A Hierarchical Manufacturing Route Planner Based on Heuristic Algorithm: Design and Evaluation

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Abstract:

This paper presents the design and evaluation of a manufacturing route planner for flexible manufacturing systems. The aim of the planner is to find the optimal manufacturing routes for jobs using well-designed cost functions. This route planner, which is based on heuristic [A] strategy, has been designed to work under dynamic arrival pattern environment. The proposed algorithm consists of two levels; the cell level, which controls the jobs flow between cells, and the machine level which controls the jobs flow between the machines inside the cells selected at first level.*

The solutions of the route planner are contained in a dynamic knowledge base that passes information to the sequencing and monitoring stage. The suggested model has also the capability to detect and response with suitable alternation for the damaged elements in the manufacturing system. To improve the performance of the planner, the design is organized into distributed programming media using the concurrent features of the modula-2 programming language. Finally, two case studies are considered to illustrate the functionality of the proposed algorithm.

Keywords: *Flexible manufacturing systems, Modeling & simulations, Artificial intelligence, Heuristic algorithms*

1. Introduction:

At the beginning of the 20th century, when mass production appeared, low cost production was achieved. Mass production is well suited to large volume production, which covers the high cost of large factories[1]. Normally, such a factory has collections of manually operated machines. Each machine was tended by its own operator, acting on instructions passed down a factory hierarchy from a supervisor. Human operators performed the important jobs of transferring materials and components in various stages. Today, computerized machines perform many operations. Much of manufacturing industry is concerned with production of goods not in large runs but in small, broken-up streams, during which factory managers frequently change the type of products to suite the demands of consumers and industrial customers, where special needs vary. The new manufacturing system offers a flexibility that can match this variation in demands [2-4]. Recently, low cost, small and middle production is made possible by a flexible manufacturing system (FMS). The benefits of using FMS are to reduce process-operating cost, to solve the problem of slow productivity growth and to enhance product quality.

Flexible manufacturing systems represent efficiently grouped machine tools linked together for batch processing. The FMS consists of production cells, each cell is responsible of producing a group of parts with similar production processes. However, FMS is a complex system due to the following features[5];

- each machine is quite versatile and capable of performing different operations,
- the system can manufacture several part types, each one may have alternative routing, and
- its constituting components are interrelated and required to operate in real-time[6].

There are many potential disturbances that affect the smooth operation of the FMS. Tools wear or break must be changed, machines can fail, defective parts can be produced, inspection and test stations can give false results. The number and variety of available jobs can change with time, as can the properties for completion of different jobs, repair and maintenance facilities may not always be effective in fixing machine failures or in finding or eliminating computer hardware and software faults. Therefore, it would be impossible task to capture all features of FMS operation in a single model. In this case, the hierarchical framework is suitable for FMS modeling and control.

This paper outlines the design and implementation of a hierarchical manufacturing route planner using a heuristic [A*] strategy. The text of the paper comprises five sections. Section 2 presents the FMS environment modeling and route planner features. The cell level and machine level route planners design and cost function calculations are described in section 3. Section 4 outlines two case studies of different topologies to illustrate the functionality of the manufacturing rout planner. Finally, the conclusions of this work are given in section 5.

2. System Organization:

The manufacturing route planner consists of two levels, the cell level and the machine level, as illustrated in figure 1. The cell level route planner is used to obtain the optimal manufacturing route between cells for the jobs wanted to be manufactured. The machine level, which represents the second stage in the hierarchy, is responsible to find the optimal manufacturing route for the jobs between group of machines inside each cell selected in the first level.

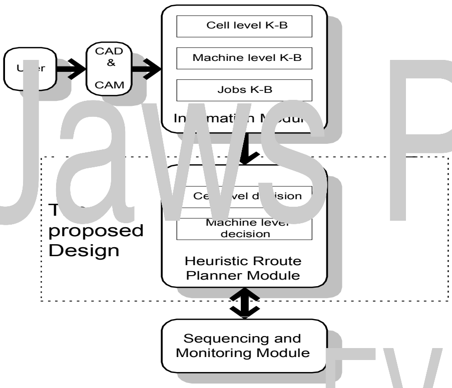


Figure 1. System organization.

2.1. FMS Environment Assumptions:

The design is based on the layout of the general manufacturing system shown in figure 2. Different types of material handling systems can be used to link between the manufacturing elements in the system. The main features of the FMS, on which the proposed route planner will work, are[7]:

- There may be multi inputs and multi outputs between the FMS and the outside environment. In the design these ports are looked to as dummy cells.
- The FMS consists of cells, the lower bound is one cell and the upper bound is open.
- Each cell has one input buffer and one output buffer.
- Any type of material handling systems may link the cells.
- There may be intermediate storage between the manufacturing cells
- Inside each cell there are number of machines. The lower bound is one machine and the upper limit is open.
- Any type of material handling systems may link the machines. The machine itself has in-buffer for jobs before manufacturing on the machine and out-buffer for jobs after manufacturing on the machine.
- There may be intermediate buffering storage between the machines inside the cell. These buffers are assumed to be dummy machines.

