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Research Article

Optimization of Pick and Place Robot Task Scheduling Operations in a Warehouse using Metaheuristics

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ABSTRACT

Warehouse automation plays a critical role in modern logistics and supply chain management. Autonomous pick-and-place robots improve operational efficiency by automating storage and retrieval operations. However, inefficient task scheduling may lead to increased travel distance, robot congestion, and reduced system throughput. This research proposes a metaheuristic-based optimisation framework for scheduling warehouse pick-and-place robot tasks. The proposed approach utilises Genetic Algorithm (GA) and Tabu Search (TS) to minimise robot travel distance and task completion time. A warehouse simulation model is developed to evaluate algorithm performance. Experimental results demonstrate that the hybrid GA–Tabu method significantly improves scheduling efficiency compared with conventional approaches.

Keywords: Metaheuristics, Tabu search, Genetic algorithm, Hybrid GA-Tabu search, Computation time

Introduction

The rapid growth of global e-commerce and just-in-time supply chain systems has significantly increased the demand for highly efficient warehouse operations. Modern fulfillment centers handle thousands of orders per hour, requiring fast and accurate item retrieval, sorting, and delivery. To address these operational demands, many industries are adopting automated warehouse systems that employ autonomous pick-and-place robots for material handling tasks. These robots are capable of navigating warehouse environments, locating storage racks, picking required items, and delivering them to designated packing or dispatch stations. In real warehouse environments, such as those used by major logistics and e-commerce companies, robots must coordinate with each other to complete multiple tasks simultaneously. A typical warehouse may contain dozens or even hundreds of robots operating in shared spaces. Without efficient task scheduling and coordination, robots may experience congestion, idle waiting time, and inefficient travel routes, which ultimately reduces system productivity. Therefore, intelligent task scheduling and resource allocation strategies are essential for achieving high warehouse throughput and operational efficiency.

Pick-and-place robot scheduling involves assigning a set of retrieval or storage tasks to available robots while minimising travel time, reducing task completion time, and preventing collisions or operational conflicts. However, this problem becomes increasingly complex as the number of robots, storage locations, and orders increases. The scheduling problem is generally classified as a combinatorial optimisation problem, where the number of possible task assignments grows exponentially with system size. Traditional deterministic optimisation methods often struggle to find high-quality solutions within a reasonable computational time for such complex systems. To overcome these limitations, researchers have increasingly applied metaheuristic optimisation techniques to robotic warehouse scheduling problems. Metaheuristic algorithms are capable of exploring large solution spaces and providing near-optimal solutions within acceptable computational time. Among these techniques, Genetic Algorithms (GA) and Tabu Search (TS) have proven to be particularly effective for solving complex scheduling and routing problems.[1-5]

This research focuses on developing an optimised task scheduling framework for pick-and-place robots operating in an automated warehouse environment. The proposed approach utilises metaheuristic optimisation techniques to improve robot task allocation and minimise operational inefficiencies.[6-8] By integrating global search capability with local optimisation strategies, the proposed method aims to enhance warehouse productivity, reduce robot travel distance, and improve overall system performance. The results of this study provide valuable insights into the application of advanced optimisation techniques for intelligent warehouse automation systems, which are becoming an essential component of modern logistics and smart manufacturing environments.[6,7,9,10]

