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SELECTION OF OPTIMUM FLOW PATH (OFP) FOR AGVS IN FMS USING 0-1 INTEGER PROGRAMMING

Debamalya Banerjee and Dibyendu Barai

Production Engg. Dept., Jadavpur University, Kolkata-700 032, India.

ABSTRACT

Automated Guided Vehicles (AGVs) are used currently for transportation of materials in pre-determined paths in Flexible Manufacturing Systems (FMSs). The guide path layout for an AGV system is a critical component in the overall design of FMSs. Not only does it influence the total distance traveled by vehicles but also affect the vehicle requirements and space utilization of the FMS. In this study, the problem of optimum flow path selection of AGVs in an FMS has been addressed. The situation has been modeled and solved as a 0-1 Linear Integer Program with the objective of minimizing the total distance traveled by each individual AGV. Then the OFP has been found out with the help of a general linear optimization computer software package, named LINDO.

Keywords: AGV, 0-1 Integer Programming, LINDO.

1. INTRODUCTION

The material handling system (MHS) is the backbone of a Flexible Manufacturing System. It connects various production functions and regulates horizontal part movement. From different types of material handlers available for an FMS the Automated Guided Vehicle System (AGVS) is the most adaptable and capable one. AGVS comprises several microprocessor controlled, battery powered, automatically steered, driverless vehicles, designed to follow defined pathways under the control of a computer [1]. Since their introduction in 1955, the number of areas of application and variations in types of AGVs has increased significantly. AGVs are widely used in automated material handling systems and even in container terminals to transport containers [2,3,4,5]. These AGVs belong to Automated Guided Vehicle System (AGVS). In an AGV system several parts can be distinguished, namely the vehicles, the transportation network, the physical interface between the production/storage system and control system. The AGV system itself might be a part of a larger system, for example, of an intelligent manufacturing system.

1.1 Automated Guided Vehicles (AGVs)

Automated Guided Vehicles (AGVs), e.g., driverless trains, pallet trucks, unit load carriers etc. will certainly play an important role in automating the future manufacturing environment, because they are the most flexible means to interconnect all important locations of the factory floor for the horizontal movement of materials.

Unlike other more conventional material handling devices, an AGV can select its own path from among many pre-defined guide paths to reach a designated workstation or a warehouse. Some AGVs can alter dynamically their route based on congestion information and track availability. Some are capable of automatically loading and unloading unit loads. Usually AGVs are interfaced with other automated systems to achieve full benefits of integrated as well as flexible automation.

1.2 Functions To Be Performed To Operate An AGVS Successfully

There are several functions that must be performed to operate any Automated Guided Vehicle System (AGVS) successfully. These functions are—

a) Vehicle guidance,
b) Routing,
c) Traffic control and Safety, and,
d) System Management.

2. DESIGN AND OPERATIONAL ISSUES IN AN AGV BASED MATERIAL HANDLING SYSTEM

The power and smaller size of microprocessor and sensing devices have given AGVs the capability of operating autonomously, even in complex transport applications [6].**.** The design of material handling system using AGVs must address the following issues:

a) Number of vehicles required
b) The layout of AGVS tracks in the shop
c) The traffic flow pattern along the AGVS tracks

d) Determination of pick up and drop off points in the layout
e) AGV dispatching rules
f) Traffic management prediction and avoidance of collision and deadlocks
g) AGV routing
h) Positioning of the idle AGVs

2.1 Review Of Past Research On Guide Path Layout Design

AGVs can travel along fixed guide paths, which are indicated by, for example, wires embedded on the floor. A flow path connects machines, processing centres, stations and other fixed structures along aisles. This layout is usually represented by a directed network in which aisles intersections and pick-up and delivery points are considered as nodes and the guide path between nodes along which the AGVs travel are considered as arcs. Directed arcs indicate the direction of travel of AGVs through the aisle.

