# Simulation Modeling for End-of-Aisle Automated Storage and Retrieval System

Behnam Bahrami[1, a)] El-Houssaine Aghezzaf [2, b)]
and Veronique Limere[3, c)]

[1,2] *Department of Industrial Systems Engineering and product design, Faculty of Engineering and Architecture, Gent University, Gent, Belgium*

[3]*Department of Business Informatics and Operations Management, Gent University, Gent, Belgium*

[a)]Corresponding author: Behnam.Bahrami@ugent.be
[b)] ElHoussaine.Aghezzaf@ugent.be
[c)] Veronique.Limere@ugent.be

**Abstract.** This paper presents a simulation study of an End-of-Aisle automated storage and retrieval system. Various elements of AS/RS control policies are combined to compare and analyze the performance of an End-of-Aisle automated storage and retrieval system. The extensive simulation study shows the isolated effects of various policies by comparing several combinations of policies and rules. This comparison provides a base for selecting the most suitable policy in the evaluated system.

Keywords: Warehousing, Automated storage and retrieval systems, Simulation

## INTRODUCTION AND LITERATURE

Automated storage and retrieval systems (AS/RS) consist of multiple aisles of storage racks, storage/retrieval machines and input/output stations and are typically implemented for transporting unit loads (e.g., fully loaded pallets) within the system; but, in many cases, only part of the unit-load may be needed to fulfill a customer's order. A common option to resolve this situation is when the AS/RS drops off the retrieved unit loads at a workstation at the end of the aisle. An operator at this workstation takes the required amount of products from the unit-load, and then the AS/RS moves the remainder of the load back into the storage rack. This system is often known as an End-of-Aisle (EOA) system. If the unit-loads are bins, then the system is generally named a miniload AS/RS (Roodbergen, 2009). In an End-of-Aisle miniload system with two pick positions there are two load stations, one at the end of each aisle, to perform order picking. The configuration of these systems are such that each aisle has a left and a right pick position. While the order picker is picking items from one unit-load in one pick position, the S/R machine picks up the unit-load in the other pick position, restores it in the rack, and returns to the next operation ( Figure 1)

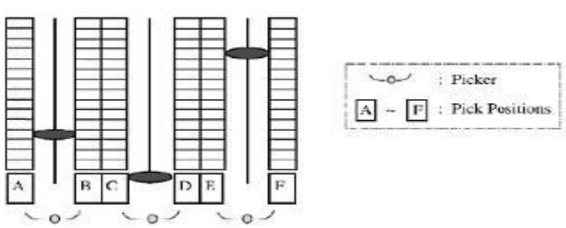


Figure 1: End-of-Aisle miniload system with two pick positions. (Hwang et al., 2002.)

Bozer and White (1990) have proposed a mathematical model to analyze the performance of an End-of-Aisle order picking system. In their study, they investigated on a system with high peaks in demand and they considered both uniform and exponential pick  time distributions. Accordingly, they evaluated the performance of End-of Aisle order-picking systems with multiple pick positions per aisle and multiple aisles per picker (Bozer and White, 1996). Meller and Mungwattana (2005) applied simulation to evaluate the benefits of different dwell point policies in a unit load automated storage and retrieval system. The results indicate that the position of dwell point has an negligible effect on system respond time when the AS/RS has high utilization.

Vanderberg et al. (2000) have developed a simulation study and examined various aspects of unit load automated storage and retrieval system control policies: storage location assignment policies, request selection rules, open location selection rules and urgency rules. Considering randomized storage and class-based storage they concluded that using a FCFS sequence for the retrievals by implementing urgency rules results in better performance. Using simulation,. For the simulation models, most of researchers only developed some of the physical design aspects and the combination of control policies is very limited. Moreover, only a limited number of configurations and types of AS/RSs have been studied in combination with fixed values for various input factors.

