# Performance Comparison of Automated Warehouses Using Simulation

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**Abstract**

The purpose of this study is to compare the performance of two types of warehouses, both of which use autonomous vehicles (AVs). One warehouse uses movable racks (MR) for storing mini-loads, whereas the other uses fixed racks (FR). In general, warehouse automation not only increases the speed of the fulfillment process but also makes the picking process more accurate. We simulate three scenarios for the MR and FR systems using Simio. Four performance measures are considered for the comparison – the average order processing time ($W_R$), the average utilization of AVs ($U$), the average order processing queue length ($N_q$) and the average distance travelled by AVs ($d$). We also estimate the capital costs of both systems and use it to compare the two systems. On the basis of our assumptions and simulation results, we find that the FR system not only requires an average 56 % less capital investment than the MR system, but it also provides a more efficient warehousing automation option with relatively lower utilization of AVs, lower order processing time and lower average number of orders waiting to be processed.

## 1. Introduction

Automation in warehousing has witnessed significant advancements in the last decade. Automation which was employed heavily in manufacturing industries, has found numerous applications in warehousing. The need to use automation in warehousing was initially prevalent in European countries and Japan, the major drivers being high labor cost, limited availability of space and ergonomic restrictions. With the growth in the e-commerce market, this need has now escalated to other parts of the world. With e-commerce companies expanding their product offerings and geographical area they serve, it has become challenging for them to process incoming orders quickly and accurately. With the introduction of concepts such as same-day delivery or next-day delivery, it has become increasingly difficult for these companies to depend on manual labor, especially for order picking in a warehouse. In a traditional warehouse, order picking process is one of the biggest cost contributor among all other costs involved in order fulfillment [10].

Amazon Robotics and Symbotic LLC represent companies that incorporate two alternative warehouse automation systems. Warehousing automation in both the companies uses autonomous vehicles, which can process pick requests by bringing the required item to the shipper with no human intervention. However, the main difference between these two systems is that in one, an entire rack is brought to the order picker, whereas in the other only the tote with required item is brought to the order picker. In this article, we refer to the Amazon Robotics type of warehouse automation as the Movable Rack (MR) system and the Symbotic type of warehouse automation as the Fixed Rack (FR) system.

### 1.1 Movable Rack (MR) System

MR system uses a combination of moving racks and autonomous vehicles (AVs) for automating the order-picking operation. These AVs are autonomous robots which are small enough to fit below a moving rack. Each AV is equipped with a mechanism that allows it to lift inventory pods (movable racks) off the ground. A typical MR system consists of a storage area which is subdivided into storage cells and a path for accessing the storage cells. These storage cells are used for parking movable racks. Apart from the storage area, a warehouse with an MR system has several picking stations located in the warehouse. These manual picking stations are typically located near the docks so operators can compile an order in a carton and load it on a truck. The number of picking stations depends on the required order processing rate and also on the size of storage area. Once an order-picking request is initiated, the system assigns AVs to bring the required racks (those that contain the items in the order list) to the picking station where the operator will pick the required types and quantities of the products in the order list. Once the picking is completed, the AV returns the rack to a storage cell. The new location of the storage cell is determined by the system with an objective of minimizing the time to release the AV as well as the time to bring the rack to the next picking station where it might be needed. In the MR system, each AV is equipped with a computer and uses artificial intelligence to decide on a path to deliver the movable racks. In addition to Amazon Robotics, companies such as Swisslog, GrayOrange and Grenzebach also offer MR systems.

### 1.2 Fixed Rack (FR) System

Like the MR system, the FR system also uses autonomous vehicles for bringing the items in an order to a picker, but unlike the MR system, an AV in the FR system travels on guided tracks horizontally and uses lifts for vertical movement._The AV delivers totes from their respective locations on fixed racks to the designated picking station, instead of moving the entire rack. The storage area in this system looks like a traditional AS/RS but instead of having a crane to store and retrieve the product from racks, FR system uses AVs to travel to the specific locations and pick the totes. Unlike an MR system, an FR system is capable of using the entire storage cube and thus requires less relatively less space. Warehouse automation provided by Demantic, Vanderlande and Cimcorp Automation, along with Symbotic Systems, offer FR systems.