While designing the layout for a particular manufacturing system different researchers worked out different types of layouts. These are presented below—

a) Conventional: In this type of layout one or more AGVs are used and AGVs move from one station to another station along the arcs. One AGVmay flow from one zone to another zone i.e. there is no control zone.

b) Tandem Configuration: A Tandem Configuration flow path design consists of non-overlapping single vehicle loops with load transfer stations in between. To transport a load from its origin to its destination, more than one AGV are required. At the end of each zone the load is transferred from one AGV to another.

c) Segmented flow configuration: The layout of the flow path can also be designed by using segmented flow approach. Mutually independent zones are divided in non-overlapping single AGV. Each segment is served by a single AGV, which can travel in both directions on the segments. Between the end of the two segments, stations are located where the loads are transferred from one AGV to another AGV.

d) Single loop Layout: In a single loop layout AGVs move in a loop. This is fixed sequence of processing centres, which need to be visited. Single loop layouts are comparable to networks for equipment like conveyors.

Again depending upon the direction of flow of AGV along an arc joining two nodes and no. of paths (i.e. arcs) existing between nodes, we get—

Unidirectional layout: This is the system in which the flow between any two adjacent nodes is only in one direction.

Bi-directional layout: In this type of layout the flow along any segment is in both the direction.

Multiple lane layout: In the above two examples a single lane is existing between two adjacent nodes. To have the advantages of the systems, multiple lane guide paths are used. In this type of layout, vehicles flow in both directions along separate arcs, which are laid side by side.

Gaskins and Tanchoco were the pioneers, who worked on the guide path design of the AGVS with unidirectional arcs in their paper [7]. The problem has been presented as a network and formulated as 0-1 integer programming model. The objective was to minimize the total loaded transportation distance of AGVs. The solution of the model indicated the optimal direction of each arc. For practical problem, the number of variables and related computation time increased enormously. Therefore **Kaspi and Tanchoco** describe a model with extra constraints and gave a computational efficient procedure, namely branch and bound procedure. It has been concluded that, for large sized problem with 10-16 intersections, a better computational performance is obtained by applying their approach instead of the model of **Kaspi and Tanchoco** . Also based on the same model (**of Kaspi and Tanchoco**) is the work of **Sinriech and Tanchoco** [8]. They proposed a branch and bound method, which has to deal with a smaller set of nodes in the flow path network. As a result the branch and bound method has been sped up.

3. OBJECTS AND SCOPE OF PRESENT STUDY

In the present research the layout for Automated Guided Vehicle System operating through 3 departments has been designed and 0-1 integer programming has been chosen to solve the problems. The layout used here of conventional type and all the arcs are of unidirectional. Though many researchers have worked on layout design problem using 0-1 integer programming but there exists a difference between the present research work with that of previous ones. In all the previous works every researcher developed their own algorithm to solve their problems, e.g. Multipurpose Optimization System Computer Package (MOSCP) used by Gaskins and Tanchoco (1987). Goetz and Egbelu [9] used Mathematical Programming Systems Extended (MPSX). In this research work 0-1 integer programming has been solved using *LINDO* software package.

4. GENERAL FORMULATION OF 0-1 INTEGER PROGRAMMING

General formulation based upon the following definitions of the notation. is stated below:

1. Decision Variables

$$X_{i,j}= \begin{cases} 1 & \text{if the direction from node } i \text{ to node } j \text{ is included in the final layout} \\ 0 & \text{if otherwise (i.e. not included in the final network)} \end{cases} \quad (1)$$

2. Parameters

$d_{m,n,p}$= Distance from node m to node n using path p
$f_{m,n}$ = Flow intensity from node m to node n
n_p = Total number of arcs in the path p

3. Objective function

Minimize

$$T=\sum_m \sum_n f_{m,n} \sum_p \left[d_{m,n,p} X_{m,q} X_{r,n} \right]$$

$$q, r \in p; \forall f \quad (2)$$

Linearization of non-linear product terms:

The objective function presented above contains some product terms of the form of $X_{i,j}X_{k,l}$. In the general model with multiple load pick-up/delivery station consideration, the product terms of two and more binary variables will be encountered. A function of the form

$$f = \ldots\ldots\ldots + c_k X_s X_t X_q + c_t X_a X_b + \ldots\ldots \quad (3)$$

where X_i=0 or 1 and c_t is a constant, can be easily linearized through the use of the additional variable and constraints. Thus, the nonlinear function f above after linearization converts to the following system of the function and constraints.

$$f = \ldots\ldots + c_k X_{s,t,q} + c_t X_{a,b} + \ldots\ldots\ldots \quad (4)$$

Subject to

$$X_s + X_t + X_q - X_{s,t,q} \le 2 \quad (5)$$

$$X_a + X_b - X_{a,b} \le 1 \quad (6)$$

$$-X_s - X_t - X_q + 3X_{s,t,q} \le 0 \quad (7)$$

$$-X_a - X_b + 2X_{a,b} \le 0 \quad (8)$$

$$X_s, X_t, X_q, X_{s,t,q}, X_a, X_b, X_{a,b} = 0 \text{ or } 1 \quad (9)$$

Using this form of conversion, the objective function becomes,

Minimize

$$T = \sum_m \sum_n f_{m,n} \sum_p \left[d_{m,n,p} X_{m,q,r,n} \right] \quad (10)$$

Subject to

$$\left.\begin{array}{l} X_{m,q} + X_{r,n} - X_{m,q,r,n} \le 1 \\ -X_{m,q} - X_{r,n} + 2X_{m,q,r,n} \le 0 \\ X_{m,q}, X_{r,n}, X_{m,q,r,n} = 0 \text{ or } 1 \end{array}\right\} \forall f_{m,n}, \forall p$$

Constraints

a) Constraints to ensure unidirectionality of network $X_{ij} + X_{ji} = 1$ for all adjacent node pair i and j

b) Constraints to ensure when the beginning and ending arcs in a path are selected, all the intermediate

c) arcs are also selected $(n_p-2)X_{m,q} + (n_p-2)X_{rn} - \sum_{\forall i, j \ne m,n} X_{i,j} \le (n_p - 2)$ in the path p

d) Constraints to ensure at least one entry arc to each node $\sum_{\forall i} X_{i,j} \ge 1$ $\forall j$; i is adjacent to j

e) Constraints to ensure at least one exit arc from each node

$$\sum_{\forall j} X_{i,j} \ge 1 \qquad \forall i \text{ ; j is adjacent to i}$$

f) An optimal constraint to force flow balance at four-way node is given by

$$\sum_j X_{i,j} \ge 2 \text{ j is a 4 way node } \forall i \text{ ; adjacent to j} \quad (11)$$

4.1 Determination Of Optimal Flow Path Layout (OFL) Of An AGVS Operating Through Three Departments

a) Problem description:

This manufacturing facility consists of three departments. Material flow frequencies from one department to other are shown in table 1. The initial layout of the problem is shown in the fig 1(a). The corresponding node and arc diagram of the corresponding layout is shown in fig 1(b). From the diagrams and tables it is clear that layout consists of 11 nodes and 13 arcs. Dimensions of each department are taken as 10 by 10 units. The nodes also labeled by P_1 and D_1 represent the load pick-up and drop off points respectively. In some departments P_1 and D_1 are taken as same point.

For the ease of computation, number of pick-up/delivery points in each department has been taken as one and all the routes are unidirectional.

