

Fuzzy heuristic algorithm for simultaneous scheduling problems in flexible manufacturing system

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ABSTRACT

This paper addresses the flexible manufacturing system (FMS) problems considering both machines and automated guided vehicles (AGVs), simultaneously. A new fuzzy heuristic (FH) is proposed for solving the simultaneous scheduling problem, in order to minimize the makespan by considering the available resources. For increasing the performance of FMS one of the important factors is scheduling AGV with an integral part of the machine scheduling activity. The algorithm is tested based on 82 benchmark problems and the achieved makespan are compared with other algorithms.

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1. Introduction

To achieve wide-variety and wide-range of products, flexible manufacturing system (FMS) is a sophisticated system in the area of manufacturing. While increasing the demand for goods, the management is motivated to find new ways to increase the output with available resources. FMS is the only alternative for conservative manufacturing system (Rathinam et al., 2015; Babu et al., 2018). FMS has a number of benefits such as cost reduction, better rate of utilization, reduced work levels in process, etc. Moreover, there are a number of drawbacks during the life cycle of FMS. These drawbacks are likely scheduling, planning, control and design. During the operations of the scheduling, control problem is dynamic in FMS including assignment of AS/RS storage, routing of AGV, flexible parts and flexible tools. This paper concentrates mainly on FMS scheduling problems. Decisions are made not only based on the sequencing of the jobs but also according to routing the jobs in FMS scheduling. Apart from the machines, AGVs and AS/RS must be considered. For efficient production in FMS we need to employ AGVs as handling system. The efficiency of AGV depends on many factors like allocation of tasks to AGVs; specifying the path of AGVs and determining the start and finish times of the assigned work.

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2. Literature review

FMS consists of NC machine, AGVs and computer network. This network works through controlling and directing the whole system. Stecke (1985) described FMS design problems, FMS planning problems, FMS scheduling problems and FMS control problems. Kusiak (1986) developed a FMS scheduling system using a rule-based expert system following priority rules to scheduling jobs. If a job is not scheduled due to resource conflicts then decision table can be used to select alternative machines, tools, fixtures and material handlers. Han and McGinnis (1989) provided a discrete time control technique for a FMS cell based on a single-stage cell with some parallel workstations, machine failures, limited buffer capacities and various inputs from upstream cells. Nasr and Elsayed (1990) proposed a method to optimize the mean flow time in a job shop machining system with alternative machine tool routings. Sabuncuoglu et al. (1993) considered the FMS scheduling with both machine and AGV based on the due date criterion. These rules are evaluated under various experimental circumstances and the sensitivity of AGV was also investigated. Fang et al. (2011) adopted a shop scheduling approach by minimizing the completion time through a general multi-objective mixed-integer formulation. Pach et al. (2014) proposed reactive scheduling method for FMSs, which integrates the overall energy consumption of the production. The method was justified by the growing needs of manufacturers for energy-aware control subject to some environmental criteria in the context of high reactivity. Also real experiments were carried out to show the feasibility of the approach on a real system and validate the simulation results. Salido et al. (2017) followed rescheduling in job shop problems for sustainable manufacturing system with optimum completion time by looking into the performance measures such as mean flow time, makespan, maximum lateness and total absolute deviation from due dates.

