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Research Article

Optimal dynamic routing for 2 forklifts in narrow-aisle racking warehouse

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ABSTRACT

Determining storage location and planning path are the two most important components in warehouse management. Simultaneous resolution of these problems not only reduces the storage and retrieval time but also avoid the loss of goods. The article offers a scenario of a practical cold warehouse system with narrow aisle racking, where space optimization and time scheduling are always top priority. There are 2 forklift were considered to work parallel in system so aisle dispute is considered to minimize safety risks in warehouse. Two algorithms used to optimize the path were introduced in the paper, which is the closest open location – COL and A star algorithm. The COL helps to determine the most appropriate storage location according to the user's requirements, including type of goods to be exported or imported, finding storage location of the nearest empty cell by refer the weight of the road and obstacle were might happen by two forklift truck in the system. The result of this algorithm are determined Input and Output point of each forklift path. The coordinate index of these two points are returned as input to the A star algorithm to determine the shortest path for the forklift. With the A star algorithm, a clear path will be sought, including the comparison of clashes between vehicles in the system, preferring the shortest path for moving between two points. The travel route results are exported for goods execution devices. The system is simulated by MATLAB combined with V-Rep software for an intuitive interface and fully illustrates each task of each vehicle from time to time. Some traditional or single algorithms with the same assumptions about the system were also simulated and compared to see the effectiveness of the combination of two COL and A star algorithms in a narrow aisle racking system.

Key words: storage process, storage location, route planning, optimal route, closest open location

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INTRODUCTION

Determining storage location - localization is understood as the process of selecting the optimal storage location among different position, so that the travel time is minimization, thus saving the total operating costs of the warehouse. In addition, each storage location should be closely managed based on information such as type of goods, stored time, coordinates. Planning path is defined as a process for selecting the most optimal path from all the solutions. The optimal path is determined based on two factors: the distance from I/O point to selected storage location is the shortest and there is no deadlock or traffic jams while vehicles move in the system. Strategy of route planning could be classified into two categories: Static and dynamic routing [1–3]. For the static routing, there is only 1 storage location and 1 fixed path is choose in advance for each task of the forklift, the selection will not change during the task execution.

This paper contribute by constructing an algorithm base on dynamic routing strategy to solve the problem. Storage location is determine by the Closest Open Location algorithm - COL and collision is solved through the time windows concept [4,5]

METHOD

Assumption made Layout design

The system is built based on some special characteristics of cold store for preservation of aquatic products but we can adjust it to suit different types of storage.

- The capacity of system are 480 storage locations; each location contains 1 SKU (stock keeping unit – an inventoried item). System containing 6 types of frozen shrimp which are named A1, A2, A3, A4, A5 and A6.
- Goods are organized into the pallet. Each pallet is a SKU. This is the smallest item in system. Pallet is placed on single pallet racking and other picker can reach all items in the rack regardless of rack's height.
- Pick out time is undefined for all SKUs in system.

For frozen shrimp products, the requirement in storage process is if goods were come first, it will be sorted in pallet racking first (First Come First Served - FCFS) and travel distance for each moving cycle is the shortest to prevent damage under wrong temperature. In

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retrieval process, pallet is removed base on import day, the oldest good in system is the earliest move out. This requirement is necessary to ensure the goods are not in warehouse too long.

Layout design

Caron, Marchet, and Perego (2000) found that the layout design greatly affected to order picking distance. According to their study, layouts affect over 60% of the total distance traveled in storage [Dr. Peter]. Therefore, designing layout is an important foundation task before building the management algorithm [6].

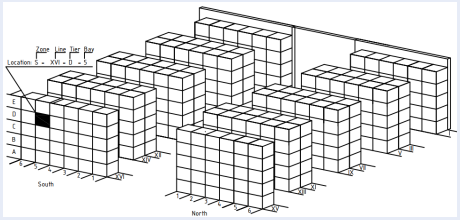

Figure 1: **Warehouses tructure.**

From assumptions were presented in section Assumption made Layout design, warehouse system with 1 single pick aisle and 2 storage aisles is recommended (see **Figure** 1). Warehouse space is divided into 16 pallet racking (16 lines). The line consider in this paper include 5 tiers (A, B, C, D and E) and 6 bays (are distinguished by the digits from 1 to 8), totally 40 storage locations is located at each line. These lines are named Roman numerals I to XVI. The design help to be easily reach all items in the pallet racking and access to depot by using 2 separate Input and Output points.

