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RESEARCH ARTICLE

Risk-Based Minimum Cost Flow Model for AGVs Path Planning

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Abstract:

Objective:

In this paper, a risk-based minimum cost flow mathematical model is developed for path planning of multiple Autonomous Guided Vehicles (AGVs) in a manufacturing system.

Methods:

The assignment of AGVs to production stations are based on AGVs travel time and stations due dates. Risk of time violation is considered by severity and probability of time violation.

Results:

Time violation includes delays in processing the tasks by AGVs.

Conclusion:

The main contribution of the paper is to consider risk cost integrated with operation time in AGVs path planning.

Keywords: Autonomous Guided Vehicle (AGV), Risk, Minimum Cost Flow, Path Planning, Manufactauring, System.

1. INTRODUCTION AND LITERATURE REVIEW

An Autonomous Guided Vehicle (AGV) is a driverless device being controlled by computer for handling materials and transportation for a wide range of industries. AGVs are used in manufacturing systems to move among different points and perform functions such as load transferring, small components assembling, pallet loading and transportation, towing or lifting products and tooling change out, without the aid of a human driver. Flexible Manufacturing Systems (FMSs), container terminals, warehousing systems, and service industries including hospital transportations are employing AGVs for the material handling to maintain flexibility and efficiency of production and distribution. For the efficient operation, it is requested to realize the synchronized operations for the simultaneous scheduling of production systems and transportation systems [1, 2].

Robots process various tasks such as material handling leading to signify the better decision making in areas namely: robot type selection, sequencing, motion planning etc. This for example, goes beyond the application of agent-based control in Computer Numerical Controller (CNC) machines that are usually part of Flexible Manufacturing Systems (FMS). Agents are employed having programs stored on them to handle decisions for operations in different circumstances [3]. The dynamic task planning for AGVs is significant due to changes occur in the shop floor and machines and devices. Thus, complex environment is evolved requiring appropriate planning and coordination between resources and tasks [4]. Agent based models are not generic to cover all aspects of dynamic operations using multiple resources for handling various tasks in a flexible manner. Expansion of robotic devices and their corresponding

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capabilities lead to better integration of different hardware and software configurations.

Traditionally, AGVs were mostly used at manufacturing systems, but currently other applications of AGVs are extensively developed in other areas, such as warehouses, container terminals and transportation systems. Fazlollahtabar and Saidi-Mehrabad [5] reviewed two problems of scheduling and routing for AGVs with respect to different categories of applications. The works reviewed were classified based on the approach of modeling and optimization such as mathematical methods (exact and heuristics), simulation studies, metaheuristic techniques and artificial intelligent based approaches.

The impact of uncertainty on path planning was investigated extensively in computer science and operations research application areas such as communication networks and transportation systems [6 - 8]. Uncertainty in network systems can be due to several reasons such as congestions, failures, occasional conditions and etc. leading to influence travel time. Thus, users can not have a certain value and a possible range is considered instead for decision making to have a tradeoff between travel times and risk of each choice [9 - 11].

Fazlollahtabar *et al.* [12] developed a scheduling problem of several AGVs in a manufacturing system considering the concepts of earliness and tardiness. Their problem and solution approach were significant for satisfying the production/delivery cycle time. Also, a mathematical model was proposed and a novel heuristic solution approach was designed and implemented.

Fazlollahtabar *et al.* [13] considered a complex problem of path planning for multiple AGVs in which a new concept of turning point was presented as a deadlock resolution approach. They showed the applicability and effectiveness of the model in a real industrial case. They suggested a commercial user interface to work as a decision support in manufacturing system having AGVs to prevent deadlock and conflicts of AGVs. More analytical models and reviews can be referred to [14].

Shirazi *et al.* [15] developed a nonlinear mathematical model for a multi-objective material follow by Tandem AGVs. To counteract variability the concept of six sigma was employed. Also, a modified ant colony optimization was developed as solution approach since the problem was very hard and time consuming to solve with conventional methods.

Fazlollahtabar and Shafieian [16] concerned with the design of a computer integrated manufacturing system to identify an optimal path in a Vehicle Routing Problem (VRP) network regarding to triple criteria. In most VRPs just one criterion, either time or cost was considered in decision making. They considered all time, cost, and AGV capability in decision making, simultaneously. To satisfy a Material Requirement Planning (MRP) by providing the bill of material (BOM), AGVs are suitable devices.

Fazlollahtabar *et al.* [17] considered a bi-criteria optimization of AGV path planning in a robotic manufacturing system. In the system time and cost were considered together for different operational parameters. Due to stochastic nature of operational parameters a stochastic programming mathematical model was proposed to optimize production time and material handling cost. To handle the nonlinearities of the mathematical model a Successive Linear Programming (SLP) technique was employed. For larger sized problem instance a Genetic Algorithm (GA) was presented due to inefficiency of the proposed approach.

