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SIMULATION AND ANALYSIS OF A PREEMPTIVE TRANSPORTATION MODEL USING FLEXSIM SOFTWARE

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Abstract
This paper presents a simulation model for a preemptive transportation system where vehicles can have tasks dynamically reassigned to optimize overall efficiency. The model, built using Flexsim software, includes 9 storage areas and 8 vehicles. Exponential distributions, validated with real logistics warehouse data, generate stochastic task arrivals. Recursive logic implements the preemption algorithm. Comparative analysis over a 10-hour duration shows that the preemptive mode increases average transport volume by 13 % and reduces vehicle travel distance by 13 % compared to a non-preemptive baseline. The results demonstrate the value of preemptive transportation in enhancing system responsiveness and operational efficiency.

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Key Words: Preemptive Mode, Transport Efficiency, Process Flow

1. INTRODUCTION

Preemptive task scheduling plays a crucial role in computing and artificial intelligence domains. It allows a task sequence with a higher priority to interrupt the currently executing task sequence when there is an urgent need for execution. This ensures that tasks of high importance are dealt with swiftly. Accordingly, operating systems can better handle interruptions, support tasks that require immediate attention, and distribute system resources more equitably. Preemptive task scheduling stands in contrast to non-preemptive scheduling, wherein a task must finish its execution before another task can interrupt it [1]. Preemptive task sequencing can be triggered under specific scenarios, such as emergencies, significant occurrences, or the rise of specific needs. For instance, the need to interrupt a task sequence might arise due to a critical incident, ensuring that essential operations receive immediate attention.

Preemptive scheduling serves as a dynamic dispatch strategy in the AGV transport sector as well, allowing tasks of higher priority in transport to disrupt those of lower priority [2]. This approach is especially prevalent in transport settings that demand quick responses [3]. In intelligent transportation systems, resources can be scientifically allocated through the dispatching of AGVs (Automated Guided Vehicles) and route planning. In the context of logistics warehouses that utilize AGVs, adopting a preemptive mode of transport can significantly boost the efficiency of picking and delivering tasks. Particularly in e-commerce distribution centres, the control centre possesses the ability to dynamically adjust the allocation of tasks to AGVs [4]. In instances where certain orders demand immediate attention, the centre can deftly redistribute tasks, assigning them to the nearest available AGV. This adaptive approach can significantly enhance warehouse operational efficiency and curtail energy consumption, offering a marked improvement over non-preemptive AGV transport modes.

In order to conduct a comprehensive study of the preemptive transportation model of AGVs, this article initially establishes a 3D model, serving as the foundation for the entire simulation. In this section, we utilize Flexsim's 3D modelling capabilities to design the layout of the logistics warehouse. The Flexsim's A* algorithm is applicated for designing optimal routes for AGVs, enhancing their ability to prevent collisions effectively. Subsequently, we construct a logic flow. This section utilizes Flexsim's Process Flow module to interconnect the 3D model,

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enabling the entire model to operate according to a predefined logic. The recursive algorithm has been applied to the Process Flow to enhance the operational efficiency of the model. Thirdly, the operation process of the model is described using pseudocode, making the model more comprehensible. In the results and discussion section, we have thoroughly compared the two modes of transportation, which includes analysing aspects such as the volume of goods transported, the distances covered, and the overall status of AGVs, accompanied by visualization of the data.

2. LITERATURE REVIEW

The concept of preemptive task sequencing in the transport field has obtained attention from numerous scholars. Some researchers have concentrated on the sequencing of preemptive tasks utilizing mathematical models. Nielsen et al. addressed the challenge of organizing mobile robots' activities, emphasizing preemptive tasks in a flexible manufacturing system (FMS) [5]. They developed a mixed-integer programming (MIP) model aiming to identify the best solutions for these challenges. Their investigative simulations demonstrated the effectiveness of their proposed model, which streamlined the sequencing of preemptive tasks among robots, proving its utility for addressing problems on a smaller or intermediate scale. In order to design an efficient AGV-based transportation system, Boccia et al. proposed an original mixed integer linear programming formulation based on the bottleneck generalized assignment problem. They also proposed a three-step matheuristic based on the sequential solution of the two subproblems arising from the natural decomposition of the ASP-BC and a local search heuristic [6].

