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Establishment of AGVs fleet size in FMS Using Petri-Net

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***Abstract*— Automated guided vehicles are widely used material handling devices in Flexible Manufacturing Systems (FMS) environment. The efficient operations of FMS require a careful and detailed study for estimation of optimal fleet size of AGVs. In this article, an analytical model considering waiting / blocking time, empty travel time and load handling time, for determination of minimum number of AGVs, without impairing the efficiency of FMS is developed. In this research, a Petri-Net model is also presented to highlight the path followed by AGVs through various machines.**

***Index Terms*— Petri Net, Transition Probability Matrix, Automated Guided Vehicles, Flexible Manufacturing system (FMS).**

I. INTRODUCTION

The main components of FMS are machine tools, and material handling system which are connected by a network of computers and a controller for controlling the system. Necessities in present market scenario have generated much interest in development of both simulation and analytical techniques for designing material handling systems like Automated Guided Vehicles (AGVs). Automated Guided Vehicles (AGVs) are one of the most important material handling system components that affects the performance and efficiency of FMS. The control system along with its hardware / software decides the critical route of AGVs, among the stations. In spite of various problems associated with AGVs, particularly in dealing with multi vehicle system, AGV based material handling systems find wide ranging applications in assembly, warehousing and transfer of tools / parts.

In this paper, an analytical model for estimating the maximum number of AGVs has been proposed. In the proposed analytical model, number of times an AGV moves to various machines per unit flow is represented by flow matrix and the probability of each route undertaken by AGV is determined, adopting the transition probability matrix. Besides this, an attempt has been made in this research to capture the graphical power of Petri net to model AGVs in FMS.

The paper is further organized as follows. The following section focuses on the efforts of various researchers in the area pertaining to modeling of FMS. Section 3 discusses the design problems of AGVs based Material Handling System (MHS). The system is described along with the analytical model in section 4. Section 5 illustrates the solution methodology. An illustrative example is detailed in section 6. Section 7 describes the Petri net modeling methodology. The paper is concluded in section 8.

II. LITERATURE REVIEW.

Mahadeven and Narendran [5] presented a mathematical model to design an automated guided vehicle based system for an FMS. But, their model was a simplified one without considering scrap rate, demand of parts etc. Rajotia *et al.*[7] presented simulation based analysis to determine optimal fleet size of AGVs. But there are some drawbacks in using simulation based models. These are too time consuming and provide solution for specific problem. Moreover, Simulation models can not be used for dynamic problems. Yim and Linn [12] dealt with the same topic and also used Petri-Net based simulation to investigate effect of different push and pull dispatching rules on system performance. Petri-Net based models have also been used to obtain production rates, throughputs delays, resource utilization, capacity, reliability measures and dead lock avoidance for FMS. The detailed information about these applications can be found in [2], [8], [3], [6], [10]. The details of Petri-Net can be found in various other literatures [9], [10].

III. DESIGN PROBLEMS OF AN AGVS BASED MHS

The achievement of high performance from AGVs is affected by several design and control issues that are required to be solved before the installation of system. Some of these issues along with their effects have been discussed here. First of all, type and number of vehicles put into service should be specified. It is desirable to keep number of vehicles as less as possible because of the fact that increase in number of AGVs [16] calls for a sophisticated software requirements for controlling purpose and thus making the system installation expensive. An appropriate guide path configuration along with the proper locations of load and transfer station, and buffer spaces are also major decision variables that govern the resolution of dead lock [17], bottlenecks and accidents etc. Rules for vehicle dispatching need to be specified in order to

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maximize the throughput from the system. Unit load sizes, central and / or local work in process storage capacity etc. are also to be known in advance. In order to achieve an optimal system performance in terms of maximum throughput and system efficiency, it is essential that the system is to be administered by a judicious mix of aforementioned parameters.

IV. SYSTEM DESCRIPTION AND ANALYTICAL MODEL

The configuration and layout of an FMS considered for this study is diagramed in Fig. 1. The proposed FMS consists of four machines, one central buffer, one input (I/P) and output (O/P) buffers and four safe zones.