Table 1: From To Chart of Material Flow Representing $F_{m,N}$ Values

From \ To	Dept. 1	Dept.2	Dept.3
Dept.1	-	70	70
Dept.2	50	-	100
Dept.3	80	30	-

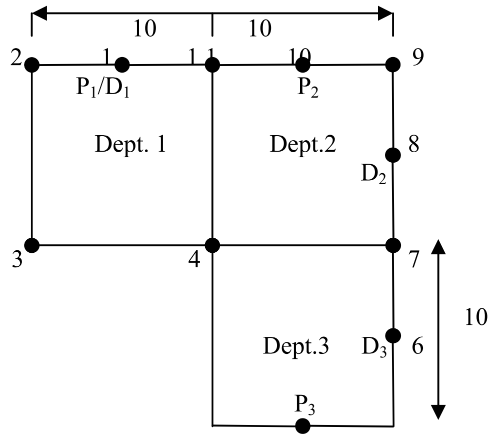

Figure 1(a): Initial Layout Of The Facility

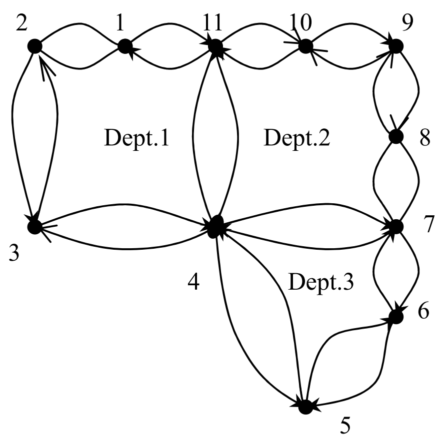

Fig 1(b): Node And Arc Layout Of The Facility (Initial)

b) Formulation of the problem:

To develop the objective function, our main criterion is to minimize the total distance travelled. For this reason, the available alternatives are first found and then the paths of minimum distance are selected. Say, for example when material flows from department 1 to department 2, then it can leave the pick-up point P_1 on two ways, either $X_{1,2}$ or $X_{1,11}$ and correspondingly it can enter the drop-off location in two ways which is either $X_{9,8}$ or $X_{7,8}$. So there are four possible combination, which are $X_{1,11}X_{9,8}$ $X_{1,11}X_{7,8}$ $X_{1,2}X_{9,8}$ $X_{1,2}X_{7,8}$. For each of the path there is a shortest path. Say for example, for the combinations, the lengths of the shortest paths are given as 20, 30, 50 and 40 respectively. So the objective function is given as

$$\text{Min } T=70(20\, X_{1,11}X_{9,8}+30\, X_{1,11}X_{7,8}+50\, X_{1,2}X_{9,8}+40X_{1,2}X_{7,8})$$

