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An Optimal Guide Path Design of Bi-Directional Automated Guided Vehicle Systems(AGVS)

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Abstract

Guide path design is the most important factor in planning automated guided vehicle systems(AGVS) in manufacturing shop environments. This paper studies a heuristic procedure to design an optimal bi-directional guide path with the objective of the minimum total travel time of the vehicles. An example is solved to validate the procedure developed.

1. Introduction

Automated guided vehicles (AGV) are unmanned vehicles used to transport unit loads, large or small, from one location on the work center to another without operator intervention. These vehicles are operated with or without wire guidance and are controlled by a computer. In computer-integrated manufacturing system(CIMS) and flexible manufacturing system(FMS), the vehicle is often the most visible part of the system.

optimization problems related to AGVS can be divided into two subptoblems, design and operational problems. The design problems include layout design, guide path design and specification of the hardware such as the numder of vehicles, vehicle speed, vehicle capacity, pallet size and buffer size. The operational problems include routing and dispatching of the vehicles. Since the routing and dispatching methods chosen will affect the final design specifications of the system, an iterative procedure will be necessary before AGVS can be implemented.

Up until now, various approaches have deen taken to solve those problems related to AGVS. Maxwell & Muckstadt [6] proposed a method of determining a minimal number of vehicles required and the vehicle routes so that required material handling load is satisfied. Egbelu & Tanchoco [7] also addressed the problem of vehicle dispatching. In their study,

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heuristic rules are used to determine the dispatching of the vehicles. Gaskins & Tanchoco [9] developed a matematical formulation to determine an optimal uni-directional guide path for AGV transport systems.

This paper is concerned with flow path design for the case of bi-directional movements of vehicle. Bi-directional movements occur when vehicles can travel in two directions along a given segment of the guide path. It is assumed that layout of the system is already determined which includes each location of individual departments, pick up and delivery stations, storage facilities and aisles. A heuristic procedure is proposed to find an optimal bi-directional guide path which is proposed by minimum total travel time.

2. Mathematical Formulation

A mathematical model of the system is developed based on the follwing assumptions:

1. a layout of work centers, aisles and pick-up(P) and delivery(D) stations along with the location of these P/D stations are given.
2. a from-to chart containing the material flow intensities between work centers is available.
3. guide path is fixed path and parallel track on each aisle.
4. vehicle type is unit load vehicle.

The first step for the mathematical formulation is to translate all the informaation listed in the first assumption into a graph G(V, A) where $V=(v_1, v_2, \cdots, v_m)$ is the set of nodes and $A=(a_1, a_2, \cdots, a_n)$ is the set of arcs. All the intersections and P/D stations are represented by nodes and identified by numbers. $a_i=(v_j, v_k)$ is an arc originating at node v_j and ending at v_k and represented by a zero-one variable $X_{j,k}$ as the following:

$$X_{j,k} = \begin{cases} 1 & \text{if the arc from node j to node k is included in an optimal design} \\ 0 & \text{otherwise} \end{cases}$$

We want to find an optimal path design with the objective of a minimum total length of the guide path through which work loads flow between work centers. The problem can be formulated as the following zero-one integer programming.

Let

V = set of all nodes

d_{ij} = distance from node i to node j

n_p = total number of arcs in path p

S_p = set of pick-up nodes

S_d = set of delivery nodes

A_p = set of nodes adjacent to node $p \in S_p$

A_d = set of nodes adjacent to node $d \in S_d$

TD = total length of guide path in the system

$$\text{Minimize} \quad TD=\sum_{i,j}\sum_{\in V} d_{i,j}\,(x_{i,j}+x_{j,i})$$

subject to

$$(n_p-2)X_{m,q}+(n_p-2)X_{r,n}-\sum_{\substack{i,j\neq m,n \\ \text{in path } p}} X_{ij} \leqq (n_p-2) \quad m\in S_p, n\in S_d, \; q\in A_p, r\in A_d$$

$$(n_p-2)X_{m,q}+(n_p-2)X_{r,n}-\sum_{\substack{i,j\neq m,n \\ \text{in path } p}} X_{ij} \leqq (n_p-2) \quad m\in S_d, n\in S_p, \; q\in A_d, r\in A_p$$

$$\sum_{\forall_k\in(A_p U A_d)} X_{k,j} \leqq 1 \qquad \forall_j \in (S_p U S_d)$$

$$\sum_{\forall_k\in(A_p U A_d)} X_{j,k} \leqq 1 \qquad \forall_j \in (S_p U S_d)$$

$$X_{i,j}=0 \text{ or } 1 \qquad \forall_{i,j}\in V$$

The first and second constraints define feasible path of loaded and empth vehicles. The third and fourth constraints require that for a feasible path at least one are must exist which connects P/D nodes to other nodes. The solutions of this problem represent optimal guide path.