Another group of researchers has utilized simulation methods. Zhao et al. evaluated the foundational principles of multi-task scheduling and management in logistics machinery, taking AGV as an instance. They set three-dimensional representations of the equipment through MDT and established the relationships between downstream and upstream machinery [7]. Their efforts marked a significant exploration into the simulation methods for multi-task scheduling and management in AGV systems. Additionally, they applied these scheduling strategies to AGV transport in a cigarette manufacturing setting, offering an in-depth analysis of AGVs' transport routes and distribution methodologies. Zhao and Zhang designed an AGV scheduling application based on spring framework in 2022. The application consisted of four modules, intelligent scheduling module, traffic control module, equipment management module and communication protocol module. Through interaction with AGV vehicle-mounted applications, the intelligent scheduling module realized the function of automatic task allocation and vehicle body accepting tasks autonomously, which solved the problem of low efficiency of existing applications [8].

However, the complexity and often non-linear nature of actual transport systems pose challenges to these traditional approaches in achieving optimal solutions. The mathematical model's efficiency wanes as the number of robots increases, leading to slower computational performance. Researchers of AGV system simulation focused mainly on the structure of AGV systems and the strategizing of local routes, without dynamically simulating the entire system or conducting a comprehensive evaluation of the system's performance. Furthermore, there is insufficient research comparing the performance of preemptive and non-preemptive modes. Therefore, it is evident that this field holds significant potential for further advancements.

3. RESEARCH METHODOLOGY

3.1 Logistics warehouse layout model design

In a real logistics warehouse transportation system, the AGVs are engineered to autonomously determine the most efficient routes and bypass obstacles based on real-time conditions, thus minimizing human intervention and enhancing operational efficiency [9]. A typical layout of the warehouse is depicted in Fig. 1.

Figure 1: A typical logistics warehouse scene.

Fig. 1 illustrates how AGVs autonomously transport goods in the warehouse environment, shifting goods from the receiving area to storage or from storage to the packing and shipping sections [10]. These AGVs are specifically designed to navigate utilizing only right-angle turns. This design choice not only ensures that AGVs execute their movements with exceptional accuracy but also simplifies their construction [11]. By limiting their mobility to right-angle turns, these AGVs are simpler to manufacture and maintain, leading to cost savings in production and upkeep. The current operational mode of the warehouse's transport system does not allow for the interruption of tasks once they have commenced. However, there is a plan to enhance the efficiency of this transport mode [12].

The challenge of optimizing the transport process in the warehouse is compounded by several factors, including the presence of physical barriers, the unpredictable timing of task assignments, and the critical requirement for AGVs to avoid colliding with one another. Traditional mathematical models and algorithms often fall short in delivering optimal solutions for improving transport in such a complex environment. Making direct changes to the actual system could increase costs and disrupt the routine movement of goods [13]. To address this, the study introduces a preemptive task mode into the warehouse's transport system using Flexsim simulation software. This simulation approach offers a visual representation of the transport systems, enabling an interactive analysis of various scenarios and parameters.

This paper undertakes a simulation of a preemptive mode transport model utilizing the Flexsim platform. FlexSim is renowned for its professional-grade 3D simulation capabilities, extensively applied across transport, logistics, and manufacturing sectors. Specifically, for transport simulations, FlexSim excels with its advanced 3D visualization tools [14]. Regarding the real logistics warehouse, it spans 40 m in both length and width, featuring multiple obstructions along the AGV navigation paths. These AGVs are designed to execute right-angle turns solely and are outfitted with collision avoidance features. To illustrate the warehouse layout, the study employs a physical model in FlexSim, composed of 8 AGVs tasked with goods transport, 9 randomly situated temporary storage locations, and four impediments. The warehouse's perimeters are represented by blue square outlines, as depicted in Fig. 2. Each temporary storage spot is identified by a unique colour, correlating with the colour of the products they handle. The four grey squares positioned centrally signify the obstructions. Incorporating the A* module from FlexSim, which includes advanced algorithms for collision avoidance and optimal pathfinding, enables AGVs to bypass collisions effectively and identify the most efficient transport routes promptly.

The production intervals of products in the temporary storage areas vary randomly. Upon the completion of a product, the respective storage spot signals the nearest AGV for transport, assigning it the task of conveying the item to another temporary storage location. By adopting these settings, the simulation replicates a real-life warehouse transport scenario closely.