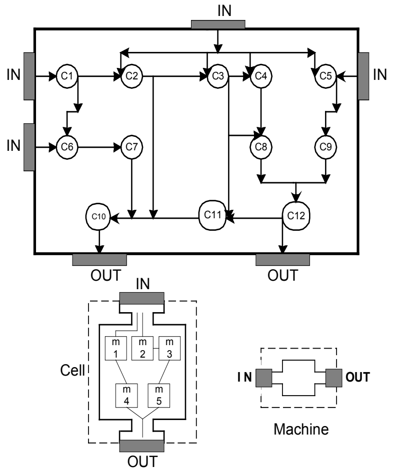


Figure 2. General layout of FMS.

2.2. The Route Planner Features:

It is obvious that the heuristic [A^*] search algorithm is complete, optimal and efficient among all optimal search algorithms[8]. This search algorithm has been used in the design of the manufacturing route planner, which has the following features:

- The route planner is of predictable approach, since it depends upon a heuristic knowledge.
- A good reduction in the nodes needed to be tested to reach the goal, that is because of the nature of the [A^*] algorithm which always selects the more promising nodes. Time of search activity will be reduced as a result of the above reduction.
- The cost function, which is the base of the heuristic algorithm, must be well designed to work in the FMS environment. However, the total cost function consist of two elements as follows :

$$f(n) = g(n) + h(n)$$

where;

g(n): represents the path cost from the start node to the node under test.

h(n): represents the estimated cost function for the cheapest path from node (n) to the goal.

- The following main factors, which affect the manufacturing processing, are taken into consideration:

a). The distance that is traveled by the job through it's manufacturing route.

b). The load distribution of the manufacturing operations between the cells and the machines in the FMS.

c). The execution time needed to manufacture the job.

3. Route Planner Design:

As mentioned before, two decision levels are suggested in the proposed planning algorithm. The first one specifies the manufacturing route at the cell level, and the other specifies the manufacturing route at the machine level.

3.1. The Cell Level Route Planner:

The decision of the heuristic algorithm is based on the cost functions related to each cell in the system The cost function elements of the proposed manufacturing route planner at the cell level are;

$g_1(n)$: The cost of the transportation from the start cell to the cell (n).

$g_2(n)$: The cost of the load distribution from the start cell to the cell (n).

$h_1(n)$: The estimated heuristic manufacturing cost in term of the remaining operations related to the manufacturing job from the cell(n) until reaching the manufacturing goal.

$h_2(n)$: The estimated heuristic transportation cost on a straight line from the cell(n) until reaching the manufacturing goal.

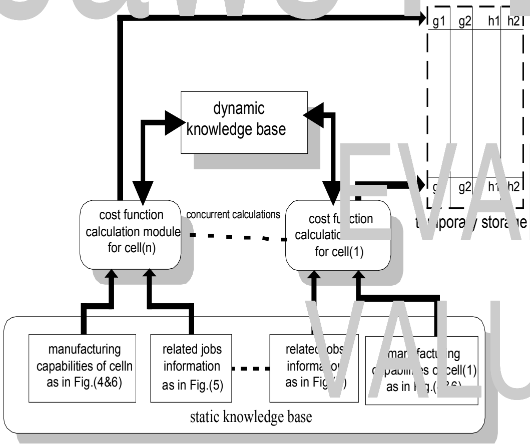


Figure 3. Concurrent interactions at cell level.

In this work, the manufacturing process knowledge has been distributed into three parts; general knowledge, job knowledge and cell/machine knowledge[9]. Figure 3 explains the concurrent interaction with the knowledge base modules to calculate the cost function elements. The values of these elements are stored in a temporary storage. The route planner will use these elements to make it's decision.

a). Calculation of $g_1(n)$:

It depends on the links information between cells given in array(1), figure 4.

b). Calculation of $g_2(n)$:

This cost function element balances the load between the cells by guiding the algorithm to optimize the rout toward

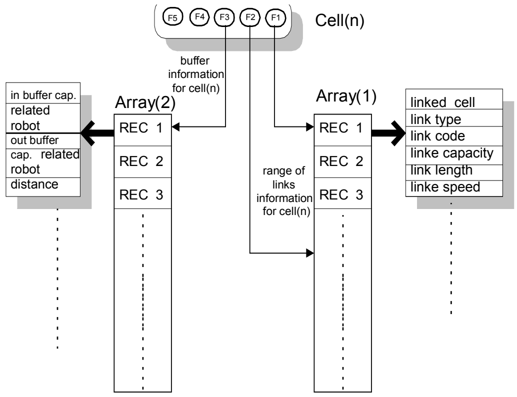


Figure 4. Cell level knowledge base.

the best distribution of the manufacturing load. This element consists of two subelements;

$$g_2(n) = a*g_{21}(n) + b*g_{22}(n)$$

The first subelement gives a picture for the manufacturing load on the machines needed by the current job and the previous jobs. The second subelement gives a picture for the manufacturing load on the machines not used by the current job but used by the previous jobs. These two parts are weighted by two variables (a and b).