Figure 1: Movable Rack System

*Source: http://www.fastcompany.com/1754454/kiva-powers-web-commerce-new-bot-bot-action*


Figure 2: Fixed Rack System

*Source: Bastian Solutions*

### 2. Literature Review

The MR and FR systems represent advanced forms of autonomous vehicle storage and retrieval system (AVS/RS). This type of systems when installed in a fulfillment center not only increases the speed of the fulfillment process but also increases the accuracy and flexibility of the process [1]. Compared to the traditional warehouse automation using automated storage and retrieval (AS/RS) systems, the AVS/RS offers more flexibility [3], [4]. Under certain conditions, the AVS/RS performs better than an AS/RS. Using a simulation study, Ekren and Heragu [3], [4] demonstrate that the AVS/RS performs better than an AS/RS in different scenarios. Also there are many other studies done in the past to understand the factors affecting the performance of

AVS/RS automations [5], [7], [9].

Researchers have used several analytical modelling techniques for studying the performance of these systems [5]. Of all the analytical techniques, semi-open queuing network provides the best frame work to model an AVS/RS or AS/RS, but all these analytical techniques fail to include the detailed operations and stochastic behavior of these systems into the model. The fact that these detailed operations and randomness make some specialized system very unique, limits the use of analytical techniques for the study of warehouse automation systems. Simulation on the other hand, can include a significant level of detail in the model, and can thus be used for evaluating or comparing different warehouse automation systems [5].

AVS/RS with all the advantages it possesses has been able to attract much interest from scholars and researchers around the world. In this study, we compare the performance of the MR and FR systems. We developed simulation models of both the MR and FR systems in Simio and obtain key performance measures for both. The aim of this study is to analyze the performance of both the systems, and infer which system is better under different scenarios. We consider four performance measures – the average order processing time ($W_R$), the average utilization of AVs ($U$), the average order processing queue length ($N_q$) and the average distance travelled by AVs ($d$). We also estimate the capital cost of both systems and use it to compare the two.

## 3. Simulation Model

For purposes of our study, we model a warehouse with 4,000 miniload spaces for the MR and FR systems. These miniload spaces can accommodate totes of a standard size. The number of picking stations is set at three for both warehouse automation alternatives. For the MR system, a rack has four levels of storage whereas in the FR system, a rack has ten rows and ten columns of miniload spaces. The MR system has 1,000 movable racks distributed among 25 aisles with 20 racks on each side. For the FR system, four blocks of racks, each with ten racks, are distributed among 5 aisles. Each movable rack can be independently accessed in a MR system, whereas in a FR system, each block has one input and one output lift shared between 5 racks.

In our model we assume that for both systems, each AV uses its own drive unit to travel horizontally. In the FR system, the AV uses a lift to travel vertically. The AVs for MR system move along grid of lines marked on the floor and identify their location by reading QR codes marked along the lines. In an FR system, however, the AV uses a network of guide rails for movement in the warehouse.

The other important assumptions of the model are as follows:-

1. There are 100 SKUs randomly spread among 4,000 miniload spaces. The distribution of 100 SKUs follows the 80:20 rule, i.e. 20 % of SKUs occupy 80 % of the miniload spaces and so on.