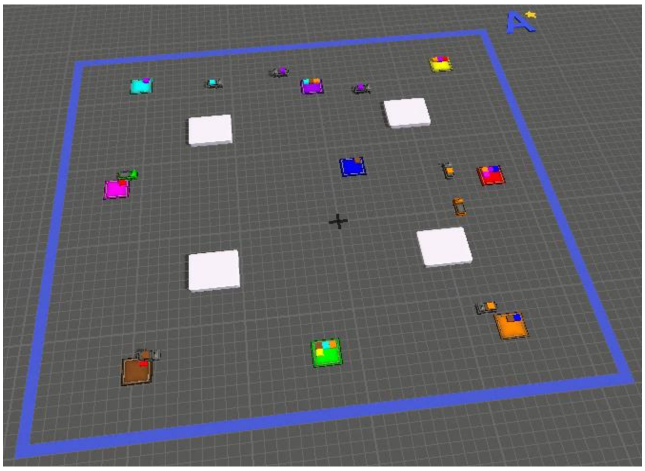


Figure 2: The physical model of the warehouse.

In Flexsim, to streamline the process of accessing staging areas and AGVs, both are organized into a single list. This setup allows for efficient management of handling tasks. When such a task arises, the system selects an idle AGV, specifically one unit, from this list to carry out the task from the designated staging area. Should an AGV that has become available be nearer to the target holding area than the one currently engaged in a transport task, the system opts for this closer AGV to undertake the task. Moreover, as soon as an AGV finishes its unloading task and is ready for more work, it has the capability to take on another preemptive task. Following the completion of its current duty, the AGV consults the task sequence list to identify any upcoming tasks that fulfil the criteria for preemptive action.

3.2 Product interval analysis and process flow creation

The exponential distribution is a common probability distribution in statistics, frequently applied to model the time between independent, randomly occurring events. in the context of product manufacturing, if the production follows a Poisson process, then the time gaps between manufacturing instances can be accurately represented utilizing the exponential distribution [15].

One of the remarkable features of the exponential distribution is its memorylessness. This attribute implies that the probability of future occurrences is unaffected by the history of past events. For the manufacturing sector, this translates to the insight that the timing of the last product's completion has no bearing on the probability of when the next item will be produced. In addition, this distribution is instrumental in determining the mean production pace. Provided that the exponential distribution's parameter is set, the average duration between manufacturing events remains certain.

Based on the above analysis, we utilized the exponential distribution to capture the timing of product production at a specific logistics warehouse. ExpertFit, a built-in software package integrated into Flexsim, is deployed to analyse the probability distribution of random events in simulation environments. The ExpertFit module efficiently collects a variety of data points, including service durations, intervals of arrival, and processing periods, among others. It then evaluates these data against numerous probability models to identify the most accurate match. Once it identifies the optimal distribution, ExpertFit generates its parameters for integration into Flexsim simulation scenarios [16]. We compiled data on the production intervals of 200 products, which was fed into Flexsim ExpertFit for a fit quality analysis, with the findings presented in Table I.

Table I: Critical values for level of significance.

Level of significance	0.250	0.100	0.050	0.025	0.010	0.005
Critical values	0.734	1.059	1.317	1.586	1.953	2.237

According to running results of Flexsim ExpertFit, the test statistic is 0.62552, the critical values are ranging from 0.734 to 2.237. It indicates that at different level of significance, all the critical values are greater than 0.62552, leading us to validate the hypothesis that the production interval times adhere to an exponential distribution with a parameter of 30.276.

To mitigate the effect of data correlation on our experimental findings, it is critical to verify the data's independence. This analysis is a vital component of statistical analysis, aiming to determine the presence or absence of statistical correlation among data points. Should autocorrelation be detected in the dataset, it might trigger a chain reaction of errors, thereby skewing the estimations and causing bias from the actual values. We applied the ExpertFit in Flexsim for this purpose, and the independence test results, illustrated in Fig. 3, indicate that the correlation coefficients closely approximate zero, confirming the data's independence.

