Flow Path Design for AGV Systems

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Abstract: In this paper, we address the problem of unidirectional guide path layout design for automated guided vehicle systems associated with a given facility layout organized into departments. The departments have specific geometric shapes and defined boundaries. Two layout design procedures are proposed for single loop flow paths and tandem configuration. In a first part, an approach to determine the optimal single loop design is developed through the application of tabu method as a neighborhood search technique. Here, the determination of the initial solution for the search method is obtained from geometrical considerations. The second part deals with the tandem configuration. A partitioning procedure of departments based on the hierarchical classification is proposed. The similarity coefficient takes into account the volume flow as well as distances between departments, while granting more importance to the proximity. The problem of partitioning the guide flow paths into several adjacent loops is discussed. An example is used to illustrate the proposed approaches.

Keywords: automated guided vehicle systems, flow path, tandem, single loop, tabu method, hierarchical classification.

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1. Introduction

An automated guided vehicles system (AGVS) is a type of material handling device in flexible manufacturing systems (FMS) that uses self propelled vehicles to transport loads from one location on the facility floor to another without any accompanying operator. Movements are accomplished using some types of guide path in or on the floor, on-board computer or other controls [Tsukagoshi 87] [Wakaumi 89]. The use of Automated Guided Vehicle Systems (AGVS), increases the flexibility since the flow path can easily be reconfigured to accommodate production changes. The design of a material handling system using AGVs must address some of the critical issues such as guided path design, vehicle dispatching strategies, traffic control and capacity requirements planning [Mahadevan 90]. The flow path layout has a significant implication on the overall system performances since it has a direct impact on the travel time, on the installation costs and, particularly, on the complexity of the control system software. The problem of guided path design has been addressed in several research papers. They propose several flow network design concepts: single line, single loop, tandem or complex networks. Complex network layouts [Gaskins 87] [Goetz 90] [Kaspi 90] offer considerable flexibility; however the system is often subject to traffic congestion. With the existence of more alternative routes and conflicting intersections, it is not easy to accomplish the control task in an effective way. It requires not only a considerable effort to develop an efficient control system, but also to resolve the difficulties met in the implementation phase of the system [Tanchoco

94]. Another potential problem of these layouts is shop locking, in which some parts of layout are poorly served by AGVs, leading in turn to accumulations of parts at the output buffers and the blocking of AGVs [Egbelu 84].

To circumvent the difficulties inherent to conventional networks, the search of a best and less complex guide path design has received far more attention than any other one. The goal is to design a configuration that eliminates some tasks the system's controller is in charge of, by reducing the number of conflict points in the flow path layout. When the factory floor is complex, it may be useful to decompose the layout into several non-overlapping zones which are defined following the topology of the production system. The flow path in each zone is a single vehicle single loop. Each loop serves workstations and transit areas between adjacent loops. The interference problem between vehicles is totally absent, and the distribution of the control is relatively easier since each loop is by construction a natural component of a distributed control system. But, the seminal problem that occurs with the use of tandem configuration is routing problem when the load destination resides in different zones [Lin 94]. The paper that addresses and emphasizes the problem of tandem guide paths design is due to Boser and Srinivansan [Boser 92,93]. They have proposed a partitioning procedure and used simulation to compare its throughput rate with that of a conventional system. The procedure assumes a facility layout that contains several workstations, where the flow data and the workstation locations are given, but does not take into account the shape of departments. On the other hand, it seems to be difficult to implement this procedure which requires high computational cost. Another way to reduce the complexity of control is to design a single loop guide. This configuration simplifies the physical structure of the control system, since it contains no intersections and no alternative routes [Gaskins 87, Tanchoco 92]. The single loop flow path design problem has been approached from different perspectives [Afentakis 93, Kim 96]. Almost all of these approaches are more suitable when used to design FMS, where workstations need to be arranged in an efficient manner rather than to design a flow path network for a given facility layout. A procedure for designing single loop flow path has been developed by Tanchoco and Srinivansan, when an actual facility layout is given and departments have specific geometric shapes and defined boundaries [Tanchoco 92]. In their approach, a mathematical linear programming is used which gives a starting solution for an enumerative search. Three rules have been applied to reduce the field of exploration and to eliminate loops whose performances are dominated by others. A modification of this procedure at the level of the search of the initial solution has been proposed [Sinreich 93]. It consists in forming a loop from boundaries of the department that possesses the most adjacent departments, and in annexing other departments to the current loop under some conditions.