In this study, we focus on an End-of-Aisle automated storage and retrieval system with two pick positions. We use simulation to evaluate the performance and to find the most suitable combination of several control policies to be set in the system. One aspect in such a system is the determination of the storage location for incoming products. For this problem two storage policies, namely random-based storage and class-based storage, are considered. In particular, based on the shape and the size of each class, four different configurations for class-based storage are tested . A second aspect to be considered in End-of-Aisle systems is the configuration of the rack. To provide a better basis for analyzing the system, in this study, five rack configurations are assumed. A third aspect is the choice of sequencing rules for storage and retrievals requests. In this study, the End-of-Aisle system is analyzed for two strategies, i.e., first-come-first-served and nearest-neighbour. The goal of this research is to examine various combinations of the control policies mentioned, to find the best configuration for such a system by comparing the performances of the different scenarios. The measures of performance are defined as the total travel time of the crane, the total number of storages and retrievals performed by the crane and the average idle time of the crane.

## SIMULATION MODELING OF THE SYSTEM

This study is performed as part of a project in cooperation with a real distribution center. In the system analyzed, a crane serves a single aisle with storage racks placed on one side of the aisle. The aisle has a left and a right pick position at one end of the aisle. All storage locations are identical in size and each location can hold one unit-load. Each unit-load (e.g., pallet) contains a number of boxes of one item type. Although the pallet sizes are constant, the sizes of the boxes on the pallets differ for different item types. When the simulation starts, both pick positions are empty and the position of the crane is at one of the pick positions. On arrival of the first demand, the crane travels into the aisle and picks the requested pallet. Then, it returns to one of the pick positions and deposits the pallet. When the pallet is brought to the station, the picker consults a pick list and extracts the items from the unit-load. While the order picker is extracting the boxes from the pallet, the crane returns to the aisle to retrieve the requested load for the second pick position. Then, the crane waits at the pick position until the order picker finishes picking the pallet. Next, it returns the pallet to its storage location, and moves to the location of the next requested demand. In the model, the calculation for the crane’s pick-up and deposit time is according to the size and number of boxes on the pallet; for pallets with a higher number of boxes and larger boxes, the time for pick-up and deposit is higher. Moreover, the time for unloading boxes from pallets by the operator is calculated according to the boxes’ dimensions. The crane carries one pallet and it travels simultaneously in the horizontal and vertical direction. The actual time to travel between two locations in the rack is measured by the maximum of the isolated horizontal and vertical travel times (Chebyshev distance metric). Crane acceleration and deceleration are assumed instantaneous. There are two operation modes for a crane in a miniload End-of-Aisle AS/RS: single command (SC) and dual command (DC) which both are considered in this research.

### Storage Assignment Policies

A storage location assignment policy imposes constraints on the selection of open locations for incoming unit-loads. In this model, two storage policies are considered, i.e. random-based storage and class-based storage. In random-based storage, any cell within the rack is equally likely to be selected for storage. A class-based storage policy, however, classifies items into classes and assigns a specific area to each class. Pallets with higher demand frequencies are assigned to class I, while pallets with smaller demand frequencies are assigned to class II, and so on. The position of class I is the best location close to the pick positions. For class II, the position is the second best location near the pick position. According to the shape and the size of each class, class-based storage can have different configurations. In order to compare various configurations of class-based storage, this study evaluates four shapes(Figures 3-6). For each shape, two scenarios are developed. The first scenario is the one where the storage locations within each class are selected randomly. For the second scenario, the storage locations inside each class are selected by choosing the best available position first.

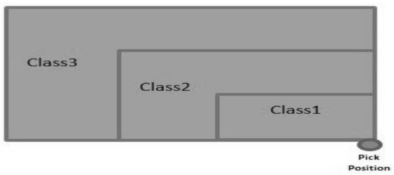

Figure 2: Class-based storage Type A

Figure 3: Class-based storage Type B

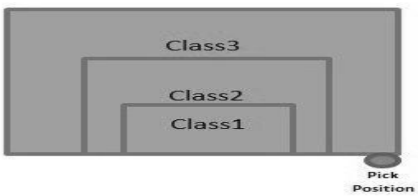

Figure 4: Class-based storage Type C

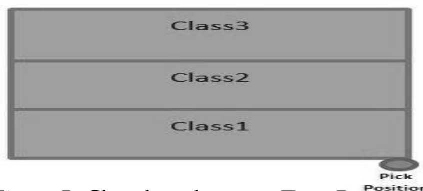

Figure 5: Class-based storage Type D

## Configurations of Rack

Since cranes can move vertically and horizontally simultaneously, an effective balance between rack's height and length can help to reduce travel times. In this study, five configurations are assumed. The first configuration consists of 10 bays and 10 levels, the others include 20 bays and 10 levels, 15 bays and 5 levels, 10 bays and 5 levels, and the last one has 5 bays and 15 levels.