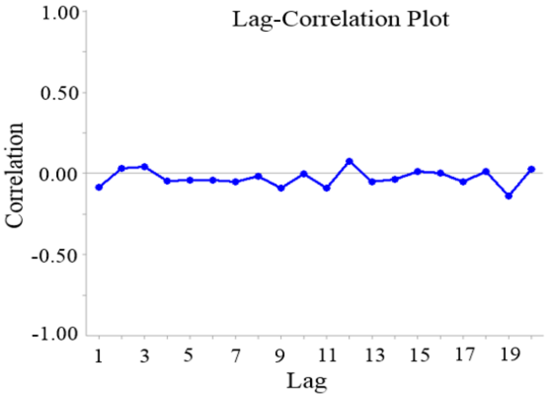


Figure 3: Autocorrelation chart of production data.

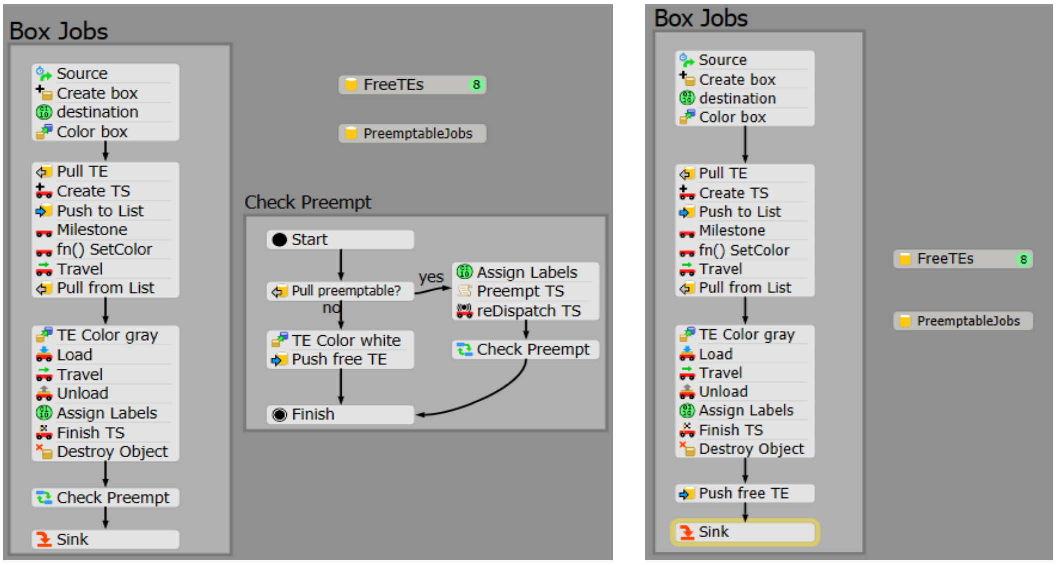
After analysing the product production interval time data, it is essential to integrate preemptive logic into the 3D model judiciously [17]. In the Flexsim toolkit, a Process Flow module is also available [18], which serves as an innovative platform for creating and simulating complex logical operations. This tool empowers users to effortlessly design and execute process logic, integrating intuitively with a 3D model discussed earlier to bring to life sophisticated preemptive transport scenarios. This integration significantly simplifies the modelling and analysis of complex systems [19].

According to Fig. 4, we see a side-by-side analysis of logical flows in preemptive versus non-preemptive transport, as facilitated by the Process Flow module. In Fig. 4 a, the preemptive logic flowchart is presented, highlighting the 'Box Jobs' subprocess, which represents the AGV transport process in detail. Firstly, an incentive adhering to an exponential distribution is established in the Source component, dictating that the production interval of products adheres to this predefined exponential distribution. Various product types are then generated across different staging areas through the Create box function. Secondly, a staging area secures an available AGV, setting off the creation of transport and handling operations. This segment constructs its logical flow around a carefully planned task sequence, offering a flexible framework that allows for dynamic adjustments in task execution as the model operates. For instance, the incorporation of new tasks or change of task executors based on specific criteria enhances the model's adaptability and responsiveness.

The 'Check Preempt' subprocess depicted in Fig. 4 a outlines the decision-making process concerning the need for preemption, aiming to execute the steps described in Algorithm 1. In the preemptive transport mode, the competition for handling tasks among multiple AGVs is a continuous cycle, with preemption processes recurring until certain prerequisites are satisfied. Here, the method of recursive calling is employed to cycle through this process, with the emphasis on establishing a definitive condition to conclude recursion, thereby averting potential risks of infinite loops and stack overflow errors.