2.1 Scheduling and routing of AGV through heuristic algorithm

During the past few decades, there has been tremendous efforts on developing heuristics to solve scheduling problems. Johnson's algorithm (1954) is among the first method for scheduling two machines. Each machine can handle only one item at a time and each item must be produced through machine one and machine two. The set up time plus work time for each item and for each machine is known. A simple decision rule is proposed by author for the optimal scheduling of the production for minimizing the total elapsed time and three machine problems is also discussed for restricted case. Palmer (1965) proposed a heuristic for the flow shop scheduling with makespan minimization. In this connection, number of items must pass through a number of processes in the same order and it was suggested that the optimum scheduling may be approximated by giving priority to items according to the extent to which process time increases with process number in order. Campbell et al. (1970) proposed a simple algorithm for large sequencing problems without the use of computers. It produces approximate solutions to the n job, m machine sequencing problem where no passing is considered and the criterion is the minimum elapsed time up to $m-1$ sequences. Gupta (1971) proposed a functional heuristic algorithm to look for a fast approximate solution of n -job, M -machine flow shop scheduling problem under the assumptions that all jobs are processed on all machines in the same order and no passing of job is permitted. This algorithm can be used manually for reasonably large size problems and yielded solutions which are closed to optimal solutions than those obtained by palmer slope index algorithm. Nawaz et al. (1983) proposed a well-known constructive heuristic for the general flow-shop scheduling giving top priority for a job with high total processing time on all machines. Ruiz and Stützle (2007) presented a greedy algorithm by applying iteratively in two phases' viz., destruction and construction. In destruction phases some jobs are eliminated from the incumbent solution, where as in construction phase, the eliminated jobs will be reinserted into the sequence using the well-known NEH construction heuristic. Vallada and Ruiz (2009) adopted a cooperative metaheuristic method for the permutation flow shop scheduling problem by considering the total tardiness and makespan individually. Heydari and Mohammadi (2010) proposed a fuzzy heuristic algorithm based on extended Johnson's algorithm for more than two machines problems. Performance of proposed algorithm for small size problems and the results were compared with optimum scheduling. Modrák and Pandian (2010) presented flow shop scheduling algorithm to multi stage job problems where

simple priority rules were used to obtain solutions of minimum total processing time. The authors presented algorithm based on converting m -machine problem to a 2-machine problem. Based on testing and comparison with other relevant methods, the proposed algorithm was offered as a competitive alternative for practical application when solving n -jobs and m -machines problems. Semančo and Modrák (2012) made a comparative study on constructive heuristics for makespan minimizing in the flow-shop scheduling. The computational experiment shows that the proposed algorithm was a feasible alternative for practical application when solving n -job and m -machine in flow-shop scheduling problems to give relatively good solutions in a short-time amount of Time. Zupan et al. (2016) adopted hybrid algorithm which is a combination of heuristic algorithm extended with priority rules, discrete event simulation and genetics algorithm. The simulation result for the proposed model was the optimal sequence of the selected orders for the selected time interval while taking into account three criteria: the minimum flow time of all orders, the maximum average utilization of workplaces, and the minimum waiting time of the orders. This paper proposes a fuzzy heuristic algorithm for solving simultaneous scheduling problems in FMS.

3. Problem statement

The FMS environment, example problem assumptions, input data for FMS, objective function and vehicle heuristic algorithm for the current work are given below.

3.1 FMS Environment

The FMS environments with some considerations are given below:

1. Flexible numerical controlled (NC) machines, furnished with automatic tool changing.
2. An automated material handling systems (MHS) such as conveyors, carts, Industrial robots, AGVs or a combination of them are used to move parts and tools.
3. The entry and exit of the parts take place through Loading/Unloading (L/U) stations.
4. Use coordinate measuring machines for inspection purpose.
5. Sufficient buffer space is provided to near by the machine to store the raw and semi-finished work pieces.
6. Provide tool magazine to store the tools on the machine.
7. A hierarchical control system (HCS) is used to NC machines, tools and MHS.
8. Two operations of a job cannot be done simultaneously.
9. Machine cannot be performing more than one operation at a time.
10. Anticipation of operations or AGV trips is not permitted.
11. The duration for AGVs trips is sequence dependent.

3.2 Assumptions

The FMS environments with following assumptions are given below:

1. Initially all the vehicles start from the load/unload station.
2. The number and type of machines are known.
3. Each machine performs more than one operation.
4. Both the processing times and travel times are known in advance.
5. Initially all jobs and AGVs are available at zero time.
6. Number of AGVs are known
7. Layout and Flow path are known.
8. Assume design and setup times have already been considered.
9. Pallet and other necessary equipment are allocated.
10. The speed of AGV kept at 40 m/min.

