Simultaneous Scheduling of Machines and Material Handling System in an FMS

B. Siva Prasad Reddy* and C.S.P. Rao**

*Department of Mech. Engg., KITS, Warangal-506 015 (A.P) INDIA.
**Department of Mech. Engg., REC, Warangal-506 004 (A.P) INDIA.

Abstract

This paper exploits the interactions between the machine scheduling and the scheduling of Material Handling System in a given Flexible Manufacturing System (FMS) layout with an objective of minimization of makespan and to study the overall feasibility of generation of optimal simultaneous schedules. A heuristic scheduling algorithm is developed which takes into account both machine and vehicle scheduling constraints and determines the starting and completion times of operations for each job and the trips between workstations together with the vehicle assignment.

Keywords: flexible manufacturing system, automated guided vehicles, makespan, scheduling, heuristic

1 Introduction

Today Flexible Manufacturing System (FMS) seem to be a very promising technology as they provide a variety of flexibility that is essential for many manufacturing companies to stay competitive in the highly dynamic and changing manufacturing environment. Asynchronous material transfer is one of the most often phenomenon in most of the FMS. Material transfer between machines is performed by a number of identical automated guided vehicles (AGVs).

In the literature reported, the subject of scheduling the material handling system has generally been set out either as a comparison of various vehicle dispatching rules in relation to a prespecified schedule and on a particular layout [1, 2] or in relation with the design phase [3, 4]. Egbelu and Tanchoco evaluated a number of dispatching rules for AGVs via a simulation model applied to a particular layout. Sabuncuoglu and Hommertzheim investigated the performance of machine and AGV scheduling rules against the mean flow time criterion using a simulation model. The role of vehicle dispatching in system design was discussed by Maxwell and Muckstadt. For finding the minimum number of vehicles required, Mahadevan and Narendran proposed an analytical model which depends on the production plan.

A large number of papers on FMS devoted to the scheduling problem reflects the importance of this area for the efficient utilization of an FMS [5, 6]. Many researchers have emphasized the importance of material handling system on the overall efficiency of the system [7, 8]. An increase in the performance of the Flexible Manufacturing System would be expected as a result of the coordination of machines and material handling system during the machine scheduling phase [9, 10]. Sawik, Sabuncuoglu and Hommertzheim developed online dispatching and control rules for machines and AGVs. A deterministic off-line scheduling model formulated as an integer programming problem and solution procedure based on concepts of project scheduling under resource constraints is presented by Raman. Blazewicz considered an FMS with parallel identical machines arranged in a loop. Another off-line model for makespan minimization is presented by Bilge and Ulusoy who investigated the problem for multiple AGVs.

Simultaneous scheduling of machines and automated guided vehicles becomes difficult due to the sequence dependent nature of travel times for dead heading trips between successive loaded trips of AGVs. The problem is NP hard and is attempted by a heuristic algorithm which considers both machine and vehicle scheduling constraints and determines the starting and completion times of operations for each job and the trips between the workstations together with the vehicle assignment with an objective to minimize the makespan.

In the earlier work on simultaneous scheduling of machines and material handling system, the vehicles are always returned to L/U station after completion of each task, which increases the total schedule duration, decreases the actual utilization of vehicles and increases non-availability of vehicles for further tasks. However, in the proposed method, the vehicles can move immediately to the next task which enhances the vehicle utilization and reduces the schedule time.

2 Problem Statement

Given an FMS environment with workstations, AGVs and set of jobs, determine the starting and completion times of operations for each job and the trips between workstations together with the vehicle assignment. The objective is to minimize the makespan (C_{max}) which implies that the cost of a schedule depends on the duration for which the whole system is allocated to process a set of jobs.

3 System Modeling

The FMS considered is assumed to process P_i (i = 1, 2, 3 . . . P) kinds of parts. Each part type i requires K_i number of operations before completion. The processing of the parts is completed on a number of machines M_m (m = 1, 2, 3 . . . . . M) each provided with a buffer of capacity B_m (m = 1, 2, . . . M). As soon as the parts are received at the loading/unloading (L/U) station they are loaded into a number of pallets H_h (h = 1, 2, . . .P) and thereafter dispatched for processing. The part along with the pallet is stored in the empty buffer space of the concerned machine, if there is any further operation to be performed on the part or otherwise returned back to the L/U station.

The FMS operates under the following considerations :

1. The types and number of machines are known, operations are non-preemptive. There is sufficient input/output buffer space at each machine.

