TIME EFFICIENCY ANALYSIS OF AN AUTOMATED PARKING SYSTEM

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ABSTRACT

In this paper, a time analysis for parking and retrieval process of an Automated Parking system (APS) is provided. The time analysis is to check the performances of five different APS configurations, which is based on the varying combinations of system parking spaces and the numbers of entries and exits. As a result of the analysis, the relationship between the number of parking spaces in an APS and the corresponding number of entries/exits for an efficient parking/retrieval process are identified. Furthermore, suggestions are made for the future simulation analyses.

INTRODUCTION

An automated parking system (APS) is an advanced method of parking and retrieving a vehicle inside a parking structure without any human interference. In an automated parking system, a driver drives a vehicle inside a room in the APS and parks it on a pallet inside the room for scanning. Upon completion of the scanning process, the driver walks out of the room with a ticket generated by the machine kept outside. The automated guided vehicle (AGV) responsible for pallet movement inside the APS, takes control of the pallet on which the vehicle is parked. The AGV lifts the pallet and places it at a specified location inside the APS. The parking spot of the pallet with the vehicle is decided by a logic controller responsible for AGV movement. When the vehicle owner returns to drive away the vehicle, the ticket generated automatically during parking is swiped by the vehicle owner, upon payment of the parking charges, the AGV starts the retrieval process of the vehicle with the pallet. The system informs the owner about the exit location if there are multiple exit points. The number of AGV in an APS is equal to the number of entry and exit points required in the APS for parking and retrieval process in fastest time [1].The time efficiency of an APS is calculated in terms of the time taken by an AGV to park/ retrieve a vehicle. The fewer parking spaces an AGV covers, the less time it will take for parking / retrieval process. Hence, one of the objectives of this paper is to find the critical number of parking spaces. At the critical number, the system should include an extra entry and exit points with AGVs to maintain the maximum acceptable time limit of 2.5 minutes for parking/retrieval process [2].The number of parking space requirement, the numbers of entry and exit points and AGVs must be effectively decided to perform the parking and retrieval process in minimum time.
Simulation of an automated parking and retrieval system has been a popular area of application [3]. Ford developed simulation software named GENAWS in 1972. IBM developed one in 1973 called IBM ware hour simulator. The inputs for modeling includes: number of AGV’s, rack , row height, Input point, Output Point, AGV machine speed, Longest distance travelled by the AGV, Pickup and deposited times. These criteria are the basis for performing the simulation of any parking and retrieval system and the same criteria are adopted in this paper for time analysis of AGV in an APS.

Ekren and Heragu [4] presented a simulation based regression analysis for the location of the parking spots inside a building. The results suggested the warehouse designs to be in horizontal axis as long as possible. This leads the AGV system to function at its maximum time efficiency. In this paper, the horizontal axis method has been adopted for parking space arrangement inside the APS to obtain the maximum time efficiency. Also, for optimal allocation of cars to parking spaces the FIFO and by TURN allocation process proposed by Peng [2] is modified and applied in this work. In addition, for the parking space arrangement and shortest path of AGVs movement the research works by Fujimura and Samet [5] and Ekren and Heragu [4] are applied in this paper. Bozer and White performed a simulation to find efficiency of the travel time of an APS. The result suggested that a system having less average waiting time is more efficient in travel time. Also, maximum time for retrieval is the worst case scenario and the time taken by the AGV is always less than the maximum time for retrieval. Guo and Liu [6] simulated an automated storage and retrieval system on Arena 8.0 simulation software to check the performances of a shuttle system. Simulation result suggest that, the twin shuttle system is 40% more efficient than the single shuttle system in terms of time and it would be a better investment if the input and output stations are at separate locations. In this paper, the concept of multiple entries/ exit system along with multiple AGVs for parking/retrieval process is adopted from Guo and Liu reserach. Pulat [7] has presented a comparative approach to find the time efficiency of a storage and retrieval system with the help of simulation. The result obtained by Pulat endorses the concept of fastest time for storage/retrieval process in an APS by Peng [3]. The concept of fastest time is used in this paper to calculate the fastest time for parking/retrieval and relative time efficiency in percentage. Chow [8] described the development consideration and logic for simulation for an automated storage and retrieval system which inspired the simulation method presented in this research. The dimensions of the parking spaces provided by Hsu, Li [1] is used to calculate the maximum distance the AGV needs to travel for parking/ retrieval process inside an APS.
Although there are many researches on producing better models of APS, research with respect to time efficiency of an APS is really scarce. Therefore, in this paper simulations are performed on efficiency of an APS and to suggest the number of AGV required for parking / retrieval process for a given number of parking spaces and within 2.5 minutes permissible time.

