI, K.: Modified Differential Evolution Algorithm for U-Shaped Assembly Line Balancing Type 2, *International Journal of Intelligent Engineering and Systems*, Vol. 14, No. 4, pp. 452-462, 2021. https://doi.org/10.22266/ijies2021.0831.39

[29] JIAO, Y., DENG, X., LI, M., XING, X., XU, B.: Balancing of parallel U-shaped assembly lines with a heuristic algorithm based on bidirectional priority values, *Concurrent Engineering*, Vol. 30, No. 1, pp. 80-92, 2022.

[30] ZAKARAIA, M., ZAHER, H.: Solving Stochastic Multi-Manned U-shaped Assembly Line Balancing Problem Using Differential Evolution Algorithm, *International Journal of Production Management and Engineering*, Vol. 10, No. 1, pp. 13-22, 2022.

[31] SABUNCUOGLU, I., EREL, E., ALP, A.: Ant colony optimization for the single model U-type assembly line balancing problem, *International Journal of Production Economics*, Vol. 120, No. 2, pp. 287-300, 2009.

[32] ADEPPA, A., UPPIN, M.S.: An Overview of Assembly Line Balancing, *International Journal of Engineering and Innovative Technology*, Vol. 7, No. 8, pp. 38-42, 2018.

[33] ADEPPA, A.: A Study on Basics of Assembly Line Balancing, *International Journal on Emerging Technologies*, Special Issue on NCRIET-2015, Vol. 6, No. 2, pp. 294-297, 2015.

[34] JIA, G., ZHAN, H., PENG, Y.: A genetic algorithm-based robust approach for type-II U-shaped assembly line balancing problem, *International Journal of Innovative Computing and Applications*, Vol. 13, No. 5-6, pp. 296-302, 2023.

[35] ZAKARAIA, M., ZAHER, H., RAGAA, N.: A Greedy Randomized Adaptive Search for Solving Chance-Constrained U-Shaped Assembly Line Balancing Problem, *International Journal of Applied Metaheuristic Computing*, Vol. 13, No. 1, pp. 1-18, 2022.

[36] EL AHMADI, S.E.A., EL ABBADI, L., BELGHITI, M.T.: *A Review Paper on Algorithms Used for Simple Assembly Line Balancing Problems in the Automotive Industry*, Proceedings of the International Conference on Industrial Engineering and Operations Management Pilsen, Czech Republic, July 23-26, 2019, pp. 1840-1846, 2019.

[37] IMAD, B., MOHAMED, M., SAID, E., ANASS, CH., ZAKARIA, E.: Solving Assembly Line Balancing Problem Using A Hybrid Genetic Algorithm With Zoning Constraints, *International Journal of Business and Management Invention*, Vol. 6, No. 5, pp. 34-40, 2017.

[38] KAMARUDIN, AB. RASHID, M.F.F.: Modelling of Simple Assembly Line Balancing Problem Type 1 (SALBP-1) with Machine and Worker Constraints, *Journal of Physics: Conference Series*, Vol. 1049, 2018.
https://doi.org/10.1088/1742-6596/1049/1/012037

[39] BAGHER, M., ZANDIEH, M., FARSIJANI, H.: Balancing of stochastic U-type assembly lines: an imperialist competitive algorithm, *The International Journal of Advanced Manufacturing Technology*, Vol. 54, pp. 271-285, 2011.
https://doi.org/10.1007/s00170-010-2937-3

[40] POLAT, O., MUTLU, O., ÖZGORMUS, E.: A Mathematical Model For Assembly Line Balancing Problem Type 2 Under Ergonomic Workload Constraint, *The Ergonomics Open Journal*, Vol. 11, pp. 1-10, 2018.

Review process
Single-blind peer review process.