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Quantitative Analysis of AGV System in FMS Cell Layout

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ABSTRACT

Material handling is a specialised activity for a modern manufacturing concern. Automated guided vehicles (AGVs) are invariably used for material handling in flexible manufacturing systems (FMSs) due to their flexibility. The quantitative analysis of an AGV system is useful for determining the material flow rates, operation times, length of delivery, length of empty move of AGV and the number of AGVs required for a typical FMS cell layout. The efficiency of the material handling system, such as AGV can be improved by reducing the length of empty move. The length of empty move of AGV depends upon despatching and scheduling methods. If these methods of AGVs are not properly planned, the length of empty move of AGV is greater than the length of delivery. This results in increase in material handling time which in turn increases the number of AGVs required in FMS cell. This paper presents a method for optimising the length of empty travel of AGV in a typical FMS cell layout.

1. INTRODUCTION

Material handling is an important, yet sometimes overlooked aspect of automation. The estimates of handling cost run as high as two-thirds of the total manufacturing cost[1]. Most of the production time is consumed in handling materials before, during and after the manufacturing. This cost and lead time can be drastically reduced when machining stations are linked by automated material handling devices that are controlled by computerised information system. Flexible manufacturing systems (FMS) provide a solution for this problem by integrating material handling with computer-aided manufacturing. The FMS contains many manufacturing cells. Each cell normally contains one to four production machines and a transfer system, like automated guided vehicles (AGVs) and conveyors for the workpieces and for the tools.

1.1 Automated Guided Vehicle System

The conventional conveyor systems many a times are inadequate to satisfy the requirements of plants where production is carried out through interconnected work cells, and where flexibility and rapid changeover times are of primary importance. Automated guided vehicle (AGV) system offers a viable solution for such needs[2].

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This system is a material handling system that uses independently-operated, self-propelled vehicles that are guided along defined pathways in the floor. They can operate in the range of 10-70 m/min. Ladder configuration contains rungs on which work stations are located. The rungs increase the possible ways of getting from one machine to the next. This reduces the average travel distance, thereby reducing the transfer time between work-stations. The AGVs are particularly used in ladder-type FMS layout as shown in Fig. 1.

several approaches that can be used to represent the material handling problems for visualisation and analysis purpose. Tabular and graphical techniques are quite helpful for visualising the moves. Quantitative approaches can be useful for determining material flow rates, operation times and other aspects of performance in material handling[3-5].

From-to-charts that display information about the material flow are shown in Tables 1 and 2. These charts are prepared for the layout shown in Fig. 3.

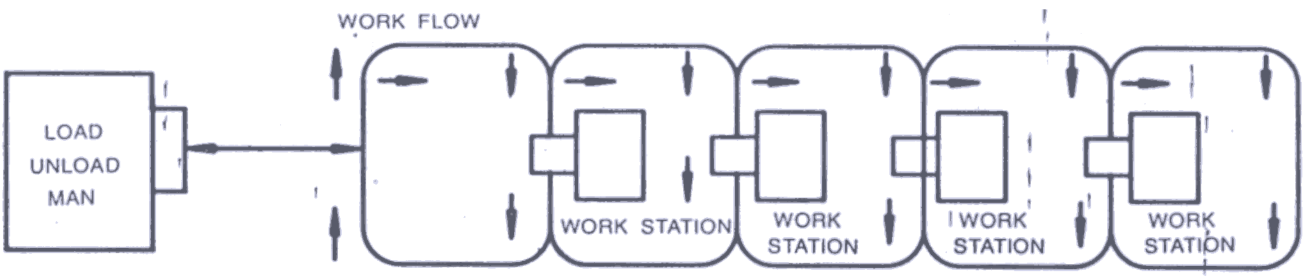

Figure 1. Ladder FMS layout

1.2 Material Handling Analysis Techniques

The planning for a material handling system must begin with an analysis of the materials to be moved. The factors to be considered are the quantity of material to be moved, the rate of flow required, the scheduling of the moves, and the route by which the materials are to be moved. There are

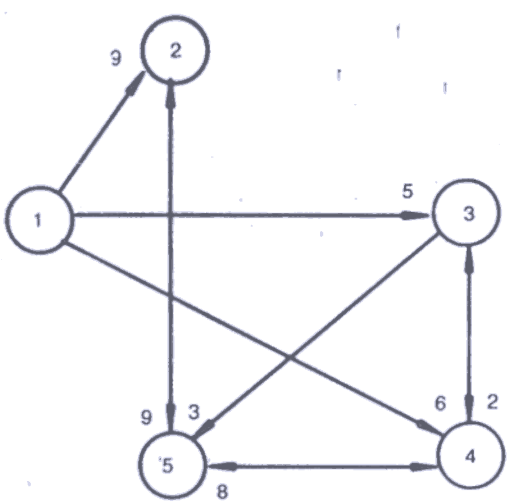

Figure 2. Flow diagram showing material flow between different loading and unloading stations.