This subprocess employs the 'Pull preemptable?' to assess whether the executing AGV is nearer to the destination compared to any available AGVs. If a shorter distance is identified, then the decision path follows the 'Yes' direction, where customized code changes the AGV currently assigned to the preemptive task. Following this adjustment, a recursive evaluation reconsiders the distance for the newly assigned AGV, cycling the process back to the starting point for another distance comparison. This recursive methodology continuously evaluates the proximity of all AGVs to the destination until there are no more suitable AGVs to undertake the current task. This process ends the recursion and completes the sequence.

As presented in Fig. 4 b, in a non-preemptive mode, if an AGV is designated by a staging area, that AGV is committed to navigate to the specified staging area to fulfil the handling task without any disruptions. To analyse the efficiency of the non-preemptive mode, we omit the recursive 'Check Preempt' operation presented on the right side of Fig. 4 a, leaving only the primary 'Box Jobs' operation on the left. This adjustment effectively implements the conditions of the non-preemptive mode.



a) Preemptive mode b) Non-preemptive mode

Figure 4: Process flow under two modes.

We have also tracked the transfer of tasks, identifying the timings and occurrences of task transfers throughout the transport process as evidenced in Table II. This data highlights the frequent task sequences during the transport phase.

Table II: Task transfer events during program operation.

Time (s)	**Task Transfer Event**
17.73	TaskExecuter8 stealing task from TaskExecuter1
34.47	TaskExecuter1 stealing task from TaskExecuter2
45.35	TaskExecuter8 stealing task from TaskExecuter7
45.35	TaskExecuter7 stealing task from TaskExecuter3
51.57	TaskExecuter1 stealing task from TaskExecuter3
51.74	TaskExecuter5 stealing task from TaskExecuter3
56.40	TaskExecuter2 stealing task from TaskExecuter3
……	…………

3.3 Algorithm design

To quantitatively describe preemptive transport tasks, we have designed the following algorithm: where N refers to the number of buffer areas, M indicates the number of available vehicles, d_{ik} denotes the distance between storage area i and vehicle k, D_{pre_sum} represents the total distance travelled by all AGVs in preemptive mode, $D_{non\_pre\_sum}$ stands for the total distance travelled by all AGVs in non-preemptive mode; $TRANS_{pre\_sum}$ illustrates the total cargo transported by all AGVs in preemptive mode, $TRANS_{non\_pre\_sum}$ denotes the total cargo transported by all AGVs in non-preemptive mode.

Algorithm 1 quantitatively describes AGV transportation under preemptive mode.

Algorithm 1: Description of transport process under preemptive mode.

```
Begin:
$D_{pre\_sum} \leftarrow 0$,/* Set the initial values for total distance and cargo volume. */
Repeat{/* Repeat operation */
For ($i$=1; $i$<=$N$; $i$++)/* Traverse each storage area.*/
Repeat{/* Repeat mutation operation */
$StagingArea_i \leftarrow AGV_k$;/*The storage area $i$ locks the idle AGV $k$ to transport goods.*/
Calculate the initial distance $D_{ik}$ from $i$ to $k$. /* The distance is calculated by the A$^*$ algorithm.*/
$Flag \leftarrow 0$; /* Flag indicates whether there is a closer AGV in the temporary storage area, if Flag > 0, then exit the loop. */
For($t$=0; $t <= \frac{D_{ij}}{v}$; $t$=$t$+0.01)
        $d_{ik} \leftarrow D_{ik} - t*v$; $p \leftarrow k$; $Min \leftarrow d_{ik}$;/*The AGV $k$ approaches the corresponding buffer area at speed $v$, and the step length can be adjusted flexibly. The distance is calculated by the A$^*$ algorithm.*/
        For($j$=1; $j$<=$M$; $j$++)/* Compare the distance between $d_{ij}$ and $d_{ik}$. */
            If ($d_{ij} < d_{ik}$)
                $Min \leftarrow d_{ij}$;
                $p \leftarrow j$;
                $Flag$++;
            End
        End
        If ($Flag$>0) /* If $Flag$>0, it indicates preemption has occurred, the current loop needs to be interrupted and the AGV need to be relocked. */
            Break;
        End
End
$k \leftarrow p$; $D_{pre\_sum}$+=$t*v$;}/* Until $d_{ik} = 0$ */
$TRANS_{pre\_sum}$+=1; /* Accumulated total cargo volume.*/
End}/* Until the specified time is over.*/
```

Algorithm 2 quantitatively describes AGV transportation in non-preemptive mode.