Note that as the number of work centers becomes larger, the number of the constraints of the mathematical formulation increase at a far greater rate. Thus even with a moderate size of nodes, it is difficult to solve with any solution procedure developed for zero-one integer programming. Therefore, a heurisric procedure for optimal guide path design is proposed.

3. Heuristic procedure

This heuristic procedure begins with the graph G(V,A), node-arc network, into which the layout configuration of work centers is converted.

step 1) Find the shortest path matrix and route matrix of node-arc network

with the concept of multiterminal shortest-route problem, the shortest path matrix and route matrix of the node-arc network are found through Floyd's or Hu's algorithm [9]. The shortest path matrix contains the current estimates of the lengths of the shortest chains. The route matrix is to identify the intermediate node of the shortest chains.

step 2) Formulate the transportation network model with a from-to chart representing flow of loaded vehicles and solve the model.

The transportation network model is formulated in order to identify the required number of AGV trips and pick-up nodes at which empty vehicles should be dispatched through shortest path. A from-to chart can be derived from process sequence and flow intensity. In transportation network model, deposit nodes of each work center are treated as sypply nodes and pick-up nodes are treated as demand nodes because the destination of empty vehicles should be found. The amounts of supply and demand are determined through the from-to chart. The transportation cost elements are related to shortest path matrix found at previous step.

step 3) Find the shortest path for each travels of loaded & empty vehicles

The paths on which empty vehicles travel are identified by the solutions of the transportation network model and non-zero cells of the from-to chart indicate the routes of loaded vehicles. The shortest path of each travel is found from the route matrix generated at first step.

step 4) set $X_{i,j} = 1$ if arc(i, j) is an element of the paths identified at the previous step

4. Applications

Consider the layout of eight work centers producing five different products as shown in figure 1. other relevant data regarding the operations are given in table 1. This example is quoted from Egbelu [2]. The figure 2. is corresponding node-arc network of the figure 1.

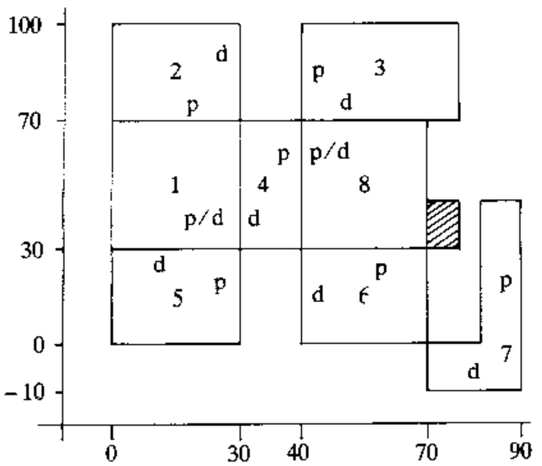

Figure 1. example layout

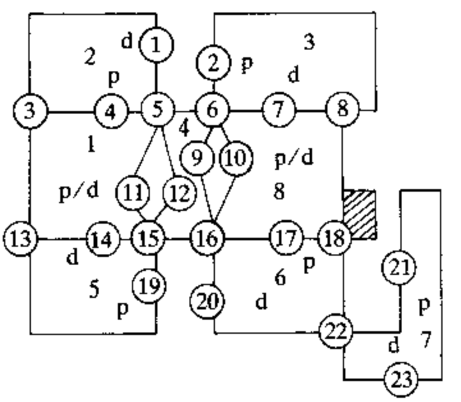

Figure 2. node-arc network

Table 1. data for the example

product type	process	flow intensity
A	1-3-2-5-8	30
B	1-6-5-4-7-8	25
C	1-4-6-8	20
D	1-7-2-3-8	15
E	1-2-6-3-5-7-4-8	10

average vehicle traveling speed=35 m/min.
average load and unload times=1 min.
efficiency of vehicles ≅100%
no battery recharge is required per one day period

With Hu's algorithm of network, table 2 can be found for the shortest route matrix. Suppose we want to find the shortest path, p(1, 2), from node 1 to 2. The table indicates that node 2 can be reached from node 1 via node 5 and via node 6 from node 5. Thus p(1, 2) is 1–5–6–2.