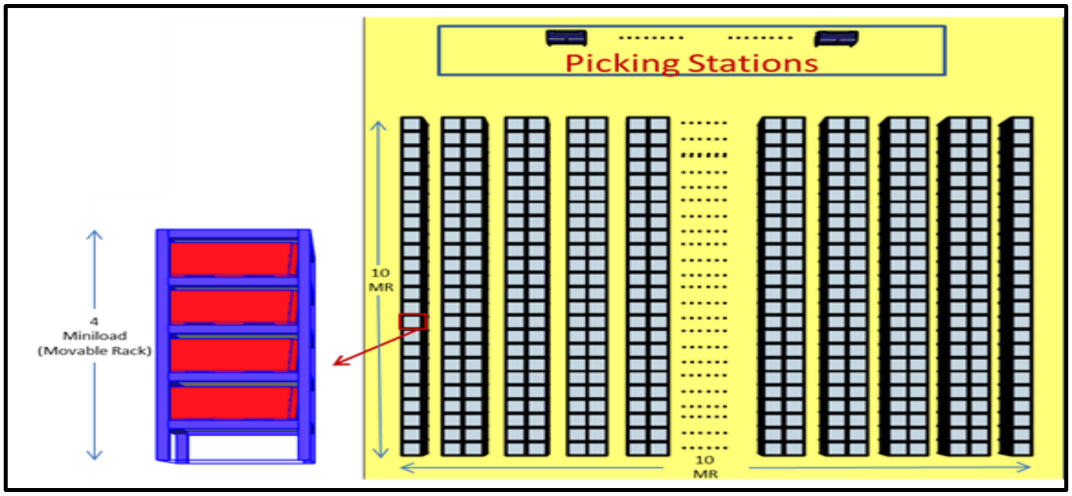


Figure 3: MR Simulation Configuration

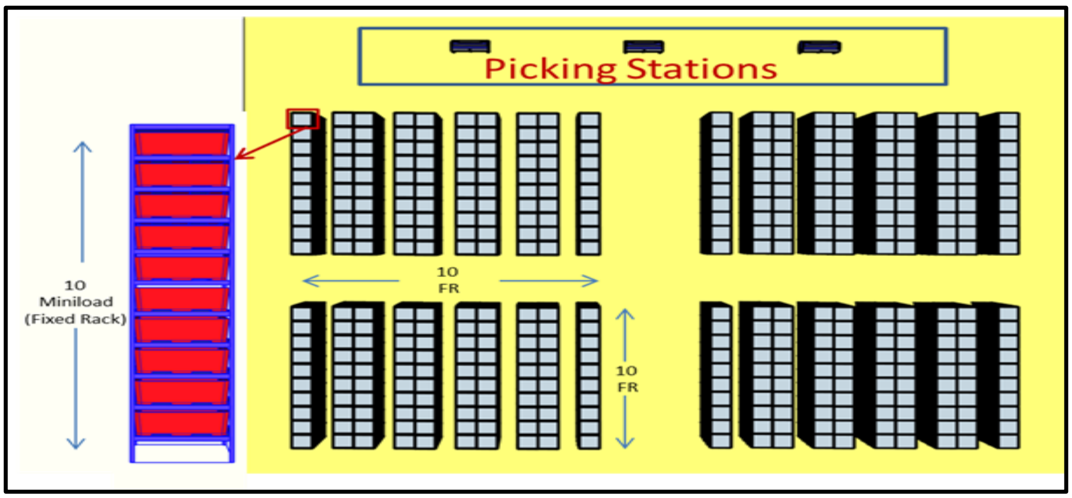


Figure 4: FR Simulation Configuration

2. A miniload space can carry only one type of SKU.
3. Our system only simulates the picking process. We assume that replenishment is an external process and is done in a shift prior to when the picking is expected to occur.
4. Items required for picking are assumed to be available in one or more storage locations.
5. The picking stations are evenly distributed on one side of the storage area.
6. The retrieval transactions are served on a first-come, first-served (FCFS) basis.
7. Each order consists of a single SKU.
8. Both the systems have defined dwell points for the robots.

9. Acceleration and deceleration are not considered.
10. In the FR system, the AVs drop the miniload in a conveyor connected to the picking stations, whereas in the MR system the AVs take the racks to their respective picking stations and then brings them back to their corresponding storage locations.
11. The speed of an AV in the MR and FR systems are 3 miles per hour and 25 miles per hour, respectively.
12. The loading and unloading time in the MR system is assumed to be ten seconds, whereas in the FR system, it is five seconds.
13. Order arrival begins at 8:00 am daily and lasts until 3:00 pm. The picking process continues until the last order of the day is processed. Since all the orders are processed on the same day it was generated, we kept the simulation run length to be 9 hours.