## Sequencing of Storage and Retrieval Requests

The role of the sequencing rules typically is to create tours in order to minimize the total time to complete all requests. The effective use of sequencing rules can lead to improvements in the overall performance (Roodbergen et al., 2009). In this study, two sequencing policies are assumed, i.e. first-come-first-served and nearest-neighbour policy. The nearest-neighbour strategy pairs storages and retrievals that are in close proximity, to minimize the travel-between time required in the S/R machine's dual command cycle. This study compares the sequencing of storage and retrievals for both random-based storage and class-based storage policies including:

- The storage policy is random-based storage and retrievals are performed by first-come-first-served. (S1)
- The storage policy is random-based storage and retrievals are performed by nearest-neighbour. (S2)
- The storage policy is class-based with random locations within each class and retrievals are designed by first-come-first-served. (S3)
- The storage policy is class-based with random locations within each class and retrievals are designed by nearest-neighbour. (S4)
- The storage policy is class-based with a selection of best locations within each class and retrievals are designed by first-come-first-served. (S5)
- The storage policy is class-based with a selection of best locations within each class and retrievals are designed by nearest-neighbour. (S6)

## Simulation Results

The simulation results are given in the following tables. The simulation results are based on 100 replications for each scenario, and the average results are reported. In order to examine the performance of the model more closely, we ran the model twice. First with one operator that works on both pick positions, and a second time with two operators , i.e. one for each pick position.

Table 1: Total crane's travel time (TT), total number of storages and retrievals (S/R), and the average idle time of the crane (AVE) for random-based storage.

| Rack configuration | Sequencing Rule | Random-based storage | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1 Operator | | | 2 Operators | | |
| | | TT | S/R | AVE | TT | S/R | AVE |
| 5*15 | S1 | 1425 | 148 | 4.21 | 1510 | 156 | 4.26 |
| 5*15 | S2 | 1337 | 150 | 4.1 | 1413 | 157 | 4.11 |
| 10*10 | S1 | 2406 | 130 | 6.4 | 2605 | 148 | 6.21 |
| 10*10 | S2 | 2390 | 137 | 5.4 | 2492 | 142 | 5.82 |
| 10*20 | S1 | 2112 | 135 | 6.9 | 2337 | 144 | 6.9 |
| 10*20 | S2 | 2429 | 137 | 6.81 | 2664 | 149 | 6.84 |
| 15*5 | S1 | 2347 | 130 | 7.56 | 2445 | 136 | 7,5 |
| 15*5 | S2 | 3008 | 136 | 7.18 | 3112 | 139 | 7.15 |
| 20*10 | S1 | 4035 | 114 | 11.23 | 4262 | 121 | 11.1 |
| 20*10 | S2 | 3740 | 118 | 10.27 | 3933 | 123 | 10.29 |

Table 2: Total crane's travel time (TT), total number of storage and retrievals (S/R) and average idle time of the crane (AVE) for Class- based storage with 1 operator