Table 2. shortest route matrix

from \ to	1	2	3	4	5	.6	.7	.8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	–	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
2	6	–	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
3	4	4	–	4	4	4	4	4	4	4	4	4	13	13	13	13	13	13	13	13	13	13	13
4	5	5	3	–	5	5	5	5	5	5	5	5	3	5	5	5	5	5	5	5	5	5	5
5	1	6	4	4	–	6	6	6	6	10	11	12	11	11	11	11	11	11	11	11	11	11	11
6	5	2	5	5	5	–	7	7	9	10	5	5	9	9	9	9	9	9	9	9	9	9	9
7	6	6	6	6	6	6	–	8	6	6	6	6	6	6	6	6	8	8	6	6	8	8	8
8	7	7	7	7	7	7	7	–	7	7	7	7	7	7	7	18	18	18	18	18	18	18	18
9	6	6	6	6	6	6	6	6	–	16	16	16	16	16	16	16	16	16	16	16	16	16	16
10	6	6	6	6	6	6	6	6	6	–	16	16	16	16	16	16	16	16	16	16	16	16	16
11	5	5	5	5	5	5	5	5	15	15	–	15	15	15	15	15	15	15	15	15	15	15	15
12	5	5	5	5	5	5	5	5	15	15	15	–	15	15	15	15	15	15	15	15	15	15	15
13	3	3	3	3	3	3	3	3	14	14	14	14	–	14	14	14	14	14	14	14	14	14	14
14	15	15	13	15	15	15	15	15	15	15	15	15	13	–	15	15	15	15	15	15	15	15	15
15	11	11	11	11	11	11	11	11	16	16	11	12	14	14	–	16	16	16	16	16	16	16	16
16	9	9	9	9	9	9	9	9	9	10	15	15	15	15	15	–	17	17	15	20	20	20	20
17	16	16	16	16	16	18	18	16	16	16	16	16	16	16	16	16	–	18	16	16	18	18	18
18	17	17	17	17	17	17	8	8	17	17	17	17	17	17	17	17	17	–	17	17	22	22	22
19	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	–	15	15	15	15
20	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	–	22	22	22
21	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	–	22	22
22	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	18	18	20	20	21	–	23
23	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	–

The number of trips for each vehicle which moves from a pick-up station to a deposit station is described in table 3. Figure 3 shows the transportation network corresponding to this example and table 4 lists an optimal solution to the problem.

Table 3. from-to chart for ABVx(loads per shift)

		to work center							
		1	2	3	4	5	6	7	8
	(node #)	(11)	(4)	(2)	(9)	(19)	(17)	(21)	(10)
from work center	1(11)		10	30	20		25	15	
	2(1)			15		30	10		
	3(7)		30			10			15
	4(12)						20	25	10
	5(14)				25			10	30
	6(20)			10		25			20
	7(23)		15		10				25
	8(10)								

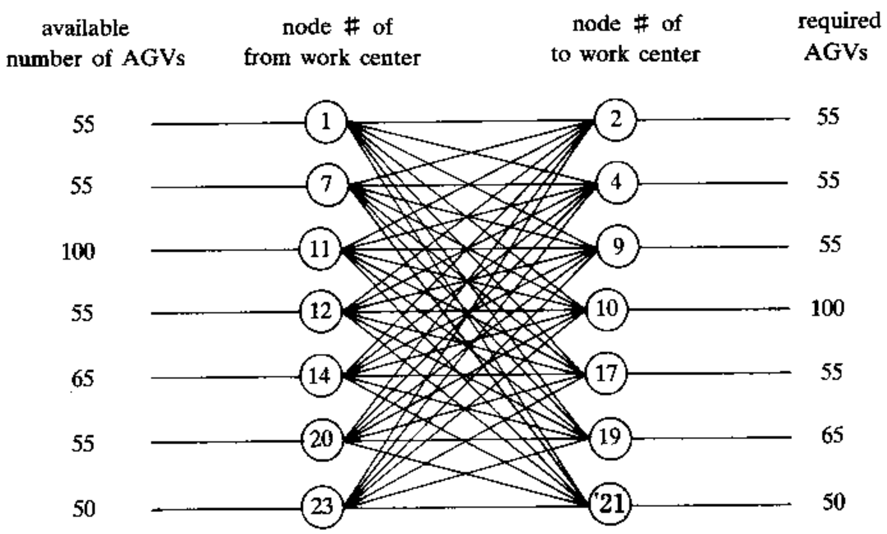

Figure 3. transportation network model tof the example problem

Table 4. optimal solution for transportation network model

node # : deposit (from work center)	1 (2)	7 (3)	7 (3)	11 (1)	11 (1)	12 (4)	14 (5)	14 (5)	20 (6)	20 (6)	23 (7)
node # : pick-up (to work center)	4 (2)	2 (3)	9 (4)	2 (3)	17 (6)	19 (5)	10 (8)	19 (5)	9 (4)	10 (8)	21 (7)
# of vehicle's trips	55	10	45	45	55	55	55	10	10	45	50