2. Processing, setup, loading, unloading times are available and are deterministic.

3. The number of AGVs is known and the AGVs are all identical in the sense that they have the same speed and load carrying characteristics.

4. The flow path layout is given and travel times on each segment of the path are known.

5. A load/unload (L/U) station serves as a distribution center for parts not processed and as a collection center for finished parts. All vehicles start form the L/U station initially and return there after accomplishing all their assignments. There is sufficient input/output buffer space at the loading/unloading station.

6. AGVs carry a single unit-load at a time. They move along predetermined shortest paths, with the assumption of no delay because of congestion. Preemption of trips is not allowed. The trips are called loaded or dead heading (empty) trips depending whether a part is carried or no part is carried during that trip, respectively. The duration for the dead heading trips are sequence dependent and are not known until the vehicle route is specified.

7. Machine loading i.e the allocation of tools to machines and the assignment of operations to machines is made. Pallets and other necessary equipment are allocated to parts. The set of part types to be produced during the planning period and the routing of each part type are available before making scheduling decisions.

8. Ready times of all jobs are known. Initially, partially processed parts might be available at machines waiting for further processing, and they can be treated as jobs having zero ready times and their routing consists of the remaining operations.

4 Heuristic Scheduling Methodology

The simultaneous scheduling problem is formulated considering the machine and vehicle scheduling constraints which interact together such that the whole job set is processed in a minimum time.

Notations:

c_i : Completion time for operation i
p_i : Processing time of operation i
SL_i : Starting time of the loaded trip i
t_i : Travel time for the loaded trip i including loading and unloading times
ET_i : Ending time of operation i
t_{ij} : Dead heading time
ST_j : Starting time of operation j
r_i : Ready time or arrival time of operation i
T_i : The completion time of loaded trip i

The objective function is to minimize makespan C_{max}.

$$\text{Minimize} \sum_{j=1}^{n} c_j$$

Under the constraints :

$$c_i - c_{i-1} \geq p_i + t_i \quad (1)$$
$$T_i \leq c_i - p_i \quad (2)$$
$$T_i - t_i \geq c_{i-1} \quad (3)$$

$$c_{i-1} + t_i \le T_i \le c_i - p_i \quad (4)$$
$$c_{i-1} \le ST_i \le c_i - p_i - t_i \quad (5)$$
$$ET_I + t_{ij} \le ST_j \quad (6)$$
$$SL_i + t_i + t_{ij} < ST_j \quad (7)$$

The material handling trip associated with loading the processing operation i cannot start earlier than the