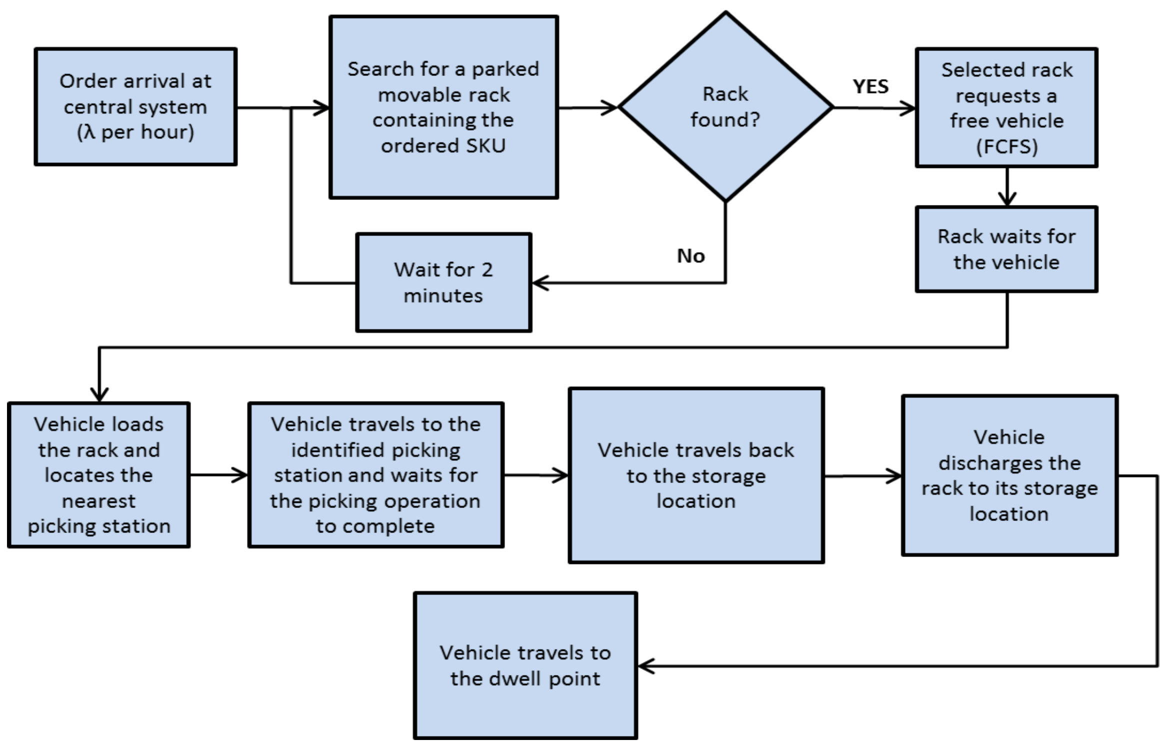


Figure 5: Order cycle of MR System

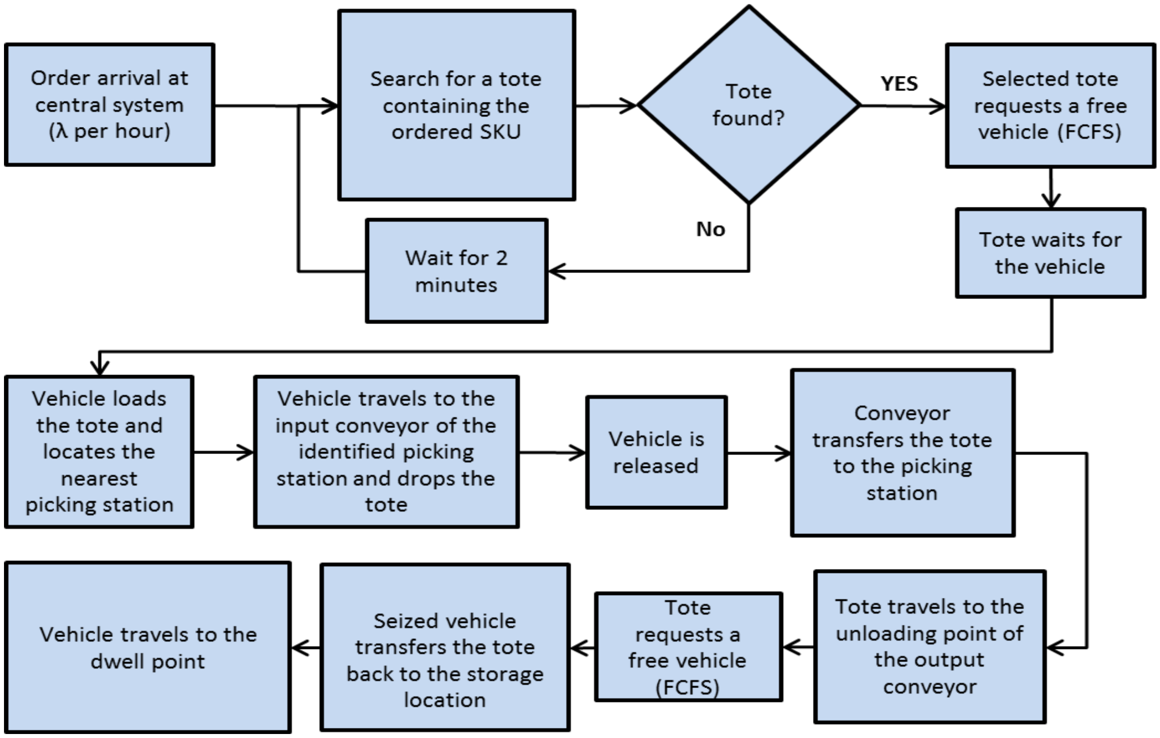


Figure 6:- Order cycle of FR System

## 4. Methodology

We begin by balancing the two systems for an order arrival rate of 250 orders per hour (λ). Because the MR and FR systems use completely different configurations of racks and AVs for storage and retrieval purposes, it is important to balance the AV utilization in the two systems for comparison purposes. For the purpose of balancing the AV utilization, we varied the number of AVs in both the systems for an arrival rate of 250 orders per hour. The aim was to find the number of vehicles for both systems which would ensure the average utilization of vehicles is between 80 to 85 %, for the arrival rate of 250 retrieval transactions per hour. Using a trial and error approach, we found the number of AVs for the MR and FR systems (that provided a utilization between 80 to 85%) to be 17 and 4, respectively.

After determining the number of AVs for both systems, we simulated three scenarios of both systems. Three order arrival rates, λ=225 orders/h, 250 orders/h and 275 orders/h, were used to construct the three scenarios. We observed four performance measures – $W_R$, $U$, $N_q$, $d$ – from the simulation results. For all the mentioned analysis we run 10 replication of each of the scenarios with run length of 30 days and confidence interval of 95 %.

We also estimate the capital cost of both systems. We considered infrastructure (building) cost, cost of racks, guidance system, lifts and AVs for estimating the total cost. Table 1 shows our cost assumptions.

Table 1: Cost Assumptions

| Cost Assumptions | | |
|---|---|---|
| *Costs* | *MR System* | *FR System* |
| Infrastructure(Building) | $ 200/ft$^2$ | $ 200/ft$^2$ |
| Guidance System | $ 2/ft$^2$ | $ 50/ft |
| AVs | $ 20,000/AV | $ 10,000/AV |
| Racks | $ 180/Rack | $ 3,600/Rack |
| Lifts | NA | $ 40,000/Lift |

We guesstimated the costs for each component on the basis of information provided on websites and our knowledge of material handling systems. We caution the reader that our assumptions and computation of capital cost may not be accurate, but it provides a basis to compare the two systems. The cost of these systems may vary from manufacturer to manufacturer and sometimes might also be different for different customers from the same manufacturer, therefore our comparison of the capital cost should be considered to be rudimentary.