3.3 Input data

The input data are adopted from the paper by Bilge and Ulusoy (1995). Travel time data for the example problem are given in Table 1. Table 2 gives the 10 job sets data, each job contains five to eight different jobs and each job is processed on three to five machines and the number besides machine number is process time of specific job (Bilge & Ulusoy 1995). The load/unload (L/U) station are given as distribution center and collection center for parts.

Table 1
Example problem travel time data for four layouts in meters

Layout-1						Layout-2					
From/To	L/U	M1	M2	M3	M4	From/To	L/U	M1	M2	M3	M4
L/U	0	6	8	10	12	L/U	0	4	6	8	6
M1	12	0	6	8	10	M1	6	0	2	4	2
M2	10	6	0	6	8	M2	8	12	0	2	4
M3	8	8	6	0	6	M3	6	10	12	0	2
M4	6	10	8	6	0	M4	4	8	10	12	0

Layout-3						Layout-4					
From/To	L/U	M1	M2	M3	M4	From/To	L/U	M1	M2	M3	M4
L/U	0	2	4	10	12	L/U	0	4	8	10	14
M1	12	0	2	8	10	M1	18	0	4	6	10
M2	10	12	0	6	8	M2	20	14	0	8	6
M3	4	6	8	0	2	M3	12	8	6	0	6
M4	2	4	6	12	0	M4	14	14	12	6	0

Table 2
Job set data with process time used in example problems

JobSet-1 Job 1: M1(8); M2(16); M4(12) Job 2: M1(20); M3(10); M2(18) Job 3: M3(12); M4(8); M1(15) Job 4: M4(14); M2(18) Job 5: M3(10); M1(15)	JobSet-2 Job 1: M1(10); M4(18) Job 2: M2(10); M4(18) Job 3: M1(10); M3(20); Job 4: M2(10); M3(15); M4(12) Job 5: M1(10); M2(15); M4(12) Job 6: M1(10); M2(15); M3(12)	JobSet-3 Job 1: M1(16); M3(15) Job 2: M2(18); M4(15) Job 3: M1(20); M2(10) Job 4: M3(15); M4(10) Job 5: M1(8); M2(10); M3(15); M4(17) Job 6: M2(10); M3(15); M4(8); M1(15)
JobSet-4 Job1: M4(11); M1(10); M2(7) Job2: M3(12); M2(10); M4(8) Job3: M2(7); M3(10); M1(9); M3(8) Job4: M2(7); M4(8); M1(12); M2(6) Job5: M1(9); M2(7); M4(8); M2(10); M3(8)	JobSet-5 Job 1: M1(6); M2(12); M4(9) Job 2: M1(18); M3(6); M2(15) Job 3: M3(9); M4(3); M1(12) Job 4: M4(6); M2(15) Job 5: M3(3); M1(9)	JobSet-6 Job 1: M1(9); M2(11); M4(7) Job 2: M1(19); M2(20); M4(13) Job 3: M2(14); M3(20); M4(9) Job 4: M2(14); M3(20); M4(9) Job 5: M1(11); M3(16); M4(8) Job 6: M1(10); M3(12); M4(10)
JobSet-7 Job 1: M1(6); M4(6) Job 2: M2(11); M4(9) Job 3: M2(9); M4(7) Job 4: M3(16); M4(7) Job 5: M1(9); M3(18) Job 6: M2(13); M3(19); M4(6) Job 7: M1(10); M2(9); M3(13) Job 8: M1(11); M2(9); M4(8)	JobSet-8 Job 1: M2(12); M3(21); M4(11) Job 2: M2(12); M3(21); M4(11) Job 3: M2(12); M3(21); M4(11) Job 4: M2(12); M3(21); M4(11) Job 5: M1(10); M2(14); M3(18); M4(9) Job 6: M1(10); M2(14); M3(18); M4(9)	JobSet-9 Job 1: M3(9); M1(12); M2(9); M4(6) Job 2: M3(16); M2(11); M4(9) Job 3: M1(21); M2(18); M4(7) Job 4: M2(20); M3(22); M4(11) Job 5: M3(14); M1(16); M2(13); M4(9)
JobSet-10 Job1: M1(11); M3(19); M2(16); M4(13), Job2: M2(21); M3(16); M4(14) Job3: M3(8); M2(10); M1(14); M4(9), Job4: M2(13); M3(20); M4(10) Job5: M1(9); M3(16); M4(18), Job6: M2(19); M1(21); M3(11); M4(15)		

