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A literature review on assembly line optimization using data structure algorithm

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Abstract

In the automotive industry and other manufacturing sectors, a final assembly line is responsible for assembling different components of a product in the production system. The productivity of a manufacturing process is determined by its duration, the quantity of workstations employed, and the proficiency of its operators. Therefore, in order to effectively oversee or rival several industrial sectors, or to enhance efficiency in a certain assembly line to uphold productivity. This study details the enhancement process of a four-circuit pressure valve assembly line through the utilization of simulation approaches. This study proposes the utilization of data structure as a means to enhance the efficiency of assembly line operations. The main objectives of this program are to reduce workstation operations and enhance product output, as well as to offer recommendations for optimizing the manufacturing process to attain superior outcomes. The study utilized qualitative methodologies, whereby the procedural sequence was observed and data was gathered in accordance with the data framework specifications. The data structure was built using the collected data, followed by analysis of the results. Subsequently, new simulations were developed, incorporating improvements, to finalize the outputs.

Keywords: Productivity; Assembly line optimization; Manufacturing process, Random Start of Shortest Distance Permutation algorithm; Traveling Salesman Problem

1. Introduction

Industries that presently acquire their products through assembly lines encounter significant challenges. Initially, due to the market's want for variety, a significant quantity of product models and their variations must be assembled in their production lines. due to the market's requirement for a specific degree of diversity. Ensuring an adequate workforce and allocation of resources is another challenge. The act of reconciling operations is apparent in this situation. Workstation equilibrium tasks are performed to enhance productivity and reduce operational costs of the assembly line. Various methodologies, such as precise, heuristic, meta-heuristic, and simulation approaches, can be employed to achieve these objectives. Hence, the objective of the research is to continue the case study from the previous investigation, employing the Data structure as an alternative method to tackle it. This study showcases the utilization of Data structure as a viable remedy for the challenges encountered by a company involved in the production of air processing units. Presently, efficient systems are characterized by remarkably rapid production cycles for all models, a high level of automation, the need for novel technologies, and significant construction expenses linked to assembly line development. These attributes prompted designers to recognize emerging challenges, leading them to create new product lines and continuously improve old ones. They also focused on establishing accurate and appropriate software tools to streamline the line design process.

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2. Literature Review

The Assembly Line Balancing (ALB) problem was introduced by Helgeson et al. in 1954, spawning various solution approaches categorized by Ghosh and Gagnon (1989) into four groups: Single Model Deterministic (SMD), Single Model Stochastic (SMS), Multi/Mixed Model Deterministic (MMD), and Multi/Mixed Model Stochastic (MMS)[1]. This paper focuses on the SMD category, examining dedicated, single-model assembly lines optimizing efficiency criteria. Notably, SMD has received substantial research attention, with 64 articles published since 1983. Existing literature explores solution methods including Linear Programming (LP), Integer Programming (IP), Dynamic Programming (DP), and Branch-and-Bound (B&B) approaches. Due to the impracticality of exact methods for larger problems, heuristic approaches gained prominence. Notable heuristics such as Dar-El's MALB (1973), Dar-El and Rubinovitch's MUST (1979), Baybars' LBHA (1986), Tonge's (1965), Moodie and Young's . Researchers employ genetic algorithms for assembly planning by initializing sequences, evaluating fitness, and iteratively evolving solutions through selection and genetic operations until meeting specific termination criteria. Variations include diverse initialization strategies and termination conditions, with approaches emphasizing user-supplied populations, unique categorization of sequences, and considerations for diverse fitness criteria. These methods showcase the adaptability of genetic algorithms in optimizing assembly plans based on problem complexity and user-defined preferences. Chen keeps the population size constant while including both user-supplied and random beginning populations. The process is stopped when the overall fitness achieves a stable state. Hong and Cho concentrate on restricting the number of children created by applying particular probabilities, determining fitness based on assembly cost, and ending the process after a predetermined number of generations or when maximum fitness stabilizes.In a comparative analysis of selection techniques, Senin et al. demonstrate that genetic algorithms outperform other approaches in identifying superior plans that can be completed in realistic amounts of time, especially when dealing with complicated scenarios. Lazzerini and Marcelloni use multi-dimensional genetic encoding, take into account a number of factors, and stop their process when the average fitness of the population becomes close to the maximum fitness value. Greg C. Smith, Shana S.-F. Smith, [2] An enhanced genetic algorithm for automated assembly planning,Robotics and Computer-Integrated Manufacturing. The research on U-lines, relatively new compared to traditional straight lines, divides into two categories: Line Balancing (ULB) and Production Flow Lines, with ULB focusing on minimizing cycle time or the number of stations, while Production Flow Lines study design factors and their impact on performance. The evolution of ULB research began with Monden's introduction of U-lines in 1993, followed by Miltenburg and Wijngaard's pioneering study in 1994, which minimized stations for single-model U-lines and introduced a heuristic for larger problems. Miltenburg and Sparling in 1995 developed Dynamic Programming (DP) and Branch-and-Bound (B&B) algorithms, favoring B&B's efficiency. Urban in 1998 introduced an Integer Programming (IP) formulation solving problems with up to 45 tasks, while Scholl and Klein in 1999 adapted a B&B algorithm (ULINO) for minimizing stations in U-lines. Additionally, Sparling and Miltenburg in 1998 devised a heuristic for mixed-model U-lines handling up to 25 tasks, and Miltenburg in 1998 proposed a DP formulation for facilities with multiple U-lines connected by multiline stations. Sparling in 1998 developed heuristics considering travel time for U-line facilities with up to nine U-lines and 18 tasks each. Despite exact methods being limited to solving up to 45-task problems due to complexity, the need for more computationally effective heuristic procedures for larger problems (>100 tasks) is recognized. Hence, the paper introduces a procedure capable of handling more than 100-task problems effectively. E. Erel et al. discussed Balancing of U-type assembly systems using simulated annealing process [32]