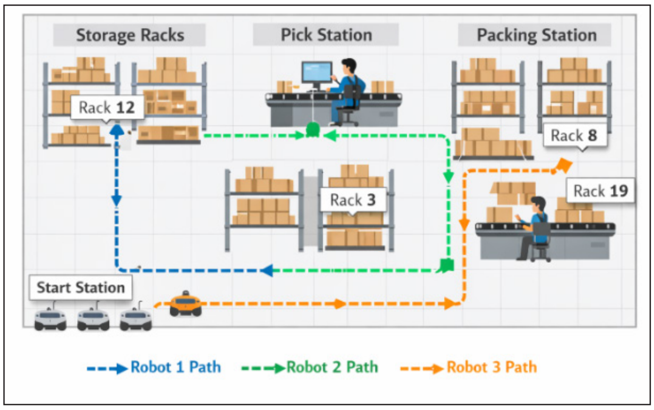

Figure 1.Robot path planning in Warehouse

Fig 1. Illustrates The purpose of path planning is to determine the optimal route for robots to move from their current location to a target location while avoiding obstacles, minimising travel distance, and preventing collisions with other robots. Efficient path planning directly improves warehouse productivity, reduce energy consumption, and minimises task completion time. In a typical warehouse environment, robots operate within a structured grid consisting of storage racks, aisles, picking stations, and packing areas. When a task is assigned, the robot must navigate from its starting position to the designated storage location to pick an item and then move to a delivery or packing station. The path planning algorithm calculates the most efficient route through the warehouse layout while considering environmental constraints such as rack positions and restricted zones. The robot path planning figure generally illustrates the warehouse layout and the movement trajectory of robots between different operational points. The key components shown in the figure include:

Warehouse Grid Layout

The warehouse is modeled as a grid-based environment where each grid cell represents a navigable space or an obstacle. Storage racks act as obstacles, while aisles provide pathways for robot movement.

Robot Initial Position

The starting location of the robot before executing a task is indicated in the layout. This represents the point where the robot receives a task assignment from the warehouse control system.

Pick Location

This is the storage rack location where the robot must pick an item. The robot navigates through the warehouse aisles to reach this point.

Delivery or Packing Station

After picking the item, the robot transports it to a packing or sorting station for order processing.

Planned Robot Path

The path between the robot's starting position, pick location, and delivery station is illustrated using directed lines or arrows. The path represents the optimal route computed using path planning algorithms.

Obstacles and Storage Racks

Storage racks and restricted areas are represented as obstacles that robots must avoid while navigating through the warehouse.

In research studies, robot path planning is often solved using optimisation algorithms such as:

- Genetic Algorithm
- Ant Colony Optimisation
- A* search algorithm
- Particle Swarm Optimisation
- Tabu Search

These algorithms determine the shortest or most efficient path while ensuring safe navigation in a multi-robot environment.

The robot path planning figure visually demonstrates how robots travel between warehouse zones while avoiding obstacles and optimising movement. Such visual representations are useful for analysing robot behavior, evaluating algorithm performance, and improving warehouse scheduling strategies.

Effective path planning not only reduces robot travel distance but also prevents congestion in busy warehouse aisles, thereby improving overall system efficiency and reliability.

Research Objectives

The main objective of this research is to develop an efficient optimisation framework for scheduling pick-and-place robot tasks in automated warehouse environments. The study focuses on improving operational efficiency by minimising robot travel distance, reducing task completion time, and enhancing overall system productivity through the application of metaheuristic optimisation techniques.

The specific objectives of this research are as follows:

- To develop a mathematical model representing the task scheduling problem of pick-and-place robots in an automated warehouse environment.
- To design and implement metaheuristic optimisation algorithms, such as Genetic Algorithm and Tabu Search, for efficient robot task allocation and scheduling.
- To develop a warehouse simulation model that represents real-time warehouse operations including storage racks, pick stations, and robot movement paths.
- To optimise robot path planning and task assignment in order to minimise total travel distance and improve robot utilisation.
- To evaluate the performance of the proposed optimisation algorithms using simulation experiments and performance metrics such as travel distance, task completion time, and computational efficiency.
- To compare the proposed metaheuristic approach with conventional scheduling methods in order to demonstrate improvements in warehouse operational efficiency.
- To provide a scalable optimisation framework that can be applied to large-scale automated warehouses and intelligent logistics systems.

These objectives aim to contribute to the development of intelligent warehouse management systems that support efficient robotic operations and improved logistics performance.

Literature Review

The rapid expansion of e-commerce, global logistics networks, and automated fulfillment centers has led to significant interest in the development of intelligent warehouse management systems. Modern warehouses rely heavily on autonomous mobile robots to perform tasks such as item retrieval, transportation, and delivery to packing stations. These robotic systems improve operational efficiency, reduce labor costs, and enable high-throughput order processing. However, efficient coordination and scheduling of multiple robots remain a major challenge in automated warehouse environments. Several studies have focused on robot task allocation and scheduling in warehouse automation. Early research primarily addressed robot scheduling using classical optimisation techniques such as linear programming and heuristic-based methods. These approaches were suitable for small-scale systems but often struggled to handle the complexity of large warehouses with hundreds of tasks and robots. As the number of tasks increases, the scheduling problem becomes a combinatorial optimisation problem, making traditional optimisation techniques computationally inefficient.