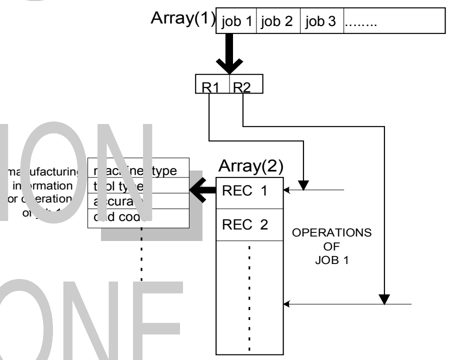


Figure 5. Job knowledge base.

c). Calculation of $h_1(n)$:

The procedure of $h_1(n)$ calculation starts when the cost calculation module of each cell enter the job knowledge base in figure 5, then it receives the information in the fields (1,2,3) of the records belonging to all the operations of the related job. It is the group of records in array(2) surrounded by the pointers of array(1). These fields represent the machine type, the tool type and the accuracy needed by the operations to be manufactured. Then each cost calculation module reads F4 and F5 from figure 6 of the related cell to check from the knowledge base if this cell can or cannot manufacture the operation. In the case of failing, the cost calculation module puts a tag on the related operation else it will go deeply in the knowledge base through array(2) and selects only the machines with accuracy equal to or better than the accuracy needed by the related operation. The final step in this procedure is to

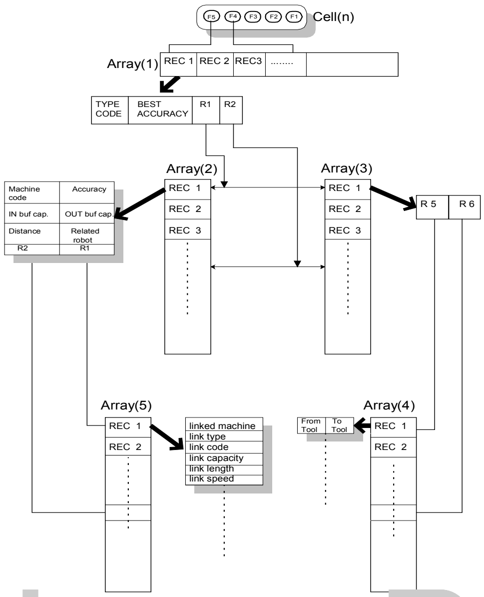


Figure 6. Machine level knowledge base.

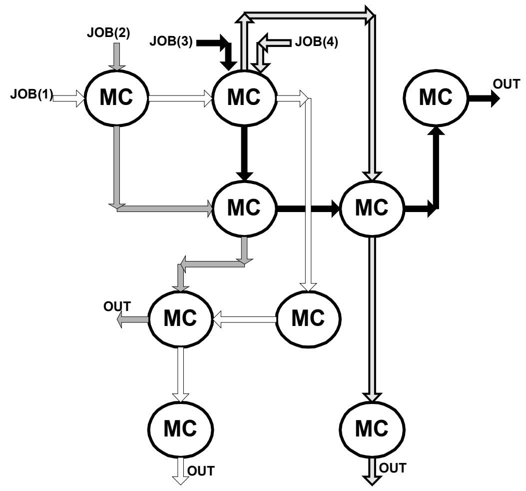


Figure 7. Route planner output at cell level.

know if any of the machine with suitable accuracy in the group discovered above has the suitable tool or not. This is done by going into array(3) and array(4). Again the failure in finding the suitable tool for the related operation will cause to tag this operation indicating that the cell can not manufacture it, otherwise, the operation is added to the group of operations that can be manufactured by the cell. Then, each sequence of operations, which can be manufactured by the cell, is grouped together. Assume a job with 8 operations to be manufactured and operations (op1, op2, op3, op7 and op8) are manufactured in a certain cell. Therefore, $h_1(n)$ is calculated according to the unmanufactured group which includes operations (op4, op5 and op6). It is clear that $h_1(n)$ is an admissible heuristic function, since the cell can manufacture at least one of the above two groups of operations if the optimal solution passes through it. For example, if the first group is manufactured, then the actual $h_1^*(n)$ is a function to operations (op4,op5,op6,op7,op8) and this is greater than the calculated $h_1(n)$ which is a function to (op4,op5,op6).

d). Calculation of $h_2(n)$:

The value of the distance from the output buffer of each cell to the nearest external port of the FMS can be extracted from the knowledge base in array(7) shown in figure 4. Again, this heuristic cost is admissible since the direct distance is certainly less than or equal to the real distance between any two points. Hence, the condition is also achieved here to get the optimized solution according to the rule of the admissibility of the A* search type.

After finding the optimal manufacturing route for such a job, the algorithm selects the next job from the job knowledge base of figure 5 according to the level of priority. Figure 7 illustrates an example for four manufacturing planning routes resulted from cell level.