Subject to

Constraint equations to convert non-linearity into linearity

$X_{1,11}+X_{9,8}- X_{1,11,9,8} \le 1$; $-X_{1,11}-X_{9,8}+2X_{1,11,9,8} \le 0$;
$X_{1,11}-X_{9,8}+2X_{1,11,9,8} \le 1$; $-X_{1,11}+X_{7,8}+2X_{1,11,7,8} \le 1$;
$X_{1,2}+X_{9,8}- X_{1,2,9,8} \le 0$; $-X_{1,2}-X_{9,8}-2X_{1,2,9,8} \le 1$; $X_{1,2}+X_{7,8}-X_{1,2,7,8} \le 0$; $-X_{12}-X_{7,8}+2X_{1,2,7,8} \le 1$;
$X_{10,11}+X_{5,6}-X_{10,11,5,6} \le 0$; $-X_{10,11}-X_{5,6}-2X_{10,11,5,6} \le 1$;
$X_{10,11}+X_{7,6}-X_{10,11,7,6} \le 0$; $-X_{10,11}-X_{7,6}+2X_{10,11,7,6} \le 1$;
$X_{10,9}+X_{7,6}-X_{10,9,7,6} \le 0$; $-X_{10,9}-X_{7,6}+2X_{10,9,7,6} \le 1$;
$X_{10,9}+X_{5,6}-X_{10,9,5,6} \le 0$; $-X_{10,9}-X_{5,6}+2X_{10,9,5,6} \le 1$;
$X_{5,4}+X_{11,1}-X_{5,4,11,1} \le 0$; $-X_{5,4}-X_{11,1}+2X_{5,4,11,1} \le 1$;
$X_{5,4}+X_{2,1}-X_{5,4,2,1} \le 0$; $-X_{5,4}-X_{2,1}+2X_{5,4,2,1} \le 1$;
$X_{5,6}+X_{11,1}-X_{5,6,11,1} \le 0$; $-X_{5,6}-X_{11,1}+2X_{5,6,11,1} \le 1$;
$X_{5,6}+X_{2,1}-X_{5,6,2,1} \le 0$; $-X_{5,6}-X_{2,1}+2X_{5,6,2,1} \le 1$;
$X_{1,2}+X_{7,6}-X_{1,2,7,6} \le 0$;$-X_{1,2}-X_{7,6}+2X_{1,2,7,6} \le 1$;
$X_{1,2}+X_{5,6}-X_{1,2,5,6} \le 0$; $-X_{1,2}-X_{5,6}+2X_{1,2,5,6} \le 1$;
$X_{1,11}+X_{7,6}-X_{1,11,7,6} \le 0$; $-X_{1,11}-X_{7,6}+2X_{1,11,7,6} \le 1$;
$X_{1,11}+X_{5,6}-X_{1,11,5,6} \le 0$; $-X_{1,11}-X_{5,6}+2X_{1,11,5,6} \le 1$;
$X_{10,11}+X_{11,1}-X_{10,11,11,1} \le 0$ $-X_{10,11}-X_{11,1}+2X_{10,11,11,1} \le 1$;
$X_{10,11}+X_{2,1}-X_{10,11,2,1} \le 0$; $-X_{10,11}-X_{2,1}+2X_{10,11,2,1} \le 1$;
$X_{10,9}+X_{11,1}-X_{10,9,11,1} \le 0$; $-X_{10,9}-X_{11,1}+2X_{10,9,11,1} \le 1$;
$X_{10,9}+X_{2,1}-X_{10,9,2,1} \le 0$; $-X_{10,9}-X_{2,1}+2X_{10,9,2,1} \le 1$;
$X_{5,4}+X_{7,8}-X_{5,4,7,8} \le 0$; $-X_{5,4}-X_{7,8}+2X_{5,4,7,8} \le 1$;
$X_{5,4}+X_{9,8}-X_{5,4,9,8} \le 0$; $-X_{5,4}-X_{9,8}+2X_{5,4,9,8} \le 1$;
$X_{5,6}+X_{7,8}-X_{5,6,7,8} \le 0$; $-X_{5,6}-X_{7,8}+2X_{5,6,7,8} \le 1$;
$X_{5,6}+X_{9,8}-X_{5,6,9,8} \le 0$; $-X_{5,6}-X_{9,8}+2X_{5,6,9,8} \le 1$;

(12)

Similarly when material flows from Dept.1 to Dept.3, Dept.2 to Dept.1, Dept.2 to Dept.3, Dept.3 to Dept.1, Dept.3 to Dept.2 the corresponding objective functions are obtained. And these are summed up to get the overall objective function. Then non-linear parts are transferred into linearity. Then the objective function becomes as follows—

Constraints to ensure unidirectional network

$X_{1,2}+X_{2,1}=1$; $X_{2,3}+X_{3,2}=1$; $X_{3,4}+X_{4,3}=1$; $X_{4,5}+X_{5,4}=1$; $X_{4,7}+X_{7,4}=1$; $X_{4,11}+X_{11,4}=1$;
$X_{5,6}+X_{6,5}=1$; $X_{6,7}+X_{7,6}=1$; $X_{7,8}+X_{8,7}=1$; $X_{8,9}+X_{9,8}=1$; $X_{9,10}+X_{10,9}=1$; $X_{10,11}+X_{11,10}=1$;
$X_{1,11}+X_{11,1}=1$; (13)