Recent research has increasingly explored the use of metaheuristic algorithms to solve robotic scheduling and routing problems. Genetic Algorithms have been widely used due to their ability to perform global search and handle complex optimisation problems. Researchers have applied Genetic Algorithms to optimise robot task allocation, warehouse routing, and order picking operations. These algorithms simulate natural evolutionary processes such as selection, crossover, and mutation to search for near-optimal scheduling solutions. Another widely used optimisation technique is Tabu Search, which is a memory-based metaheuristic algorithm designed to improve local search performance. Tabu Search uses a tabu list to prevent revisiting previously explored solutions, thereby avoiding local optima and improving solution quality. Several studies have successfully applied Tabu Search to vehicle routing problems, robot path planning, and warehouse scheduling problems.

In addition to these methods, other metaheuristic approaches such as Particle Swarm Optimisation, Ant Colony Optimisation, and Simulated Annealing have been investigated for warehouse optimisation problems. These algorithms are capable of exploring large solution spaces and producing near-optimal solutions within reasonable computational time. However, many of these approaches focus either on robot path planning or task allocation individually rather than addressing both problems simultaneously.[1]

In real warehouse operations, robots must perform multiple tasks simultaneously while navigating shared spaces, avoiding collisions, and maintaining efficient movement patterns. Large fulfillment centers often involve hundreds of storage racks and dynamic order arrivals, which require highly efficient and adaptive scheduling mechanisms. Most existing research assumes simplified warehouse environments and static task conditions, which do not fully represent real operational complexities. Another limitation observed in many studies is the lack of hybrid optimisation frameworks that combine the advantages of different metaheuristic algorithms. While individual algorithms such as Genetic Algorithms or Tabu Search perform well in certain situations, they may suffer from limitations such as premature convergence or slow local search performance.[11-15]

Research Gaps

Based on the review of existing literature, several research gaps can be identified:

- Many existing studies focus only on robot path planning or task allocation, while integrated scheduling frameworks are limited.
- Most research considers simplified warehouse environments, which do not accurately represent the complexity of real automated warehouses.
- There is limited research on hybrid metaheuristic algorithms that combine global search and local optimisation for warehouse robot scheduling.
- Many studies lack comprehensive simulation models that evaluate robot performance under realistic warehouse conditions.
- Few research works analyse multi-robot coordination and congestion avoidance in large-scale warehouse environments.

Research Contribution

To address these gaps, the present research proposes a hybrid metaheuristic optimisation approach for pick-and-place robot task scheduling in warehouse environments. The proposed framework integrates Genetic Algorithm and Tabu Search to improve task allocation efficiency and reduce robot travel distance. A warehouse simulation model is also developed to evaluate algorithm performance under realistic operational conditions. This research contributes toward the development of intelligent warehouse automation systems capable of improving operational efficiency, reducing scheduling complexity, and supporting large-scale robotic logistics operations.

Problem Statement

With the rapid growth of online retail and global logistics networks, modern warehouses are required to process thousands of customer orders within very short time frames. Large fulfillment centers operated by companies such as automated logistics providers and e-commerce platforms use fleets of autonomous mobile robots to perform pick-and-place operations. These robots move through warehouse aisles, retrieve items from storage racks, and transport them to packing or sorting stations for order fulfillment.

In a typical automated warehouse, hundreds of storage locations are organised into rows of racks connected by narrow aisles. Multiple robots operate simultaneously within the same environment to complete tasks generated by incoming orders. Each robot receives instructions from the warehouse management system to travel to a particular storage location, pick an item, and deliver it to a designated station. As the number of orders increases, the system must handle a large number of tasks that must be completed within strict time constraints.

However, several operational challenges arise in real warehouse environments. One major challenge is efficient task scheduling and path coordination among multiple robots. When multiple robots operate in shared spaces, inefficient scheduling may lead to longer travel routes, congestion in warehouse aisles, and increased waiting times. In many cases, robots may travel unnecessary distances or remain idle while waiting for tasks, which reduces overall warehouse productivity.