Auto – Localization [7–9]

For frozen shrimp products, the shorter duration of sorting, the less risk of failure of goods, so pallet should be entered into inventory under FIFO and COL strategy. For FIFO policy, if goods are shipped to warehouses before, it will be sort in pallet racking before. With COL strategy, each pallet was added into appropriate storage location whose time to I/O point is the shortest. To apply FIFO and COL strategy, A* algorithm was propose to find the optimal storage location.

First published in 1968 by Peter Hart, Nils Nilsson and Bertram Raphael, A* is an informed search algorithm, meaning that it solves problems by searching among all possible paths to the solution (goal) [7,8].

Evaluation function:

$$f(n) = g(n) + h(n) \quad (1)$$

• Operating cost function, g(n) – Actual operating cost having been already traversed.

• Heuristic function, h(n) – Information used to find the promising node to traverse, the heuristic function must be admissible.

Each storage location in warehouse is represented by a node, it will be used as an object of the algorithm in this section. Some notations is given below:

• Open list (O) stores nodes for expansions

• Closed list (C) stores nodes which we have explored

• Selected list (S) stores nodes which is in the shortest path was defined

Figure 2 demonstrates how to determine an optimal storage location using the star algorithm: n

The $g(n_{best})$ in this flow chart represents the exact travel distance of the path from the starting point to any vertex n_{best} – which is defined as a shortest node in each step of the loop and $h(n_{best})$ represents the heuristic estimated distance from vertex n_{best} to the selected storage location x. h(n) value is calculated using the Euclidean distance formula. Each time through the main loop, it examines the vertex n that has the lowest (1) with each:

$$g(n) + h(n_{best}, x) < g(x) \quad (2)$$

One more node in the shortest path is found. The main loop repeat until latest node is determined – which represent selected storage location.

The auto-localization algorithm base on A-star approach is clear. It is easy to implement and allows very fast route computations since this method only cares about the start and end of each row and ignore the time dependent between forklifts. How-ever, when system was performed by 2 forklifts, various drawbacks are caused by deadlock and traffic jam have a deteriorating effect on the system performance (see **Figure** 3).

To deal with the problems of the model given in previous Section, a different approach that computes shortest (traveling time) and conflict-free routes simultaneously is propose which time-dependent between vehicles is considered [5,7,10].

After the storage location is defined base on continuous cluster method, Time windows help to finding the shortest distance path and conflict free between an origin node and a destination node in a system, based on scheduling restrictions (time windows) for each one of the path nodes. The main purpose is optimization of the total travel distance of the transportation task so the operation cost is minimization. With

the scenario that there are 2 tasks were assigned to Forklift 1 and 2, one to store pallet from I/O point to storage location and the other one to retrieval pallet from selected location. After The A* algorithm shows the shortest static path for the two tasks of FL1 and FL2, path of those forklift is created.