3. Simulation technique and case study done by researches

To optimize time efficiency, we may eliminate non-value added or semi-value added tasks from the assembly line by using the data structure algorithm. This technique will be utilized in simulating the operations of the four circuit protection valve assembly line station. The data structure algorithm requires certain inputs, such as cycle time, the number of workstations required, takt time, customer demands, production hours, work flow type, etc., in order to operate the simulation. By utilizing this data, we can minimize the amount of time wasted on unproductive tasks, so enhancing our overall productivity in the long run. Four circuit protection valves is used to control the pressure from compressor as shown in Figure 1

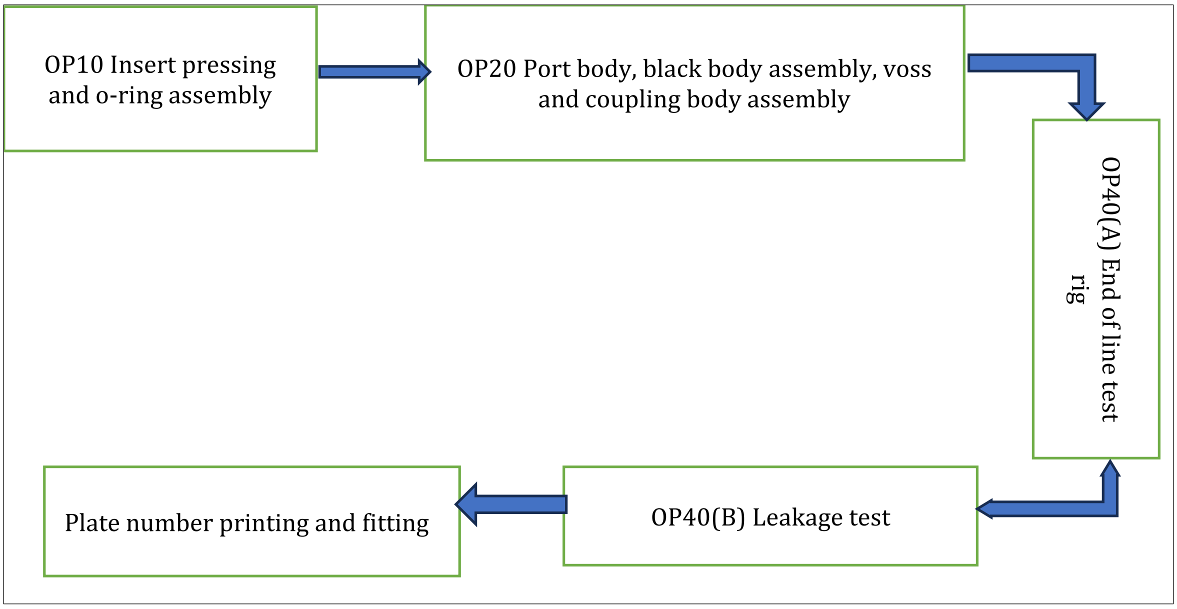

Figure 1 Four circuit protection valve

3.1. Cycle time of each station based on customer demands:-

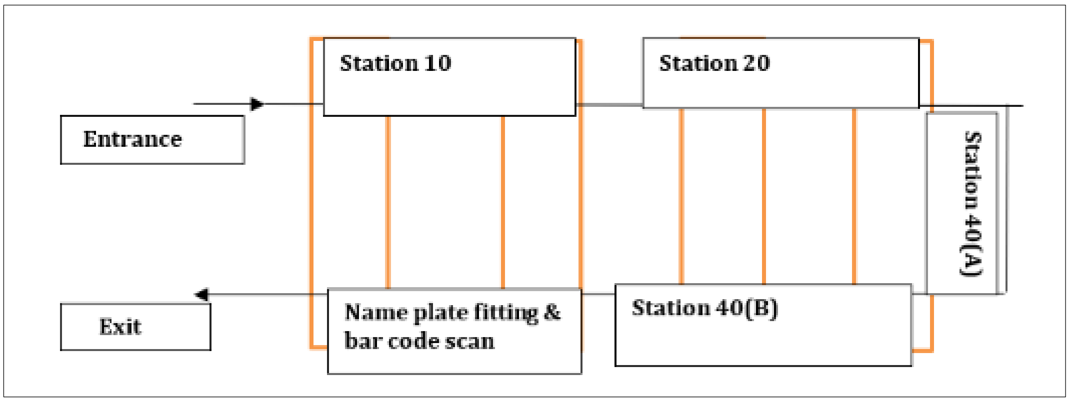

Figure 2 Structure of Four circuit protection valve

Table 1 Summary of work done by researches

Sr. No	Title And Author	Methodology	Findings
01	Ong, N. -S., & Tan, W. -C. (2002). Sequence placement planning for high-speed PCB assembly machine. Integrated Manufacturing Systems	Sequence planning and feeder arrangements.	Burke et al.(1999) introduced a new heuristic and model for the component placement in PCBA; namely the nearest neighbor method for the hypertour problem . The study presented a new model for the multi-headed placement machines.
02	Miltenburg, J. (2004). One-piece flow manufacturing on U-shaped production lines: a tutorial. IIE Transactions, 33(4), 303-321.	Product-Process Evolution	Different production systems suit various product life stages. Job shops start for new products, evolving into batch and line flows as demand grows. Shorter product cycles and

			customization now make batch flow permanent. To improve cost and quality, integrating line flow principles creates one-piece flow systems, balancing flexibility, innovation, cost, and quality for medium-volume production.
03	S.G Ponnambalam, P Aravindan, M Subba Rao, Genetic algorithms for sequencing problems in mixed model assembly lines, Computers & Industrial Engineering, Volume 45, Issue 4,2003,	Addressing the mixed-model assembly line (MMAL) sequencing problem in just-in time (JIT) production framework.	