Route Optimization of AGVs with an Improved Fishbone Warehouse Layout

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Abstract: AGV (Automated Guided Vehicles) as one of the most intelligent technologies is widely applied in the warehousing operations with a high speed development in the intelligent logistic fields. Automated material warehousing systems have proved that they would improve the effectiveness of material loading, unloading and handling company as well as reducing the labor cost and strengthening the working safety. AGV, as one part of the automated material warehousing systems, preforms powerful actions in the full chain of cargo handling in warehouse. Effective planning of AGV running route is the key for improving the efficiency of material loading and unloading. Based on this, this article aims to improve warehouse operation efficiency and control capabilities with an innovated fishbone layout warehouse design. Firstly, the improved fishbone warehouse layout is designed by an embedded central corridor compared to classical layout. Then, AGV route optimization model is proposed, which is transformed into secondary allocation model for getting a better and more optimal solution. Finally, the genetic algorithm is used to verify the feasibility of the proposed model. The results show that the proposed route optimization method for AGV can effectively reduce the distance among materials shelf and loading point according to the improved fishbone layout warehouse. Under the same circumstances, the reduction of total distance of AGV can reach to 12.8% compared to the benchmark example.

1. Introduction

With the increasing automation of warehousing logistics, automated Guided Vehicles (AGVs) are increasingly used in modern warehousing logistics. Compared with traditional forklifts, AGV has the advantages of driving route dynamics and flexibility, and can adapt to a variety of operating environments, thus ensuring operational efficiency and saving a lot of labor costs. However, under the traditional dual-channel material warehouse structure, there is no shuttle between channels, and the handling and handling efficiency of materials is difficult to improve effectively.

At present, the route planning research of AGV trolleys in warehouse focuses on the storage material planning and the construction of the shortest route. For example, scholars such as Hsieh (2006)¹ considered the influence of various factors of the warehouse system on the selection and transportation of materials, and took the minimized operation route as the best performance index, and carried out integrated planning and design of warehouse material resources; The shortest route problem is mostly proposed in the form of classic combinatorial optimization problems. Like Nazemi et al. (2013)² once proposed a neural network model to solve the shortest route problem. The main
idea is to use linear programming to replace the shortest route problem. Cheng et al. (2015)\cite{3} put forward the shortest route solution idea at the most likely rate; In addition, scholars such as HWANG et al. (2016)\cite{4} and Wang (2016)\cite{5} have studied the shortest route problem under random conditions and the shortest constraint route problem in the transportation network.

In general, most warehouses use traditional parallel warehouses and traditional vertical warehouses, and some warehouses use fish bone warehouses. N.Vimal Kumara, C.Selva Kumar\cite{6} by generating AGV feasible routes for parallel, traditional vertical, traditional horizontal, fishbone warehouse layout, the results show that the traditional mode makes the AGV travel route relatively short; Pohl et al. (2009)\cite{7} compared with the traditional layout, the fishbone layout reduces the expected driving distance by 10-15%; Luis F. Cardona (2015)\cite{8} under all unit load operating conditions, the herringbone layout is more effective than the traditional layout. When comparing a herringbone layout with a parallel channel design, it is necessary to weigh the area cost and the material handling cost. Comparative experiments show that the fishbone design only increases the total cost of small projects by 2.06%, and the total cost of large warehouses only increases by 1.8%. However, the traditional horizontal and vertical routes reduce the route time of the AGV, and the fishbone mode can improve the efficiency. Therefore, this paper proposes to improve the fishbone warehouse model based on the fishbone model, and add a main channel for AGV to pass through under the premise of the fishbone mode.

Based on the actual access requirements of automated warehouse materials, this paper analyzes the AGV access operation process, puts forward the operation model based on improving the AGV in and out of the warehouse under the fish bone warehouse, and uses genetic algorithm to verify the proposed model. The conclusion can effectively solve the problem of AGV route planning under multi-channel allocation, which is of great practical application to automated warehouse planning and design and AGV route planning.