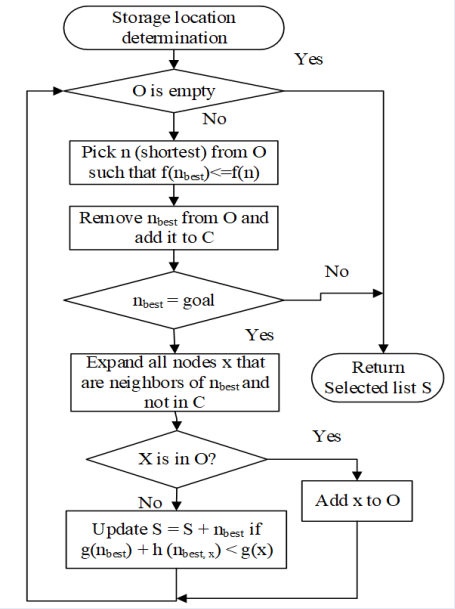

Figure 2: **Determine Storage location by A* algorithm.**

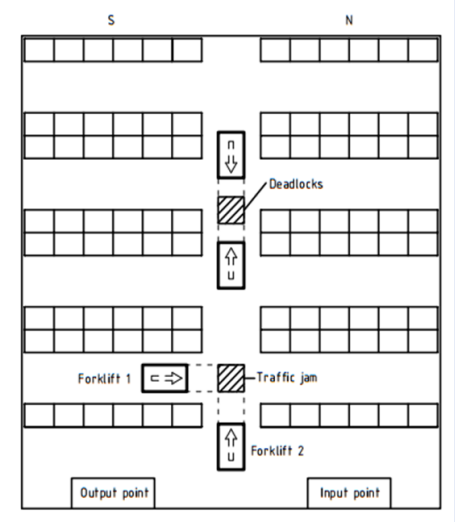

Figure 3: **Deadlock and Traffic Jams.**

The idea of the algorithm is that find a conflict-free shortest-time route in the case there is collision potential in the aisle (see **Figure 4**). According to the approach, after the shortest path to the storage location is found by the A* algorithm, a time-dependent histogram is established. Based on distance and velocity data, the position of each vehicle at each time on the map is determined and then a free-conflict path is formed by using the waiting time for the vehicle (see **Figure 5**).

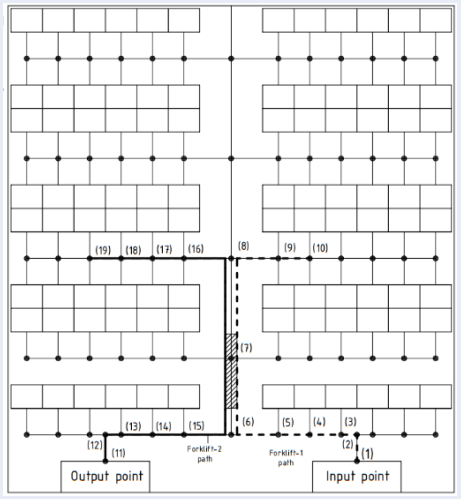

Figure 4: **Path of 2 forklift with deadlock.**

SIMULATION RESULT AND DISCUSSION

Goods management is done through a UI interface on MATLAB as shown in **Figure 6**, the warehouse space is simulated on V-REP (see **Figure 7**). The constructed algorithms will be tested by two comparisons: the time efficiency between the COL strategy and random algorithms; dynamic routing by time window with conflict-free routing by using double pick aisle.

Comparison of Closest open location COL and random algorithms

Under the Random algorithm, each pallet is randomly stored, approximately 80% of the warehouse capacity is used, sorted sequence and time consumption is shown in **Figure 8**

The result shown that under built algorithm (optimal dynamic routing base on A* algorithm), the travel time less than about 21.75% compare with Random strategy.