| Rack configuration | Sequencing Rule | Types of Class-based storage | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Type A | | | Type B | | | Type C | | | Type D | | |
| | | TT | S/R | AVE | TT | S/R | AVE | TT | S/R | AVE | TT | S/R | AVE |
| 5*15 | S3 | 1467 | 139 | 4 | 1516 | 139 | 4.3 | 1487 | 140 | 4.1 | 1545 | 140 | 4 |
| 5*15 | S4 | 1395 | 141 | 4 | 1519 | 140 | 4.1 | 1401 | 141 | 3.76 | 1544 | 140 | 3.7 |
| 5*15 | S5 | 1218 | 148 | 3 | 1378 | 147 | 3.4 | 1278 | 153 | 3.3 | 1390 | 152 | 3.1 |
| 5*15 | S6 | 1165 | 156 | 3.4 | 1327 | 160 | 3.4 | 1240 | 153 | 3.2 | 1356 | 151 | 3 |
| 10*10 | S3 | 2379 | 134 | 5.5 | 2467 | 134 | 6.2 | 2428 | 134 | 6.1 | 2556 | 135 | 6.1 |
| 10*10 | S4 | 2248 | 137 | 5.1 | 2305 | 134 | 6.1 | 2300 | 136 | 5.6 | 2417 | 137 | 5.5 |
| 10*10 | S5 | 1417 | 144 | 3.5 | 1958 | 140 | 5 | 1690 | 141 | 3.68 | 1946 | 142 | 3.2 |
| 10*10 | S6 | 1214 | 149 | 3.1 | 1923 | 146 | 4 | 1625 | 148 | 3.5 | 1947 | 147 | 2.8 |
| 10*20 | S3 | 2355 | 132 | 6.9 | 2534 | 131 | 6.5 | 2445 | 131 | 7.3 | 2594 | 131 | 6.8 |
| 10*20 | S4 | 2129 | 138 | 6.7 | 2257 | 134 | 6.8 | 2178 | 136 | 7 | 2297 | 134 | 6.5 |
| 10*20 | S5 | 1395 | 146 | 4.8 | 1492 | 143 | 5.2 | 1448 | 143 | 3.53 | 1511 | 144 | 4.3 |
| 10*20 | S6 | 1191 | 148 | 4.6 | 1520 | 147 | 4.9 | 1409 | 148 | 3.36 | 1568 | 147 | 4.2 |
| 15*5 | S3 | 3208 | 128 | 7.7 | 3365 | 128 | 7.6 | 3324 | 128 | 8 | 3389 | 129 | 7.9 |
| 15*5 | S4 | 2964 | 129 | 6.7 | 3032 | 129 | 7.1 | 2970 | 129 | 7.10 | 3091 | 130 | 6.78 |
| 15*5 | S5 | 2184 | 134 | 4.6 | 2542 | 133 | 6.1 | 2456 | 133 | 5.51 | 2599 | 133 | 4.7 |
| 15*5 | S6 | 2086 | 138 | 4.3 | 2559 | 136 | 5.9 | 2166 | 138 | 4.9 | 2564 | 138 | 3.9 |
| 20*10 | S3 | 3548 | 119 | 10 | 3778 | 119 | 10 | 3700 | 118 | 11.2 | 3895 | 117 | 11 |
| 20*10 | S4 | 3433 | 120 | 9,8 | 3623 | 120 | 10 | 3567 | 121 | 10.1 | 3690 | 118 | 10 |
| 20*10 | S5 | 3137 | 120 | 3.8 | 3337 | 120 | 7.4 | 3216 | 120 | 4.81 | 3347 | 120 | 3.6 |
| 20*10 | S6 | 2906 | 125 | 4.3 | 3268 | 125 | 7.1 | 3201 | 125 | 4.98 | 3323 | 127 | 3.0 |

Table 3: Total crane's travel time (TT), total number of storage and retrievals (S/R) and average idle time of the crane (AVE) for Class- based storage with 2 operators