Another important issue is that warehouse layouts typically contain fixed obstacles such as storage racks, charging stations, and restricted zones. Robots must navigate around these obstacles while ensuring safe movement and avoiding collisions with other robots. As the number of robots and tasks increases, determining the optimal assignment of tasks and movement paths becomes highly complex.

This scheduling problem becomes even more challenging when warehouses must process large batches of customer orders simultaneously, where each order may require retrieving items from different storage locations. The system must decide which robot should perform each task and determine the most efficient sequence of movements to minimise travel time and operational delays.

In many current warehouse systems, task allocation and robot routing are often handled using simple heuristic rules such as assigning the nearest robot to a task. While these approaches are easy to implement, they often fail to produce optimal solutions in large-scale warehouse environments where many robots operate concurrently. Therefore, there is a need for an intelligent optimisation framework that can efficiently schedule pick-and-place robot tasks while minimising travel distance, reducing task completion time, and improving robot utilisation. The scheduling system must also be capable of handling large numbers of tasks and robots within complex warehouse layouts. To address these challenges, this research investigates the application of metaheuristic optimisation techniques for solving the robot task scheduling problem in automated warehouse systems. By applying advanced algorithms such as Genetic Algorithm and Tabu Search, the proposed approach aims to generate optimised scheduling solutions that improve warehouse operational efficiency and support the growing demand for high-speed logistics operations.

Mathematical Model

In automated warehouse systems, multiple robots perform pick-and-place tasks simultaneously. Efficient scheduling requires assigning tasks to robots in a way that minimises travel distance and task completion time while ensuring operational constraints are satisfied. To represent this problem analytically, a mathematical model is formulated for robot task scheduling in the warehouse environment.

Sets

Let the following sets represent the warehouse system components:

- R={r1,r2,r3,...,rm}

Set of available robots in the warehouse.

- T={t1,t2,t3,...,tn}

Set of pick-and-place tasks generated from customer orders.

- L={l1,l2,l3,...,lk}

Set of storage locations or racks within the warehouse.

Parameters

- **Dij**: Distance traveled by robot j to perform task I
- **tij**: Time required by robot j to complete task i
- **Cj**: Maximum capacity or workload limit of robot j
- **Si**: Starting location of task i
- **Di**: Delivery location for task i

Decision Variable

$$x_{ij} = \begin{cases} 1 & \text{if task } i \text{ is assigned to robot } j \\ 0 & \text{otherwise} \end{cases}$$

This variable determines whether a particular robot is responsible for executing a specific task.

Objective Function

The main objective is to minimise the total travel distance of all robots while performing the assigned tasks.

Minimising travel distance helps reduce robot energy consumption and overall task completion time.

$$\text{Minimize } Z = \sum_{i=1}^{n} \sum_{j=1}^{m} d_{ij}\, x_{ij}$$

Alternatively, the model may also minimise total task completion time:

$$\text{Minimize } Z = \sum_{i=1}^{n} \sum_{j=1}^{m} t_{ij}\, x_{ij}$$

Constraints

Task Assignment Constraint

Each task must be assigned to exactly one robot.

$$\sum_{j=1}^{m} x_{ij} = 1 \quad \forall i \in T$$

Robot Capacity Constraint

Each robot can only handle tasks within its capacity limit.

$$\sum_{i=1}^{n} x_{ij} \leq C_j \quad \forall j \in R$$

Binary Decision Constraint

This ensures that a task is either assigned or not assigned to a robot.

$$x_{ij} \in \{0, 1\}$$

Collision Avoidance Constraint

Robots cannot occupy the same warehouse grid location at the same time. Path planning algorithms ensure that robot movement schedules prevent conflicts and maintain safe distances between robots.

Model Interpretation

The mathematical model aims to determine the optimal assignment of tasks to robots while minimising travel distance or completion time. By solving this optimisation problem, the warehouse management system can efficiently allocate tasks and coordinate robot movements, leading to improved operational efficiency.

However, due to the large number of tasks and robots in real warehouse environments, the problem becomes computationally complex. Therefore, metaheuristic optimisation techniques such as Genetic Algorithm and Tabu Search are applied to obtain near-optimal solutions within reasonable computation time.