3.2. The Machine Level Route Planner:

The output resulted from the cell level route planner is a temporary knowledge for each cell on the manufacturing route. This knowledge contains groups of machines, and each group represents the candidate machines that are suitable to manufacture one of the operations of the desired job in the related cell. The set of machine groups per cell represents the state space of the problem at the machine` level inside that cell as shown in figure 8. The machine level planner will find the optimal manufacturing routes inside each of the above cells. The cost function F(n) is designed to face the traveling problem and the manufacturing execution problem . For this reason, the cost function is proposed to consist of multiple elements;

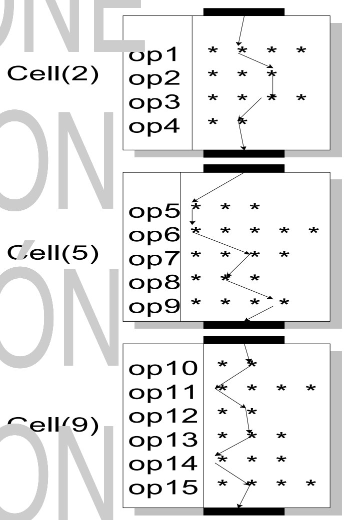


Figure 8. Machines state space.

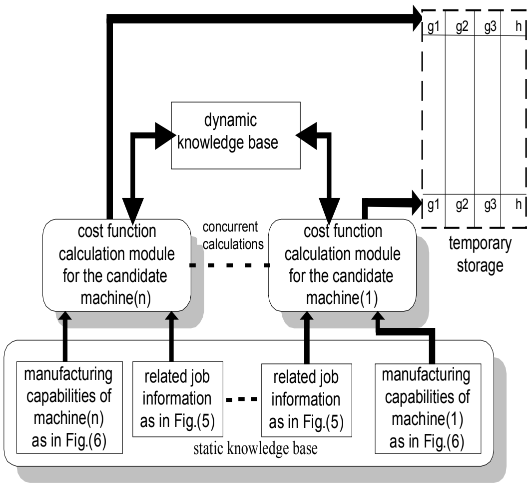


Figure 9. Concurrent interactions at machine level.

$$F(n)= g_1(n) + g_2(n) + g_3(n) + h(n)$$

where;

$g_1(n)$: The transportation cost from the input buffer of the cell to machine(n).

$g_2(n)$: The time execution cost from the input buffer of the cell to machine(n).

$g_3(n)$: The load distribution cost from the input buffer of the cell to machine(n).

$h(n)$: The heuristic transportation cost on a straight line from machine(n) to the output buffer of the cell.

Inside each cell, the machine level planner will specify a software module for each machine in the state space. Figure 9 illustrates the proposed concurrent design between these modules and the effect of the dynamic knowledge base on the cost function calculation.

Calculation of $g_1(n)$:

The calculation of this element starts by interaction with the machine level knowledge base in figure 6. Pointers are used to reach the information about the set of links for the machine under test in array(5). Then this information is passed to the cost function calculation module. The results of transportation cost output from the cost function calculation module are used by the route planner to calculate $g_1(n)$.

Calculation of $g_2(n)$:

The calculation of this cost function element depends upon the information extracted for each related operation from figure 5, which consists of the parameters (tool type; accuracy; CAD code). The cost function calculation module will merge this information with the capability of the candidate machines, which are selected for manufacturing the related operation at cell level. The final results are stored in the temporary storage to calculate the total $g_2(n)$.

Calculation of $g_3(n)$:

It depends on the manufacturing load distribution per each machine in the state space of such a cell. This cost function element will improve the solution, so that the machine with the minimum load becomes more promising to be selected.

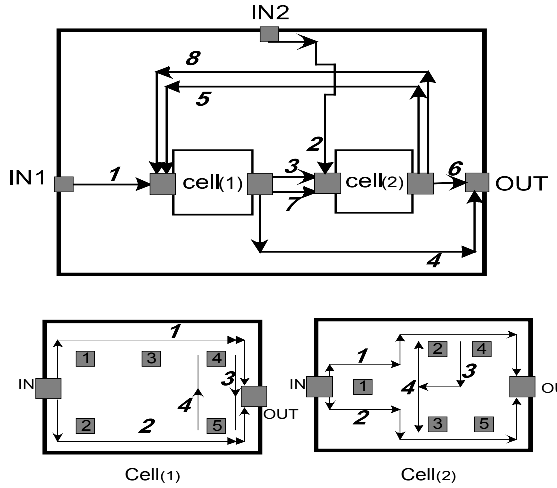


Figure 10. Case study (1).

At the end of each manufacturing route plan decision, each related machine has a history of all operations to be executed by itself. This history is stored in a dynamic knowledge base. The route planner for any job always takes into account the results of the route plans for the previous jobs stored in that dynamic knowledge base to calculate the new $g_3(n)$.

Calculation of $h(n)$:

It is extracted for each machine from the field of distance information given in array(2) in figure 6. At the end of the machine level route planner, the manufacturing route inside each cell from cell level will be decided as set of machines. The manufacturing path, shown in figure 8, illustrates an example of the machines selected by the machine level planner.