Because of their importance as components of tandem configuration, loops layout form our main focus of attention [Aarab 97]. In this paper, we address the flow path design problem associated with a given facility layout where the shape, area and boundaries of the departments are given. In order to avoid an enumerative search, we propose an approach for solving the single loop design problem based on the use of the tabu search metaheuristic [Hertz 90]. Its application in the resolution of strongly combinatorial optimization problems seems to promise good performance [Widmer 91]. The solution procedure starts by identifying an initial loop, with a search improvement then being made to that solution to transform it into a final solution. For the determination of this initial solution, we propose an algorithm based on geometrical considerations. For tandem AGV system, we plan to configure a layout facility organized in functional departments. A partitioning procedure based on hierarchical clustering is proposed. In order to minimize the inter-zone moves of parts, the similarity coefficient is taken as a function of volume flow and distances between departments.

The paper is organized as follows. Section 1 deals with a two-phase solution procedure design for a single loop. The first phase is concerned with the determination of an initial solution, while the second one is devoted to improve this solution using the tabu search method. The second Section considers an approach for the tandem configuration design. A numerical example for finding the optimal single loop and for partitioning the facility into zones is given. Concluding remarks of this paper are made in the last Section.

2. Design Procedure of Single Loop Path

In this Section, we consider the single loop design problem for a given facility organized into departments. Each department D_i (i=1..d) (Figure 1) has a specified shape as considered by Tanchoco and Srinivasan [Tanchoco 92]. A department D_i can be represented by a set of nodes N_{ij} ($j=1..n_i$). The goal is to find a shortest loop that happens by all departments. A direct loop is defined as an ordered sequence of adjacent lines:

$S = (s_1, s_2, .., s_{i-1}, s_i, s_{i+1}., s_d)$.

Each line s_i consists of segments that connect some nodes of department D_i. It can be characterized by the terminal nodes(N_{ik}, N_{il}). Corresponding to each line (N_{ik}, N_{il}) there is a length $L(s_i)$ from node N_{ik} to node N_{il}. The direction in each department is assumed to be clockwise. The problem is therefore to find the loop that has the minimum length $L(S)= = \sum_{i=1}^{d} L(s_i)$, where for each department D_i there is at least one line s_k that made part of the boundary of D_i.

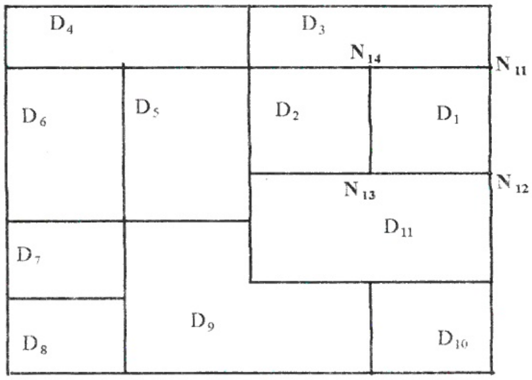


Figure 1. Facility Layout

This problem can be formulated as a travelling salesman problem [Tanchoco 92], which is known to be NP-hard. Consequently, rigorous methods are abandoned as soon as the size of the problem becomes large for the benefit of approximated solutions. In our approach, the proposed procedure for solving this problem uses tabu search. As an improvement procedure, tabu method is based on the fact that one compares the efficiency of the new neighbor solution to the previous one. This iterative method allows also to continue the exploration of solutions without becoming ineffective in the absence of improving moves and attempts to escape from local optima. This is accomplished through the storage of the search process in a finite list called tabu list. This list is used to exclude all evolution returning to a previously visited solution and to orient some future search. It is renewed in a cyclic manner at the end of some number of iterations. As the initial solution is one of the parameters that affects the performance of an algorithm using the tabu search method. in the following we propose a procedure for the determination of the initial loop.