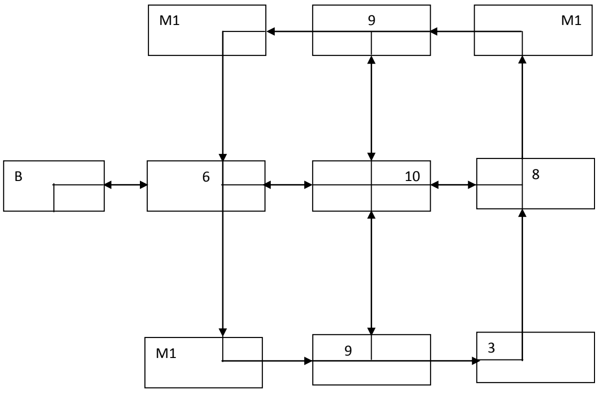

Figure 1: A typical FMS taken under consideration

The proposed FMS configuration is modified version of the configuration discussed earlier by Rajotia *et al*. [7], Bozer and Shrinivasan [1] and Yim and Linn [12]. Components of system considered in this study are:

- Machines M1, M2, M3 and M4 (numbered 1 to 4)
- Buffers – Central Buffer (C. B., Numbered 5), and I/P and O/P buffer (B., numbered 10).
- Safe zones (as shown by numbers 6, 7, 8 and 9). These are provided by decrease the traffic problems. Only one job can enter in the control zone at a time and control zones are also provided with buffers for queuing of the vehicles.
- Some of the AGV tracks provided bi-directional movement, shown by double sided arrows.
- AGV always choose shortest path between two locations.
- It takes two minutes to pass through any AGV tract and one minute to pass through control zone.
- It takes half minute to load or unload a part.

Each machine is provided with suitable sensor to show the completion of job processing.

V. SOLUTION METHODOLOGY

Determination of number of AGVs in FMS has become a significant as well as complicated task. This decision is largely affected by other design and control parameters as discussed in previous sections. In addition to these parameters, the above decisions also depend on the operating behaviour of the systems, because the operating dynamics are influenced by the randomness in part arrivals, availability of alternative processing units, dispatching strategies relative to parts and vehicles, availability of alternative vehicles routes, traffic congestion etc.. To avoid the exhaustive computation analysis in determination of individual impact of each parameters on system, a probability based approximate analysis is advocated in this research to address the problem. In the proposed model, a percentage of time an AGV moves to various machines for unit flow is denoted by flow matrix and idea based on transition probability matrix employed to determine probability for each route to be under taken by the AGV.

5.1. Notations

D_i : Demand for job i (%)

L_a : Numbers of loads removed for machine a to another location.

M_{ij} : Number of machines, job i has to visit to complete processing in the j^{th} sequence

[NAGV] : Number of AGVs

P_{ij} : Probability that the job i is processed using j^{th} sequence.

R_i : Net requirement for job i.

Seq_i : Number of sequence in job i can be processed.

S_i : Scrap rate for job i

T_a : Mean processing rate for machine a.

T_{ab} : Time taken by AGV to travel between two locations a and b.

T_{av} : Total available time of AGV per shift.

T_{ija} : Processing time of job i in the a^{th} machine when undergoing processing using j^{th} sequence.

T_{total} : Total AGV time required per shift.

X : Number of parts processed simultaneously.

Here [NAGV] refers to least integer greater that NAGV.

Complete solution approach is discussed in following steps:

Step 1: Calculate the net requirement of jobs (in percentage)

$R_i = D_i / (1 - S_i)$ …(1)

Step 2 : Define and calculate the element of flow matrix

Considering I/P and O/P buffer as $(m + 1)^{th}$ machine the element of flow matrix, f_{ab} two machines a and b is given by :-

$$f_{ab} = \sum_{i=1}^{X} R_i \sum_{j=1}^{Seq_i} P_{ij} * \sigma_{ab} \qquad \ldots (2)$$

Here a, b = 1, 2,..., (m + 1) $\forall$ a $\neq$1

And,

$$\sigma_{ab} = \left| \begin{array}{ll} 1; & \text{if } b^{th} \text{ machine is visited} \\ & \text{immediately after } a^{th} \text{ machine in} \\ & \text{the } j^{th} \text{ sequence of job I.} \\ 0; & \text{else} \end{array} \right.$$

On simplification equation (ii) can be rewritten as-

$f_{ab} = R_1 (P_{11} * \sigma_{ab} + P_{12} * \sigma_{ab} + P_{13} * \sigma_{ab} +$ ---- $P_{1Seqi} * \sigma_{ab}) + R_2 (P_{21} * \sigma_{ab} + P_{22} * \sigma_{ab} + P_{23} * \sigma_{ab} +$ ---- $P_{2Seqi} * \sigma_{ab}) +$ -------- $R_X (P_{X1} * \sigma_{ab} + P_{X2} * \sigma_{ab} + P_{X3} * \sigma_{ab} +$ ---- $P_{XSeqi} * \sigma_{ab})$ …(3)