Based on the results of table 3 and 4,we find the shortest path on which loaded and empty vehicles travel utilizing the shortest route matrix and then include those arcs consisting of the shortest paths in the design. The above procedure is summarized at table 5 and figure 5 shows an optimal guide path.

Table 5. sequence of arcs in shortest paths

path for loaded Vehicle's travel	P(4, 11) : 4 – 5 – 11 P(4, 7) : 4 – 5 – 6 – 7 P(4, 23) : 4 – 5 – 11 – 15 – 16 – 20 – 22 – 23 : : P(10, 7) : 10 – 6 – 7 P(10, 12) : 10 – 16 – 15 – 12 P(10, 14) : 10 – 16 – 15 – 14 P(10, 20) : 10 – 16 – 20 P(10, 23) : 10 – 16 – 20 – 22 – 23
path for empty vehicle's travel	P(1, .4) : 1 – 5 – 4 P(7, 2) : 7 – 6 – 2 P(7, 9) : 7 – 6 – 9 : : P(23, 21) : 23 – 22 – 21
an optimal solution	$X_{15} = X_{51} = X_{26} = X_{62} = X_{45} = X_{54} = X_{56} = X_{65} = 1$ $X_{511} = X_{115} = X_{512} = X_{125} = X_{67} = X_{76} = X_{69} = X_{96} = 1$ $X_{610} = X_{106} = X_{916} = X_{169} = X_{1016} = X_{1610} = 1$ $X_{1115} = X_{1511} = X_{1215} = X_{1512} = X_{1415} = X_{1514} = 1$ $X_{1516} = X_{1615} = X_{1519} = X_{1915} = X_{1617} = X_{1716} = 1$ $X_{1620} = X_{2016} = X_{1718} = X_{1817} = X_{2022} = X_{2220} = 1$ $X_{2221} = X_{2122} = X_{2223} = X_{2333} = 1$ and other $X_{i,j}=0$

Next, the comparison between uni-directional and bi-directional guide path is carried out. on the example, an optimal uni-directional approach by Gaskins and Tanchoco [12] is applied and the total travel time and the minimum required number of vehicles are determined utilizing Maxwell and Muckstadt's work [8]. Table 6 shows the bi-directional design gives smaller number of vehicles required with shorter length of guide path compared to those by uni-directional design and brings curtailment of expenditure.

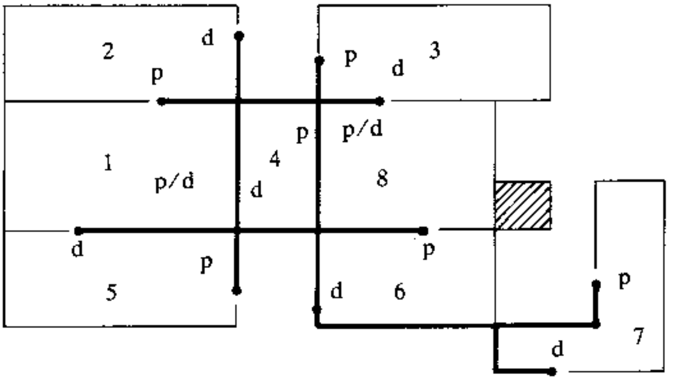

Figure 4. optimal guide path design for the example

Table 6. result of comparison

	uni-directional guide path	bi-directional guide path
total loaded vehicle travel time	2146.43 min.	1806.43 min.
total empty vehicle travel time	1096.43 min.	430.71 min.
total travel time	3242.86 min.	2237.14 min.
the minimal required # of vehicles	8 (7.54)	6 (5.20)
total length of guide path	720m	610m

5. Conclusion

We developed a heuristic procedure based on Hu's algorithm and the work by Maxwell for the design of an optimal bi-directional guide path. Through an example problem, the validity of the procedure is examined.

An alternative approach to find the best guide path would be simulation. This would give a more practical comprehension of the AGVS. For example, simulation approach can consider possible vehicle blockings and congestions. A better approach may be to carry out the proposed heuristic procedure and then obtain the practical view of the guide path design through simulation.

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