4. System Evaluation:

To test the performance of the proposed manufacturing route planner, several case studies were performed and compared with other well known algorithms.

(a). Case study (1):

This case assumes an FMS, figure 10, with the following features;

For cell level: two inputs (IN1 & IN2), two cells (C1 & C2), one output (OUT), and two types of transportation links (CONVEYER & AGV).

For machine level: cell(1) contains 5 machines, cell(2) contains 5 machines, transportation links between machines are of conveyer type only.

Job knowledge base: this knowledge base describes the orders demanded by the manufacturer. Two orders are tested, as given in Table 1. The first order consists of 3 jobs, and the second consists of 4 jobs.

Tests show that the performance of the proposed manufacturing route planner gives an optimal behavior (under the given considerations) compared with the uniform algorithm[10], as illustrated in Table 2.

Job No.		Machine Type	Tool Type	Accuracy	CAD Code
Job1,	Op.1	5	6	0.006	1:1
	Op.2	1	28	0.006	1:2
	Op.3	1	72	0.006	1:3
	Op.4	7	15	0.006	1:4
	Op.5	6	43	0.006	1:5
Job2,	Op.1	5	4	0.0002	2:1
	Op.2	2	117	0.0002	2:2
	Op.3	1	87	0.0002	2:3
	Op.4	7	38	0.0002	2:4
	Op.5	6	205	0.0002	2:5
	Op.6	5	11	0.0002	2:6
	Op.7	2	80	0.0002	2:7
Job3,	Op.1	4	13	0.02	3:1
	Op.2	7	5	0.02	3:2
	Op.3	6	132	0.02	3:3
	Op.4	3	24	0.02	3:4
	Op.5	2	98	0.001	3:5
	Op.6	2	128	0.001	3:6
	Op.7	1	81	0.001	3:7

(a). For Test (1)

Job No.		Machine Type	Tool Type	Accuracy	CAD Code
Job1,	Op.1	5	3	0.0002	1:1
	Op.2	1	67	0.00[illegible]	[illegible]
	Op.3	4	13	0.00[illegible]2	[illegible]:3
	Op.[illegible]	6	13[illegible]	0.00[illegible]2	[illegible]:4
	Op.5	2	3	0.00[illegible]	[illegible]:5
	Op.[illegible]	1	52	0.00[illegible]2	[illegible]:6
[illegible]	Op.1	5	2[illegible]	0.00[illegible]2	[illegible]:1
	Op.[illegible]	5	2[illegible]	0.00[illegible]2	[illegible]
	Op.3	3	44	0.0002	2:3
	Op.4	2	137	0.0002	2:4
Job3,	Op.1	7	18	0.00002	3:1
	Op.2	6	139	0.00002	3:2
	Op.3	5	3	0.00002	3:3
	Op.4	2	19	0.00002	3:4
	Op.5	1	66	0.00[illegible]02	3:[illegible]
Job4,	Op.1	7	37	0.00[illegible]2	4:[illegible]
	OP.2	3	85	0.00[illegible]	4:[illegible]
	Op.3	3	89	[illegible].002	4:[illegible]
	Op.4	1	25	0.002	4:4
	Op.5	7	79	0.002	4:5
	Op.6	6	231	0.002	4:6

(b). For Test (2)

Table 1. Job knowledge-base for case study (1).

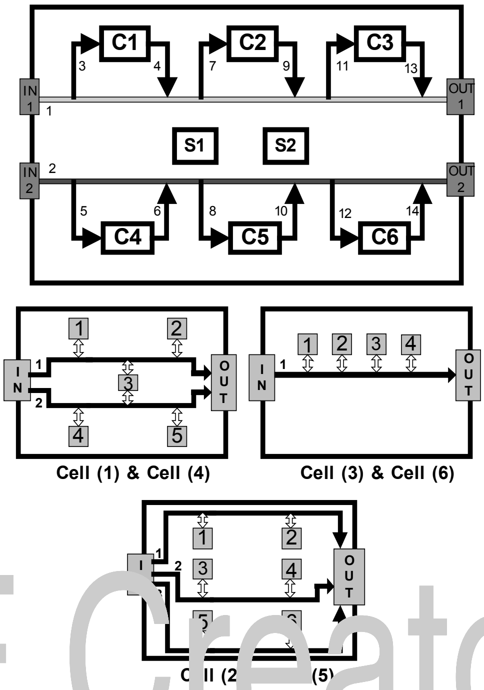
(b). Case study (2):

Figure 11 shows another case study of different topologies, it has the following features;

- For cell level: two inputs (IN1 & IN2), six cells (C1, …, C6), two intermediate storage buffers (S1 & S2), one output (OUT), and two transportation links.
- For machine level: the cell pairs (C1&C4), (C2&C5) and (C3&C6) are similar and may differ from each other in tools sets available on the machines.
- Job knowledge base: two manufacturing orders are tested. The first order consists of 4 jobs, and the second order consists of 6 jobs, as given in Table 3.