Algorithm 2: Description of transport process under non-preemptive mode.

```
1  Begin:
2  $D_{non\_pre\_sum} \leftarrow 0, TRANS_{non\_pre\_sum} \leftarrow 0$; /* Set the initial values for total distance and cargo volume. */
3  Repeat{/* Repeat operation */
4  For ($i$=1; $i$<=$N$; $i$++)/* Traverse each storage area.*/
5      $Queue_i \leftarrow TE_k$ ;/* The storage area $i$ locks the idle AGV $k$ to transport goods.*/
6      Calculate the initial distance $D_{ik}$ from $i$ to $k$; /* The distance is calculated by the A$^*$ algorithm.*/
7      $D_{non\_pre\_sum}$ +=$D_{ik}$ ; /* Accumulated total distance.*/
8      $TRANS_{non\_pre\_sum}$ +=1; /* Accumulated total cargo volume.*/
9  End
10 }/* Until the specified time is over.*/
```

In line 22 of Algorithm 1, D_{pre_sum} is the result of accumulating $t*v$. In line 7 of Algorithm 2, $D_{non\_pre\_sum}$ is the result of accumulating D_{ik}. If preemption occurs in the process of AGV transport, the loop in line 9 of Algorithm 1 ends prematurely. At this time, due to $t*v < D_{ik}$, during the continuous accumulation process, D_{pre_sum} is less than $D_{non\_pre\_sum}$, and due to the reduced transport distance, $TRANS_{pre\_sum}$ is greater than $TRANS_{non\_pre\_sum}$, resulting in an increase in the transport capacity of AGV.

4. RESULTS AND DISCUSSION

In this section, we explore the practical implications of our quantitative findings from Algorithm 1 and Algorithm 2 by analysing and comparing the effectiveness of non-preemptive and preemptive transport modes. This comparison focuses on the transport capacity and transport distance of AGVs. Utilizing the Dashboard module in Flexsim, we closely track and evaluate the AGVs' operational status, movement distances, and transport capacities in a live setting. The Dashboard serves as a crucial component of Flexsim, offering a user-friendly interface for the visualization of data across various aspects of the model. This feature facilitates easy access to key performance indicators (KPIs) and vital data, establishing itself as a critical tool for real-time oversight of system operations and informing decision-making processes in simulation studies [20]. For the purpose of this analysis, we standardize the operational duration of the model to a 10-hour window (08:00-18:00).

By employing the Dashboard, we are able to track and display the hourly transport capacities of eight vehicles operating under both modes. As illustrated in Fig. 5, the average hourly transport capacity across eight AGVs under the non-preemptive mode stands at 119.58. Conversely, in the preemptive mode, this average increases to 135.17, denoting a 13 % boost in transport efficiency in comparison to its non-preemptive mode.

To evaluate the significant difference in transport capacities observed between the two modes, we transfer the data into Excel for detailed analysis [21]. The p-value obtained from the test is 6.94×10^{-8}, significantly below the 0.05 threshold, confirming a significant difference in performance. This significant upturn in transport capacity under the preemptive mode highlights its effectiveness.