3.4 Objective Function

Minimization of makespan is objective function and the formulas used are given below:

$$\text{Operation completion time } (O_{ij}) = T_{ij} + P_{ij}, \quad (1)$$

$$\text{Job completion time } (C_i) = \sum_{j=1}^n O_{ij}, \quad (2)$$

$$\text{Makespan} = \max(C_1, C_2, C_3, \dots, C_n), \quad (3)$$

where j =operation, i =job, T_{ij} =travelling time, P_{ij} =operation processing time.

3.5 Vehicle scheduling methodology

Two AGVs are considered for simultaneous scheduling in FMS and both the vehicles are assigned randomly for the first two operations. From third operation onwards, the following algorithm is used for selecting one of the two vehicles.

1. Identify the AGVs location and ready time.
2. Vehicle empty traveling time is to be calculated.
3. To obtain the completion time of vehicle add empty travel time of vehicle to the ready time.
4. If necessary vehicle wait until completing the previous operation.
5. Consider maximum value of vehicle empty travel time and previous operation completion time for further calculations.
6. To obtain the vehicle loaded travel time consider the vehicle from previous operation machine to present operation machine.
7. To obtain the completion time of vehicle loaded trip add the maximum value obtained in step 5.
8. The AGV is ready for the next operation after completing the loaded trip and the algorithm is repeats at every operation.

To reduce the waiting time and improve the resource utilizations this vehicle heuristic helps in FMS and the flow chart for machine and automated guided vehicle is given in Fig. 1.

4. Fuzzy sets heuristic algorithm

Fuzzy Heuristic (FH) algorithm is used for this particular scheduling problem. FH was suggested by Heydari and Mohammadi (2010) and was developed initially to find solutions for small size NP hard problems. According to Johnson's rule all jobs are associated to one of two sets $U = \{j/t_{j1} < t_{j2}\}$ or set $V = \{j/t_{j1} \geq t_{j2}\}$, on the other hand, job processing time on the two machine problem will be changed increasingly (U) or decreasingly (V). Here we went to extended Johnson's rule for more than two machines. In Fuzzy heuristic algorithm fuzzy set U with membership function $u_u(J)$ and fuzzy set V with member ship function $u_v(J)$ are considered. The proposed algorithm is as follows,

Step 1: Calculate $S_{j1} = \sum_{k=1}^a t_{jk}$ and $S_{j2} = \sum_{k=a}^n t_{jk}$, where $a = \frac{n}{2} + 1$ for each Job 'J'

Step 2: Calculate $u_u(J) = \frac{S_{j1}}{S_{j1}+S_{j2}}$ and $u_v(J) = \frac{S_{j2}}{S_{j1}+S_{j2}}$

Step 3: Arrange members of U decreasingly according $u_u(J)$ to t_{j1} or arrange members of V increasingly according to $u_v(J)$

Step 4: A sequence of arranged U or V will be an acceptable schedule.