Simulated results obtained from the second case study indicate that the rout planner algorithm is not sensitive to the pattern of data, as illustrated in Table 4.

On-line scheduling is an important task for obtaining



efficiency and high productivity in flexible manufacturing systems. A hierarchical on-line scheduler based on colored

Figure 11. Case study (2).

Cell Level		Route Cells		Route Links	
Test No.		Proposed Algorithm	Uniform Algorithm	Proposed Algorithm	Uniform Algorithm
Test1	Job1	IN1,C1,C2,OUT	IN1,C1,C2,OUT	1-3-6	1-3-6
	Job2	IN1,C1,C2,C1,OUT	IN1,C1,C2,C1,OUT	1-3-5-4	1-3-5-4
	Job3	IN2,C2,C1,OUT	IN2,C2,C1,OUT	2-5-4	2-5-4
Test2	Job1	IN1,C1,C[illegible],C1,OUT	IN1,C1,C2,C1,OUT	1-3-5-4	1-3-5-4
	Job2	IN1,C[illegible],OUT	IN1,C1,OUT	1-4	1-4
	Job3	IN2,C[illegible],C[illegible],OUT	IN2,C2,C1,OUT	2-5-4	2-5-4
	Job4	IN2,C[illegible],C[illegible],OUT	IN2,C1,C2,OUT	2-5-3-6	2-5-3-6

Machine Level		Route Machines		Route Links	
Test No.		Proposed Algorithm	Uniform Algorithm	Proposed Algorithm	Uniform Algorithm
Test1, Job1	C1	IN,2,5,5,OUT	IN,2,5,5,OUT	2-2-2	2-2-2
	C2	IN,2,4,0UT	IN,2,4,OUT	1-1-1	1-1-1
Test1, Job2	C1	IN,2,4,5,OUT	IN,2,4,5,OUT	2-4-3-2	2-4-3-2
	C2	IN,[illegible],5,OUT	IN,3,5,OUT	2-2-2	2-2-2
	C1	IN,1,4,OUT	IN,1,4,OUT	1-1-1	1-1-1
Test1, Job3,	C2	IN,1,2,4 OUT	IN,1,2,4,OUT	1-1-1-1	1-1-1-1
	C1	IN,3,4,[illegible],5,OUT	IN,3,4,4,5,OUT	1-1-1-3-2	1-1-1-3-2
Test2, Job1,	C1	IN,2,[illegible],OUT	IN,2,5,OUT	2-2-2	2-2-2
	C2	IN,[illegible],4,OUT	IN,1,4,OUT	1-1-1	1-1-1
	C1	IN,4,5,OUT	IN,4,5,OUT	1-3-2	1-3-2
Test2, Job2,	C1	IN,1,1,3,4,OUT	IN,1,1,3,4,OUT	1-1-1-1	1-1-1-1
Test2, Job3,	C2	IN,[illegible],4,OUT	IN,2,4,OUT	1-1-1	1-1-1
	C1	IN,2,4,5,OUT	IN,2,4,5,OUT	2-4-3-2	2-4-3-2
Test2, Job4,	C2	IN,3,OUT	IN,3,OUT	2-2	2-2
	C1	IN,3,3,5,OUT	IN,3,3,5,OUT	1-3-2	1-3-2
	C2	IN,3,[illegible],OUT	IN,3,5,OUT	2-2-2	2-2-2

Table 2. Route cells, machines and links for case study (1).

Petri nets has been designed and used in our system, this work is presented in reference[11]. This scheduler consists of two levels; the cell level and the machine level. One of the tasks achieved by the scheduler is to monitor and control the concurrency, dynamic arrival of the jobs, and the use of limited resources in the system.

Job No.		Machine Type	Tool Type	Accuracy	CAD Code
Job1,	Op.1	4	8	0.0002	1:1
	Op.2	2	12	0.0002	1:2
	Op.3	3	10	0.0002	1:3
	Op.4	1	4	0.0002	1:4
	Op.5	8	46	0.0002	1:5
Job2,	Op.1	4	67	0.0002	2:1
	Op.2	9	5	0.0002	2:2
	Op.3	5	24	0.0002	2:3
	Op.4	6	78	0.0002	2:4
	Op.5	3	17	0.0002	2:5
	Op.6	8	22	0.0002	2:6
Job3,	Op.1	4	2	0.00002	3:1
	Op.2	9	146	0.00002	3:2
	Op.3	10	104	0.00002	3:3
	Op.4	11	5	0.00002	3:4
	Op.5	3	9	0.00002	3:5
	Op.6	1	9	0.00002	3:6
	Op.7	8	34	0.00002	3:7
	Op.8	7	60	0.00002	3:8
Job4,	Op.1	2	1	0.002	4:1
	Op.2	9	105	0.002	4:2
	Op.3	5	16[illegible]	0.002	4:3
	Op.4	5	10[illegible]	0.002	4:4
	Op.5	6	80	0.0[illegible]	4:5
	Op.6	3	9	0.0[illegible]	4:6
	Op.7	8	23	0.001	4:7
	Op.8	7	77	0.001	4:8

