Automated Guided Vehicles Routing

Hassan haleh¹, Arman Bahari²*

1. Department Industrial Engineering, Assistant Professor, Golpayegan University of Technology, Golpayegan, Iran
   hhaleh@gut.ac.ir
2. Department of Industrial Engineering, Islamic Azad University of Science and Research of Tehran, Tehran, Iran
   Corresponding author Email: arman_bahari@eng.usb.ac.ir

ABSTRACT: Automated guided vehicles (AGVs) are widely used in container terminals for the movement of material from shipping to the yard area and vice versa. Research in this area is directed toward the development of a path layout design and routing algorithms for container movement. The problem is to design a path layout and a routing algorithm that will route the AGVs along the bi-directional path so that the distance traveled will be minimized. This thesis presents a bi-directional path flow layout and a routing algorithm that guarantee conflict-free, shortest time routes for AGVs. Based on the path layout, a routing algorithm and sufficient, but necessary conditions, mathematical relationships are developed among certain key parameters of vehicle and path. A high degree of concurrency is achieved in the vehicle movement. The routing efficiency is analyzed in terms of the distance traveled and the time required for AGVs to complete all pickup and drop-off jobs. Numerical results are presented to compare performance of the proposed model. The research provides the foundation for a bi-directional path layout design and routing algorithms that will aid the designer to develop complicated path layouts.

Keywords: Automated guided vehicles, Bi-directional Model, bi-directional path flow layout

INTRODUCTION

Automated guided vehicles (AGVs) are self-driven vehicles used to transport material from one location on the facility floor to another without any accompanying operator, and are widely used in material handling systems, flexible manufacturing systems, and container handling applications. With the advance of technology, more sophisticated machines are available, which considerably reduce machining and internal setup time. The aim of production planning has shifted from fast production to the efficient transportation of material between the workstations and in and out of storage. Flexible material handling systems are required to perform an efficient routing of material. The use of AGVs increases flexibility, since the flow path can easily be reconfigured to accommodate production changes. The design of material handling guide path has a significant implication on the overall system performance and reliability, since it has a direct impact on the travel time, the installation cost, and the complexity of the control system software.

FLOW PATH NETWORKS

AGV flow path networks can be classified into three categories, namely, unidirectional, bi-directional, and mixed models. The operational control of a unidirectional model [Fig.1(a)] is very simple, since the controller need not require the functionality to accommodate bi-directional travel. However, the simplicity comes at the cost of reduced system throughput. A mixed model [Fig.1(c)] can be used to overcome deficiencies in the unidirectional model.
A bidirectional model [Fig. 1(b)] with controller can be used to achieve the same objective. Bi-directional models achieve significant reduction in the total travel distance and the space requirements for a flow path network, and are economical with fewer vehicles. The proposed research focuses on the bi-directional path layout and routing algorithm for a container handling application. A bi-directional path layout consists of two parallel lanes, L1 and L2, and a bridge connecting the lanes at the workstations. Vehicles are allowed to travel in both directions, and the functionality is accomplished by providing a bridge connecting two parallel lanes at the P/D station. All P/D jobs are divided into two disjoint subsets depending on the positions of the P/D jobs. Accordingly, AGVs are also classified into two disjoint subsets, which will run parallel along a bidirectional path layout in opposite directions.

In this system, the task and routes for each vehicle are determined in advance as part of the system design, not part of the controller planning function, and the system is controlled thorough a centralized control mechanism. Thus, the possible communication between an AGV and the central controller is kept to a minimum. Also, even if the loading and unloading time is not uniform, it does not affect the routing, as these
operations are scheduled at the beginning and end of the P/D jobs. The proposed path layout and routing algorithm will route AGVs without conflict, and within the shortest possible time.

**RELEVANT LITERATURE REVIEW**

Vehicle route planning involves selection of a route for the vehicle, in addition to scheduling the vehicle’s journey through the route. The path layout design and a routing algorithm for conflict-free AGV routing have been addressed in several papers in past research such as:

Broadbent et al. (1985) first introduced the concept of conflict-free routing. The routing procedure described is based on Dijkstra’s shortest path algorithm. Potential conflicts among the vehicles are detected by comparing path occupation times, and thereby avoided in advance. Glover et al. (1985) developed a polynomially bounded shortest path algorithm, called the partitioning shortest path (PSP) algorithm, which finds the shortest distance from one node to another in a network.