| Rack configuration | Sequencing Rule | Types of Class-based storage | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Type A | | | Type B | | | Type C | | | Type D | | |
| | | TT | S/R | AVE | TT | S/R | AVE | TT | S/R | AVE | TT | S/R | AVE |
| 5*15 | S3 | 1667 | 144 | 4.1 | 1746 | 144 | 4.3 | 1687 | 144 | 4.1 | 1777 | 144 | 4 |
| 5*15 | S4 | 1595 | 146 | 4 | 1695 | 146 | 4.1 | 1601 | 146 | 3.8 | 1756 | 146 | 3.7 |
| 5*15 | S5 | 1418 | 153 | 3.6 | 1542 | 152 | 3.4 | 1458 | 153 | 3.31 | 1599 | 152 | 3.2 |
| 5*15 | S6 | 1385 | 159 | 3.5 | 1527 | 159 | 3.4 | 1440 | 159 | 3.19 | 1556 | 159 | 3 |
| 10*10 | S3 | 2569 | 139 | 5.5 | 2663 | 138 | 6.2 | 2628 | 139 | 6.04 | 2756 | 139 | 6.1 |
| 10*10 | S4 | 2438 | 142 | 5.1 | 2516 | 140 | 6 | 2470 | 141 | 5.68 | 2617 | 140 | 5.7 |
| 10*10 | S5 | 1610 | 149 | 3.4 | 2026 | 147 | 5 | 1890 | 147 | 3.76 | 2146 | 147 | 3.3 |
| 10*10 | S6 | 1434 | 153 | 3 | 2003 | 150 | 4.9 | 1835 | 151 | 3.51 | 2097 | 151 | 2.8 |
| 10*20 | S3 | 2555 | 136 | 6.8 | 2734 | 135 | 6.9 | 2645 | 135 | 7.22 | 2794 | 135 | 6.8 |
| 10*20 | S4 | 2329 | 143 | 6.7 | 2457 | 140 | 6.7 | 2378 | 141 | 7.09 | 2597 | 142 | 6.5 |
| 10*20 | S5 | 1595 | 149 | 4.8 | 1702 | 147 | 5.1 | 1611 | 147 | 3.73 | 1741 | 147 | 4.4 |
| 10*20 | S6 | 1371 | 153 | 4.6 | 1740 | 151 | 5 | 1697 | 153 | 3.42 | 1808 | 152 | 4.2 |
| 15*5 | S3 | 3438 | 131 | 7.7 | 3585 | 130 | 7.6 | 3456 | 130 | 8.16 | 3639 | 131 | 8.1 |
| 15*5 | S4 | 3134 | 131 | 6.7 | 3252 | 129 | 7.1 | 3120 | 129 | 7.17 | 3291 | 131 | 6.9 |
| 15*5 | S5 | 2384 | 137 | 4.6 | 2712 | 136 | 5.9 | 2646 | 136 | 5.56 | 2799 | 136 | 4.7 |
| 15*5 | S6 | 2221 | 141 | 4.7 | 2769 | 139 | 5.9 | 2566 | 141 | 4.92 | 2814 | 140 | 3.9 |
| 20*10 | S3 | 3798 | 123 | 10,4 | 3908 | 121 | 10.8 | 3850 | 121 | 11.3 | 3995 | 121 | 11.6 |
| 20*10 | S4 | 3634 | 125 | 9.7 | 3843 | 122 | 10.5 | 3743 | 123 | 10.19 | 3900 | 124 | 10.7 |
| 20*10 | S5 | 3346 | 127 | 3.7 | 3545 | 123 | 7.2 | 3444 | 126 | 4.88 | 3547 | 124 | 3.6 |
| 20*10 | S6 | 3101 | 130 | 3.1 | 3345 | 128 | 7 | 3277 | 130 | 5.01 | 3403 | 128 | 3.1 |

## Conclusion

In this paper, a simulation study of an End-of-Aisle automated storage and retrieval system has been presented. The extensive simulation study shows the isolated effects of various policies, as well as compares several combinations of policies and rules. This comparison provides a base for selecting the most suitable policy in the evaluated system. We considered the following storage location assignment policies: randomized storage and class-based storage with four different layouts for the classes. The analysis demonstrates that the class-based storage type "A" outperformed the other policies. The results achieved by the simulation model, also reveal that the nearest-neighbour rule provides a superior results for selecting an open location within the storage area for randomized storage or within a class for class-based storage. The obtained results for different rack configurations indicate that with increasing the number of bays, the total travel time increases and the total number of storages and retrievals decreases. In conclusion, the combination of class-based storage type "A" with a selection of the locations nearest to the pick positions within each class, and nearest-neighbour policy for picking from storage locations when the system operates by two operators, one for each pick position, provides a superior performance.

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