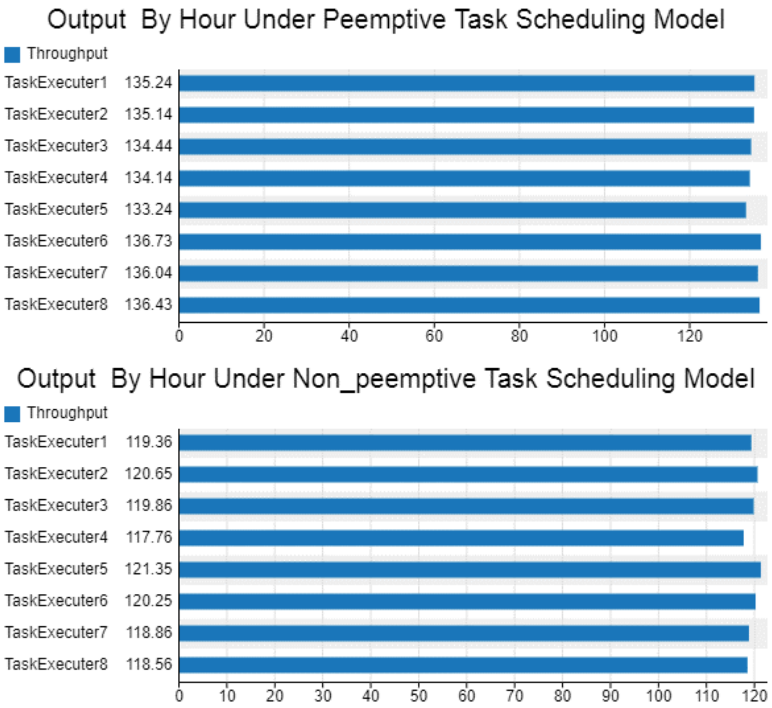


Figure 5: Output per hour in two modes.

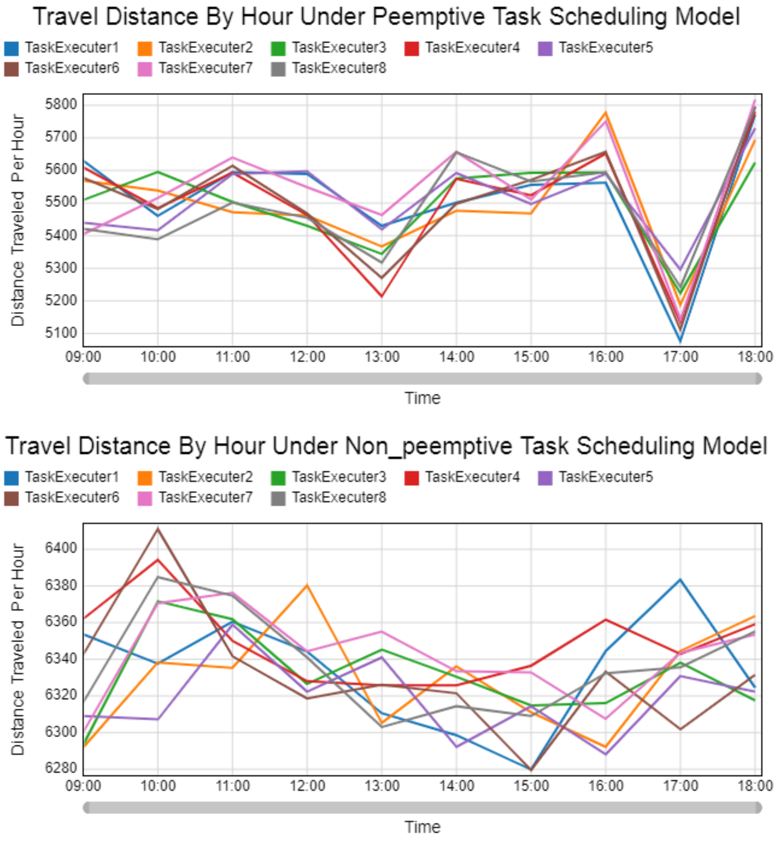
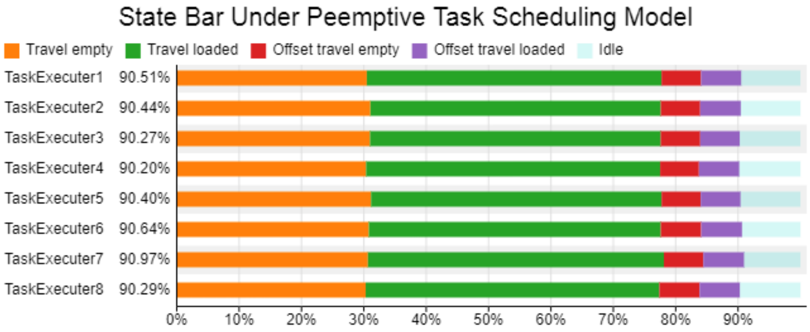


Figure 6: Travel distance by hour in two modes.