This research explores sequencing challenges in mixed model assembly lines (MMALs) to meet diverse customer demands and boost product variations. It focuses on optimizing line utilization by addressing task allocation and model sequencing. Previous studies have investigated various methods, including genetic algorithms and heuristic approaches, aiming to minimize parts consumption variability. This paper compares the efficiency of different strategies, particularly assessing their performance in handling multilevel variations, an area less explored in assembly line optimization.
04	Ruey-Shun Chen, Kun-Yung Lu, Shien-Chiang Yu, A hybrid genetic algorithm approach on multi-objective of assembly planning problem, Engineering Applications of Artificial Intelligence, Volume 15, Issue 5, 2002,	Focuses on flexible assembly system, essential for small batch orders promptly in a competitive market. Various optimization problem within assembly line planning has been studied , including assembly line balancing	This study addresses the complexity of assembly line planning with the goal of workstation task optimization. It emphasizes how crucial workable plans are to increasing manufacturing efficiency. This is a challenging field for flexible assembly systems; multi-workstation jobs remain challenging even though many optimization difficulties have been solved with heuristics. In order to decrease search time and increase solution quality, the study suggests using a hybrid Genetic Algorithm and self-tuning technique. Promising improvements over conventional techniques are demonstrated in experimental trials, providing effective assembly blueprints for adaptable systems.
05	McGovern, S. M., & Gupta, S. M. (2004). . Environmentally Conscious Manufacturing III. 2-Opt Heuristic for the disassembly line balancing problem	Parts and components of value are methodically extracted during disassembly. Combining a 2-Opt method with a greedy algorithm.	Combining the Greedy and 2-Opt algorithms, the technique maximizes the efficiency and safety of the disassembly line by upholding precedence relationships, giving removal of dangerous components first priority, and balancing part sequences for consistent workstation idle periods.
06	SD. Lapierre et.al Balancing assembly lines : an industrial case study	Complex workstation-task matching	Since these characteristics aren't preset for the workstations, the research stressed the need of carefully matching activities with workstation characteristics. Because complicated matching between jobs and workstation characteristics is needed, this real-world industrial balancing problem is more