(a). For Test (1)

Job No.		Machine Type	Tool Type	Accuracy	CAD Code
Job1,	Op.1	4	55	0.0002	1:1
	Op.2	2	49	0.0002	1:2
	Op.3	9	87	0.0002	1:3
	Op.4	10	7	0.0002	1:4
	Op.5	11	4	0.0002	1:5
	Op.6	3	16	0.0002	16
	Op.7	1	140	0.0002	1:7
	Op.8	7	2	0.0002	1:8
Job2,	Op.1	3	44	0.0002	2:1
	Op.2	1	5	0.0002	2:2
	Op.3	8	68	0.0002	2:3
Job3,	Op.1	4	1	0.00002	3:1
	Op.2	2	24	0.00002	3:2
	Op.3	9	99	0.00002	3:3
	Op.4	5	200	0.00002	3:4
	Op.5	6	34	0.00002	3:5
	Op.6	8	3	0.00002	3:6
	Op.7	7	2	0.00002	3:7
Job4,	Op.1	4	4	0.002	4:1
	OP.2	2	2	0.002	4:2
	Op.3	9	9	0.002	4:3
	Op.4	10	10	0.002	4:4
	Op.5	11	11	0.001	4:5
	Op.6	1	1	0.001	4:6
	Op.7	8	8	0.001	4:7
	Op. 8	7	7	0.00[illegible]	4:8
Job5,	Op.1	5	210	0.00002	5:1
	OP.2	6	123	0.00002	5:2
	Op.3	6	78	0.00002	5:3
	Op.4	3	10	0.00002	5:4
	Op.5	1	17	0.00002	5:5
	Op.6	1	56	0.00002	5:6
	Op.7	8	41	0.00002	5:7
Job6,	Op.1	4	4	0.002	6:1
	OP.2	2	2	0.002	6:2
	Op.3	9	9	0.002	6:3
		9	9	0.002	6:4
	Op.4	3	3	0.001	6:5
		7	7	0.001	6:6
		7	7	0.001	6:7

(b). For Test (2)

Table 3. Job knowledge-base for case study (2).

Cell Level		Route Cells		Route Links	
Test No.		Proposed Algorithm	Uniform Algorithm	Proposed Algorithm	Uniform Algorithm
Test1	Job1	IN1,C1,C3,OUT1	IN1,C1,C3,OUT1	1-3-4-1-11-13-1	1-3-4-1-11-13-1
	Job2	IN2,C4,C5,C6,OUT2	IN2,C4,C5,C6,OUT2	2-5-6-2-8-10-2-12-14-2	2-5-6-2-8-10-2-12-14-2
	Job3	IN2,C4,C2,C3,OUT1	IN2,C4,C2,C3,OUT1	2-5-6-2-1-7-9-1-11-13-1	2-5-6-2-1-7-9-1-11-13-1
	Job4	IN1,C1,C2,C6,OUT1	IN1,C1,C2,C6,OUT1	1-3-4-1-7-9-1-2-12-14-2	1-3-4-1-7-9-1-2-12-14-2
Test2	Job1	IN1,C1,C2,C3,OUT1	IN1,C1,C2,C3,OUT1	1-3-4-1-7-9-1-11-13-1	1-3-4-1-7-9-1-11-13-1
	Job2	IN2,C6,OUT2	IN2,C6,OUT2	2-12-14-2	2-12-14-2
	Job3	IN2,C4,C5,C3,OUT1	IN2,C4,C5,C3,OUT1	2-5-6-2-8-10-2-1-11-13-1	2-5-6-2-8-10-2-1-11-13-1
	Job4	IN2,C4,C5,C6,OUT2	IN2,C4,C5,C6,OUT2	2-5-6-2-8-10-2-12-14-2	2-5-6-2-8-10-2-12-14-2
	Job5	IN1,C2,C3,OUT1	IN1,C2,C3,OUT1	1-7-9-1-11-13-1	1-7-9-1-11-13-1
	Job6	IN1,C1,C6,OUT2	IN1,C1,C6,OUT2	1-3-4-1-2-12-14-2	1-3-4-1-2-12-14-2