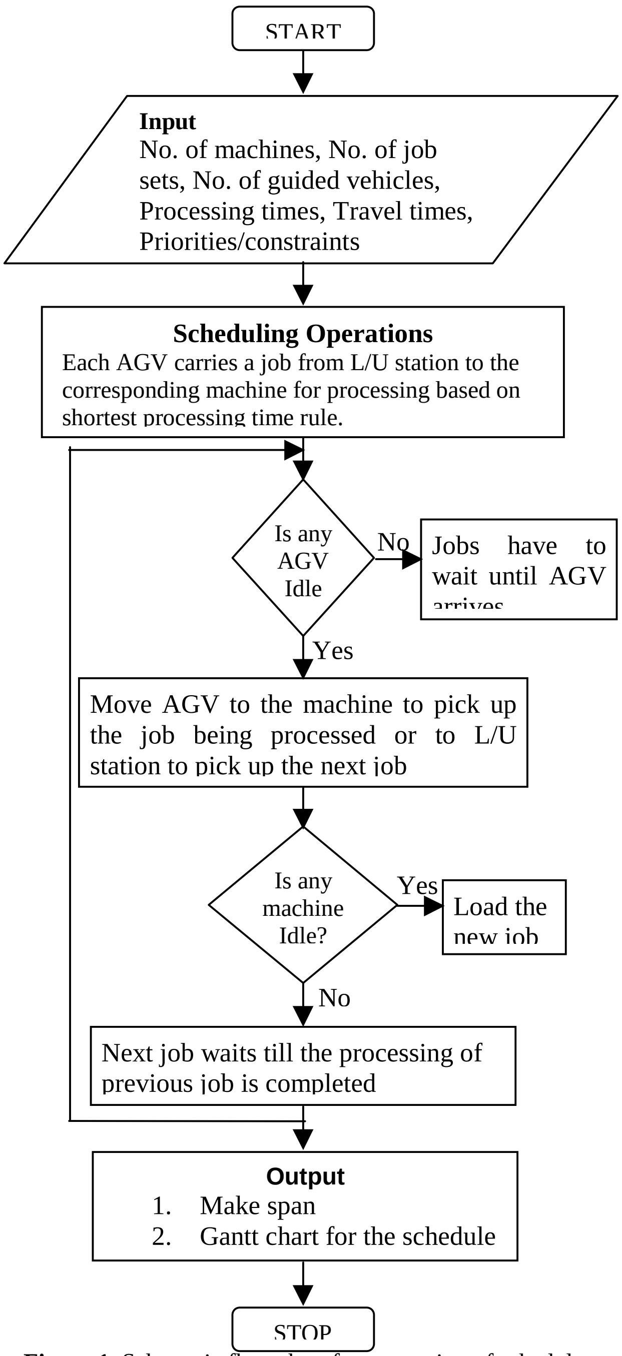

Figure 1. Schematic flow chart for generation of schedule.

completion time of the previous operation i–1 and its latest starting time is such that operation i can be completed at its scheduled time.

Considering the operation sequencing, where each operation denotes the processing of a specific part family on a specific machine centre and the corresponding assignment of AGVs that will carry the workpiece from and to the machine centres a heuristic scheduling algorithm is developed. The algorithm allows to check whether it is possible to deliver all the required raw material to their destinations by considering the operation sequence and AGV assignment. It anticipates the complete set of flow requirements for given machine schedule and makes vehicle assignments accordingly. The algorithm works based on first come first serve (FCFS) and shortest processing time (SPT) rules. The operations are assumed to be scheduled at the earliest starting time resulting in a non-delay schedule. Parts are processed on the machine following the FCFS rule. When two parts arrive at the same machine at the same time then SPT rule is used to break the tie in the ordering of these parts for processing. The software is developed in VB (Visual Basic). The flow chart of algorithm is shown in Figure 1.

5 Numerical Example

A scheduling situation with 3 machines (M_1, M_2, M_3), 3 jobs (1, 2, 3) and 2 AGVs (V_1, V_2) is considered. A total of 7 operations are to be performed on the three jobs.

The details are presented in Table 1, Table 2 and Table 3. Figure 2 shows the layout and AGV routes.

Table 1. Job set details.

Jobs	1	2	3
Operations	a, b, c	a, b	a, b
Machines	M_1, M_3, M_2	M_1, M_3	M_3, M_2
Representation	1, 2, 3	4, 5	6, 7

Table 2. Travel times.

Machine	L/U	M_1	M_2	M_3
L/U	0	6	8	10
M_1	12	0	6	8
M_2	10	6	0	6
M_3	8	8	6	0

Table 3. Processing times.

Job	Operation	Machine	Processing

No.			time
1	1	M_1	9
	2	M_3	3
	3	M_2	12
2	4	M_1	6
	5	M_3	15
3	6	M_3	3
	7	M_2	9

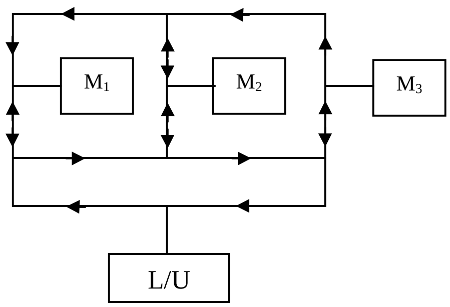

Figure 2. Layout configuration.

6 Results

Assignment details of the machines and vehicles are shown in the Gantt chart (Figure 3).

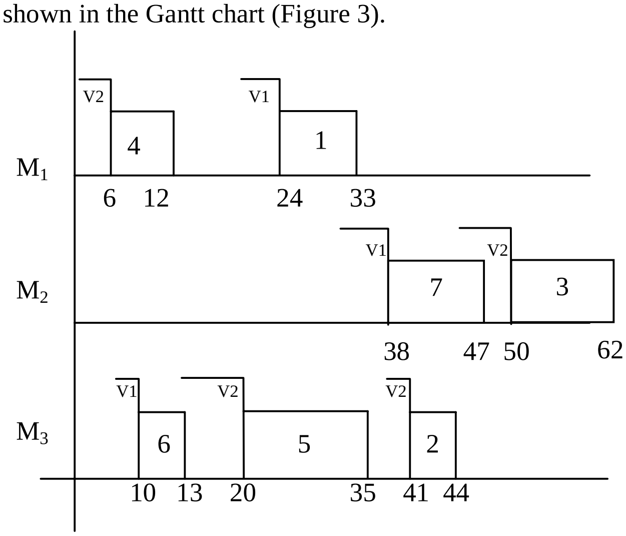

Figure 3. Gantt chart for the schedule.