The optimization of Material Handling Systems (MHSs) can lead to substantial cost reductions in manufacturing systems. Choosing adequate and relevant performance measures is critical in accurately evaluating MHSs. The majority of performance measures used in MHSs are time-based. However, moving materials within a manufacturing system utilize time and cost. Tavana *et al.* [18] considered both time and cost measures in an optimization model used to evaluate an MHS with AGVs. They took into account the reliability of the MHSs because of the need for steadiness and stability in the automated manufacturing systems. Reliability was included in the model as a cost function.

2. STATEMENT OF THE PROBLEM

This research proposes a framework of an AGV- based station control system, which consists of a manufacturing system for decisions of AGV dispatching selection. AGVs and station paths planning are usually made at planning level. For financial analysis it is more effective to obtain an estimation of the losses before or during implementation of such a system. A very helpful method to handle uncertainty is risk analysis. AGVs are dispatched according to a request from a station. Products are processed in stations according to process plan and job sequences. A complicated system of AGVs, paths, and stations is configured. The proposed mathematical model formulates the task and resource assignment problem as a Minimum-Cost network Flow (MCF) problem during each planning horizon. The risk is defined as the product of probability of collision and severity of collision hazard.

The scheduling determines the AGV-station schedule during each planning horizon. A set of candidate AGVs and a set of candidate stations are selected to formulate into a minimum-cost network flow problem. It is assumed that during each operation, an AGV may require more than one station for a process. Each process step of an AGV with a different type of station is called an operation sequence.

Let's consider a network configuration to simplify modeling and optimization. During each planning horizon, a set of candidate tasks and resources are selected at each level from the proposed manufacturing system to be formulated as a Minimum Cost Flow (MCF) problem. The task ready time and resource (station) available time are considered as if they were static. The task/resource assignment is further formulated as a minimum network flow problem illustrated in Fig. (**1**).

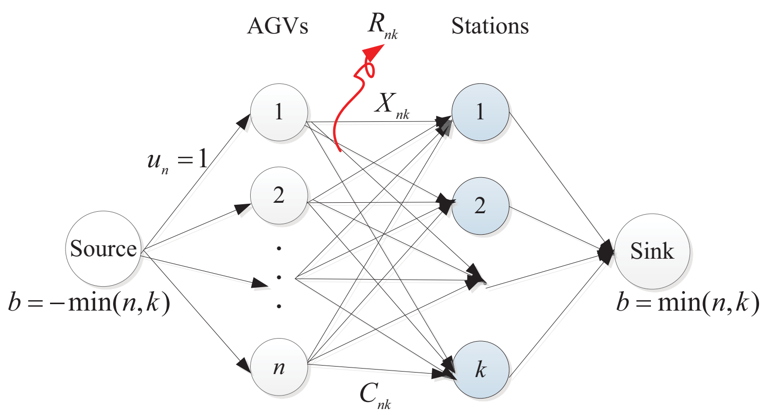

Fig. (1). The proposed network flow model of task assignment.

Nodes in n are candidate tasks (*e.g.* AGVs). Nodes in k show stations that can be handled by candidate tasks. Two dummy nodes called "source" and "sink" serve as start and end nodes.

The links between candidate tasks and stations imply a substituent allocation of the stations to tasks. The capacities of all links are unit. It is assumed that at the beginning of computations the net flow in the start node is the minimum value of the numbers of candidate tasks and stations. Reversely, the net flow at the final node is negative value of the beginning node. The net flow values for all the remaining nodes are zero.

3. MATERIALS AND METHODS

All links between start node and the candidate AGV handling task nodes are associated with cost coefficients which are set zero at the beginning. Also, the cost coefficients (C_{nk}) for links between station nodes and end nodes are set zero, too. The cost coefficients related to alternative assignments of station to AGV handling task are determined to optimize risk based cycle time of tasks.