2. Warehouse layout

![Figure 1 Improved fishbone warehouse diagram](image)

It can be seen from Figure 1 that the improved fish-bone warehouse is based on the layout of the fish-bone warehouse, a part of the goods storage points in the middle are discarded. By opening the original middle storage points and changing them into aisles, the upper parts of the warehouses on both sides can be connected. Half of the area, there is no need to detour through the V-shaped route of the channel. Reduced the AGV driving pressure in the upper half of the warehouse. In addition, although the improved fishbone warehouse reduces the average storage space of the warehouse, as a multi-channel storage space, it is conducive to the coordinated use of equipment when certain materials are in and out of the warehouse, and improves the operating efficiency of the AGV trolley. In the following, based on the above-mentioned improved fishbone warehouse material transportation scenario, AGV trolley is used as the basic transportation tool to establish the matching of outbound and inbound nodes, so as to determine the optimal route of AGV trolley operation under multi-channel distribution.

3. Model description

3.1 Analysis on the Entry and Exit Routes of AGV Trolleys Based on the Improved Fishbone Warehouse

Taking into account the actual loading and unloading needs of trucks in front of the automated warehouse, the automation is based on the improved material storage area in front of the fishbone
warehouse as $C_1$ and $C_2$. Among them $C_1$ is inbound and $C_2$ is outbound, as shown in Figure 2. Suppose $C_1$ has $m$ inbound points, denoted as $p_1, p_2, ..., p_m$; $C_2$ also has $m$ outbound points, denoted as $q_1, q_2, ..., q_m$, and denoted as $M = \{1, 2, ..., m\}$. Assume that the AGV first starts from $C_1$, sends the material of $C_1$ to the given $p_j (j \in M)$ via the route $c_1p_j$, and then goes to the given $q_j (j \in M)$ via the route $pq_j$. Take the material transported to $C_2$, and then transport the material to $C_2$ via the route $q/c_2$, and finally return to $C_1$ via the route $c2c1$. Therefore, the distance between any two points and is $L(A, B)$, and the route diagram is shown in Figure 1. In order to reduce the pick-up time and fully coordinate the outbound and inbound operations, the shortest model of the AGV trolley running route $L$ is established under the assumption that the AGV trolley speed is given and is not affected by external factors, as follows:

$$\min L = \sum_{i=1}^{m} L(C_1, p_i) + \sum_{i=1}^{m} x_{ij}L(p_i, q_j) + \sum_{j=1}^{m} L(q_j, C_2).$$

(1)

$$s.t. \sum_{j=1}^{m} x_{ij} = 1, \sum_{j=1}^{m} x_{ji} = 1, x_{ij} \in \{0, 1\}, i, j \in M.$$

In order to facilitate the use of genetic algorithm [9-12] to solve the above model, in the process of entering and leaving the warehouse, let this closed-loop route be $s_{piqj}$, and its distance is $L(s_{piqj})$, we can see:

$$L(s_{piqj}) = L(C_1, p_i) + L(p_i, q_j) + L(q_j, C_2) + L(C_2, C_1)$$

(2)

When there is no previous route planning, the total random distance brought by the in and out activities of materials $C_1$ and $C_2$ for the AGV trolley is $L(s_{piqj}) + L(s_{pqj}) + ... + L(s_{pqj})$, where there are $p_i \neq p_i$ and $q_j \neq q_j$, constraints for any $n \in M$ and $t \in M$, $n' \in M$ and $t' \in M$, that is, the AGV does not repeat $p$ and $q$. Therefore, formula (1) can be expressed as the shortest route problem of formula (3).

$$\min L = L(s_{piqj}) + L(s_{pqj}) + ... + L(s_{pqj}),$$

(3)

$$s.t. \ L(p_i, p_{i'}) \neq 0, L(q_j, q_{j'}) \neq 0, n - n' \neq 0,$$

$$t - t' \neq 0, n \in M, n' \in M, t \in M, t' \in M.$$

All feasible routes of the AGV trolley are shown in Figure 3 below:
Figure 3  Schematic diagram of all routes based on the improved fishbone warehouse AGV trolley entry and exit operations

3.2 Modeling and Solving the Optimization of Simultaneous Entry and Exit Routes of Dual AGV Trolleys Based on Improved Fishbone Warehouse

Due to limited capabilities, in order to reduce the complexity of the algorithm, the optimization of the operation route of the AGV trolley proposed in this paper based on the improved fishbone warehouse requires the following assumptions: only the matching between the inbound node and the outbound node is established; regardless of AGV loading capacity, fuel consumption, etc..