Starting and completion times of jobs are shown in Table 4.

Table 4. Job schedule details.

Job No.	Loaded trip starting time	Travell-ing time from L/U	Job Ready Time	Job Process-ing Time/ Travelling time	Job Comple-tion time	Job waiting time
3	0	10	10	12/6	47	19
2	0	6	6	21/8	35	0
1	18	6	24	24/14	62	18
Makespan = 62						

Starting and completion times of operations for each job are shown in Table 5.

Table 5. Operation schedule details.

Opera-tion No	Loaded trip starting time	Travell-ing time	Job Ready Time	Job Process-ing Time	Job Comple-tion Time	Job Waiting time
4	0	6	6	6	12	0
6	0	10	10	3	13	0
5	12	8	20	15	35	0
1	18	6	24	9	33	18
7	32	6	38	9	47	19
2	33	8	41	3	44	0
3	44	6	50	12	62	0
Makespan = 62						

Machine and vehicle assignment details are shown in Table-6.

Table 6. Machine and vehicle assignments.

Machines	Operations	Processing Times
M_1	4, 1	15
M_2	7, 3	21
M_3	6, 5, 2	21

AGVs	Operations	Travelling Time
V_1	6, 1, 7	38
V_2	4, 5, 2, 3	36

The first vehicle carries operations (6, 1 and 7) and the other vehicle carries the remaining operations (4, 5, 2 and 3).

7 Conclusions

The purpose of this study is to make AGV scheduling an integral part of the overall scheduling activity. A

typical model of an FMS has been considered together with constraints of both machine and vehicle scheduling with an objective to minimize the makespan. The heuristic scheduling algorithm developed is tested extensively with various FMS environments - varying layouts, AGVs and jobs. About 50 different FMS configurations were tested successfully. The same may also be extended for due date performance criteria and dynamic scheduling
.

References

1. Egbelu P. J and Tanchoco J.M.A, “Characterization of automatic guided vehicle dispatching rules”, International Journal of Production Research, 22 pp.359-374, 1984.
2. Sabuncuoglu, I and Hommertzheim, D. L., “Experimental Investigation of FMS machine and AGV scheduling rules Against the mean flow time criterion”, International Journal of Production Research, 30, pp.1617-1635, 1992.
3. Mahadevan, B., and T.T. Narendran, “Design of an Automated Guided Vehicle-Based Material Handling System for an FMS” International Journal of Production Research, 28, pp.611-1622, 1990.
4. Maxwell, W.L., and J.A. Muckstadt, “Design of Automated Guided Vehicles”, IIE Trans. 14, pp.114-124,1982J. Blazewicz, H.A. Eiselt, G. Finke, G. Loporte and J. Weglacz, “ Scheduling tasks and vehicles in a flexible manufacturing system”, The international journal of flexible manufacturing systems, Vol.4 pp.5 – 16, 1991.
5. Tadeusz Sawik, “Modelling and scheduling of a flexible manufacturing system, European Journal of Operational Research 45, pp.177-190, 1990.
6. N. Raman, F.B. Talbot and V.Rachamadugu, “Simultaneous scheduling of Machines and material Handling devices in Automated Manufacturing”, Proceedings of the second ORSA/TIMS Conference on Flexible Manufacturing Systems, pp.455-466, 1986.
7. U. Bilge & G. Ulusoy, “Simultaneous scheduling of machines & automated guided vehicles”, International Journal of Production Research Vol. 31, pp.2857 – 2873, 1993.
8. U. Bilge & G. Ulusoy, “A time window approach to simultaneous scheduling of machines & material handling system in an FMS”, Operations Research Vol 43, No.6, pp.1058 – 1070, 1995.
9. Sabuncuoglu, I and Hommertzheim, D. L., “Dynamic dispatching algorithm for scheduling machines and automated guided vehicles in a flexible manufacturing system. International Journal of Production Research, 30, pp.1059-1079, 1992.