Here,

$$\mu_{a(ij)} = \left| \begin{array}{ll} 1; & \text{if machine a is visited in } j^{th} \\ & \text{sequence of job i.} \\ 0; & \text{else} \end{array} \right.$$

Step 3 : Define the element of transition probability matrix

Transition Probability Matrix **TP** = $[TP_{ab}]$ is obtained by normalizing the flow matrix **F** = $[f_{ab}]$

Step 4 : Calculation of mean processing rate of each machine

$$\lambda_a = \sum_{i=1}^{X} \sum_{j=1}^{Seq_i} \sum_{b=1}^{M_{ij}} \left\{ \frac{R_i P_{ij} \mu_{a(ij)}}{\sum_{i=1}^{X} \sum_{j=1}^{Seq_i} R_i P_{ij} \mu_{a(ij)}} \right\} \ldots (4)$$

Step 5 : Calculate total time required by the AGV to complete the given task on each machine.

In this step different possibilities for routing of part from one machine to another after processing are taken under consideration. First of all due to limited buffer storage capacity in front of the machines, it may be required to put the semi finished parts at the central buffer in case AGV finds a machine busy. Let ϕ is the proportion of time in which this happens. Secondly it may also be possible that the time required to move from machine to central buffer and central buffer to machine is more than that the time required to complete in process part loaded on machine. In this case AGV will prefer to wait at machine centre instead of going to central buffer. Let ψ is proportion for this possibility. Hence equipped with these possibilities equation for total time can be expressed as -

$$\begin{aligned} T_{total} = {} & \phi \left\{ \sum_{a=1}^{m+1} L_a \left[\sum_{b=1}^{m+1} TP_{ab} \left(u_a + t_{ab} + t_{bB} + t_{Bb} + u_B + I_B + I_b \right) \right] \right\} \\ & + \psi \left\{ \sum_{a=1}^{m+1} L_a \left[\sum_{b=1}^{m+1} TP_{ab} \left(u_a + t_{ab} + t_w + I_b \right) \right] \right\} \\ & + (1 - \psi - \phi) \left\{ \sum_{a=1}^{m+1} L_a \left[\sum_{b=1}^{m+1} TP_{ab} \left(u_a + t_{ab} + I_b \right) \right] \right\} \end{aligned} \qquad ..(5)$$

Where,

I_i : Loading time at station i.
u_i : Unloading time at station i.
t_w : Waiting time.
t_{ij} : Travel time between stations i and j.

Step 6 : Calculate number of AGVs required.

Finally knowing the total time available per AGV, per shift, the number of AGVs is obtained by dividing total required time from total available time.

So, $N_{AGV} = T_{total} / T_{AGV}$

But this comes out to be a real value generally, hence smallest integer greater than N_{AGV} i.e. $[N_{AGV}]$ is taken.

Step 7 : Calculate the mean utilisation of AGVS

$U_m = ([N_{AGV}] / N_{AGV}) * 100$

Here, U_m denotes mean utilization of AGV system.

VI. AN ILLUSTRATIVE EXAMPLE

The configuration of FMS described in figure 1 is again referred to determine the AGVs requirement for the system. Data pertaining to the processing time of jobs on the machines are listed in table 1. Details about vehicle travel time between various pairs of stations are presented in table 2. The relevant information related to job flow, demand mix, scrap rate, sequence probability etc. are given in table 3. The values of t_w, ψ and ϕ are taken 11 minutes, 0.4 and 0.25 respectively.

After executing step 1, step 2 and step 3 outlined in section 4, the flow matrix and transition probability matrix are constructed and shown in table 4 and table 5. Mean processing rate and number of loads from the machine are calculated for the given data after execution of step 4. For machine 1 calculation of mean processing rate is given in table 6. Calculation of number of loads for same machine is done as –

$L_1 = 480 / \lambda_1 \cong 22$ (Taking 8 hours shift.)