Huang et al. (1989) proposed a polynomial time labeling algorithm to find the shortest time path for routing a single vehicle in a bi-directional path network. This algorithm allows the path segments to be shared within their free time windows. The algorithm also finds the shortest path through the use of time windows on arcs or nodes in order to avoid collision. Kim and Tanchoco (1991) presented Dijkstra’s shortest-path algorithm for conflict-free shortest-time routing of AGVs in a bi-directional path. In a time window graph, where the node set represents the free time windows, and the arc set represents the reachability among free time windows, the graph is used to determine whether the vehicle will reach from one time window to another. Then AGV routing is accomplished through the free time windows of the time window graph instead of the physical nodes of the path network.

Tanchoco and Sinriech (1992) suggested an optimal closed loop guide path layout configuration for an AGV system. They developed an algorithm based on integer programming to find the optimal single loop. In the model, if all the vehicles run in the same direction with uniform speed, there will be no collision, because the optimal single loop path has no intersections. Lin and Dgen (1994) provided an algorithm for routing control of a tandem AGV system. The system is composed of several non overlapping loops, and the stations within each loop are served by a single dedicated vehicle. If the destination station is not located within the same loop, a load needs more than one vehicle to carry out the task. A task-list time-window algorithm is employed to find the shortest route from a source workstation to the destination without disrupting the travel schedules of other vehicles.

Kim et al. (2002) presents a construction algorithm for designing a guide path of an AGV system. The total travel time is used as a decision criteria and the direction of the path segments on a unidirectional path layout is determined. A reinforcement learning (Q learning) technique is used to estimate the travel time of the vehicles on the path layout.

Wu and Zeng (2002) present a colored Petri net model for deadlock avoidance in an AGV system, whereby the model is developed and an effective control law is presented. The deadlock is completely avoided by observing the state of the system and checking the free spaces available in some of the circuits. The model was developed for an AGV system in a unidirectional path layout, which decreases the system performance.

**MODEL DEVELOPMENT**

This section of research describes the formulation of an AGV system model, which consists of a bi-directional path layout and a routing algorithm. A bi-directional path layout is designed to formulate the model. In order to simplify solution to the model, we make some definitions and assumptions. The bi-directional path layout, assumptions, and definitions are as described below.

**Bi-directional Path Layout**

The bi-directional path layout with N number of pickup and drop-off stations placed along lane 1 L is as shown in Figure 3. An AGV picks up a load from a workstation and drops to another workstation. Once the route is determined, only one AGV can drop the load at any workstation. The bi-directional path layout given by Qiu and Hsu (2001) is given in Figure 2.
In the path layout (Qiu and Hsu 2001) as shown in Figure 2, the vehicle park (0), where AGVs rest initially, is provided. As the P/D task is assigned to each vehicle, the vehicle moves from the park to a source workstation. This empty travel trip (deadheading) reduces the routing efficiency, and hence, the system throughput. In the proposed path layout, park can be removed, and the buffer space can be enlarged, where park will be provided for the AGVs. By this modification, empty travel trip time can be saved. Also, the floor space utilization will remain the same, increasing the system throughput. The new bi-directional path layout has been proposed as shown in Figure 3.

The proposed path layout is as below:

(1) There are two parallel lanes L1 and L2. Parking space and buffer is provided at each station along lane L1. For simplicity in presentation, we assume that a workstation lies off the main travel area and is only entered by an AGV, when a pickup or drop-off has to be made. A vehicle can stop at the buffer to either pick up or drop-off the load. A buffer is an area off the main travel space where an AGV can wait, usually to permit another AGV to move on the path.

(2) There is a bridge connecting two lanes at each station. The points, where bridges are connected to lane L2 are referred as mirror stations, denoted by N ±1, N ± 2, L, N ± N. Thus, a bridge can be identified by an ordered pair (i, N + i). However, there is no buffer storage at the mirror stations.

(3) The lanes and bridges are bi-directional, and the distance between any two adjacent stations is equal (D).

(4) The width of the lanes and bridges is such that the only one vehicle can pass at a time. However, a vehicle can pass by a station, while loading or unloading process of another vehicle is being carried out in the buffer.

(5) The zone length is vehicle length plus twice the safety allowance, which will protect the vehicle from collision.