In order to reduce the insufficiency of the above hypothesis on the actual scene description, the route length of any point pair composed of the inbound point and the outbound point is made obvious, to reduce the interference of the AGV trolleys during the inbound and outbound operations, thereby increasing the AGV trolleys The flexibility of operation improves the efficiency of operation. And select $L(p_i, q_j), L(p_i, q_j)$ from the final set of inbound and outbound points, Let the correlation between $L(p_i, q_j)$ and $L(p_i, q_j)$ be:

$$r^* = \min \sum_{i \in M} \sum_{j \in M} \left(r^*\left(p_i, q_j\right), \left(p_i, q_j\right)\right).$$

$$L\left(p_i, q_j\right) = \frac{\max_{i \in M, j \in M} L\left(p_i, q_j\right) - \min_{i \in M, j \in M} L\left(p_i, q_j\right)}{\min_{i \in M, j \in M} L\left(p_i, q_j\right) - \min_{i \in M, j \in M} L\left(p_i, q_j\right)}.$$

In order to meet the dual-objective requirements of the minimum related metric $\gamma$ and the closed-loop route distance $L$, the following formula (6) optimization model is constructed. And from equation (6), it can be seen that the AGV trolley running route optimization model based on the improved fishbone warehouse condition is transformed into a secondary distribution model.

$$\min \gamma = \sum_{i \in M} \sum_{j \in M} \sum_{k \in M} x_{i,j} r^*\left(p_i, q_j\left(p_i, q_j\right)\right) + \sum_{i \in M} \sum_{j \in M} x_{i,j} L\left(p_i, q_j\right).$$

$$s.t. \sum_{k \in M} x_{i,j} = 1, \sum_{k \in M} x_{i,j} = 1, x_{i,j} \in \{0,1\}, i, j, k \in M.$$
4. Instance analysis

This article refers to a certain logistics warehouse as the basis for warehouse layout analysis, in which the width of the passage for AGV trolleys is 4.0m, and the specific structure is shown in Figure 4 above. Part of the blank rectangular area in the article can be used as a temporary material transfer area, which is only used temporarily when \( p_i (i \in M) \) or \( q_j (j \in M) \) is crowded. The AGV can temporarily store materials in the blank rectangular area, and the materials will be transported from the temporary transfer area to \( p_i (i \in M) \) or \( q_j (j \in M) \) after the storage area is cleared.

The optimization model is constructed as shown in the following formulas (7)-(8), and the value of the matrix \( D \) of the distance point matrix is calculated.

\[
\min \gamma = \sum_{i=1}^{10} \sum_{j=1}^{10} \sum_{k=1}^{10} \left( 1 - \frac{\text{abs}(d_{ijk} - d_{ijk})}{\max\{d_{ijk}, d_{ijk}\}} \right) x_{ijk}^* = \sum_{i=1}^{10} \sum_{j=1}^{10} (d'_{ijk} x_{ijk})
\]

\[
\text{s.t.} \quad \sum_{i=1}^{10} x_{ijl} \leq 1, \sum_{i=1}^{10} x_{ijl} \in \{0, 1\}, x_{ijk} \in \{0, 1\}, i, j, k, l \in \{1, 2, \ldots, 10\}.
\]

\[
d'_{ijk} = \frac{d_{ijk} - \min_{l \neq k} d_{il}}{\max_{l \neq k} d_{il}}
\]

\[
r' = \frac{d_{i1k} - d_{i1k}}{\max\{d_{i1k}, d_{i1k}\}}
\]

After calculation, the total length of the eight optimal routes is 241.60m.