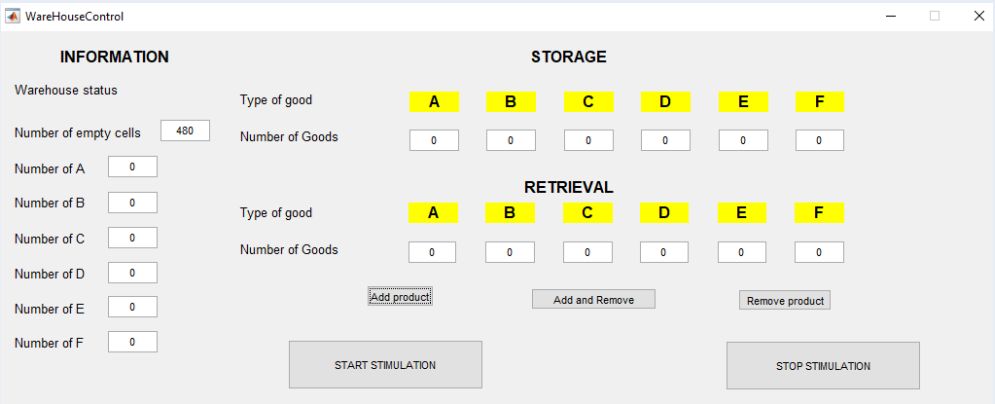

Figure 6: **Software interface.**

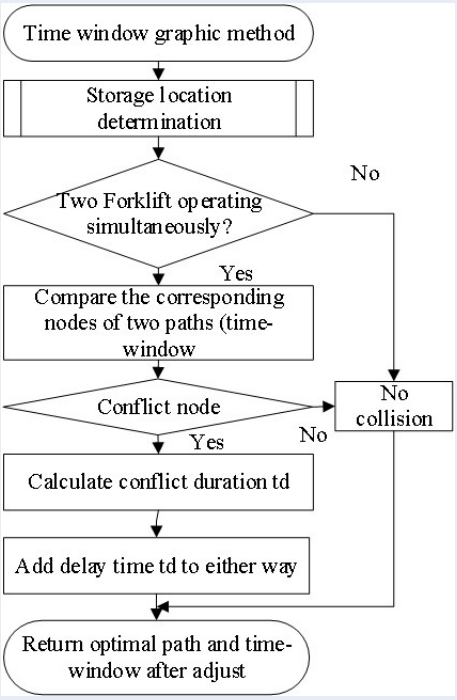

Figure 5: **Time window for dynamic routing.**

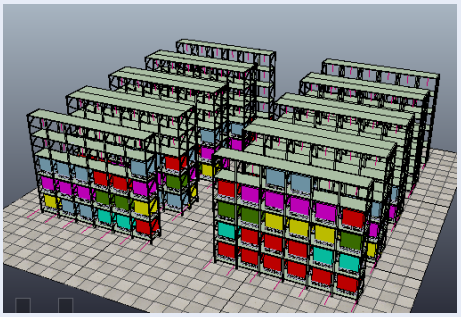

Figure 7: **Warehouse layout simulation.**

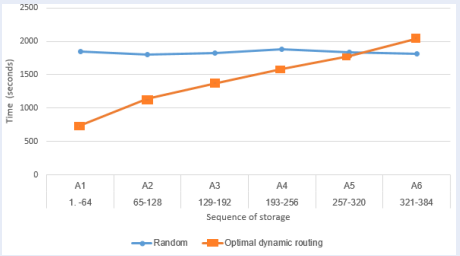

Figure 8: **Time consumption under random and COL policy.**

Comparison of dynamic routing (single aisle) and double pick aisle

In fact, in order to solve the collision problem, a parallel aisle system is formed, vehicle will avoid each other by going on different paths, which is to change the ware-house layout instead of using complex algorithms to find an optimal path for single pick aisle as the article (see **Figure 9**). For this method, the algorithm to localization is same with dynamic routing approach.

The comparison result shown that travel time of optimal dynamic routing is approximately 7.33% less than double aisle approach (shown in **Figure 10**)

CONCLUSION

The article presents a new approach to the planning route for narrow aisle warehouse by dynamic routing for simultaneous 2 forklifts, combining the first in first out and the closest open location strategy to help re-