MODEL DEVELOPMENT

In this section, a time simulation of an automated parking system with AGV movement is performed in the Pro-Model simulation software. The simulation is to calculate the time taken by an AGV system to park/ retrieve a vehicle placed on a pallet in an APS. The time taken by the AGV to park and retrieve is calculated for different parking spaces starting from 50 up to 2500 spaces. The systems is simulated with one entry /one exit, two entries/ two exit, three entries/ three exit, four entries/four exit and five entries/ five exit with two, four, six, eight and ten AGVs respectively. The time period chosen for simulation is 2000 hours. The number of pallets in an APS is equal to number of parking spaces required plus the number of AGV's [2]. In case of one entry/one exit system with 50 parking spaces, numbers of pallets are:

$$N_{pallet} = n + n_{agv} \tag{1}$$

Where, N_{pallet} represents the number of pallets, n represents the number of parking spaces and n_{agv} indicates the number of AGV's required. Equation 1 gives the number of pallet in case of 50 parking spaces for one entry/one exit system as 52, Similarly, in case of two entries/two exit system for 50 parking spaces, the number of pallets is 54. The same method is applied to calculate the number of pallets required for parking spaces with one-entry/one-exit, two-entries/ two-exit, three-entries/three-exit four-entries/four-exit and five-entries/five-exit system in APS.

AGV movement: The AGV movement in an automated parking system determines the time efficiency of the automated parking system. The total time taken by an AGV depends on the distance it needs to travel in an APS for parking / retrieval. In the first simulation, 50 parking spaces are considered to find the maximum time for parking /retrieval process using two AGV's. Since, 1.5 minutes is the fastest time recorded for parking/retrieval process by an AGV [3], and the fastest time obtained in this paper during Pro-model simulation for five entries/ five exits system with ten AGV's is 1.51 minutes. Hence, the fastest time for relative time percentage calculation is assumed to be 1.5 minutes. In this paper 1.5 minutes is the best time for a parking/retrieval process. This implies the system will be 100% efficient if it is able to park/retrieve a vehicle in 1.5 minutes. During the simulation, if the time taken by an AGV is more than 1.5 minutes, it is considered as the relative time to the standard time of 1.5 minutes for parking/retrieval process.

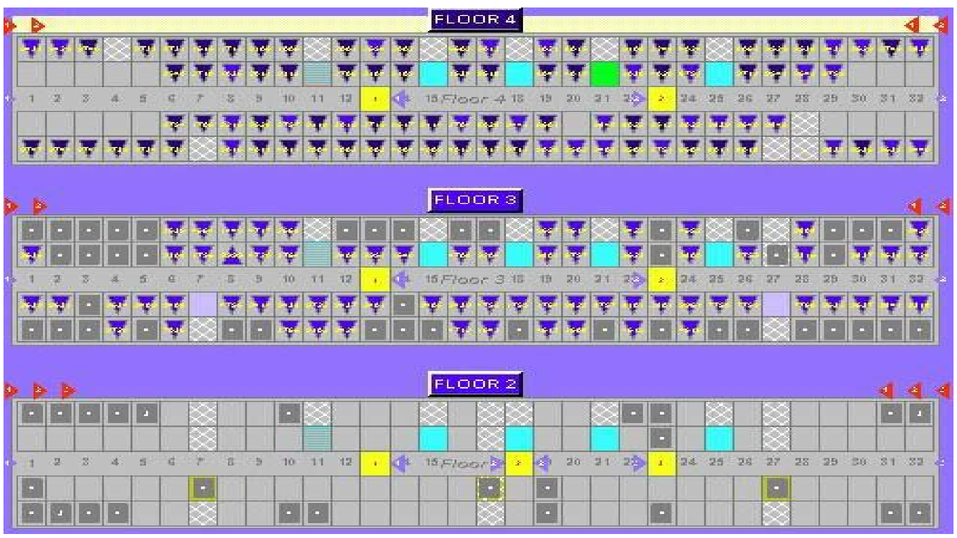

Figure 1: Horizontal Parking arrangement in an Automated Parking System

Parameter for 50 Parking Spaces: If the parking spaces are arranged in two rows [7], the longest distance travel by an AGV in horizontal direction will be the 25th and the 50th spot in the parking area. In this case, the time taken by AGV to travel the longest distance is considered. The figure 1 above represents a sample horizontal parking arrangement. The parking spaces are arranged in two horizontal rows and the spaces between two opposite parking spaces are kept for AGV movement. The Horizontal arrangement of parking spaces allows the AGV's movement at its maximum speed, thereby reducing the time for parking/ retrieval process inside an APS.