Table 1. From-to-chart showing number of deliveries required between different stations in a layout

From	To				
		2	3	4	5
	0	9	5	6	0
2	0	0	0	0	9
3	0	0	0	2	3
4	0	0	0	0	8
5	0	0	0	0	0

Table 2. From-to-chart showing distances between different stations in a layout*

From	To				
		2	3	4	5
	0	60	120	120	NA
2	NA	0	NA	NA	90
3	NA	NA	0	90	180
4	NA	NA	NA	0	90
5	30	NA	NA	NA	0

Distances shown in metres: NA indicates that the distances are not applicable to this layout.

As indicated in the tables, the left hand vertical column lists the origination points from where the trips are made, and the horizontal row at the top of the chart lists the destination points. The chart is organised for possible material flow in both directions between the set of load/unload points in the layout. The from-to-chart is quite versatile in that it can be used to represent various parameters of the material flow problem. These parameters include the number of deliveries between points (Table 1), the distance between from-to points (Table 2), and the volume or volume rate of product flowing between various locations in the layout.

The flow diagram suggested by Muther and Haganas[5] provides information about the movement of materials and the corresponding origination and destination points of the move as shown in Fig. 2. In this diagram, the origination and destination points are represented as nodes and the material flow is depicted by arrows between the points. The nodes might represent production points between which part must be moved. The rate of material flow is indicated near the tips of the arrows in the diagram. The flow diagram is made for the layout shown in Fig. 3.

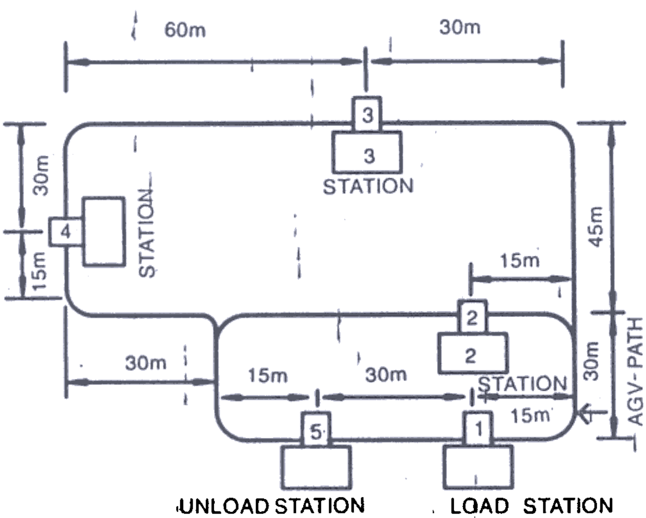

Figure 3. AGV's layout for a production system

If R_f represents the flow rate (pieces/hr) and L_d is the length of delivery (m) in the factory or warehouse, then the transport work (TW) defined by Muther and Haganas is given by

$$TW = R_f L_d \text{ pieces } m/h \tag{1.1}$$

The flow rates between origination and destination points and the distances involved may be different. These deliveries can be aggregated to determine the total transport work (TTW) by summing up the individual values of transport work (TW) for each delivery.

$$TTW = \sum R_f L_d \tag{1.2}$$

Here the summation is carried out for all the deliveries that must be accomplished. The TTW provides a measure of the total requirements that must be satisfied by the material handling system.

1.3 Reasons for Losses & Inefficiency of Material Handling System

The material handling system must be designed for a greater capacity than that given by TTW because of lost time and inefficiencies in its operation. The reasons for the losses and inefficiencies during operation of the system include loading and unloading time, return trips with no loads, system downtime for maintenance and repair, traffic congestion, scheduling problems, etc. The losses can be explained by considering a typical delivery cycle. The actual delivery involves the movement of the handling system carrier (e.g. AGV) over the distance between the origination point and the destination point (L_d). If V_c represent the speed of handling system (m/min), then the time of delivery is given by L_d/V_c min. This is considered as productive time of the handling system. In addition to this delivery time, each delivery may also involve a loading and unloading operation, and these operations often require time that is taken away from the time available for transporting materials. This time is called handling time (T_h).