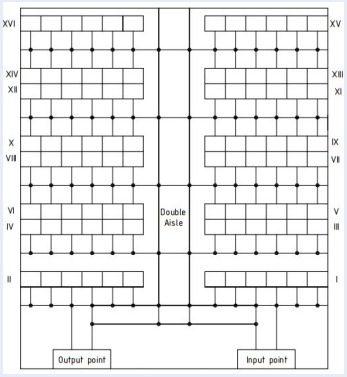

Figure 9: **Layout with double aisle.**

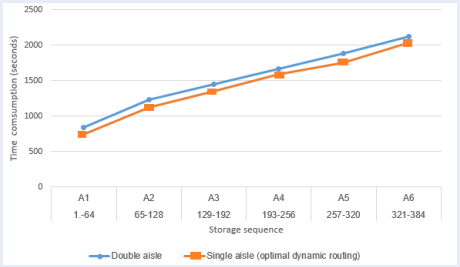

Figure 10: **Time consumption for 2 route approach.**

duce the cost cause by time consumption. This is also a positive aspect in the reduction of warehouse operating costs - a top priority in cold storage management. The 2 comparisons point out the approach help reduced about 21.75% and 7.33% travel time compare with random and double aisle approach respectively. Future work will include more complex comparisons such as the quantity of goods are delivered must be greater like the real environment. The frequency of storage and retrieval tasks need to higher than so that could validate the stable of the designed system. Moreover, mechanical system design to connect with software need to be implement, this is next step to completely build an automated storage and retrieval system in warehouse.

ABBREVIATIONS

MATLAB: MAtrix LABoratory
COL: Cloest Open Location
SKU: Stock Keeping Unit
FCFS: First Come First Serve
FIFO: First In First Out
I/O: Input/ Output
UI: User interface
V-REP: Virtual Experimentation Platform

CONFLICT OF INTEREST

The authors wish to confirm that there are no know conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

AUTHOR CONTRIBUTION

All authors conceived of the study and participated in its research and coordination and helped to draft the manuscript. The authors read and approved the final manuscript.

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Bài Nghiên cứu

Tối Ưu Hóa Giải Thuật Hoạch Định Đường Đi Cho 2 Xe Nâng Trong Nhà Kho Có Lối Đi Hẹp

Trương Ngọc Cường[1], Đặng Trường Giang[2], Nguyễn Duy Anh[1,*]

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TÓM TẮT

Xác định vị trí lưu trữ và hoạch định đường đi cho mỗi đơn vị hàng hóa trong kho là hai yếu tố quan trọng nhất trong việc quản lý kho lạnh. Giải quyết đồng thời cả hai bài toán trên không chỉ giúp giảm thời gian lưu trữ và truy hồi mà còn tránh việc mất mát hàng hóa. Bài báo này chỉ ra một giả thiết về kho lạnh thực tế với kệ chứa có lối đi hẹp, nơi mà tối ưu hóa về không gian và thời gian luôn là yếu tố được ưu tiên. Có hai xe nâng được đề xuất hoạt động độc lập trong kho, do đó các vấn đề về tranh chấp lối đi cũng được giải quyết để tránh các rủi ro về mặt an toàn. Hai giải thuật để tối ưu hóa lối đi được giới thiệu trong bài báo, bao gồm giải thuật tìm kiếm vị trí lưu trữ gần nhất COL và A star. Giải thuật COL giúp xác định vị trí lưu trữ thích hợp nhất dựa trên các yêu cầu của người dùng, bao gồm xác định loại hàng sẽ nhập hoặc xuất, tìm kiếm vị trí lưu trữ trống gần nhất theo trọng số đường đi và việc xem xét các khả năng xảy ra va chạm giữa các xe nâng. Kết quả của giải thuật là hai điểm đầu và cuối của quãng đường di chuyển hàng. Tọa độ của hai điểm này được trả về và làm giá trị đầu vào cho giải thuật A star trong bài toán xác định quãng đường di chuyển tối ưu nhất. Với thuật toán này, các lối đi thông thoáng sẽ được đề xuất, dựa trên việc loại bỏ các đụng độ trên đường đi của các xe và quãng đường ngắn nhất nối các điểm đầu và cuối ở trên. Đường đi tối ưu sẽ được xuất ra cho các thiết bị chấp hành thực hiện. Hệ thống được mô phỏng bởi phần mềm MATLAB kết hợp với V-Rep với giao diện trực quan, thể hiện đầy đủ sự vận hành hệ thống theo thời gian thực. Một số giải thuật truyền thống và đơn lẻ được mô phỏng và so sánh trong cùng các điều kiện về kho lạnh để thấy được tính hiệu quả của việc kết hợp đồng thời hai giải thuật COL và A star.

Từ khoá: Quy trình lưu trữ, vị trí lưu trữ, hoạch định đường đi, tối ưu hóa đường đi, vị trí ngắn nhất

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