Constraints to prevent a group of nodes from becoming sink nodes

$X_{1,11}+X_{3,4}=1$; $X_{11,1}+X_{4,3}=1$; $X_{10,11}+X_{8,7}=1$; $X_{11,10}+X_{7,8}=1$; $X_{5,4}+X_{6,7}=1$; $X_{4,5}+X_{7,6}=1$; (14)

Constraint (special) for a node, which is intersection of 4 arcs

$X_{11,4}+X_{3,4}+X_{7,4}+X_{5,4}\geq 2$ (15)

Constraints to ensure inclusion of intermediate arcs in a particular path

$2X_{1,11}+2X_{9,8}-X_{11,10}-X_{10,9}\leq 2$; $2X_{1,11}+2X_{7,8}-X_{11,4}-X_{4,7}\leq 2$;
$5X_{1,2}+5X_{9,8}-X_{2,3}-X_{3,4}-X_{4,11}-X_{11,10}-X_{10,9}\leq 5$;
$3X_{1,2}+3X_{7,8}-X_{2,3}-X_{3,4}-X_{4,7}\leq 3$;
$2X_{10,11}+2X_{5,6}-X_{11,4}-X_{4,5}\leq 2$; $2X_{10,11}+2X_{7,6}-X_{11,4}-X_{4,7}\leq 2$;
$2X_{10,9}+2X_{7,6}-X_{11,4}-X_{4,7}\leq 2$;
$4X_{10,9}+4X_{5,6}-X_{9,8}-X_{8,7}-X_{7,4}-X_{4,5}\leq 4$; $X_{4,5}+X_{11,1}-X_{4,11}\leq 1$;
$2X_{5,4}+2X_{2,1}-X_{4,3}-X_{3,2}\leq 2$;
$3X_{5,6}+3X_{11,1}-X_{6,7}-X_{7,4}-X_{4,11}\leq 3$;
$4X_{5,6}+4X_{2,1}-X_{6,7}-X_{7,4}-X_{4,3}-X_{3,2}\leq 4$;
$3X_{1,2}+3X_{7,6}-X_{2,3}-X_{3,4}-X_{4,7}\leq 3$;
$3X_{1,2}+3X_{5,6}-X_{2,3}-X_{3,4}-X_{4,5}\leq 3$;
$2X_{1,11}+2X_{7,6}-X_{11,4}-X_{4,7}\leq 2$; $2X_{1,11}+2X_{5,6}-X_{11,4}-X_{4,5}\leq 2$;
$3X_{10,11}+3X_{2,1}-X_{11,4}-X_{4,3}-X_{3,2}\leq 3$;
$4X_{10,9}+4X_{11,1}-X_{9,8}-X_{8,7}-X_{7,4}-X_{4,11}\leq 4$;
$5X_{10,9}+5X_{2,1}-X_{9,8}-X_{8,7}-X_{7,4}-X_{4,3}-X_{3,2}\leq 5$;
$X_{5,4}+X_{7,8}-X_{4,7}\leq 1$; $3X_{5,4}+3X_{9,8}-X_{4,11}-X_{11,10}-X_{10,9}\leq 3$;
$X_{5,6}+X_{7,8}-X_{6,7}\leq 1$;
$5X_{5,6}+5X_{9,8}-X_{6,7}-X_{7,4}-X_{4,11}-X_{11,10}-X_{10,9}\leq 5$; (16)

Constraints to ensure at least one entering node

$X_{2,1}+X_{11,1}\geq 1$; $X_{1,2}+X_{3,2}\geq 1$; $X_{2,3}+X_{4,3}\geq 1$;
$X_{3,4}+X_{11,4}+X_{7,4}+X_{5,4}\geq 1$; $X_{4,5}+X_{6,5}\geq 1$; $X_{5,6}+X_{7,6}\geq 1$;
$X_{6,7}+X_{4,7}+X_{8,7}\geq 1$; $X7_{8,7}+X_{9,8}\geq 1$; $X_{8,9}+X_{10,9}\geq 1$;
$X_{9,10}+X_{11,10}\geq 1$; $X_{10,11}+X_{4,11}+X_{1,11}\geq 1$; (17)