			challenging than simple assembly line balancing.
07	McMullen, Patrick R., and Peter Tarasewich. "Using ant techniques to solve the assembly line balancing problem." IIE transactions 35.7 (2003): 605-617.	Solving assembly line balancing (AIB)	Handling a complex ALB scenario involving Mixed models, stochastic elements, and task paralleling. Development of a heuristic based on APO principles tailored to ALB problem.
08	Erel *, E., Sabuncuoglu, I., & Sekerci, H. (2005). Stochastic assembly line balancing using beam search. International Journal of Production Research, 43(7), 1411–1426.	Examination and analysis of u-line configurations and their impact on station reduction	Stochastic vs deterministic ALBP comparison , Heuristic efficiency , U-line configuration impact , Realism in manufacturing environments
09	Sotirios G. Dimitriadis, Assembly line balancing and group working: A heuristic procedure for workers' groups operating on the same product and workstation, Computers & Operations Research, Volume 33, Issue 9,2006,	Decisions in balancing multi-manned assembly lines :	Advantages of multi-manned assembly lines, Unique nature of multi-manned workstations .
10	Joaquín Bautista, Jordi Pereira, Ant algorithms for a time and space constrained assembly line balancing problem, European Journal of Operational Research, Volume 177, Issue 3, 2007,	Space constraints and their influence ,Spatial constraints integration into problem definition	Variants of TSALBP , Problem formulation and solution type
11	Blum, C. (2008). Beam-ACO for Simple Assembly Line Balancing. INFORMS Journal on Computing, 20(4), 618–627.	Defines simple assembly line balancing problem 1 (SALB-1)focused on optimizing assembly line processes	Current scenario for SALB-1 problem , Indirect metaheuristic approach
12	Khaw, C. L. E., & Ponnambalam, S. G. (2009). Multi-rule multi-objective Ant Colony Optimization for straight and U-type assembly line balancing problem. 2009	Classifies ALBP into type-1 (minimize workstations with fixed cycle time) and type-2 (minimize cycle time with fixed workstations)	Heuristics and metaheuristics improve ALBP,S solution quality and computational time , Highlight the lack of hybridization of rules in solving UALBP with metaheuristics
13	Sirovetnukul, R., and P. Chutima. "Multi-objective particle swarm optimization with negative knowledge for U-shaped assembly line worker allocation problems." 2010 IEEE International Conference on Industrial Engineering and Engineering Management. IEEE, 2010.	Their expected popularity and benefits in achieving one-piece flow, workload balancing , and skilled workforce development	Introduces the purpose of the study to present a new perspective using PSO with negative knowledge (PSONK) to enhance optimization in UALWAPs.
14	Corominas, A., Ferrer, L., & Pastor, R. (2011). Assembly line balancing: general resource-constrained case. International Journal of Production Research, 49(12), 3527–3542.	Description of assembly line balancing as a challenging NP-hard problem due to its	Evaluates and compares solution performance using mathematical programming methods.

		combinatorial nature.	
15	Ruifeng, C., & Subramaniam, V. (2012). Increasing production rate in Kanban controlled assembly lines through preventive maintenance. International Journal of Production Research, 50(4), 991–1008. doi:10.1080/00207543.2011.551844	Kanban policy, a JIT (Just-in-Time) system, maintains a small number of parts in each buffer. Vulnerability to machine failures and excessive maintenance in Kanban controlled assembly lines.	Authors formulate an approximate model for preventive maintenance in kanban controlled assembly line . An algorithm is provided for solving this optimization problem .
16	Tanzina Zaman , Sanjoy Kumar Paul sanjoy@ipe.buet.ac.bd & Abdullahil Azeem (2012) Sustainable operator assignment in an assembly line using genetic algorithm, International Journal of Production Research,	GAs used for solving ALBP by various researchers (Salveson, Bowman, Held, Baybars, etc.). GAs offer a stochastic search inspired by Darwinian evolution theory, applied to combinatorial optimization problems.	Existing studies concentrate on job assignment optimization in workstations but overlook machine dependency of operators. Majority of research works focused on optimizing job assignment, cycle time, workload smoothness, etc