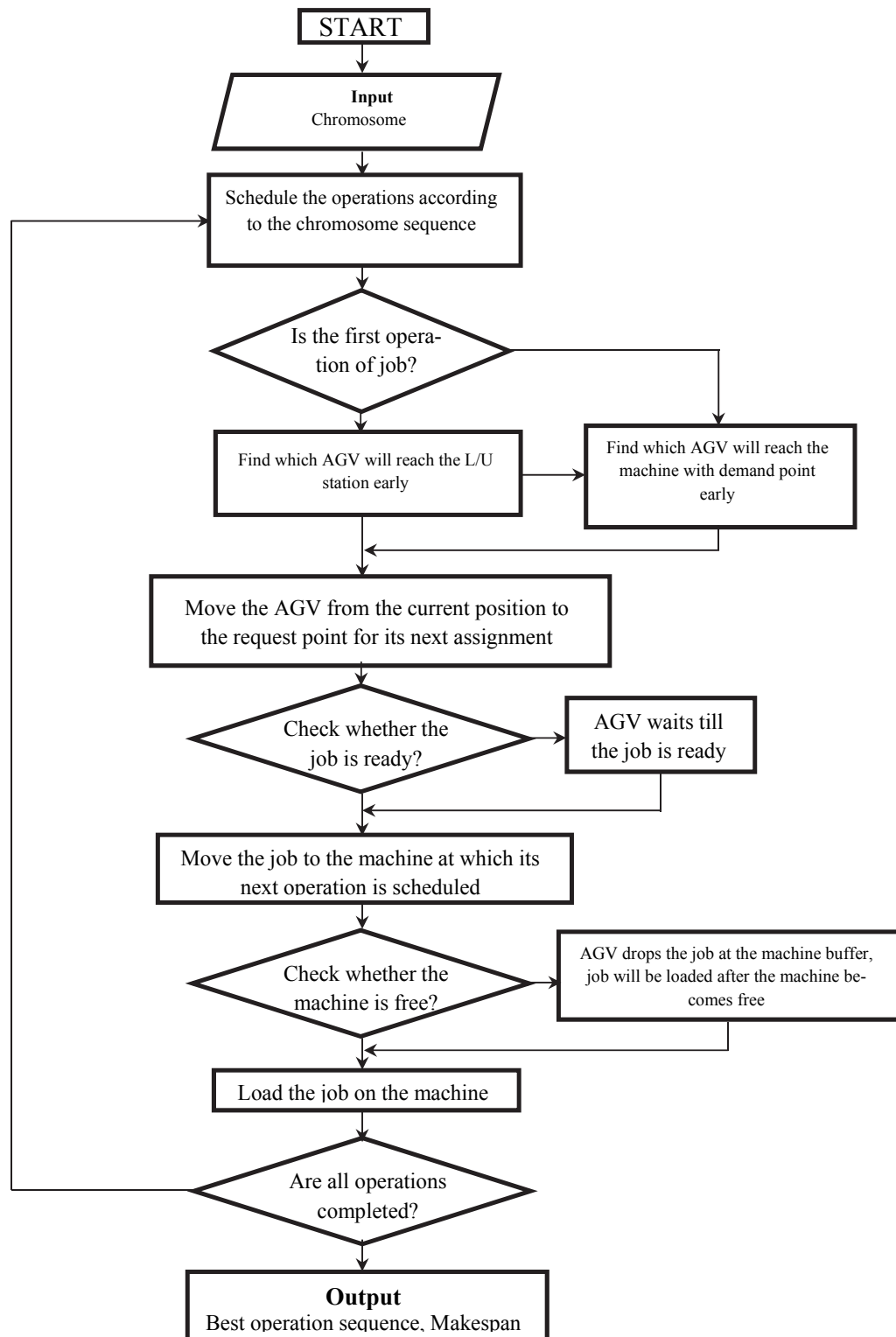


Fig. 1. Machine and automated guided vehicle scheduling flow chart.

5. Implementation of fuzzy heuristic algorithm to simultaneous scheduling problems

Developed Heuristic Algorithm to solve NP-hard problems arises in the scheduling problems. The proposed algorithms are implemented to the scheduling problems. The details of which are presented here

below. For execution of Fuzzy Heuristic Algorithm, job set number 5 and layout numbers 1 are considered.