The corresponding values for machine 2, 3 and 4 is given in table 7. There after the total time required by the AGV, so that task on each machine could be completed within the given time horizon is calculated based on the step 5. For instance the procedure to enumerate the total time required by AGV for machine 1 is illustrated as :

Putting the values of parameters t_w, ψ and ϕ in equation 5, t_{total} comes out to be

$$(T_{total})_1 = 0.4\ [22\ \{0.417\ (6+6+6+2) + 0.583\ (12+6+6+2)\ \}] +0.25\ [22\ \{0.417\ (6+11+1) + 0.583\ (12+11+1)\ \}\ ] + 0.35\ [22\ \{0.417\ (6+1) + 0.583\ (12+1)\ \}\ ] = 405.86\ \text{min}$$

The corresponding values for machines 2, 3 and 4 are given in table 7. The value of total time for the proposed problem is 1491.96 minutes. Now, let total AGV time available per shift is 420 minutes (due to time elapsed in the initial setting of AGVs.). Finally, total number of AGVs is calculated according to step 6 and this comes out to be 4.

Table 1. Processing Time of Parts

Travel Time (min)						
To From	1	2	3	4	B	C. B.
1	0	6	12	12	6	6
2	12	12	6	12	12	6
3	12	12	0	6	12	6
4	6	6	12	0	12	6
B	12	12	12	12	0	6
C. B.	6	6	6	6	6	0

Table 2. Travel Time between Two Stations

To From	1	2	3	4	B	Total
1	0.000	0.427	0.598	0.000	0.000	1.025
2	0.164	0.000	0.182	0.252	0.427	1.025
3	0.245	0.246	0.000	0.164	0.271	0.926
4	0.088	0.000	0.245	0.000	0.409	0.742
B	0.528	0.2525	0.000	0.245	0.000	1.025

Table 3. Other Related Input Data

Description of Job													No. of m/c	Net req. R_i %
Job no.	Dem-and D_1%	S_1%	Machine Visited								Probability			
			Seq 1				Seq 2				Seq 1	Seq 2		
1	40	2	1	3	2	4	4	3	1	2	0.4	0.6	4	40.82
2	35	4	1	3	2	-	1	2	3	-	0.5	0.5	3	36.46
3	25	1	2	4	1	3	2	1	3	4	0.35	0.65	4	25.25

Table 4. Flow Matrix

To From	1	2	3	4	B	Total
1	0.000	0.427	0.598	0.000	0.000	1.025
2	0.164	0.000	0.182	0.252	0.427	1.025
3	0.245	0.246	0.000	0.164	0.271	0.926
4	0.088	0.000	0.245	0.000	0.409	0.742
B	0.528	0.2525	0.000	0.245	0.000	1.025

Table 5. Transition Probability Matrix

To From	1	2	3	4	B
1	0.000	0.417	0.583	0.000	0.000
2	0.160	0.000	0.178	0.246	0.416
3	0.265	0.266	0.000	0.177	0.293
4	0.119	0.000	0.330	0.000	0.551
B	0.515	0.246	0.000	0.239	0.000

Table 6. Table to Calculate Mean Processing Rate of Machine 1

Job no. i	R_i	P_{ij}	$R_{ij} * P_{ij} * \mu_{a(ij)}$	Col 1 $R_{ij} * P_{ij}$/ Sum	Col 2 T_{ija}	Col 1 * Col 2
1	40.82	0.4	16.33	0.159	20	3.18
1	40.82	0.6	24.49	0.239	30	7.17
2	36.46	0.5	18.23	0.178	17	3.03
2	36.46	0.5	18.23	0.178	17	3.03
3	25.25	0.35	8.84	0.086	26	2.24
3	25.25	0.65	16.41	0.160	24	3.84
Sum			102.53	1.00		λ_1 = 22.49

Table 7. Various Calculated Values for Machines 2, 3, and 4.

Parameter Machine (i)	Mean Processing rate (λ_1)	Number of Loads	Total Time
2.	22.35	22	364.65
3.	22.74	21	369.17
4.	19.50	25	452.28
Sum			T_{total} = 1491.96

Table 8. Details of Places

Place Number	Description
1.	M1 is free
2.	M2 is free
3.	M3 is free
4.	M4 is free
5.	Pallet station is free
6.	Loaded pallet for PR1 is available
7.	AGV is available
8.	PR1 in M1's in buffer
9.	PR1 in M1's out buffer
10.	PR1 in M3's in buffer
11.	PR1 in M3's out buffer
12.	PR1 in M2's in buffer
13.	PR1 in M2's out buffer
14.	PR1 in M4's in buffer
15.	PR1 in M4's out buffer
16.	Counter for PR1

VII. PETRI NET MODELING METHODOLOGY

Petri nets [13], [14] are well suited to model the dynamics of flexible manufacturing systems [15]. These concisely represent the activities resources and constraints of the system in single coherent formulation.