Definitions
The following definitions are made to formulate the model:

N = The number of workstations,
D = The distance between the adjacent workstation,
P = The distance of the first workstation from the park,
K = The number of P/D jobs,
P/D = A load to be picked up from the specified workstation (origin) and then to be delivered to another different specific workstation (destination),
(Pi, Di) = An ordered pair that identifies P/D job, where Pi and Di represents the P/D jobs respectively,
J = The set of K P/D jobs, J can be represented as,
J = {(Pi, Di) | 1 ≤ Pi ≤ N, 1 ≤ Di ≤ N and Pi ≠ Di for i = 1, 2, L, K},
J+ = The set of P/D jobs, i i P < D , J+ = {(Pi, Di) | Pi < Di for i = 1, 2, L, K},
J− = The set of P/D jobs, i i P > D , J− = {(Pi, Di) | Pi > Di for i = 1, 2, L, K},
Where J+ ∩ J− = φ , J+ ∪ J− = J and 2 ≤ K ≤ N ,
CAGV = The set of ordered workstations with two AGVs, { CAGV } = C1,C2 ,L, Cs ,
EAGV = The set of ordered workstations with no AGV, { EAGV } = E1, E2 ,L, Es ,
CAGV+ = The set of workstations (pair) where , Ci < E i
CAGV + = {(Ci , Ei ) | Ci < Ei for i = 1, 2, L, s},
CAGV− = The set of workstations (pair) where , Ci > E i
CAGV − = {(Ci , Ei ) | Ci > Ei for i = 1, 2, L, s},
Tp = The time for an AGV to pick up a load,
TD = The time for an AGV to drop off a load,
T loaded_ run = The time required by a job set J when AGVs run with load,
Tmove = The time required for an AGV to move to the nearest station,
T (Pi , Di ) = The time for a loaded AGV to run from pickup station Pi to the drop-off station Di.
Accordingly,
V + = the set of AGVs (vehicles) that carry out jobs in J + ,

Fig. 3. The proposed path layout
V = the set of AGVs (vehicles) that carry out jobs in J − ,
|J +| = the number of jobs in subset J +,
|J −| = the number of jobs in subset J −,
WAGV+ = the set of AGVs (vehicles) that move along CAGV+,
WAGV− = the set of AGVs (vehicles) that move along CAGV−,
s = the number of AGV movement tasks, s = |CAGV| or |EAGV|.

Assumptions
The following assumptions are made to develop the routing algorithm
(1) All of the K P/D jobs are distinct, i.e., no two or more vehicles have the same pickup or a drop-off station.
(2) All the vehicles run with the same velocity V, on either lane L1 or L2.
(3) The velocity of the vehicle on the bridge is V / r, where r > 1, the velocity slowdown factor.
(4) Only one P/D job is assigned to a single AGV at a time.
(5) Initially, all AGVs will rest at the respective station in a park near the buffer storage.

Routing Algorithm
The aim of route planning is to achieve maximum throughput for an AGV operations. The focus is to
find an optimal (the shortest possible time path) and feasible route for every single AGV. Three aspects are
considered while making the routing decision: (a) it should detect whether there exists a route which could lead
the vehicle from its origin to the destination, (b) the route selected for an AGV must be feasible, i.e., the route
must be congestion, conflict, and deadlock free (Taghaboni and Tanchoco1995), and (c) the route must be
optimal (minimize idling runs of vehicles). The routing algorithm proposed by Qiu and Hsu (2001) was used as
a basis for parallel processing of AGVs along the bi-directional. According to the proposed path layout, the new
routing algorithm is developed. Based on the path layout (Figure 3) and assumptions, the shortest path routing
algorithm is given as below.

Routing Algorithm
1. Let K be the number of jobs. Initially, all AGVs are at the pickup station. Loading is done according
to the requirement at the respective station. After loading, all AGVs are set out to their respective drop-off
stations.
2. (a) Check the movement of AGVs in V + and V - set. If
max{ Max1≤k (Pi), Max 1≤k (Di) : ∀ Pi , Di ∈ J +} < Min { Min 1≤k (Pi) , Min 1≤k (Di) : ∀ Pi , Di ∈ J − }