2.1 Initial Solution Determination

Here, the initial loop is determined from geometrical considerations. The procedure starts from a first fictitious loop B_0 by connecting the centroids of departments. The centroids G_i are ordered according to their value of the angular $\theta_i = (OG_i, OG)$, where G is the center of G_i. Next, each centroid G_i is replaced progressively by two nodes of the corresponding department D_i such that at least one segment of every department has to be in the final guide path loop. The choice of the two nodes N_{ij} and N_{ik} belongs to department D_i and is undertaken on the basis of their contribution to the minimization of the line length [N_{ij}, N_{ik}]. The following algorithm describes the procedure steps.

Algorithm 1: Initial loop determination

```
Form the initial loop $B_0$ by connecting centroids $G_i$ of departments $D_i$ ;

$B \leftarrow B_0$
$BB \leftarrow B_0$
$LN \leftarrow G_d$
        For i=1 to d do
            $B \leftarrow B - [LN, G_i]$
For all pair nodes ($N_{ij}$, $N_{ik}$) belong to department $D_i$ do
                $B \leftarrow B + [LN, N_{ij}] + [N_{ij}, N_{ik}]$
                    If L(B) < L(BB) then
                        $BB \leftarrow B$
                        $LN \leftarrow N_{ik}$
                    End if
                End for
End for
```

Figure 2 illustrates some steps of the determination of the single loop. Step (a) represents the first phase, where we obtain a loop B_0 linking the centroids of departments. Step (b) corresponds to the replacement of the centroid G_1 by a line belonging to department D_1. Among the nodes N_{11}, N_{12}, N_{13} and N_{14} of department D_1, N_{13} and N_{14} give the minimal value of the loop length. Thus $[N_{13}, N_{14}]$ is the first segment of department D_1 that will make part of the final loop. As N_{13} and N_{14} belong also to department D_2, the centroid G_2 will be replaced by the segment $[N_{13}, N_{14}]$. At step (c), it suffices to seek a second point that contributes to the minimization of the length loop. Thus we determine the second segment $[N_{14}, LN]$ that will make part of the final loop. This procedure is repeated until the outcome step (d) that gives the configuration of the initial single loop.