Formally a Petri-Net is represented as a set of form:

$N = (P, T, F, H, \mu_0)$

Here, P : Finite non-empty set of positions or places

T : Finite non-empty set of transitions.

$F : P * T \rightarrow \{1, 2 ....\}$ and

$H : T * P \rightarrow \{0, 1, 2 ....\}$

μ_0 : Function, representing initial marking of places

Graphically, a Petri-Net work is a bi-partiet graph with two types of vertices. Vertices $p \in P$ are drawn as circles and vertices $t \in T$ are represented as bars or barriers.

In a Petri-Net places are represented by small circles (0) and markers are represented by small dots (**.**), decides the status of the places. Transitions are represented by small bars these may be either simple or timed. In this article, machine transitions represent event (start or finish), hence taken as simple transitions (-), while AGV transitions represents activities, therefore taken as time transitions (□). The arcs, generally taken as straight lines, from transition to places and places to transitions, defines the value of net function.

In this article a Petri-Net, capable of representing of flow of jobs through various machines is also presented.

VIII. CONCLUSIONS

A probability based analytical model is developed by utilizing the available information pertaining to target production plant and part routing. The problem is analysed under static condition, however some allowance for initial installation of system is considered. Determination of optimum fleet size for AGVS is an important design factor. It is very difficult to carry out a simulation analysis due to presence of multiple decision variables and high computational time. Therefore, present model is very useful to make reasonably good estimate of vehicle requirement in reasonably good time. Production rates of each machine in the FMS can be also be known using this probability based model. A simple Petri-Net model to represent flow of jobs through various machines without considering time element is also presented in figure 2. The associated place and transition notations are displayed in table 8, table 9a and 9b.

Table 9a. Details of AGV Transition

Transition Number	Description
11.	AGV transports PR1 from I/P and O/P buffer to M1
12.	AGV transports PR1 from M1 to M3
13.	AGV transports PR1 from M3 to M2
14.	AGV transports PR1 from M2 to M4
15.	AGV transports PR1 from M4 to pallet station

Table 9b. Details of Simple Transitions

Transition Number	Description
21.	M1 processing PR1
22.	M2 processing PR1
23.	M3 processing PR1
24.	M4 processing PR1
25.	Unloading and Loading of Pallet for PR1

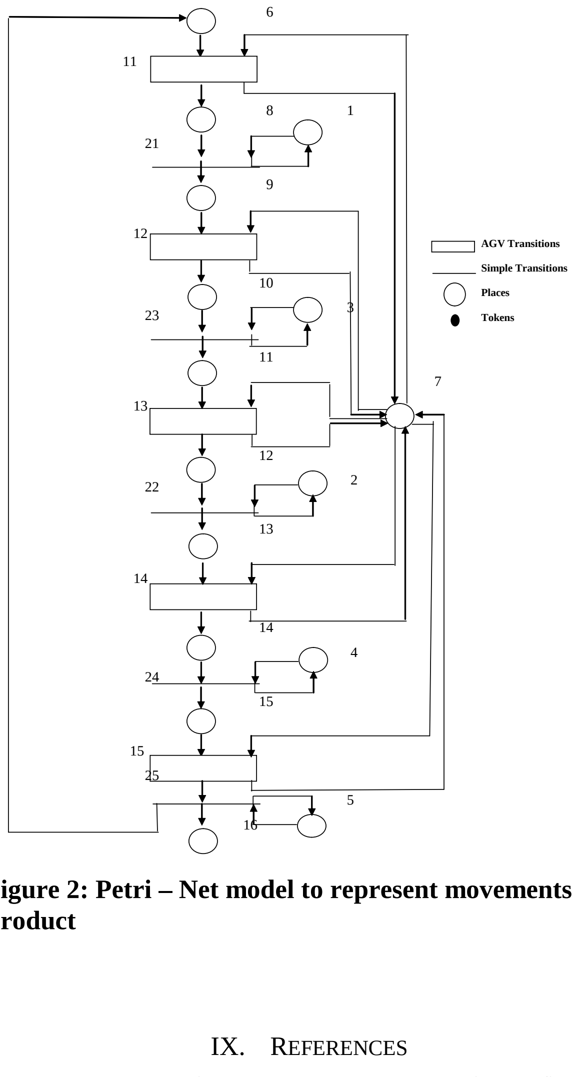

Figure 2: Petri – Net model to represent movements for Product

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