or
max{ Max1≤k (Pi), Max 1≤k (Di) : ∀ Pi , Di ∈ J +} < Min { Min 1≤k (Pi) , Min 1≤k (Di) : ∀ Pi , Di ∈ J − }
then route all AGVs along lane L 1. Go to step 3.
(b) If |J +| ≥ |J −| , all AGVs in V + advance along lane L 1 from the left side to the right side, while
AGVs in V - cross the bridge, reach their mirror-pickup stations, and advance along lane L2 from the right to the
left side. Go to step 3.
(c) If |J +| < |J −| , all AGVs in V- advance along lane L 1 from the right side to the left side, and AGVs
in V+ cross the bridge and reach their mirror-pickup stations, then advance along lane L2 in opposite
directions. Go to step 3.
(3) When AGVs moving on lane L1 reach their destinations, they immediately start unloading, and stay
in buffer after completion. However, AGVs on lane L2 have to (a) reach their mirror stations (b) cross the bridge
to reach their drop-off stations; (c) drop loads off and stay in buffers. The workstations with two AGVs and no
AGVs are arranged serially in the sets CAGV and EAGV, respectively.
4. If K < N, and CAGV ≠ Φ;
(a) Consider CAGV and EAGV sets. If Ci < Ei , take the pair of stations (Ci, Ei) in the set CAGV +
. If Ci > Ei , take the pair of stations (Ci, Ei) in the set CAGV -.Update the sets CAGV and EAGV by
deleting these number of stations.
(b) Repeat the step (a), while CAGV ≠ Φ.
5. Route AGVs in WAGV+ set and WAGV- set along lane L 1 from the left side to right and from the
right side to the left side, respectively.
(6) Once an AGV moves from a drop-off station to the nearest station (park), AGV will rest at that
station until the scheduling for the next operation is done.

Example of Routing Algorithm
AGV routing problem has been conceived to represent the system, which maps the proposed
algorithm. Consider a container port system with fourteen serial workstations. Let a set of workstations be
placed at an interval of 50 ft. The length of the bridge (Lb) is 2 ft, and the velocity reduction factor (r) on the bridge is taken as 1.2. Let the length of an AGV that protects it from collision be 1.5 ft. Consider a situation, where the load is coming from and going to the stations shown in the following set:

\[ J=\{(1,8),(2,11),(5,12),(6,9),(4,1),(12,6),(8,5),(9,2),(7,3),(10,4)\} \]

The problem is to route AGVs along the bi-directional path layout, so that the distance traveled will be minimum.

**Solution**

The step-by-step procedure of the proposed algorithm for the problem stated in example is given below.

**Step 1.** Loading is done at the respective station. Based on the positions of P/D jobs, the given set of jobs is classified into two disjoint subsets. Accordingly, AGVs are classified into two disjoint subsets. The two groups of AGV move in the opposite directions as shown in Figure 4.

\[ J^+ = \{(1,8),(2,11),(5,12),(6,9)\} \text{ and } J^- = \{(4,1),(12,6),(8,5),(9,2),(7,3),(10,4)\} \]

**Step 2.** Since \(|J^+| < |J^-|\), all AGVs in \(V^-\) advance along lane \(L_1\) from the right side to the left side, while AGVs in \(V^+\) cross the bridge, reach their mirror-pickup stations, and advance along lane \(L_2\) in opposite directions.

**Step 3.** When AGVs moving on lane \(L_1\) reach their destinations, they immediately start unloading and stay in buffers after completion. However, AGVs on lane \(L_2\) reach their mirror stations, cross the bridge to reach their drop-off stations; drop loads off and stay in buffers.

**Step 4.** Since \(CAGV \neq \emptyset\), we have, \(CAGV = \{3,11\}\), and \(EAGV = \{4,7\}\).

Accordingly, \(CAGV^+ = \{3,4\}\), and \(CAGV^- = \{11,7\}\).

**Step 5.** Route AGVs in \(WAGV^+\) set along lane \(L_1\) from the left side to the right side, and AGVs in \(WAGV^-\) set along lane \(L_1\) from the right side to the left side. Once an AGV moves from a drop-off station to the nearest station (park), AGV will rest at that station until the scheduling for the next operation is done.

**CONCLUSIONS**

The aim of this research is to achieve higher transportation efficiencies, thereby driving the logistics cost down. The AGV routing and network design is a key factor in the optimization of material transportation in a container terminal. This thesis has proposed a mathematical model for conflict-free routing of AGVs in a bi-directional path layout. The model offers a trade-off between the network optimization and efficient routing. The path layout and routing algorithm for a specific path topology are presented to route AGVs within the shortest possible time. The time required for the loading and unloading process creates no conflict, because these operations are carried out either at the beginning or at the end of operation. As AGVs are placed at each workstation, the AGV travel time is reduced, and the system throughput is increased. The advantage of the model is best realized when the ideal situation (all the vehicles move along lane \(L_1\) and only one vehicle moves to the nearest workstation after drop-off operation) occurs, and the number of P/D task increases. The model shows that the inclusion of park at the respective stations leads to a large reduction in the travel distance, and ultimately reduces the logistics cost. The proposed model may be regarded as a framework suitable for extension and application to a container terminal.

**REFERENCES**


