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OPTIMIZING SHELF MOVEMENT IN HIGH-DENSITY WAREHOUSE THROUGH SIMULATION

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ABSTRACT

This study examines the effectiveness of adjacently grouping multiple shelves before retrieving them in high-density warehouses, where shelves are positioned next to each other without any aisles in between. Our method models shelf retrieval as a game, aiming to retrieve targeted cells from a grid of empty and filled cells with minimal effort. Through simulations, we find that adjacently grouping shelves and moving them together is more efficient when two shelves are close to each other perpendicular to their goal direction and far from the goal, while the distance between shelves parallel to the goal direction is less significant.

1 INTRODUCTION

The rapid growth of sustainable logistics and e-commerce has made warehouse automation and scaling essential for maintaining efficiency and productivity. Consequently, automated guided vehicles (AGVs) are increasingly being used for goods-to-person (GTP) picking, especially in high-density warehouses where there are storage zones filled with many shelves such as the one shown in Figure 1 (a). It is particularly important to efficiently retrieve the shelves targeted to ship out of the storage zones. In this study, the retrieval process of targeted shelves is simplified by modeling it as a game where empty and targeted cells are moved on a game grid. This simulation enables the optimization of shelf-moving strategies for faster access.

2 PROBLEM DEFINITION

On a game grid, as shown in Figure 1 (b), targeted shelves are represented as orange cells, other shelves as grey cells, and blank spaces as white cells. This study focuses on the movement of empty cells and target cells, as empty cells must be relocated to create space for target cells to move by swapping positions with adjacent empty cells. A step is defined as each empty cell on the grid making a move decision – either moving up, down, left, right, swapping with a neighboring non-empty cell, or remaining stationary. A target cell is considered "finished" when it reaches its goal or is adjacent to a finished target cell. This study addresses the problem of finding the routes to finish all target cells with the minimal number of total steps.

3 STRATEGY

When a cell is adjacent to an empty cell, it takes five steps to move the cell by one cell (Gue et al. 2007). However, moving two adjacently grouped cells together with two empty cells takes only four steps per cell, offering an advantage. Therefore, as illustrated in Figure 1 (b), grouping multiple target cells at a convergence point before moving them towards the goal is an effective strategy. Nevertheless, grouping involves additional horizontal or diagonal movements, which can be slower than direct movement towards the goal. This study investigates the relative positions of the target cells to determine whether grouping or non-grouping results in fewer steps, thereby identifying the conditions under which grouping is more effective.

4 EXPERIMENTAL RESULTS

We conducted experiments to determine whether adjacently grouping or non-grouping target cells results in fewer steps to reach the goal, based on the relative positions (dx, dy), the distance (h) to the goal of two target cells and two empty cells on a grid, as shown in Figure 2 (a). Initially, cell A is positioned lower than cell B, with one empty cell placed above each target cell. The experiment covered $h = [1,20), dx = [0,20), dy = [0,20)$, excluding cases where both *dx* and *dy* are 0. For the case of grouping target cells, all grouping points in the grouping point candidate area in Figure 2 (a) were tested.

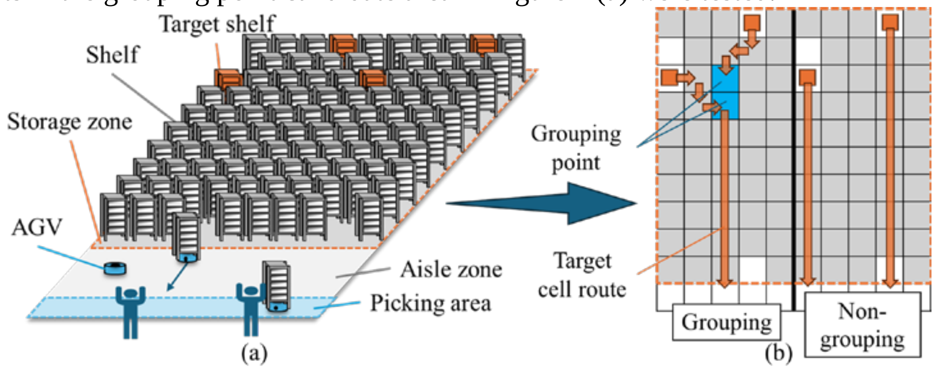

Figure 1: Components of a high-density warehouse (a) and planning the movement of target cells (b).

The results are as follows. Figure 2 shows the outcomes for $h = [1,20), dx = [0,20), dy = 2$ (b) and $h = 6, dx = [0,20), dy = [0,20)$ (c). Yellow points indicate cases that grouping is faster, purple points indicate non-grouping is faster, and orange points indicate no difference.

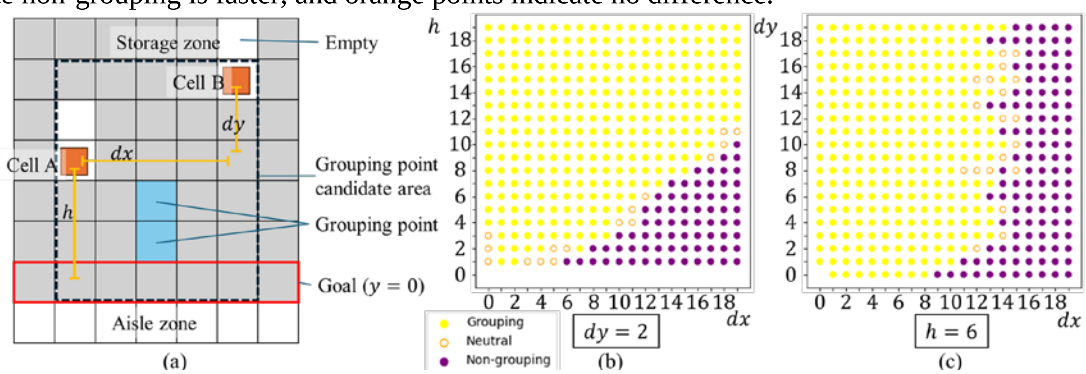

Figure 2: Game grid and variables in experiment (a) and results of the grouping decision (b), (c).

As shown in Figure 2 (b), a larger dx favors non-grouping, whereas a larger h favors grouping. In Figure 2 (c), the boundary between yellow and purple points remains relatively unchanged for $dy \geq 2$. This indicates that *dx* and *h* are crucial factors in determining whether to group or not, regardless of the value of *dy*. This result is noteworthy, as one would typically assume that *dx*, *dy*, and *h* are equally important in making this decision.

5 CONCLUSION

This paper proposed a simplified game to study the basic planning of shelf movement in high-density warehouses and also discussed effective strategies and simulation results within the game. Future work will consider optimal strategies involving AGVs.

REFERENCES

Gue, K. R. and Kim, B. S. 2007. "Puzzle-Based Storage System". *Naval Research Logistics* 54(5):556-567.