In most material handling systems, much of the time of the carriers is spent travelling without a load, and this time must be considered as inefficiency of the material handling system. If the distance of the empty move is given by L_e, the empty travelling time is L_e/V_c. The inefficiency of the material handling system is also due to traffic congestion and poor scheduling. The inefficiencies are defined by a term called traffic factor (F_t). For material handling systems in which the losses of this type are negligible, the traffic factor has a value of 1.0. For other systems, such as AGV, the traffic factor may be 0.85 or less. The various losses can be incorporated into a measure of efficiency for a material handling system, as

$$E_h = [(L_d/V_c)/(L_d/V_c + T_h + L_e/V_c)]\ F_t \quad (1.3)$$

where E_h is the overall efficiency of the material handling system. It must be planned taking into consideration this efficiency.

Required handling system capacity = TTW/E_h (1.4)

2. QUANTITATIVE ANALYSIS OF AGV SYSTEM

2.1 Need for Quantitative Analysis of AGV System

Each manufacturing cell is interlinked by automated material handling system, like AGV or conveyor. Before establishing FMS in an organisation, it is necessary to have the knowledge about how many AGVs are required for material handling within a manufacturing cell. With proper planning in despatching and scheduling methods, the length of empty travel by AGV in each cell can be reduced, thereby reducing the number of AGVs required. If a layout is designed with a minimum number of vehicles, without sacrificing the material handling requirements, the traffic problem can be avoided. With the help of quantitative analysis of AGV system, the material flow rates, the operation times, the length of delivery (Ld), the length of empty move (Le) of AGV and the number of AGVs required for a typical FMS cell layout, can be determined easily. The cost of material handling by AGVs can be reduced if the length of empty travel of AGV is less than the length of delivery.

2.2 Estimation of Number of AGVs for a Cell

The time elements for a typical AGV delivery would consist of (i) the loading operation at the pickup station and the unloading operation at the drop-off station, (ii) the travel time to the drop-off station (L_d/V_c), and (iii) the empty travel time of the vehicle between deliveries (L_e/V_c). Ignoring any effect of traffic congestion, the total time per delivery per vehicle is given by

$$T_v = L_d/V_c + T_h + L_e/V_c \text{ min} \quad (2.1)$$

The number of deliveries per hour made by each vehicle could be determined by taking the reciprocal of T_v. However, the traffic losses can have a significant effect on the performance of an AGV system. The sources of inefficiency in AGVs that are accounted for by the traffic factor include blocking of vehicles, waiting at intersections, vehicles waiting in line, poor scheduling, inefficient routing of vehicles and poor layout of the guide path. The typical values of the traffic factor for an AGV range[3] between 0.85 and 1.0.

Number of deliveries per hour per vehicle

$$= 60\ F_t/T_v \quad (2.2)$$

Using the handling system efficients E_h, defined by Eqn (1.3), Eqn (2.2) becomes

Number of deliveries per hour per vehicle

$$= 60\ Eh/(L_d/V_c) \quad (2.3)$$

Number of AGVs required = Number of deliveries required per hour/Number of deliveries per hour per vehicle. (2.4)

2.2.1 *Determination of Required AGVs in a Typical FMS Layout*

Case 1

The vehicle must return to pickup station after making each drop-off at the work centre. Figure 3 shows the layout of AGVs for a production system.

Assume all AGVs must return to station 5 and 1 after making drop-offs at stations 2, 3 and 4, the AGV travels at 45 m/min and the anticipated traffic factor is 0.85. For this layout, the from-to-charts developed are shown in Tables 1 and 2. The layout consists of a load station (station 1) from where raw work parts enter the system for delivery to any of the three production work stations (stations 2, 3 and 4). An unload station (station 5) is used to receive the finished parts from the production stations. The load and unload times at stations 1 and 5 are 0.5 min each. The production rates for each work station are indicated by the delivery requirements in Table 1 and distances between different stations in Table 2. Ignoring the effects of slightly shorter distances around the curves and at the corners of the loop, the value of average distance for a delivery (L_d) is calculated by

$$L_d = R_f \, l_d / n \tag{3.1}$$

where

R_f = Flow rate

l_d = Length of delivery between each station

n = Total number of deliveries.