Using genetic algorithm to traverse the optimal solution of the above model, it can be seen that there are \( 10! \) feasible running routes based on the improved fishbone warehouse. By traversing the distance matrix (9), 8 optimal routes are screened out by the size of the fitness and the total length of the distance, and the number of iterations is set to 500. Specifically:

\[
\zeta = \{ p_1, p_2, p_3, p_4, p_5, p_6, p_7, p_8, p_9, p_{10} \}, \quad \zeta' = \{ q_1, q_2, q_3, q_4, q_5, q_6, q_7, q_8, q_9, q_{10} \}
\]

\[
\zeta = \{ p_1, p_2, p_3, p_4, p_5, p_6, p_7, p_8, p_9, p_{10} \}, \quad \zeta' = \{ q_1, q_2, q_3, q_4, q_5, q_6, q_7, q_8, q_9, q_{10} \}
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\zeta = \{ p_1, p_2, p_3, p_4, p_5, p_6, p_7, p_8, p_9, p_{10} \}, \quad \zeta' = \{ q_1, q_2, q_3, q_4, q_5, q_6, q_7, q_8, q_9, q_{10} \}
\]

\[
\zeta = \{ p_1, p_2, p_3, p_4, p_5, p_6, p_7, p_8, p_9, p_{10} \}, \quad \zeta' = \{ q_1, q_2, q_3, q_4, q_5, q_6, q_7, q_8, q_9, q_{10} \}
\]

After calculation, the total length of the eight optional optimal routes is 241.60m.

The fishbone warehouse layout under the same conditions is shown in Figure 5.
Figure 5  Geometry structure diagram of fishbone warehouse

Find the distance matrix of fishbone warehouse (10)

\[
D_{10} = \begin{pmatrix}
17.45 & 28.45 & 39.9 & 35.45 & 33 & 51.9 & 58.45 & 62.23 & 51.45 & 48 \\
20.9 & 32.9 & 34.9 & 30.45 & 26 & 54.9 & 61.45 & 65.23 & 57.45 & 54 \\
26.35 & 37.35 & 40.9 & 36.45 & 32 & 53.9 & 60.45 & 64.23 & 53.45 & 50 \\
20.35 & 31.35 & 37.35 & 32.9 & 28.45 & 45.9 & 52.45 & 56.23 & 45.45 & 42 \\
25.9 & 21.35 & 29.35 & 24.9 & 20.45 & 37.9 & 44.45 & 48.23 & 37.45 & 34 \\
62.23 & 58.45 & 51.9 & 51.45 & 48 & 39.9 & 28.45 & 17.45 & 35.45 & 33 \\
65.23 & 61.45 & 54.9 & 57.45 & 54 & 34.9 & 32.9 & 20.9 & 30.45 & 26 \\
64.23 & 60.45 & 53.9 & 53.45 & 50 & 40.9 & 37.35 & 26.35 & 36.45 & 32 \\
56.23 & 52.45 & 45.9 & 45.45 & 42 & 37.35 & 31.35 & 20.35 & 32.9 & 26.45 \\
48.23 & 44.45 & 37.9 & 37.45 & 34 & 29.35 & 21.35 & 25.9 & 24.9 & 20.45
\end{pmatrix}
\]

Through the same genetic algorithm to traverse the optimal solution of the model

Through the same genetic algorithm to traverse the optimal solution of the model

\[
\zeta^* = \begin{pmatrix} p_1, p_1, p_1, p_1, p_1, p_1, p_1, p_1, p_1, p_1 \end{pmatrix}, \quad \zeta^* = \begin{pmatrix} q_1, q_1, q_1, q_1, q_1, q_1, q_1, q_1, q_1, q_1 \end{pmatrix}
\]

After calculation, the distances of the 9 optimal solutions are all 277.20m, which is an increase in the distance of 241.60m based on the improved herringbone warehouse under the same conditions, which increases the driving distance of the AGV and increases the cost. The improvement is based on the improvement under the same conditions. The distance of the fish-bone warehouse is reduced by 12.8%, so it is found by comparison that the improved fish-bone warehouse is better than the fish-bone warehouse under the same conditions.

5. Conclusions

This paper integrates a variety of current automated logistics warehouse layout application scenarios, and proposes the shortest route model of AGV trolleys based on improved fishbone warehouses, and solves the constructed model based on genetic algorithms, and performs optimization with fishbone warehouses under the same conditions. The optimal route distance is compared to verify the feasibility of the proposed improved fishbone warehouse. The results show that the proposed storage model based on the improved fishbone warehouse can improve the efficiency of material transportation and reduce the cost of storage and transportation time so as to ensure the efficient operation of the automated warehouse, as well as show its important practical significance for the further promotion of intelligent logistics and automated warehousing.

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