Step 1: Job set is considered

Job Set No	Layout Number	Total No of Jobs	Total No of operations	Sequence of Machines with Job Number
5	1	5	13	1: 1-2-4 2: 1-3-2 3: 3-4-1 4: 4-2 5: 3-1

Step 2: For each Job ‘J’ calculate $S_{j1} = \sum_{k=1}^a t_{jk}$ and $S_{j2} = \sum_{k=a}^n t_{jk}$, where $a = \frac{n}{2} + 1$

M. No Job.No	1	2	3	4
1	6	12	0	9
2	18	15	6	0
3	12	0	9	3
4	0	15	0	6
5	9	0	3	0

For job set 5 calculate $S_{j1} = \sum_{k=1}^a t_{jk}$ and $S_{j2} = \sum_{k=a}^n t_{jk}$

where $a = \frac{n}{2} + 1$, n= no of machines, in this problem n=4 and a=3

For job ‘1’ S_{j1} and S_{j2} are follows

$$S_{j1} = \sum_{k=1}^3 t_{jk} = 6+12+0=18$$

$$S_{j2} = \sum_{k=3}^4 t_{jk} = 0+9=9$$

In the same manner for all jobs S_{j1} and S_{j2} are

Job	S_{j1}	S_{j2}
1	18	9
2	39	6
3	21	12
4	15	6
5	12	3

Step 3: Calculate $u_u(J) = \frac{S_{j1}}{S_{j1}+S_{j2}}$ and $u_v(J) = \frac{S_{j2}}{S_{j1}+S_{j2}}$

For job ‘1’ $\mu_u(J)$ and $\mu_v(J)$ are follows

$$u_u(J) = \frac{S_{j1}}{S_{j1}+S_{j2}} = \frac{18}{18+9} = 0.666$$

$$u_v(J) = \frac{S_{j2}}{S_{j1}+S_{j2}} = \frac{9}{18+9} = 0.333$$

In the same manner for all jobs $\mu_u(J)$ and $\mu_v(J)$ are

Job	S_{j1}	S_{j2}	$\mu_u(J)$	$\mu_v(J)$
1	18	9	0.666	0.333
2	39	6	0.866	0.133
3	21	12	0.636	0.363
4	15	6	0.714	0.285
5	12	3	0.800	0.200

Step 4: Arrange members of U decreasingly according to $u_u(J)$ and t_{j1} or arrange members of V increasingly according to $u_v(J)$

According to $\mu_u(J)$ the job order is

Job	1	2	3	4	5
$\mu_u(J)$	0.666	0.866	0.636	0.714	0.800
Priority	2	5	1	3	4

According to $\mu_v(J)$ the job order is

Job	1	2	3	4	5
$\mu_u(J)$	0.333	0.133	0.363	0.285	0.200
Priority	2	5	1	3	4

Step 5: A sequence of arranged U or V will be an acceptable schedule

As per the fuzzy sets heuristic algorithm the operational sequence as

$$7 - 8 - 9 - 1 - 2 - 3 - 10 - 11 - 12 - 13 - 4 - 5 - 6$$

The makespan calculation for above sequence is shown in Table 3.

Table 3
Operations schedule through FUZZY (for Problem set 5 and layout 1)

Operation Number	Machine Number	Vehicle Number	Vehicle Previous Location	Previous Operation Machine Number	Vehicle Ready Time	Previous Operation Completion Time	Vehicle Empty Trip =VRT+RT1 (4 to 5)	Max(7,8)	Vehicle Loaded Trip =VET+RT2 (5 to 2)	Machine Ready Time	Max(10,11)	Process Time	Make Span
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
7	3	1	L/U	L/U	0	0	0	0	10	0	10	9	19
8	4	2	L/U	3	0	19	10	19	25	0	25	3	28
9	1	1	3	4	10	28	16	28	38	0	38	12	50
1	1	2	4	L/U	25	0	31	31	37	50	50	6	56
2	2	2	1	1	37	56	37	56	62	0	62	12	74
3	4	1	1	2	38	74	44	74	82	28	82	9	91
10	4	2	2	L/U	62	0	72	72	84	91	91	6	97
11	2	1	4	4	82	97	82	97	105	74	105	15	120
12	3	2	4	L/U	84	0	90	90	100	19	100	3	103
13	1	2	3	3	100	103	100	103	111	56	111	9	120
4	1	1	2	L/U	105	0	115	115	121	120	121	18	139
5	3	2	1	1	111	139	111	139	147	103	147	6	153
6	2	1	1	3	121	153	129	153	159	120	159	15	174