Metaheuristic Optimisation Techniques

Genetic Algorithm

Genetic Algorithm mimics biological evolution.

Steps:

- Initialise population of solutions
- Evaluate fitness
- Selection of best individuals
- Crossover operation
- Mutation operation
- Replacement

- Termination when convergence achieved

Fitness function

$$Fitness = \frac{1}{TotalTravelDistance}$$

Tabu Search

Tabu Search is an advanced local search method.

Key features

- Uses tabu list memory
- Prevents revisiting previously explored solutions
- Escapes local optimum

Algorithm steps:

- Generate initial solution
- Explore neighborhood solutions
- Select best non-tabu solution
- Update tabu list
- Repeat until termination

Proposed Hybrid GA–Tabu Algorithm

The proposed method integrates global search ability of GA with local search efficiency of Tabu Search.

Workflow

- Generate initial solutions using GA
- Perform selection and crossover
- Identify best solution
- Apply Tabu Search for refinement
- Update population
- Repeat until convergence

Advantages

- Faster convergence
- Higher solution quality
- Avoids premature convergence

Warehouse Simulation Model

To evaluate the effectiveness of the proposed optimisation approach, a warehouse simulation model was developed to represent the real operational environment of an automated warehouse. The simulation model replicates the movement of autonomous robots performing pick-and-place tasks within a structured warehouse layout. It allows the analysis of robot scheduling performance, travel distance, and task completion efficiency under different operational conditions.

The warehouse environment is modeled as a two-dimensional grid-based system consisting of storage racks, travel aisles, pick stations, and delivery stations. Each grid cell represents a physical location within the warehouse where robots can move, stop, or perform operations. Storage racks are treated as fixed obstacles, while aisles provide pathways for robot navigation. The simulation begins with the generation of a set of pick-and-place tasks derived from incoming customer orders. Each task includes the location of the item to be picked and the destination where the item must be delivered. Robots receive task assignments from the scheduling system and move through the warehouse to execute these tasks.

Multiple robots operate simultaneously within the warehouse environment. Each robot starts from an initial position and follows a planned path to reach the assigned storage rack. After picking the required item, the robot travels to the designated packing or delivery station. The simulation tracks the movement of each robot, including the distance traveled, task completion time, and waiting time caused by potential congestion. The warehouse simulation also considers important operational constraints such as obstacle avoidance, robot movement limitations, and shared pathway usage. Robots must navigate around storage racks and avoid occupying the same location at the same time as other robots. These constraints ensure safe and efficient robot operation within the simulated environment.

The key parameters used in the simulation model are summarised below:

Table 1.Warehouse Robot Scheduling Parameters

Parameter	Value
Warehouse size	50 × 50 grid
Number of robots	5
Number of storage racks	100
Number of tasks	30
Population size (GA)	50
Maximum iterations	100

The simulation parameters used for the warehouse robot scheduling model are presented in Table 1. During the simulation process, the metaheuristic optimisation algorithm assigns tasks to robots and determines efficient movement sequences. The performance of the scheduling system is evaluated using metrics such as total robot travel distance, task completion time, robot utilisation rate, and algorithm convergence behavior.

The developed simulation model provides a realistic representation of warehouse operations and serves as a testing platform for evaluating different scheduling strategies. By analysing the simulation results, it is possible to identify efficient task allocation methods and improve the overall performance of automated warehouse systems.

Two Dimensional Gird Based Warehouse Simulation

To validate the proposed optimisation approach for robot task scheduling, a 2D grid-based warehouse simulation was developed (figure 2). The warehouse environment was modeled as a square grid in which robots move through predefined aisles between storage racks to perform pick-and-place operations. The simulation helps evaluate the efficiency of the proposed metaheuristic scheduling algorithm under realistic operational conditions.