4. Case Study

4.1. Optimization of production line by Shortest Distance Location (SDL) algorithm

In Deokar et al. discussed Shortest Distance Location (SDL) algorithm [33] for tool travel same can be implemented in optimization of production line In this algorithm distance between two points has been calculated by the Euclidean distance formula.

$$D_i = \sqrt{(x_{1+i} - x_1)^2 + (y_{i+1} - y_1)^2}$$

By above formula distance is calculated and based on algorithm total path distance is estimated. Production line path using SDL is as shown in figure 3. In this figure 1, 2, 3, 4, 5, 6, 7, 8, 9 are the work station

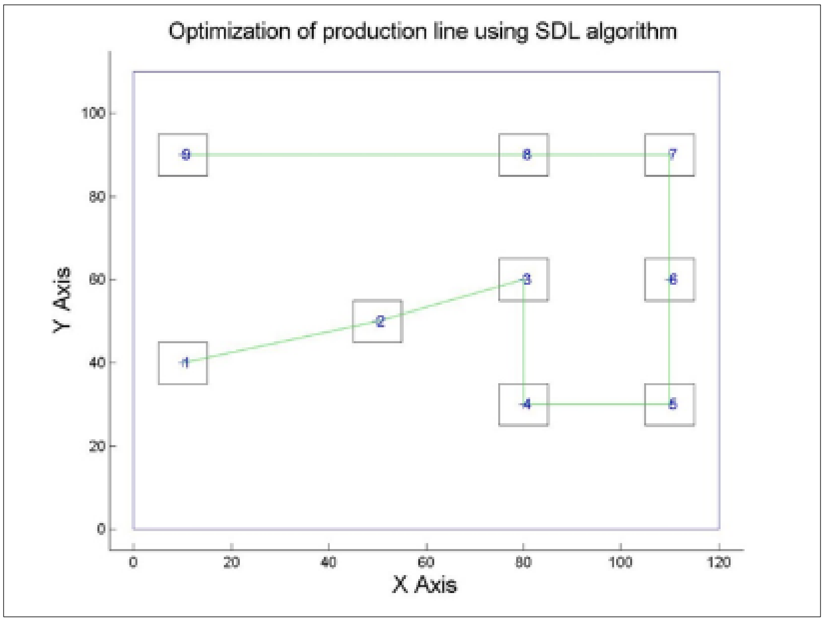

Figure 3 Production line path using SDL algorithm for rectangular area

4.2. Optimization of production line by Random Start of Shortest Distance Permutation (RSSDP) algorithm

In Random Start of Shortest Distance Permutation (RSSDP) algorithm [33] the path is decided by permutation of workstation to reduce the material handling in production line. Figure 4 shows Production line path using RSSDP.