Table 3 shows operation scheduling through fuzzy heuristic algorithm for job set 5 layout 1 is shown. From the table it is observed that operation 7 on machine 3 is completed by 19 min hence 8th operation will start after

completion of 7th operation on machine 3. In case of job set 5 and layout 1 operation 8 on machine 4 is completed by 28 min hence 9th operation on machine 1 will start after completion of 8th operation on machine 4. Similarly no operation on the particular machine will start until the operation on the machine is completed. From the vehicle heuristic algorithm for first two operations AGVs are selected randomly in case of third operation AGV '1' is selected basing on the availability of AGV with minimum travel time this constraint will be taking care in the algorithm. For job set 5 and layout 1 the operational completion time (makespan) is 174. Scheduling problems in FMS (Bilge & Ulusoy, 1995) are solved through JAVA programming.

6. Results and discussion

The simultaneous scheduling of machines and AGVs procedure through fuzzy heuristic algorithm have been developed in the 'JAVA' language. Processing time of the machines and travel time for AGVs are given as input. For 82 test problems JAVA code gives the optimal sequence of jobs. While generating the example problems the ratio of travel time and process time is the main criterion because of interaction of AGVs and machine with travel time and process time is the major parameter (Bilge & Ulusoy, 1995). Four different layouts are generated with each layout having four machines through loop or ladder or combination of both (Kusiaka, 1985). 82 example problems are generated with different combinations of ten job sets and four layouts. Problems with $t/p > 0.25$ are presented in Table 4, and problems with $t/p < 0.25$ are presented in Table 5.

Table 4
Comparison of make span values with $t/p > 0.25$

Job_No	t/p	FCFS	SPT	LPT	NEH	FUZZY
1.1	0.59	173	193	177	165	208
2.1	0.61	158	158	177	169	170
3.1	0.59	202	224	198	195	211
4.1	0.91	263	267	264	260	268
5.1	0.85	148	164	148	147	174
6.1	0.78	231	240	227	225	233
7.1	0.78	195	210	201	173	196
8.1	0.58	261	261	266	261	261
9.1	0.61	270	277	268	259	273
10.1	0.55	308	308	310	305	315
1.2	0.47	143	173	165	147	188
2.2	0.49	124	124	130	116	127
3.2	0.47	162	188	160	154	178
4.2	0.73	217	223	224	215	232
5.2	0.68	118	144	131	117	156
6.2	0.54	180	169	165	158	175
7.2	0.62	149	160	149	136	139
8.2	0.46	181	181	198	181	181
9.2	0.49	250	249	244	205	249
10.2	0.44	290	288	287	274	274
1.3	0.52	145	175	167	145	190
2.3	0.54	130	130	136	122	133
3.3	0.51	160	190	162	158	176
4.3	0.8	233	237	230	226	234
5.3	0.74	120	146	133	117	156
6.3	0.54	182	171	167	160	177
7.3	0.68	155	166	151	138	141
8.3	0.5	183	183	200	183	183
9.3	0.53	252	251	246	207	251
10.3	0.49	293	294	293	280	280
1.4	0.74	189	207	189	189	228
2.4	0.77	174	174	174	169	190
3.4	0.74	220	250	212	213	225
4.4	1.14	301	301	298	298	294
5.4	1.06	171	189	171	171	193
6.4	0.78	249	252	237	234	243
7.4	0.97	217	242	151	192	232
8.4	0.72	285	285	200	285	285
9.4	0.76	292	311	290	285	295
10.4	0.69	350	350	345	345	353