Constraints to ensure at least one outgoing arc from a node

$X_{1,2}+X_{1,11}\geq 1$; $X_{2,1}+X_{2,3}\geq 1$; $X_{3,2}+X_{3,4}\geq 1$;
$X_{4,3}+X_{4,5}+X_{4,7}+X_{4,11}\geq 1$; $X_{5,4}+X_{5,6}\geq 1$; $X_{6,7}+X_{6,5}\geq 1$;
$X_{7,4}+X_{7,6}+X_{7,8}\geq 1$; $X_{8,7}+X_{8,9}\geq 1$; $X_{9,8}+X_{9,10}\geq 1$;
$X_{10,11}+X_{10,9}\geq 1$; $X_{11,1}+X_{11,4}+X_{11,10}\geq 1$; (18)

END

These statements are needed to ensure that the variables should have integer values only

Int $X_{1,2}$; Int $X_{2,1}$; Int $X_{2,3}$; Int $X_{3,2}$; Int $X_{3,4}$; Int $X_{4,3}$; Int $X_{4,5}$; Int $X_{5,4}$; Int $X_{5,6}$; Int $X_{6,5}$; Int $X_{6,7}$; int $X_{7,6}$; int $X_{4,7}$; int $X_{7,4}$; int $X_{7,8}$; int $X_{8,7}$; int $X_{8,9}$; int $X_{9,8}$; int $X_{9,10}$; int $X_{10,9}$; int $X_{10,11}$; int $X_{11,10}$; int $X_{4,11}$; int $X_{11,4}$; int $X_{1,11}$; int $X_{11,1}$; (19)

c) Discussion on the results:

After solving the above problem as a Linear Programming Problem in the LINDO Software package we get the required solution. To draw the OFL (Optimal Flow path Layout), the variables, which are very important, are shown below with values collected from the solution. These are as follows

$X_{2,1}=1$ (20)
$X_{3,2}=1$ (21)
$X_{4,3}=1$ (22)
$X_{5,4}=1$ (23)
$X_{6,5}=1$ (24)
$X_{7,6}=1$ (25)
$X_{4,7}=1$ (26)
$X_{7,8}=1$ (27)
$X_{8,9}=1$ (28)
$X_{9,10}=1$ (29)
$X_{10,11}=1$ (30)
$X_{1,11}=1$ (31)
$X_{11,4}=1$ (32)

With these values the following layout is obtained:

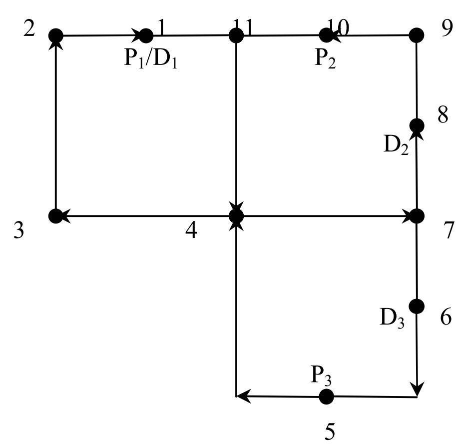

Fig 2: Optimal Flow Path Layout With Directed Arcs

5. CONCLUSIONS

The objective of the research work is to use different developed methodologies to solve the problem of layout design for Automated Guided Vehicles (AGVs) with a very generalized Linear Integer Programming Software Package like LINDO. The same results can be verified by simulating the entire problem.

Unlike mathematical programming, simulation would take into account the travel of unloaded vehicles, blocking, and congestion, but simulation has its own disadvantages. Simulation is not a normative mechanism; it does not provide the optimum solution.

This approach is best suited in environments which are flexible ones, i.e. more specifically as material flow intensity in from-to chart changes, optimal flow path may change. Assuming that the departmental layout and other assumptions do not change, constraints of the mathematical model remain same; all that will change is the coefficients of the objective function.

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