L_1 the maximum horizontal distance travel by AGV to park the vehicle
L_2 the maximum vertical distance travel by the AGV to park the vehicle
V_v the vertical velocity of AGV
V_h the horizontal velocity of AGV
T the time taken by an AGV to park /retrieve a vehicle in minutes

Also, from [8] it is assumed that the Average Speed of AGV is 0.61 meter/sec, the dimensions of a parking space in a parking system is 2.5 meters in width and 5.5 meters in length and 7.5 meters in height. Then the time required by AGV for horizontal motion is

$$T_h = \frac{L_1}{V_h} \tag{2}$$

The time required by AGV for vertical motion

$$T_v = \frac{L_2}{V_v} \tag{3}$$

And the total time taken by the AGV to park vehicle is

$$T = T_h + T_v \tag{4}$$

Equation (4) is used in Pro-model simulation for the time calculation. Similarly, in 100 parking spaces, the 50th and 100th parking spot are the farthest distance AGV travels. Each floor has 100 parking spaces arranged in two rows. For next floor, the AGV needs to travel 7.5 meters in vertical direction. As in case of 50 and 100 parking spaces arrangements, similar parking arrangement has been done for 150,200,250, 500,1000,1500,2000 and 2500 parking spaces with 100 parking spaces on each floor. The process flow diagram below represents the AGV movement scenario used for Pro-Model simulation of parking and retrieval process.

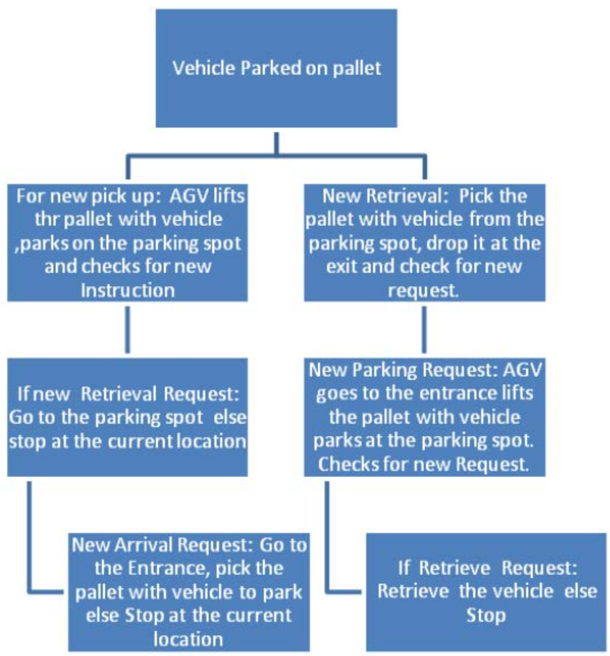

Figure 2: Flow Diagram for parking and retrieval process

ProModel Simulation and Experimental Result

The Automated parking system model is built in Pro-model simulation software and the first simulation is run to find the time efficiency of the system with 2 AGV for one entry/one exit system. In this simulation, the capacity of the parking system is 50 vehicles and the average wait time for the vehicles at the entrance is 90 seconds [9]. This time is allocated for the sensors to check the vehicle for the unwanted materials and the proper parking of the vehicle on the pallet. Since, the number of parking spaces in this case is 50; the number of pallets according to equation (1) will be 52. The simulation is performed for 2000 hours in the Pro Model to find the time required by the AGV's to park/ retrieve a vehicle in an APS. The same time simulation is performed with four AGV's for two