Based on the distances and corresponding number of trips shown in from-to-charts for the cell, the value of average distance for a delivery L_d is calculated as

$$L_d = 9 \times 60 + 5 \times 120 + 6 \times 210 + 9 \times 90 + 2 \times 90 + 3 \times 180 + 8 \times 90/(9 + 5 + 6 + 9 + 2 + 3 + 8)$$

$$= 4650/42$$

$$= 110.7 \text{ m.}$$

Determination of L_e, the average distance that a vehicle travels empty for each delivery is more complicated. It depends upon the despatching and scheduling methods that are used to decide as to how a vehicle should proceed from its last drop-off to its next pickup. Here the vehicles were to travel back to the starting point (stations 5 and 1) after each drop-off at a production work station (stations 2, 3 and 4). Assume AGVs are travelling in unidirectional path, the distances between the various work stations to the starting stations are given in Table 3.

Table 3. From-to-chart showing distances between different stations for the given layout

From	To				
	1	2	3	4	5
	0	60	120	210	NA
2	120	0	NA	NA	90
3	210	NA	0	90	180
4	120	NA	120	0	90
5	NA	90	150	240	0

Table 4. From-to-chart showing number of moves, deliveries and returns (empty) per hour between different stations

From	To				
		2	3	4	5
1	0	9L	5L	6L	0
2	9E	0	0	0	9L
3	5E	0	0	2L	3L
4	6E	0	2E	0	8L
5	0	9E	3E	8E	0

Loading vehicles are indicated by L and empty vehicles are indicated by E.

Average length of empty travel

$$(L_e) = \sum R_e \, l_e / n \tag{3.2}$$

where

R_e = Empty travel rate

l_e = Length of empty travel between each station

n = Total number of deliveries.

$$L_e = 9 \times 120 + 5 \times 210 + 6 \times 120 + 2 \times 240 + 9 \times 90 + 3 \times 150 + 8 \times 240/42$$

$$= 6510/42$$

$$= 155 \text{ m.}$$

From the given data,

$T_h = 0.5 + 0.5 = 1$ m

$V_c = 45$ m/min.

From Eqn (3.1) and Eqn (3.2),

L_d = 110.7 m and L_e = 155 m. F_t can be taken as 0.85.

From this data, using Eqn (1.3)

$E_h = 0.3028$

i.e., efficiency of AGV system for this type of loading and unloading is 30.28 per cent.

Number of deliveries per hour per vehicle

$= 60\ E_h/L_d/V_c = 7.38$

Number of AGVs required = Total number of deliveries required per hour/Number of deliveries per hour per vehicle = 42/7.38 = 5.69

i.e., six AGVs are required for this type of material handling system.

Case 2

The vehicle can do both loading a raw work part and unloading a finished part while it is stopping at a given work station. In Case 1, it has been observed that the length of empty move is greater than the length of delivery, which in turn increases the number of AGVs required. Suppose that vehicle can unload finished parts and load raw parts at the same station (stations 2, 3 and 4) so as to minimise the distances the vehicle will be travelling empty.

For this configuration from-to-chart showing distances between different stations are shown in Table 2. The number of deliveries and returns (empty) are indicated in the from-to-chart as shown in Table 5.

Table 5. From-to-chart showing number of deliveries and returns (empty) per hour between different stations

From	To				
	1	2	3	4	5
	0	9L	5L	6L	0
2	0	0	0	0	9L
3	0	0	0	2L	3L
4	0	0	0	0	8L
5	20E	0	0	0	0

L_d = Length of delivery

$L_d = 9\times 60+5\times 120+6\times 210+9\times 90+2\times 90+3\times 180+8\times 90/42$

$= 110.7\,\text{m}$

L_e = Length of empty travel

= 20 x 30/42 = 14.28 m.

Using Eqn (1.3), $E_h = 0.5535$

i.e., efficiency is 55.35 per cent.

Number of deliveries per hour per vehicle

$= 60E_h/(L_d/V_c) = 13.5$

Number of AGVs = 42/13.5 = 3.11

i.e., four vehicles are sufficient to carryout the work.

So, number of AGVs required for Case 2 were less than the number of AGVs required for Case 1.

3. CONCLUSIONS

The quantitative analysis is useful for determining material flow rate, operation time, length of delivery, length of empty move and for providing information about the number of AGVs required for a FMS cell layout. It is concluded that for improving the efficiency of an AGV system, the distance the vehicle is travelling empty must be minimised. From the two case studies, it is concluded that the empty travel time for the vehicle is minimised, if a vehicle loads a raw work part and unloads a finished part simultaneously while it is stopping at a given work station. The material handling cost is reduced, if the number of AGVs required is minimised.

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