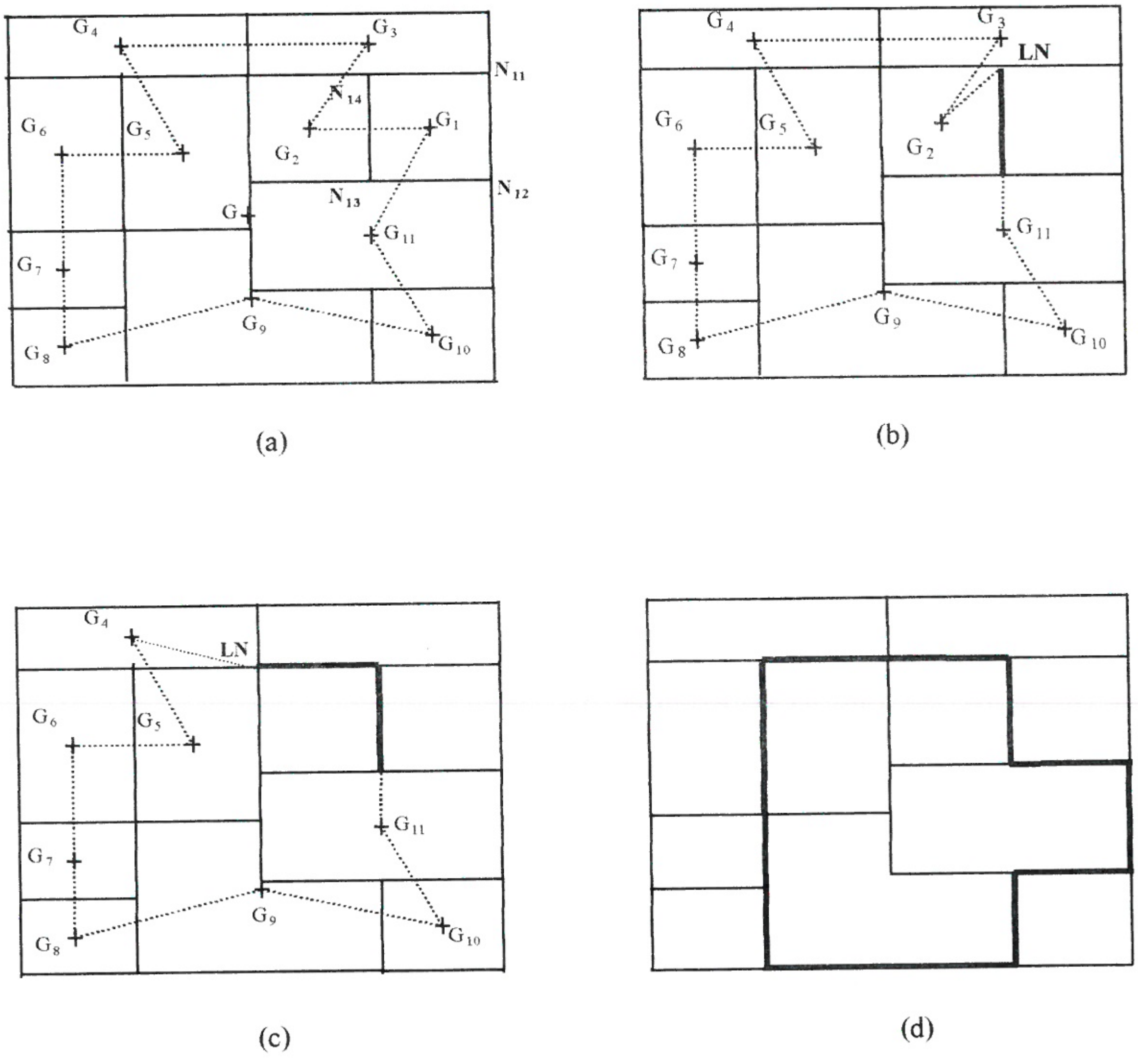
2.2 Determination of the Final Solution

Any tabu algorithm depends on the initial solution and the neighbor search heuristic. The proposed procedure starts with an initial loop, which results from the previous Algorithm 1. The neighbor search heuristic determines new neighbor solution from a given current solution. Each possible solution S is defined by a set of adjacent lines s_i :

$$S = (s_1, s_2, .., s_{i-1}, s_i, s_{i+1}.., s_d),$$

where each line s_i connects terminal nodes (N_{ik}, N_{il}) of a department D_i.

A neighbor solution S^v of S is driven by taking any line $s_i = [N_{ik}, N_{il}]$ assigned to department D_i in the current solution and by replacing it by



(a)
(b)
(c)
(d)

Figure 2. Determination of the Initial Loop

another line $s_i^v = [N_{il}, N_{ik}]$ complementary of s_i in the same department:

$$S^v = (s_1, s_2, \ldots, s_{i-1}, s_i^v, s_{i+1}, \ldots s_d).$$

A solution S^v is admissible if it contains at least one segment of every department. The evaluation of S^v consists in determining the length loop corresponding to this solution. If the efficiency has increased, the new solution is then temporarily adopted and used as a starting point for a new test. Otherwise, one returns to the previous configuration. A common criterion used to stop the process search is the maximal number N_{max} of iterations performed without any improvement of the best found solution S*. An algorithmic description of this procedure is given below.