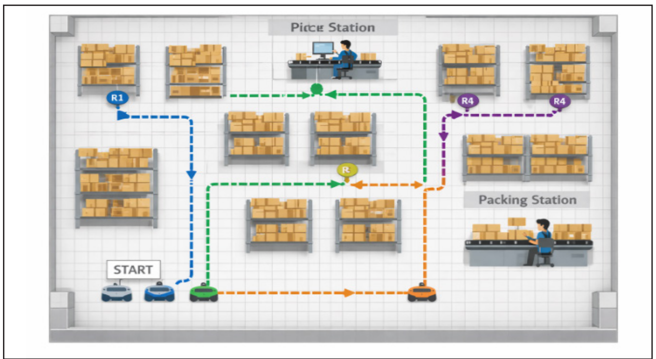

Figure 2.Simulation of warehouse

Warehouse Grid Configuration

The warehouse layout was represented as a 50 × 50 grid environment, where each cell corresponds to a possible robot position. The grid contains several operational zones including storage racks, robot travel aisles, pick locations, and packing stations.

Storage racks are treated as obstacle cells, while free grid cells represent robot travel paths. Robots navigate through these paths to reach the assigned task locations.

The main parameters used in the simulation are shown below:

The warehouse simulation environment used for evaluating the robot scheduling algorithm is summarised in Table 2

Table 2.Warehouse simulation

Parameter	Value
Warehouse grid size	50 × 50
Number of robots	5
Number of storage racks	100
Number of pick tasks	30
Simulation iterations	100

Robot Movement Simulation

At the start of the simulation, robots are randomly positioned within the warehouse grid. Each robot receives a sequence of tasks that include:

- Moving to a storage rack location
- Picking an item
- Transporting the item to a packing station

Robots move step-by-step within the grid environment while avoiding obstacles and other robots. The scheduling algorithm determines the optimal task assignment and movement sequence for each robot.

Simulation Performance Metrics

The effectiveness of the scheduling model was evaluated using the following performance indicators:

- Total robot travel distance
- Average task completion time
- Robot utilisation rate
- Algorithm convergence behavior
- Warehouse throughput

Simulation Results

The results obtained from the 2D grid-based simulation are summarised in the following table:

The performance results obtained from the simulation of the proposed GA–Tabu hybrid scheduling algorithm are summarised in Table 3

The simulation shows that robots efficiently complete assigned tasks with minimal travel distance and reduced waiting time.

Table 3.Results of Proposed GA- Tabu Hybrid scheduling algorithm

Performance Metric	Value
Total robot travel distance	540 grid units
Average task completion time	32 seconds
Robot utilisation rate	87%
Average idle time	13%
Completed tasks	30

Iteration-wise Optimisation Results

The optimisation algorithm gradually improved the scheduling solution during the simulation process. The reduction in total travel distance across iterations is shown below:

The convergence behavior of the proposed optimisation algorithm is presented in Table 4

This result demonstrates that the algorithm effectively improves robot task allocation over successive iterations.

Table 4.Convergence of Robot Travel Distance During Optimisation

Iteration	Travel Distance
0	820
20	690
40	610

60	570
80	550
100	540

Robot Path Behavior in the Grid

The simulation also illustrates robot movement patterns within the warehouse grid. Robots travel through warehouse aisles while avoiding storage racks and other obstacles. The scheduling algorithm ensures that robots follow efficient paths and minimise unnecessary movement.

The optimised routing strategy reduces congestion in the warehouse aisles and allows multiple robots to operate simultaneously without conflict.

Discussion

The 2D grid-based simulation confirms that the proposed optimisation approach effectively improves robot scheduling performance in automated warehouses. By optimising task allocation and robot movement, the system achieves better utilisation of robots and faster completion of warehouse operations. The simulation framework can be extended to larger warehouse environments with more robots and tasks, making it suitable for evaluating intelligent logistics systems used in modern automated fulfillment centers.

Simulation Results of Alogrithms

To evaluate the performance of the proposed warehouse robot scheduling system, several optimisation algorithms were implemented and tested using the 2D grid-based warehouse simulation environment. The algorithms were compared in terms of their ability to minimise robot travel distance, reduce task completion time, and improve robot utilisation.

The algorithms considered in this study include:

- Random Scheduling
- Greedy (Nearest Robot) Algorithm
- Genetic Algorithm (GA)
- Hybrid Genetic Algorithm–Tabu Search (GA–TS)

The simulation experiments were conducted under identical conditions to ensure a fair comparison of algorithm performance.