Fig. 6 presents a statistical depiction of the hourly transport distances for eight vehicles across both modes. It indicates that, in the non-preemptive mode, the average hourly transport distance for eight AGVs is 6333.95 m. Transitioning to the preemptive mode, this average drops to 5510.05 m, reflecting a 13 % reduction in transport distance per hour. This efficiency gain in the preemptive mode arises as the storage area proactively identifies and engages the nearest available vehicle, thereby shortening transport distances and enhancing the transport capacity of goods. This result lends empirical support to the algorithmic analysis presented in Section 3.3.

To determine if AGV transport distances exhibit a significant difference under two modes, we transfer the data from Flexsim into Excel for analysis to conduct a significance test. The p-value obtained from the test is 1.34×10^{-57}, significantly less than the threshold of 0.05, indicating a significant difference between the two scenarios. Implementing the preemptive mode significantly reduce the operational range of AGVs.

Fig. 7 presents a side-by-side comparison of eight AGVs operating under two diverse modes. This comparison observes that the preemptive mode notably reduces the idle transport rate of AGVs, while simultaneously increasing their idle periods. This suggests that the preemptive mode effectively minimizes unnecessary transport distances for AGVs, providing them with increased downtime for essential maintenance and inspections. This improvement is attributed to the mechanism in the preemptive mode that allows an available AGV to be temporarily secured, offering a probability during its operation to be replaced by another AGV positioned closer to the task. Therefore, the AGV taking over the task will have a reduced no-load transport distance, whereas the replaced AGV remains on standby at its current location, thereby enhancing its available idle time.


State Bar Under Peemptive Task Scheduling Model

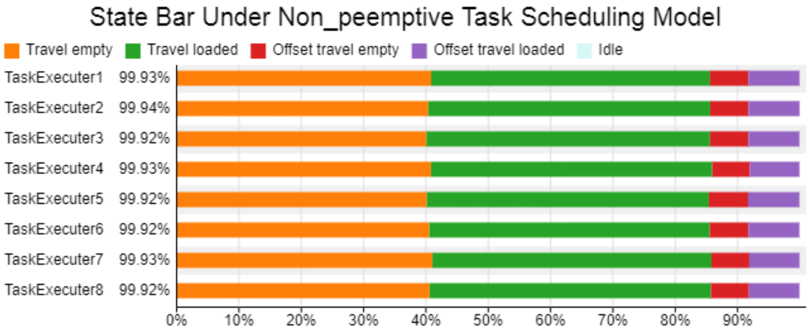

State Bar Under Non_peemptive Task Scheduling Model

Figure 7: State bar in two modes.

5. CONCLUSION

This paper demonstrates the potential of preemptive task allocation in improving the efficiency of transportation systems through a novel simulation modelling approach. Real-world production data was used to generate stochastic task arrivals, while a recursive algorithm implemented the dynamic preemption logic. Comparative experiments over a 10-hour period showed that the preemptive mode outperformed a non-preemptive baseline, increasing throughput by 13 % and reducing travel distance by 13 % on average. The results highlight the value of preemptive strategies in optimizing vehicle utilization and responsiveness to real-time transportation demands. Future work can explore the integration of AI methods for preemption decisioning and assess the performance of the proposed approach with alternate dispatching rules. The simulation framework presented here can aid transportation system designers in assessing the efficacy of preemption strategies prior to real-world implementation.

However, the application of preemptive transport algorithms encounters two practical challenges and limitations. Firstly, the real-world logistics transport framework is exceedingly complex. Preemptive transport algorithms must be capable of adjusting to these changes promptly while also managing unforeseen events, such as damage to AGVs [22]. On the other hand, despite advancements in resolving AGV deadlock scenarios, the increase in the number of AGVs could still precipitate deadlock situations [23].

In addressing the challenges outlined, this paper proposes three suggestions. Firstly, researching and developing more efficient algorithms can effectively improve the system's transport efficiency and its rapid response capabilities during emergencies. Tailoring these algorithms to fit particular operational situations can significantly enhance the system's transport efficiency. Secondly, employing machine learning methods to recognize patterns indicative of potential deadlock scenarios and to estimate the probability of such occurrences enables the system to implement preemptive measures to avert crises and to expediently resolve deadlock situations as they occur [24]. Thirdly, system architects and overseers are instrumental in enhancing transport efficiency. Their role involves the effective integration of non-preemptive and preemptive transport modes to navigate emergencies effectively and to incorporate cutting-edge technologies such as Intelligent Transport Systems, Big Data analytics, and Internet of Things innovations.

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