The formulated Risk-based Minimum network Flow problem (RMCF) can be summarized as follows:

Indices:

k index for stations

n index for AGVs

Variables:

X_{nk} Flow of arc from node n to node k

Parameters:

U_{nk} Capacity of the arc from node n to node k

U_{nk} Completion time with assigning task *n* to resource *k*

V Set of nodes in the networks

bn Net flow at node *n*

A Set of directed arcs connecting nodes in the networks

Ain(n) Set of arcs that are immediate predecessors to node *n*

Aout(n) Set of arcs that are immediate successors to node *n*

S_{nk} Severity of travel time violation of AGV *n* to station *k*

P_{nk} Probability of travel time violation of AGV *n* to station *k*

R_{nk} Risk of travel time violation for AGV *n* to station *n*

Then, risk is computed by,

$$R_{nk} = p_{nk} \times s_{nk} \tag{1}$$

and the RMCF mathematical program is,

$$Min \sum_{(n,k)\in A} R_{nk} C_{nk} X_{nk} \tag{2}$$

s.t.

$$\sum_{k\in A_{in}(n)} X_{kn} - \sum_{k'\in A_{out}(n)} X_{nk'} = b_n, \quad \forall n \in V \tag{3}$$

$$0 \le X_{nk} \le U_{nk}, \quad \forall (n,k) \in A \tag{4}$$

3.1. Data Required for RMCF Model:

td_{nk} the due time of AGV *n* for serving station *k*

tp_{nk} the processing time of AGV *n* for serving station *k*

d_{nk} the expected travel time delay of AGV *n* from its current location to station *k*

S_{nk} Severity of travel time violation of AGV *n* to station *k*

P_{nk} Probability of travel time violation of AGV *n* to station *k*

The expected travel time delay is the time to transfer an AGV from its previous operation station to its subsequent operation station. When *tdnk* is less than tp_{nk}, it means AGV *n* is ready before the station *k* finishes the last operation. If the processing time of AGV *n* plus the expected travel time delay *dnk* is greater than the risk-based due time of AGV, then the AGV *n* will be idle waiting for the station. Otherwise, AGV *n* will arrive at station *k* early and wait for product to become available. Therefore, the AGV start time can be estimated by the following expression.

$$ts_{nk} = \max_{nk}\left\{\left(tp_{nk} + d_{nk}\right), R_{nk} td_{nk}\right\} \tag{5}$$

The finish time of an AGV serving a station will be the start time plus the risk-based expected processing time of the AGV, *i.e.*

$$tf_{nk} = ts_{nk} + R_{nk} E\left(tp_{nk}\right) \tag{6}$$

Furthermore, stations are subject to breakdowns during an operation. Hence, high variation in station availability will result in significant deviation of the finish time estimation from the actual time. The objective of total weighted risk-based completion time can be approximated by total weighted task start time. Then, the cost coefficient for AGV/station assignment (completion time) becomes,

$$C_{nk} = tf_{nk} - ts_{nk} \tag{7}$$

4. NUMERICAL STUDY

To show the effectiveness of the proposed mathematical model a numerical example is presented. As for input data, the number of stations and AGVs are assumed to be 8 and 3, respectively. The existing due time for AGVs and stations are given in Table **1**. It should be noted that the existing due time between any two AGVs and stations are presented by a number and otherwise with 0.

Table 1. Existing path among stations

k / *n*	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1	-	7	0	11	0	6	0	0
2	0	-	12	0	8	0	7	9
3	0	0	-	0	0	8	5	10

Then, the severity of time violation of AGVs in all stations is assumed to be same and equal to 11.5 unit of cost. But, the probabilities of time violation for different stations are different as given in Table **2**. The probabilities are extracted from past data recorded by maintenance department.

Table 2. Travel time violation of AGVs in stations

k / *n*	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1	-	0.03	0	0.05	0	0.07	0	0
2	0	-	0.08	0	0.09	0	0.04	0.05
3	0	0	-	0	0	0.04	0.04	0.04

The processing time of AGVs to stations between any two AGV and station are given in Table **3**.

Table 3. Processing time for all AGVs and stations

k / *n*	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1	-	6	0	11	0	14	0	0
2	0	-	3	0	7	0	12	18
3	0	0	-	0	0	11	9	15

5. RESULTS AND DISCUSSION

Using above input data and employing GAMS optimization software the following outputs are obtained as shown in Table **4**.

Table 4. Outputs

X_{12}
X_{27}
X_{37}

Note that the shown variables are the ones with a flow value. The obtained results show that path between AGV 1 and station 2 is assigned to reach a minimum risk-based flow.

CONCLUSION

In order to balance the station workload and prioritize the urgent lines, the stations with earlier start time, which means a lower workload, should be chosen in the dynamic decision process. Therefore, the station with an earlier start time, which means a lower workload, will be more desirable in the dynamic decision process. The planning of AGVs using RMCF algorithm aims at minimizing the risk-based completion time considering delay time as well as processing time. The model uses the properties of network flow which is an exact and strong algorithm for assignment of AGVs to stations.

CONSENT FOR PUBLICATION

Not applicable

CONFLICT OF INTEREST

The author declares no conflict of interest, financial or otherwise.

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Declared none.

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