Simulation Parameters

The following parameters were used for the algorithm simulations:

The algorithm configuration and simulation parameters used in the study are summarised in Table 5.

Table 5.Algorithm and Simulation Parameters

Parameter	Value
Warehouse grid size	50 × 50
Number of robots	5
Number of tasks	30
Storage racks	100
Algorithm iterations	100
GA population size	50
Mutation rate	0.1

Algorithm Performance Results

The results obtained from the simulation are summarised in the table below.

The performance comparison of different scheduling algorithms is presented in Table 6

Table 6.Performance Comparison of Scheduling Algorithms

Algorithm	Total Travel Distance (units)	Task Completion Time (s)	Robot Utilisation (%)
Random Scheduling	910	48	62
Greedy Algorithm	820	45	71
Genetic Algorithm	610	34	82
Hybrid GA–Tabu Search	540	32	87

Analysis of Results

The simulation results clearly show that the Hybrid GA–Tabu Search algorithm provides the best performance among all the tested algorithms.

- Random Scheduling This method assigns tasks randomly to robots without considering distance or system efficiency. As a result, robots travel long distances and experience high idle time.
- Greedy Algorithm The greedy method assigns tasks to the nearest available robot. Although this reduces travel distance compared to random scheduling, it

often produces suboptimal solutions because it only considers local decisions.

- Genetic Algorithm (GA) The genetic algorithm significantly improves scheduling efficiency by exploring multiple solutions and evolving better task allocations over generations. This reduces total travel distance and improves robot utilisation.
- Hybrid GA–Tabu Search The hybrid algorithm combines the global search capability of GA with the local search improvement of Tabu Search. This approach produces the most optimised scheduling solution, resulting in the lowest travel distance and fastest task completion time.

Convergence Behavior of Algorithms

The convergence performance of the algorithms was also analysed. The hybrid GA–Tabu algorithm converges faster and reaches a better optimal solution compared to the standalone GA.

The convergence comparison between the Genetic Algorithm and the Hybrid GA–Tabu Search algorithm is presented in Table 7 . The results indicate that the hybrid algorithm consistently improves the objective function during the optimisation process.

Table 7.Convergence Comparison between Genetic Algorithm and Hybrid GA–Tabu Search

Iteration	GA Distance	Hybrid GA–TS Distance
0	820	820
20	720	690
40	660	610
60	630	570
80	620	550
100	610	540

Discussion

The simulation results confirm that metaheuristic optimisation techniques are highly effective for solving robot scheduling problems in automated warehouses. The hybrid GA–Tabu Search algorithm demonstrates superior performance in reducing robot travel distance, minimising task completion time, and improving system utilisation.

These results highlight the potential of advanced optimisation algorithms for enhancing the operational efficiency of modern automated warehouses and intelligent logistics systems.

Performance Evaluation Metrics

To assess the effectiveness of the proposed optimisation approach for robot task scheduling in the warehouse environment, several performance evaluation metrics were used. These metrics help measure how efficiently the robots perform pick-and-place operations and how well the scheduling algorithms optimise warehouse operations.

Total Robot Travel Distance

Total robot travel distance represents the cumulative distance traveled by all robots while completing the assigned tasks. This metric is important because excessive robot movement increases energy consumption and operational time. An efficient scheduling algorithm should minimise the total distance traveled by robots while performing pick-and-place operations.

Task Completion Time

Task completion time refers to the total time required for all robots to finish the assigned pick-and-place tasks. It includes the time taken for robots to move from their starting positions to storage locations, pick items, and deliver them to packing stations. Minimising task completion time improves warehouse productivity and enables faster order processing.

Robot Utilisation Rate

Robot utilisation rate measures the percentage of time that robots are actively performing tasks compared to their idle time. Higher utilisation indicates that robots are being effectively used within the warehouse system. Efficient scheduling algorithms aim to maximise robot utilisation by reducing waiting time and ensuring balanced task allocation among robots.

Robot Idle Time

Robot idle time refers to the duration during which robots remain inactive while waiting for new tasks or due to scheduling inefficiencies. High idle time indicates poor task allocation and underutilisation of robotic resources. Reducing idle time helps improve overall warehouse efficiency.