Machine Level		Route Machines		Route Links	
Test No.		Proposed Algorithm	Uniform Algorithm	Proposed Algorithm	Uniform Algorithm
Test1 ,Job1,	C1	IN-1-3-OUT	IN-1-3-OUT	1-1-1	1-1-1
	C3	IN-1-2-3-OUT	IN-1-2-3-OUT	1-1-1-1	1-1-1-1
Test1 ,Job2,	C4	IN-4-5-OUT	IN-4-5-OUT	2-2-2	2-2-2
	C5	IN-3-4-OUT	IN-3-4-OUT	2-2-2	2-2-2
	C6	IN-1-3-OUT	IN-1-3-OUT	1-1-1	1-1-1
Test1, Job3,	C4	IN-4-5-OUT	IN-4-5-OUT	2-2-2	2-2-2
	C2	IN-1-2-OUT	IN-1-2-OUT	1-1-1	1-1-1
	C3	IN-1-2-3-4-OUT	IN-1-2-3-4-OUT	1-1-1-1	1-1-1-1
Test1, Job4,	C1	IN-3-2-OUT	IN-3-2-OUT	1-1-1	1-1-1
	C2	IN-3-4-OUT	IN-3-4-OUT	2-2-2	2-2-2
	C6	IN-1-3-4-OUT	IN-1-3-4-OUT	1-1-1-1	1-1-1-1
Test2, Job1,	C1	IN-1-3-2-OUT	IN-1-3-2-OUT	1-1-1-1	1-1-1-1
	C2	IN-[illegible]-OUT	IN-[illegible]-OUT	1-1-1	1-1-1
	C3	IN-1-2-4-OUT	IN-1-2-4-OUT	1-1-1-1	1-1-1-1
Test2, Job2,	C6	IN-1-2-4-OUT	IN-1-2-4-OUT	1-1-1-1	1-1-1-1
Test2, Job3,	C4	IN-1-3-2-OUT	IN-1-3-2-OUT	1-1-1-1	1-1-1-1
	C5	IN-3-4-OUT	IN-3-4-OUT	2-2-2	2-2-2
	C3	IN-3-4-OUT	IN-3-4-OUT	1-1-1	1-1-1
Test2, Job4,	C4	IN-4-3-5-OUT	IN-4-3-5-OUT	2-2-2-2	2-2-2-2
	C5	IN-1-2-OUT	IN-1-2-OUT	1-1-1	1-1-1
	C6	IN-2-3-4-OUT	IN-2-3-4-OUT	1-1-1-1	1-1-1-1
Test2, Job5,	C2	IN-5-6-6-OUT	IN-5-6-6-OUT	3-3-3	3-3-3
	C3	IN-1-2-2-3-OUT	IN-1-2-2-3-OUT	1-1-1-1	1-1-1-1
Test2, Job6,	C1	IN-4-3-5-5-OUT	IN-4-3-5-5-OUT	2-2-2-2	2-2-2-2
	C6	IN-1-4-4-OUT	IN-1-4-4-OUT	1-1-1	1-1-1

Table 4. Route cells, machines and links for case study (2).

In the case of a manufacturing problem, such as damaging of a machine, which may stop all the manufacturing routes that pass through this machine, the proposed planner will obtain an alternative manufacturing route (if available) from the knowledge base to overcome such a problem. This alternative will be used until another optimal manufacturing route is calculated under the new circumstance. If more than one resource is damaged simultaneously, then the alternatives will be found in succession. This approach may result in conflict alternatives. However, this weakness is accepted because practically the damaging of more than one resource at the same time is rare. To face such multi problems, the malfunction route plans are stopped and wait for the route planner to find new manufacturing routes.
Finding an alternative may loss the optimality, since the alternative is extracted directly from the knowledge base. But this will be accepted, since it will be just for a period of time until an optimal manufacturing route is planned in the new environment.

Table 5 outlines examples for some problems tested for the above case studies. It is found that the average response time required to find the alternative solutions is quite reasonable even if the FMS is of real time nature.

Cell level:

Damaged Element	Alternative	Recovery Time (sec)
Link No. 3	Link No. 7	1.94

Machine level:

Damaged Element	Alternative	Recovery Time (sec)
Machine 1 in Cell 1	Machine 2 in Cell 1	1.1
Machine 4 in Cell 2	Machine 5 in Cell 2	1.24

(a). Case Study (1)

Cell level:

Damaged Element	Alternative	Recovery Time (sec)
Link No. 1	No local alternative	5.3

Machine level:

Damaged Element	Alternative	Recovery Time (sec)
Test1: Machine1/Cell 1	Machine 4 in Cell 1	1.26
Test1: Machine4/Cell 3	No local alternative	1.15
Test2: Machine5/Cell 2	Machine 3 in Cell 2	1.5
Test2: Machine4/Cell 4	Machine 1 in Cell 4	1.7

(b). Case Study (2)

Table 5. Recovery time

5. Conclusions

In this paper, a hierarchical manufacturing route planner is presented. This planner is based on heuristic [A*] search algorithm. It consists of two levels, the cell level and the machine level. A simulated model has been designed and implemented to test the capability of the proposed route planner. The route planner assumes to work with general FMS and under dynamic arrival pattern environment. It has shown optimal solution compared with a traditional optimal method for several case studies. The cost function components (g & h) have been well designed to suit with the FMS nature and requirements.

The decision-making tasks of the route planner are handled concurrently by executing the planner algorithm in time sharing programming media.

The weakness of the proposed algorithm in finding the alternative route, in case of damaging resource, is the loss of optimal solution. However, the gain of recovery time is an important parameter to accept this condition in real-time systems.

In order to improve the performance of the proposed planning algorithm, an additional fuzzy decision-planning algorithm will be considered. This will be our future research work.

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