Algorithm 2: tabu search method

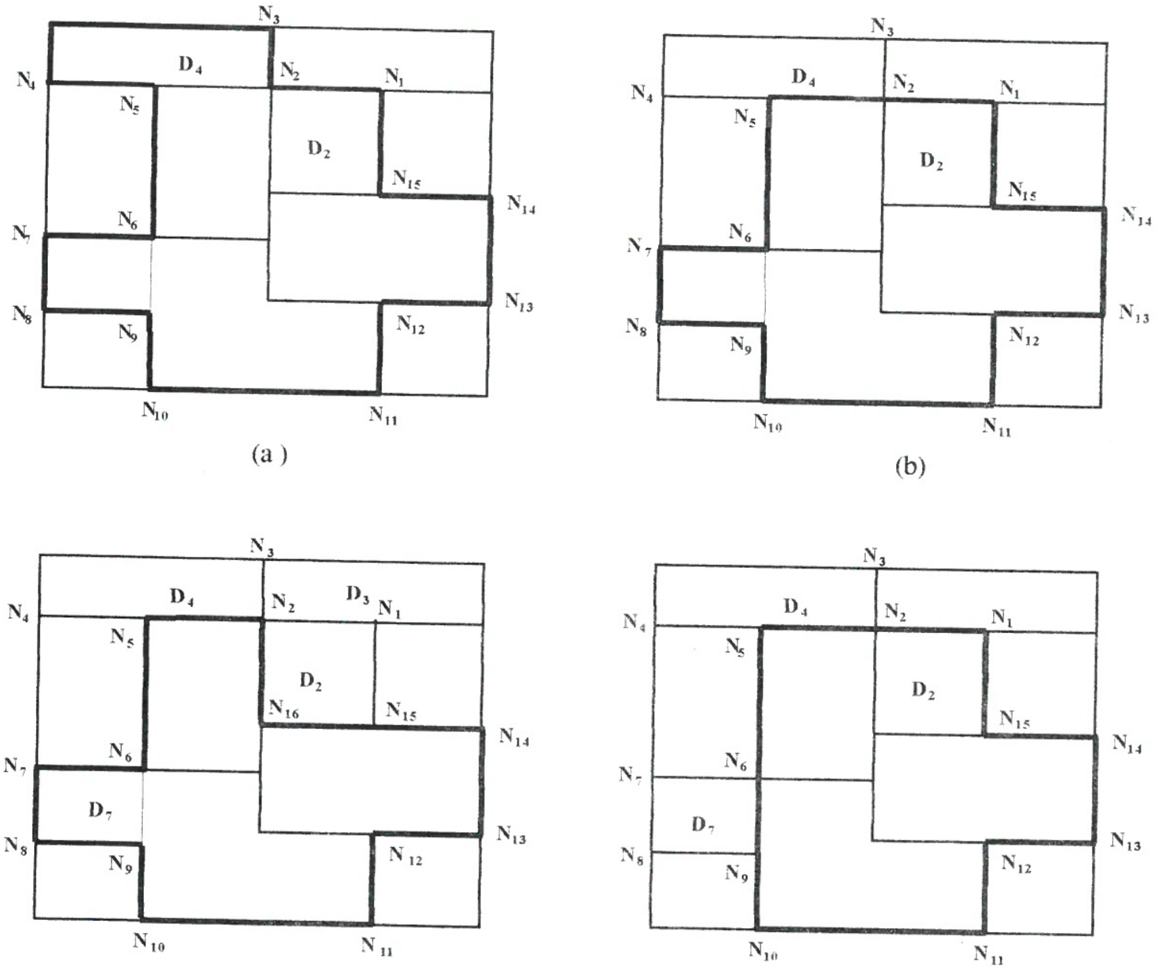
```
Initialize the tabu list
Generate the initial solution $S_0$ by application of Algorithm 1
Initialize the algorithm solution S* and the current solution S to $S_0$;
While Niter $\leq N_{max}$ do
    Niter $\leftarrow$ Niter + 1
    BV $\leftarrow \infty$
    For all candidate move do
        If the candidate move does not belong to the tabu list then
            Determine a neighbor solution $S^v$ of the current solution S
            and verify its admissibility
            MV $\leftarrow L(S^v) - L(S)$
            if MV < BV then
                BV $\leftarrow$ MV
                $S' \leftarrow S^v$
            end if
        end if
    end for
    Update tabu list T;
    if $L(S') < L(S^*)$ then
        $S^* \leftarrow S'$
        $S \leftarrow S'$;
end while
```

To illustrate the procedure steps, consider the example depicted in Figure 3. The corresponding loop of one intermediate solution, which can be characterized by a set of nodes N_i (i=1..15), is shown in Figure 3a. From this loop, a neighbor solution can be obtained by the complementary $s_4 = [N_5, N_2]$ of the segment $s_4^v = [N_2, N_3, N_4, N_5]$ in department D_4. This new solution is admissible, and the length of the corresponding loop is smaller than the previous one (step (b)). It will then be selected for the next test. The transition to step (c) results from a substitution in department D_2 of $s_2 = [N_{15}, N_1, N_2]$ by its complementary $s_2^v = [N_{15}, N_{16}, N_2]$. This solution is not admissible since the loop does not contain any segment of department D_3. Then one has to return to the solution of step (b). The solution obtained at step (d) is the best since no improvement of this solution can be obtained during the next iterations. We can note in this example that the latter solution has also been obtained directly by applying Algorithm 1.