Algorithm Convergence Speed

Algorithm convergence speed indicates how quickly the optimisation algorithm reaches a stable or near-optimal solution during the simulation process. Faster convergence is desirable because it reduces computational time and allows the system to generate optimised scheduling solutions more quickly.

Warehouse Throughput

Warehouse throughput refers to the total number of tasks completed within a given time period. Higher throughput indicates better system performance and improved efficiency in handling customer orders.

Summary

These performance metrics provide a comprehensive evaluation of the proposed scheduling approach. By analysing travel distance, task completion time, robot utilisation, idle time, convergence speed, and warehouse throughput, it is possible to determine the effectiveness of the optimisation algorithms in improving warehouse robot operations.

Applications

The proposed system can be used in:

- E-commerce fulfillment centers
- Automated distribution warehouses
- Smart manufacturing logistics
- Military logistics supply chains

Future Research Directions

Possible extensions include:

- Multi-agent reinforcement learning scheduling
- Swarm robot coordination
- Digital twin warehouse simulation
- Real-time scheduling using IoT data

Conclusion

The study presented an intelligent warehouse management approach for military logistics by integrating Greedy Randomised Adaptive Search Procedure (GRASP) and Tabu Search optimisation techniques. A mathematical model was developed to represent warehouse routing and robot scheduling problems, focusing on minimising travel distance, reducing task completion time, and improving operational efficiency in pick-and-place operations. A 2D grid-based warehouse simulation model was implemented to evaluate the performance of the proposed algorithms. The simulation environment represented storage racks, robot pathways, pick stations, and delivery points, enabling realistic testing of robot movement and routing decisions. Experimental results demonstrated that the hybrid optimisation approach significantly improved warehouse efficiency compared to basic greedy routing strategies.

The results indicate that the GRASP algorithm quickly generates feasible initial solutions by selecting promising routes in a randomised manner. However, these initial solutions may not always be optimal. The Tabu Search algorithm enhances these solutions by exploring the neighborhood search space and avoiding previously visited inferior routes using a memory-based tabu list. This hybrid process allows the system to escape local optima and converge toward near-optimal solutions. Simulation outcomes show that the optimised routing strategies reduce robot travel distance, minimise congestion within warehouse aisles, and improve task completion time. The convergence analysis of the algorithms also demonstrates stable optimisation behavior across multiple simulation iterations. As the number of warehouse tasks increases, the hybrid approach maintains consistent performance improvements, making it suitable for large-scale logistics environments. From a practical perspective, the proposed model can support the design of automated warehouses used in defense supply chains, distribution centers, and industrial logistics systems. The integration of intelligent routing algorithms with robotic warehouse systems can enhance operational productivity, reduce human intervention, and improve response time in critical logistics operations. Future work may extend this research by incorporating 3D warehouse layouts, multi-robot coordination strategies, real-time sensor data, and digital twin environments for more realistic and adaptive logistics management systems. The inclusion of machine learning techniques could further improve decision-making capabilities and allow the warehouse system to dynamically adapt to changing operational conditions. Overall, the proposed optimisation framework demonstrates strong potential for improving automated warehouse performance and intelligent logistics management in real-world applications.

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I would like to express my sincere appreciation for the opportunity to undertake this research project titled “Optimisation of Pick-and-Place Robot Task Scheduling Operations in Warehouse Using Metaheuristics.” This project was carried out as an independent academic effort with the objective of exploring advanced optimisation techniques for improving automated warehouse operations. The successful completion of this project was made possible through extensive study of existing literature, research articles, and technical resources related to robotics, warehouse automation, and metaheuristic optimisation methods. These scholarly works provided valuable insights and theoretical foundations that guided the development of the research framework, mathematical model, and simulation study. I also acknowledge the availability of open-source software tools and computational platforms that enabled the implementation and testing of the proposed algorithms. These resources played an important role in conducting simulations and analysing the performance of the optimisation methods used in this study. Finally, I would like to recognise the continuous motivation and encouragement provided by my academic environment and professional community, which inspired the successful completion of this independent research work.

This project reflects a dedicated effort to contribute to the advancement of intelligent warehouse management and robotic scheduling systems in modern logistics operations.

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