2002年日本オペレーションズ・リサーチ学会
秋季研究発表会

A partitioning algorithm to configure the guide path layout for automated guided vehicle (AGV) systems

Lee Chulung

Selecting the right guide path configuration for an automated guided vehicle (AGV) system in a given facility layout is, indeed, an important design problem, since it affects the performance of the system. Conventional AGV guide path systems usually employ unidirectional guide paths and general network layouts. Since these layouts contain intersections, often experience congestion and deadlocks. Controllers that resolve congestion and deadlocks must be provided. The difficulty of developing such controllers increases sharply with the number of departments and intersections. One approach to solve this problem is to simplify the guide path configuration. In this paper, the tandem loop with multiple vehicles (TLMV) system is proposed as an effective layout alternative. Resembling the tandem loop system, the TLMV configuration consists of non-overlapping loops and transfers between adjacent loops occur at predetermined transfer points. The TLMV system may contain more than one AGV in each loop. Thus, unless a loop has only one AGV, a unidirectional guide path is usually employed. However, if a loop contains only a few vehicles, a bidirectional guide path can be implemented using buffering spaces. The TLMV system can evenly distribute the workloads among AGVs by assigning an adequate number of vehicles to each loop. Comparing it to the single loop system, the TLMV configuration employs smaller loops that reduce travel distances. In addition, system expansion or upgrade can be easily accomplished by incorporating additional loops. Comparing it to the tandem loop system, the TLMV configuration can greatly reduce the number of interloop transfers by placing the departments with high between-department flows in the same loop. The TLMV system is also less sensitive to vehicle failure than the tandem loop system.

In spite of the advantages that TLMV can offer, the current literature provides no formal discussion of this configuration. When the TLMV system is employed, from a design point of view, the most important issue is how to develop a partitioning algorithm that can divide departments into loops. A successful configuration must incur the least amount of material handling for the given flow requirement. In order to provide a good TLMV configuration, heuristic clustering algorithms have been proposed under two different assumptions regarding the layout. When the locations of departments are interchangeable, the candidate sites are partitioned to minimize the travel distance, and departments are assigned to handle the flow requirements with minimal interloop travel. When no layout change is permitted, similarity coefficients γ_{ij} between departments i and j that consider the number of interloop transfers, as well as the total travel distance, are proposed as follows, where d_{ij} and f_{ij} represents the rectilinear distance and the flow requirement from department i to department j, respectively:

$$\gamma_{ij} = \frac{f_{ij} + f_{ji}}{d_{ij}} \qquad (1),$$

$$\gamma_{ij} = \frac{f_{ij}^2 + f_{ji}^2}{d_{ij}} \qquad (2).$$

Equation (2) stresses the flow volume between stations. The similarity coefficients in Equations (1) and (2) should be updated at each iteration of the clustering algorithm, because as workstations merge to form loops, distances between workstations assigned to different loops may have to be revised by considering new loops as obstacles.

In this study, to avoid small isolated loops, a mutual neighborhood value (MNV) is used in selecting the clusters to merge. The MNV between two stations is defined by the sum of the nearest neighbor ranks of the pair. For example, if station p is the m^{th} nearest neighbor of station q and station q is the n^{th} nearest neighbor of station p, the MNV between stations p and q is (m+n). The clustering procedure using MNV is summarized as follows:

Step 1. For each pair of stations i and j, $i \neq j$, compute similarity coefficient γ_{ij} by Equation (1) or (2) and arrange the first k stations, where k defines the neighborhood width of interest, in descending order of γ_{ij}.

Step 2. Form an integer matrix M_1 with m rows, where m is the number of stations, and (k+1) columns. In neighborhood matrix M_1, the first entry in row i, for all i, indicates station i, which is the station under consideration; the second entry in each row is the station that has the greatest similarity coefficient value with station I; the third entry indicates the second nearest neighbor and so on, until the $(k+1)^{th}$ entry indicates the k^{th} nearest neighbor.

Step 3. Set up an integer matrix M_2 with m rows and k columns, where the first entry in each row is the station under consideration, and an entry in the i^{th} row and j^{th} column, where $j \neq 1$, is the MNV between stations at positions (i, 1) and (i, j) in M_1. If two stations are not mutual neighbors for a given neighbor width, their MNV is an arbitrary large number that should be greater than 2k.

Step 4.Begin with m clusters (groups), each consisting of exactly one station. Consider the highest MNV, which is 2. Collect all station pairs having an MNV of 2. Such pairs are then arranged in descending order of their similarity coefficients. Out of all the stations having MNV = 2, select the pair whose similarity coefficient is the largest. Merge the two stations of this pair to form one group and reduce the total number of groups by one.

Step 5. Proceed by merging the pair that comes next in the hierarchy. When all the pairs having MNV = 2 are exhausted, consider the pairs having MNV = 3, and proceed merging as before. Each successful merge reduces the total number of groups by one. For a neighborhood width of k, the highest MNV to consider is 2k.

Once departments are partitioned into loops, a permutation of those departments that minimizes the total material handling time should be determined. We determine the sequence simply by arranging departments in a descending order of outflow from the department. In order to determine the locations of transfer points, the shortest interloop travel paths between departments are first obtained, and among them the transfer points that minimize the total transfer time, which is the sum of weighted transfer times, will be selected. In order to determine the direction of movement in each loop and optimal partitioning level, the generated TLMV layout should be evaluated by estimating the total material handling time. An analytic model that computes the total estimated material handling time is provided as well.

The proposed TLMV configuration is especially useful for a large scale manufacturing environment since it can easily accommodate expansion or upgrade by adding additional loops while it is still less sensitive to vehicle failure than the tandem loop configuration. In addition, by accommodating a relatively small number of vehicles in each loop, the TLMV configuration has the potential to employ bidirectional guide paths with few difficulties in control. Simulation results comparing the TLMV system with other configurations have shown that the TLMV configuration is an effective layout alternative.