## 5. Results and Discussion

Tables 2-3 contain the values of the performance measures, which were obtained by running the three scenarios for the two systems. By comparing results for both systems, we see that the FR system can provide better performance in terms of order processing time with fewer AVs. We also see that although the AVs in the FR system travel more distance than the AVs in the MR system, the average utilization of AVs for the FR system is less than that of the MR system. This is because the AVs in the FR system carry only one tote at a time whereas the AVs in the MR system carry a movable rack, thus allowing the AVs in the FR system to travel faster than the AVs in the MR system. Low AV utilization also suggests that the operating cost for the FR system will be less than that of the MR system with the same warehouse configuration and order arrival rate.

Table 2: Results of MR system

| MR AVS/RS- 17 AVs | | | | |
|---|---|---|---|---|
| $\lambda$ *Orders/h* | *U%* | *Nq* | *WR* (hrs) | *d* (meters) |
| 225 | 72.63 ± 3.15 | 21.39 ± 9.47 | 0.11 ± 0.05 | 14,857 ± 466 |
| 250 | 83.82 ± 1.49 | 68.27 ± 14.96 | 0.34 ± 0.07 | 15,470 ± 517 |
| 275 | 91.77 ± 1.02 | 149.02 ± 11.32 | 0.69 ± 0.04 | 16,830 ± 468 |

Table 3: Results of FR system

| FR AVS/RS- 4 AVs | | | | |
|---|---|---|---|---|
| *λ Orders/h* | *U%* | *Nq* | *WR* (hrs) | *d* (meters) |
| 225 | 70.24 ± 1.21 % | 14.48 ± 4.36 | 0.07 ± 0.02 | 67,756 ± 645 |
| 250 | 81.57 ± 1.28 % | 43.05 ± 13.75 | 0.21 ± 0.06 | 70,791 ± 672 |
| 275 | 91.51 ± 1.53 % | 145.9 ± 13.21 | 0.66 ± 0.05 | 78,576 ± 055 |

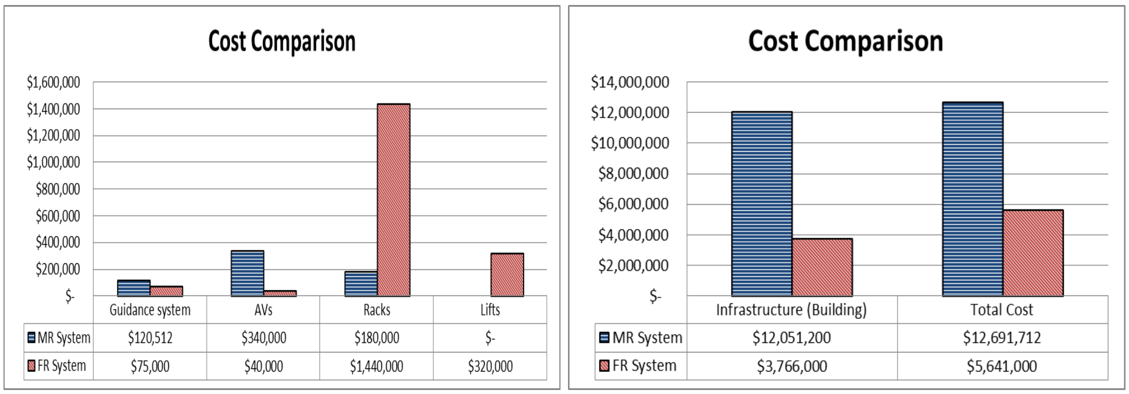


Figure 7: Cost Comparison

Figure 5 illustrates the capital cost for the MR and FR systems for the simulated warehouse configurations. From the figure, we can infer that the capital cost required for the MR system is higher for all the cost components except the cost of racks and the lifts. The total capital cost for the FR system is also much less than that of the MR system, which is mainly due to less floor space required for the FR system.

On the basis of the above results, we can conclude that the FR system provides a better option for warehouse automation, when compared with the MR. The FR system not only requires less floor space and less capital investment than the MR system, but is also more efficient in terms of average order processing time.

In the future, we will compare the two types of automation by including complex storage and retrieval rules. We will explore how order batching, random slotting, and other warehouse operational strategies impact each of these systems.

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