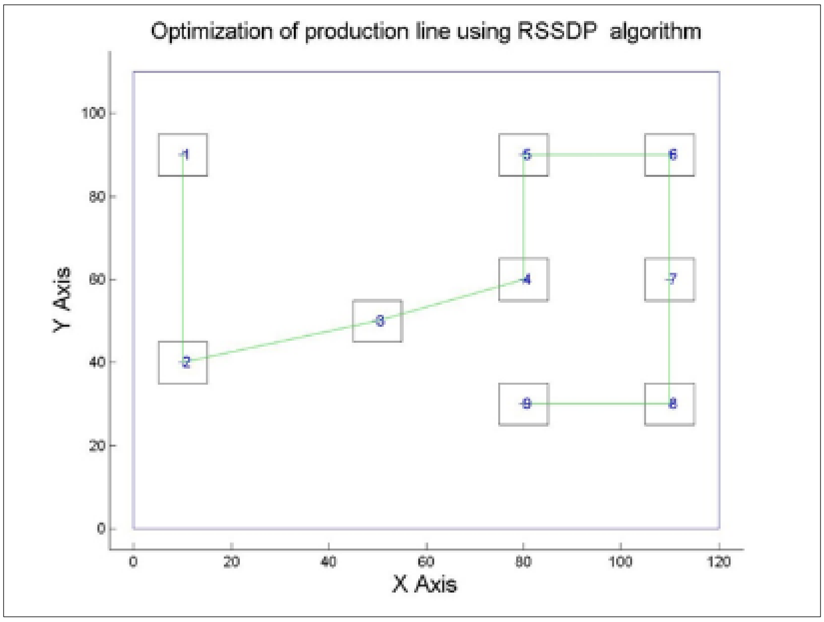

Figure 4 Production line path using RSSDP algorithm for rectangular area

4.3. Optimization of production line by First Point Start Shortest Distance Permutation (FPSSDP) algorithm

In First Point Start Shortest Distance Permutation (FPSSDP) algorithm [33] the starting point is fix and remaining point shortest location is found for reduce the material handling in production line. Figure 5 shows Production line path using FPSSDP

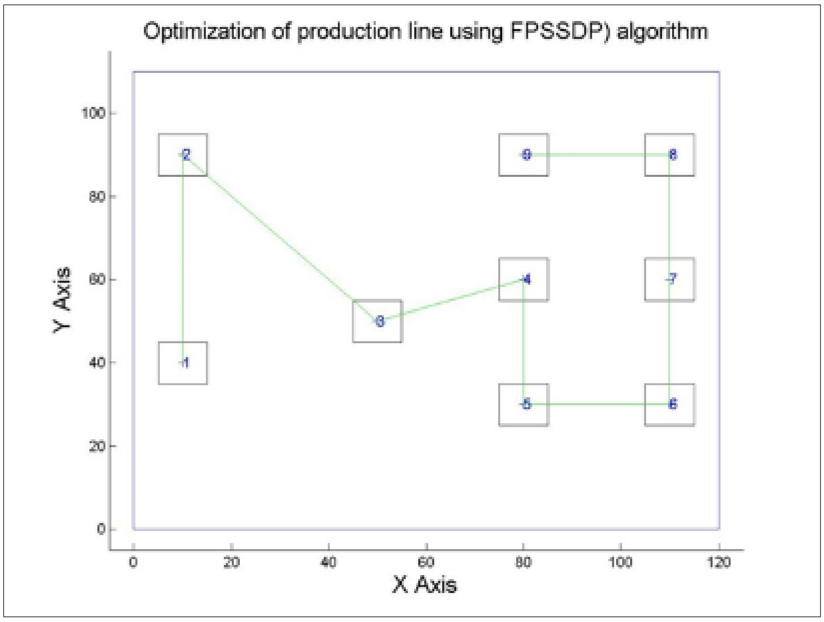

Figure 5 Production line path using FPSSDP algorithm for rectangular area

4.4. Optimization of production line by Traveling Salesman Problem (TSP) algorithm

To optimize travel path for raw material travel. Travels and salesman algorithm has been used. The production line by Traveling Salesman Problem (TSP) algorithm is shown in Figure 6.

Traveling Salesman problem formula is recursive formula here g is cost (or distance) function. TSP Formula is as follows [33]

$$g(i, s) = \min_{k \in S}\{C_{ik} + g(k, \{s\} - \{k\})\} \quad \ldots\ldots (1)$$