3. Tandem Configuration

In this Section, the design of the tandem configuration concerns an operational layout facility of departments which has been previously considered. The problem consists in establishing guide paths with several non-overlapping unidirectional loops. The main objective is to reduce the complexity of the traffic control function by the minimization of parts flow between the different loops. To configure the AGV tandem layout, a system would be at first stage partitioned into production zones on the basis of a data process plan. It would result from the aggregation of departments that present, from the flow viewpoint, a strong interaction in every loop. The flow part allows therefore to determine logical interactions that may exist between the different departments. In case of an already functional facility, the difficulty of partitioning hangs on the configuration of departments. If this configuration has been driven from the flow nature, the structure of the guide path would be easy to establish, as each group production were served through a loop. In adverse, if the layout configuration has not been made on the basis of the flow nature, or if no form of flow is dominant, the operational performances would not be sensitive to the designed flow path.

On the other hand, a partition based only on the volume flow between departments can lead inevitably to the isolation of some departments. For example, consider the layout shown in Figure 1. If departments 2, 4 and 11 present a strong interaction in the sense of the flow to form a group, department 1 is constrained to be isolated and it would be impossible to assign it to another group. Thus one must avoid generation of groups which isolate one or more departments. This can be accomplished through the analysis of all possibilities and their feasibility as proposed by Boser and Srinivansan [Bozer 92], but it would require an important computing time for problems with several departments. In our approach, we propose the application of the clustering method for partitioning of departments into zones. The clustering method proceeds by successive aggregations of elements (herein departments) two by two according to the value of their similarity coefficient [Kusiak 88]. This method is flexible, since the similarity coefficient can be defined to incorporate manufacturing data.



(a) (b)

(c) **Figure 3. Illustration of Tabu Method Steps** (d)

3.1 The Procedure of Partitioning

In our approach, the production data and distances between departments should be incorporated at an early stage of the partitioning process. The considered production parameters are those of part routing sequence and part average production volume. A routing sequence of a part determines departments which the part is sequentially processed on. Based on these parameters, the similarity coefficient between departments D_i and D_j is expressed mathematically as follows:

$$S_{ij} = F_{ij}/D_{ij} \qquad (1)$$

where D_{ij} and F_{ij} are respectively the distance and the flow volume between departments D_i and D_j.

As the similarity coefficient is proportional to the flow and conversely proportional to the distance between departments, a raised value is therefore attributed to a pair of departments having a large number of visits of products, and being localized in the same proximity.

From a given parts process plan, we determine the *from-to* material flow between departments D_i and D_j by:

$$f_{ij} = \sum_{k=1}^{N} n_{ijk} \times \tau_k \qquad (2)$$

with

$$n_{ijk} = \begin{cases} 1 & \text{if trip i-j is included in production routing of part k} \\ 0 & \text{otherwise} \end{cases} \qquad (3)$$

and τ_k is the production rate of part k.

As the flow matrix f_{ij} is non-symmetrical, the term characterizing the flow volume in the expression of the similarity coefficient is then defined by:

$$F_{ij} = \left(f_{ij} + f_{ji}\right)/2 \qquad (4)$$

3.2 Example

To illustrate the proposed tandem AGVS design, the layout of Figure 1 is considered as a facility layout. The process plan data are given in Table 1. Each department D_i is characterized by the spatial coordinates (X_i, Y_i) of its centroid. The considered distance is given by :

$$D_{ij} = |X_i - X_j| + |Y_i - Y_j| \qquad (6)$$

The coordinates of each department are shown in Table 2.