From the table job number 1.1 means job set 1 and layout 1, from the Table 5 another digit appears as 2.10, which means job set 2 layout 1 with process time double and travel time halved or 2.41 it means job set 2 layout 4 with tripled process time and travel time halved. From Table 4 it can be observed that, out of 40 problems, 6 problems give better results using fuzzy heuristic algorithm when compared with all other four algorithms and it can also be observed from Table 5 that out of 42 problems, 7 problems give better results using fuzzy when compared with all other four algorithms. When comparing the results of fuzzy algorithm with FCFS by Nageswararao et al. (2017), it is observed that Fuzzy heuristic gives better results for 14 problems out of 40 problems in the case of $t_i/p_i > 0.25$ and gives better results for 23 problems out of 42 problems in the case of $t_i/p_i < 0.25$. Similarly when comparing the results with SPT, LPT and NEH by Prakashbabu et al (2018), Fuzzy heuristic gives better results for 22,12,7 problems respectively out of 40 problems in the case of $t_i/p_i > 0.25$ and gives better results for 23,22 and 7 problems respectively out of 42 problems in the case of $t_i/p_i < 0.25$.

Table 5
Comparison of make span values with $t/p < 0.25$

Job.No	t/p	FCFS	SPT	LPT	NEH	FUZZY
1.10	0.15	207	248	252	207	278
2.10	0.15	217	217	225	185	208
3.10	0.15	257	327	282	255	300
4.10	0.15	303	328	317	277	352
5.10	0.21	152	190	187	154	225
6.10	0.16	304	281	297	272	294
7.10	0.19	231	240	264	213	235
8.10	0.14	338	338	347	332	338
9.10	0.15	390	367	359	324	382
10.10	0.14	452	429	444	398	393
1.20	0.12	194	238	246	197	268
2.20	0.12	194	194	206	167	187
3.20	0.12	241	311	270	241	285
4.20	0.12	285	312	298	248	340
5.20	0.17	142	180	184	143	217
6.20	0.12	292	260	284	251	277
7.20	0.15	212	218	249	188	210
8.20	0.11	306	319	334	306	306
9.20	0.12	380	355	347	309	372
10.20	0.11	445	423	439	388	384
1.30	0.13	195	239	247	196	169
2.30	0.13	197	197	209	170	190
3.30	0.13	240	312	271	240	284
4.30	0.13	292	317	301	255	339
5.30	0.18	141	181	183	143	216
6.30	0.24	296	261	285	252	278
7.30	0.17	215	221	250	191	213
8.30	0.13	307	320	335	307	307
9.30	0.13	381	356	348	310	373
10.30	0.12	448	426	442	391	387
1.40	0.18	213	255	254	213	288
2.41	0.13	307	307	319	267	293
3.40	0.18	261	330	282	258	305
3.41	0.12	370	476	411	310	435
4.41	0.19	434	471	451	393	504
5.41	0.18	218	269	270	222	321
6.40	0.19	310	288	299	275	303
7.40	0.24	239	251	270	221	246
7.41	0.16	329	344	385	224	332
8.40	0.18	343	343	349	339	343
9.40	0.19	396	379	370	325	388
10.40	0.17	466	445	455	415	408

7. Conclusions

In this work the optimal sequence of machine and AGVs in FMS have been determined through fuzzy heuristic algorithm. The proposed algorithm provides the flow requirements of machine and AGVs simultaneously. This work mainly concentrated to integrate the material handling scheduling with machines.

It has observed that fuzzy heuristic algorithm is an effective method while generating optimal solutions in FMS from Table 4 and Table 5. Whereas process time and travel time are comparable, the proposed algorithm has given improvement in scheduling. For the simultaneous scheduling work fuzzy heuristic is suitable tool rather than non-traditional techniques. Since, the proposed algorithm gives assurance for improvement of scheduling in FMS environment, this methodology can be extended for several multi-objectives criteria like automated storage and retrieval systems and robots can also be included with machine and AGVs scheduling of FMS in future work.

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