entries/ two exit, six AGV's for three entries/ three exit, 8 AGV's for four entries/four exit and ten AGV's for five entries/five exit points. The results of the simulation are shown in the next section.
Figure 3 represents all five systems and the maximum time taken to perform parking/retrieval process with cutoff time of 2.5 minutes. Considering the worst case scenario, the longer of the two times for parking and retrieval has been considered for plotting the graph so that, the results could be predicted more accurately. The graph has been divided in to two parts for more accurate result visibility. As shown in the graph; the curves for 50 and 100 parking spaces are within the acceptable limit of 2.5 minutes for one entry/one exit system. The curves for 150, 200, 250 and 500 exceed the maximum time limit for one entry/one exit system. However, the curve for 150 and 200 parking spaces meets the time limit for two entries/two exit systems. Similarly, the curves for 250 and 500 parking spaces are within the acceptable time limit for three entries/three exit systems. The curves for 1000, 1500, 2000 and 2500 parking spaces for all five AGV systems in an APS have been represented in the next graph.

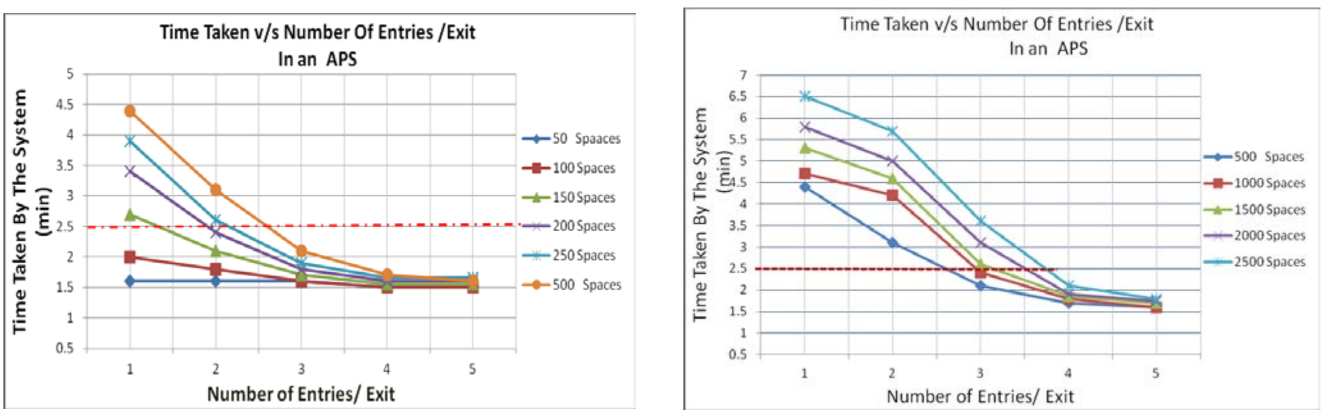

Figure 3. Graph for Time Taken v/s Number of Entries/Exit

From the above graph, the curve representing 500 and 1000 parking spaces meets the time requirement for three entries/three exits parking system. This means the system must adopt at least three entries/ three exit with six AGV's to park and retrieve vehicles efficiently. For 31
parking spaces 1500, 2000 and 2500 both four and five entries/exit systems meets the time limit of 2.5 minutes and there is not much of improvement in the time when the APS gets upgraded from four entries/exit to five entries/ exit system. Therefore, four entries/exit systems are best suited for parking spaces 1500, 2000 and 2500.

CONCLUSIONS

Pro-model simulation for time analysis of an AGV system in an APS shows that, the one entry/one exit system with two AGV's is best suited for the parking space capacities up to 100 and the APS must adopt a second entry/ exit point with additional two AGV's to meet acceptable time limit for the increased parking capacity from 100 to 200. The APS with two entries /two exits becomes inefficient for parking spaces above 200. To maintain the time limit of the system, it is advisable to adopt three entries and three exits system with six AGV's. The three entry/three exit system meets the acceptable time limit of 2.5 minutes for parking and retrieval processes until 1000 parking spaces. However, the system does not meet the acceptable time for parking spaces more than 1000. Adopting four entries/four exit system with eight AGVs is the best solution for parking spaces between 1000 and 2500 compared to five entries/five exits. The four entries/four exit system meets the acceptable time limit of 2.5 minutes and the time efficiencies from 1000 till 2500 parking spaces is also very close to the five entries/five exits. Although, five entries/five exit system is slightly better than four entries/four exit system it still doesn't justify the cost for such a small margin of time saving and excess money involved compared to four entries/four exit system.

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