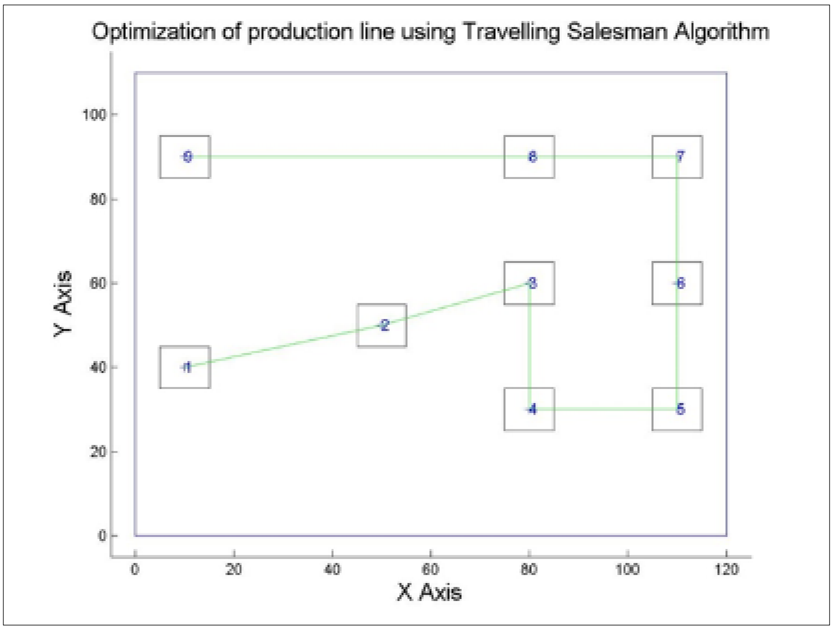

Figure 6 Production line path using Traveling Salesman Problem (TSP) algorithm for rectangular area

Table 2 Shortest path values obtain using different algorithm for production line

Sr. No.	Name of method	Distance (units)
1	Shortest Distance Location (SDL) algorithm	292.85
2	Random Start of SDP algorithm	272.85
3	First point start SDP algorithm	288.19
4	Traveling Salesman Problem (TSP) algorithm	292.85

The examination of the literature emphasizes the difficulties in maximizing facility planning in industrial production lines. Traditional heuristic techniques such as Tabu Search (TS), Simulated Annealing (SA), and Genetic Algorithms (GA) are time consuming and inaccurate in terms of machine and equipment dimensions, which makes it difficult to get the ideal layout configuration. Simulation methods become effective instruments for analysing and evaluating options for layout optimization. The importance of simulation in supporting decision-making throughout the design, analysis, and improvement of industrial systems is highlighted by Mc Lean and Kibira [24]. Computer simulations have demonstrated potential in improving productivity, quality, lead time reduction, and cost savings, especially in 2D layouts utilizing tools like Arena, Witness, and Pro model. These 2D images, however, frequently fail to accurately depict the settings and dimensions of the equipment. New developments in discrete event simulation software, such as Flexsim, have made it possible for designers to create virtual reality (VR) settings by introducing three-dimensional (3D) perspectives. This makes it easier to evaluate industrial conditions more realistically, which helps to visualize and resolve any difficulties including layout faults and safety concerns. Effective visualization and layout arrangement adjustment are made possible by the integration of problem-solving approaches for plant layout inside this 3D environment.

Prospective studies emphasize new strategies, especially the use of simple heuristics and 3D modelling technologies, to assess current layout configurations in detail. With the use of data structure algorithms, this method seeks to produce a more thorough study that will enable the best possible layout arrangement while improving computational efficiency and accuracy while evaluating facility designs.

Form case study it is observe that Random Start of Shortest Distance Permutation (RSSDP) algorithm gives short distance production line

5. Conclusion

It is important to optimize plant layout for new units or re-layout existing manufacturing units in accordance with shifting market conditions in order to maximize returns from the capacity of facilities. By taking into account various case studies, several academics have created a large number of models based on heuristic and meta-heuristic approaches. Optimization frequently uses heuristic techniques like Tabu Search (TS), Simulated Annealing (SA), and Genetic Algorithms (GA). The time-consuming nature and inability to accurately capture the sense of the real environment and dimensions of the machinery and equipment are the limitations of those heuristic approaches. In addition to heuristic approaches, simulation methodology is a potent instrument that many academics employ to generate and assess the suggested layout design prior to execution Witness and Pro-Model. The simulation programs Arena, QUEST, IGRIP, Pro-Model, and Witness are frequently used in facility planning. Given the limits of the approaches that have been covered thus far, it becomes clear that a more thorough and effective approach may be created by combining simulation techniques with heuristic methods. Additionally, it is shown that there is room for the development of multi-objective optimization methods, especially for small-scale

From case study it is found that Random Start of Shortest Distance Permutation (RSSDP) algorithm is one of the best algorithms for optimization of production line. Random Start of Shortest Distance Permutation (RSSDP) algorithm gives distance 272.85 units as compare to Shortest Distance Location (SDL) algorithm gives distance 292.85 unit. Optimization of production line by First Point Start Shortest Distance Permutation (FPSSDP) algorithm gives distance 288.19 units & Traveling Salesman Problem (TSP) algorithm gives distance 292.85 unit.

Compliance with ethical standards

Disclosure of conflict of interest

'The authors declare that they have no competing interests'.

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