Table 1. Process Plan

Part type	Production rate	Production routing
1	0.30	4-6-5-11-10-1-3
2	0.20	4-6-5-9-5-2-1-3
3	0.05	4-6-9-11-2-1-3
4	0.15	4-6-7-8-11-2-3
5	0.30	4-6-5-10-1-3

Table 2. Coordinates of Departments

Department D_i		1	2	3	4	5	6	7	8	9	10	11
Coordi-nates (m)	X_i	35	25	30	10	15	5	5	5	18.33	35	28.28
	Y_i	16.5	12.5	22	22	15	15	7.5	2.5	5.33	3	9.57

The hierarchical clustering method necessitates establishing a similarity measure between groups that will be constituted during the application of the procedure. Among the different expressions proposed in the literature [Heragu 94], we have chosen the measure of association between two groups, G_p and G_q, which is defined as:

$$S(G_p, G_q) = \underset{(D_i, D_j) \in G_p \times G_q}{\text{Max}} \{S_{ij}\} \qquad (5)$$

To determine the similarity coefficient, we transform the data shown in Table 1 into an overall flow matrix $[f_{ij}]$ by using Equations (2-4). The evaluation of similarity coefficients between the different departments is reported in Table 3.

For the partitioning of departments, one begins by grouping the two departments that have the largest value of the similarity coefficient. This value is 83; it is realized for the first group constituted by departments D_4 and D_6. At this step, one obtains the following partition:

Table 3. Similarity Coefficients Between Departments

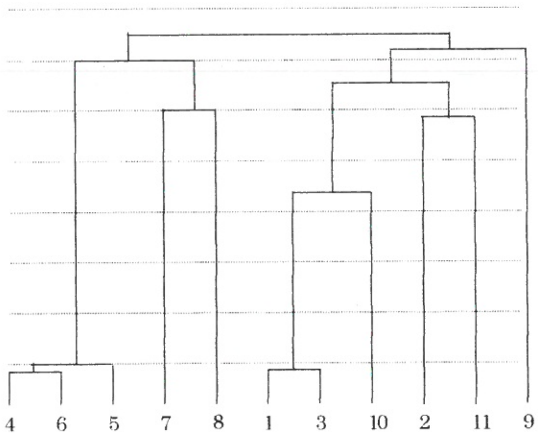
S_{ij}	**1**	2	3	4	5	6	7	8	9	10	11
1			81								
2	18		10								31
3											
4						83					
5		16							15	9	13
6					80		20		2		
7								30			
8											5
9											17
10	44										
11										23	

$\{\{D_4, D_6\}, \{D_1\}, \{D_2\}, \{D_3\}, \{D_5\}, \{D_7\}, \{D_8\}, \{D_9\}, \{D_{10}\}, \{D_{11}\}\}$

It is necessary then to apply the relationship (5) which gives the similarity measure between elements of this partition. The maximal value of this measure is reached for elements $\{D_4, D_6\}$ and D_5. The new partition is then:

$\{\{D_4, D_6, D_5\}, \{D_1\}, \{D_2\}, \{D_3\}, \{D_7\}, \{D_8\}, \{D_9\}, \{D_{10}\}, \{D_{11}\}\}$

This aggregation procedure is repeated until one group consisting of all departments is obtained. A graphical representation of this classification is shown in Figure 4. Horizontal lines represent the similarity coefficients (threshold values) which department zones merge on.



Figures 4. Dendogram of Departments

The cluster procedure described above provides one basis for designing loops in tandem AGVS. It forms only the group of departments corresponding to each loop. Generally, the different groups are not independent since it happens that some parts may require processing on departments in two or more groups. The next phase of AGV tandem configuration is more complicated by the fact that for a given partition of departments, we do not know where the transfer points are located until we know the configuration of the guide paths. There are several feasible loops which vary according to the transfer point location. It is therefore necessary to decide on the links between loops. Once the decision is made, it comes straightforward to find the optimal loop for each group by applying Algorithm 2.

For instance, if one seeks a configuration with four loops (B_1, B_2, B_3, B_4), this classification gives the following attributions:

$G_1=\{D_4, D_5, D_6\} \rightarrow B_1$

$G_2=\{D_1, D_3, D_{10}, D_{11}, D_2\} \rightarrow B_2$

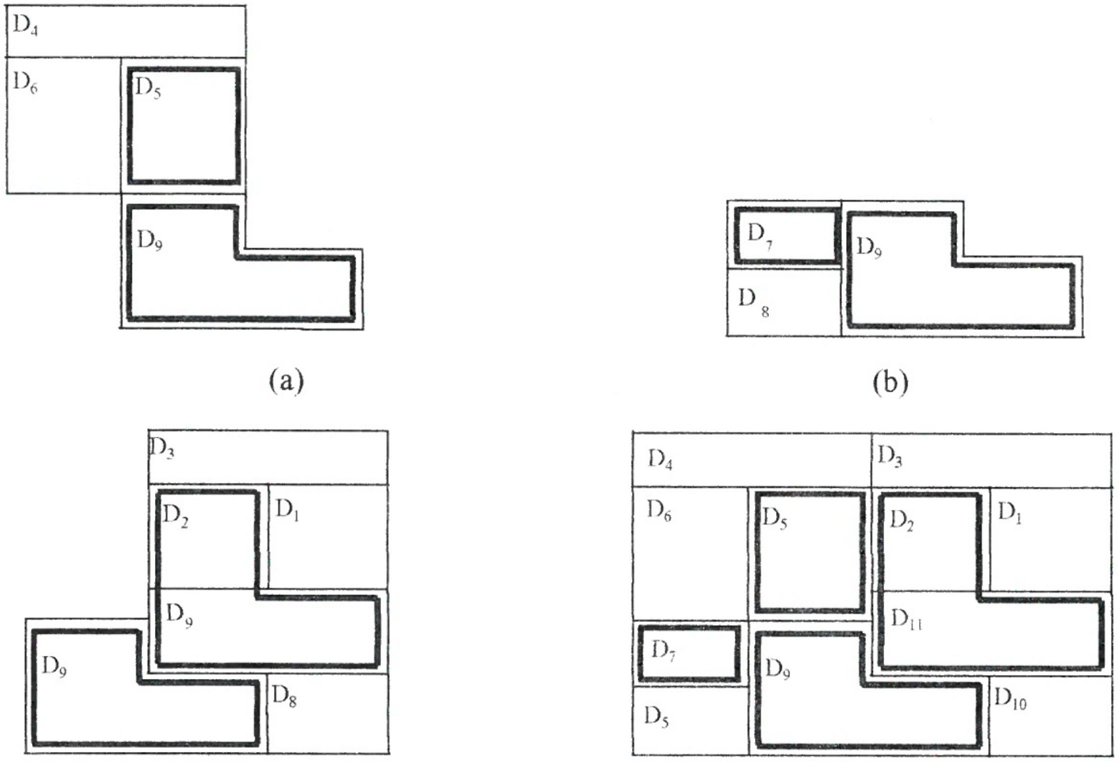
$G_3=\{D_7, D_8\} \rightarrow B_3$

$G_4=\{D_9\} \rightarrow B_4$.

The transfer of parts between G_1 and G_4 can be accomplished through a direct connection between them or bypass of other groups. As group G_4 contains only one department, the corresponding loop B_4 is formed around it. Assume that group G_4 will serve as transition for the other groups. Then it remains to design the loops B_1, B_2 and B_3. For this, loop B_4 should be considered as a department which is annexed to the corresponding groups. Algorithm 1 is then applied to

$\{D_4, D_5, D_6\} \cup \{D_9\}$, $\{D_1, D_3, D_{10}, D_{11}, D_2\} \cup \{D_9\}$ and $\{D_7, D_8\} \cup \{D_9\}$ respectively.

The solution for the latter groups is shown in Figure 5 (a), (b) and (c). The combination of these solutions leads to the tandem configuration of Figure 5 (d).



(a) (b)

(c) (d)

Figure 5. Tandem Configuration with 4 Loops

4. Conclusion

In this paper, a design procedure of the single loop flow path for a facility layout organized in departments is presented. The procedure is based on the use of tabu method whose initial solution has been determined for geometrical considerations. This approach distinguishes through its simplicity for implementation and its capability to cope with a large number of departments. For the AGVS tandem configuration, a new partitioning procedure based on the hierarchical clustering method is proposed. The similarity coefficient is a function of two parameters: the flow volume and distances between departments. This approach lets us the freedom to choose the number of loops. Finally, we have attempted to describe the issues that occur in the design of the flow guide path related to each department group through a hypothetical layout facility. A first difficulty is linked to the physical department configuration. A configuration based on the nature of the part flow would translate into an appropriate partition of departments where each production group would correspond to a loop. A second difficulty concerns the transit point location between loops. These two important issues of the AGVS tandem design should be further investigated.

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