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Integration of Process Planning and Scheduling of a Manufacturing Systems using Petri nets and Genetic Algorithm

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Abstract

This paper presents a new approach towards the integration of process planning and scheduling functions in the manufacturing systems using Petri nets and genetic Algorithm. The modelling and cost estimation technique is based on a new Petri net model: the PP-net (Process Planning net) which represents manufacturing knowledge in the form of precedence constraints and incorporates the cost of machining operations in each operation transition. Using this model as the base, the process plan for the part is developed taking into account the manufacturing costs caused by the machine, setup and tool changing in addition to the pure operation cost. The method proceeds in the cost calculation by attaching a specific data structure to each PP-net transition which describes the associated machine, setup and the tool for the operation modelled by the transition. After the model is created, it is analyzed for the cost and the minimum time of processing of the part. Scheduling is done using Genetic Algorithms to find the minimum tardiness as the objective on three parts which use the same machines and setups.

Keywords: CAPP, PNML, PP-net, Process planning, Scheduling

1. Introduction

The manufacturing of a domain part the estimation cost is seen as the cost of machining operations and associated with other activities that the total manufacturing system of the part. This estimation should be done at an early stage of the part design which decides the total cost of production. In manufacturing systems process planning and scheduling play an important role. The process planning highly related two functions i.e. each machining operation is assigned to a certain machine tool and scheduling the assignment of machine tool over time to different machine is performed.

Process planning links the design activity and production stage. It translates design specifications into manufacturing operation details. In another words, process planning is a task of precisely specifying how to manufacture a particular product with the objectives of producing product according to specifications and producing product at minimum cost[1]. It emphasizes the technological aspects of manufacture routings and resource assignments. A good scheduling strategy may help companies to respond to market demands quickly and to run plants efficiently. This helps them to be more competitive in today's market. Scheduling is the task of allocating available production resources (labor, material and equipment) to jobs over time. The scheduling objectives are to satisfy production constraints and minimize production costs.

Petri nets is a graphical and mathematical tool

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to provide a modeling, formal analysis and design of discrete event systems. The major advantage of Petri net model is used to analysis behavior properties and evaluation performance, as well as discrete event simulators and controllers. The Petri nets were named after Carl A. Petri who created in 1962 a net-like mathematical tool for the study of communication with automata. Their further development was facilitated by the fact that Petri nets can be used to model properties such as process synchronization, asynchronous events, concurrent operations, and conflicts or resource sharing. These properties characterize discrete-event systems whose examples include industrial automated systems, communication systems, and computer-based systems. These and other factors make Petri nets a promising tool and technology for application to Industrial Automation.

2. Related Work

A number of books have been published on the subject, e.g.[2] French (1982), Articles that survey the techniques and development of scheduling include Blackstone et. al. (1982),[3] Brandimarte (1992),[4] MacCarthy & Liu (1993), [5] Blazewicz et.al. (1996) and[6] Gargeya & Deane (1996). [1] Palmer (1996) defined conventional scheduling as a task that uses input from rigid process plans. [7]Sundaram & Fu (1988) were among the earlier researchers who shown that there exists a need for integrating the process planning and scheduling functions in manufacturing for productivity improvements. Some other approaches are integer programming, rule-based approach, simulated annealing approach, tabu search[3] and genetic algorithms approach.[8] Srihari, K. & Emerson, C. R., Presented Petri net models integrating job-shop process planning and scheduling.

3. Process Planning using Petri Nets

[9] A Petri net has two types of nodes, namely places and transitions. A place (P) is represented by a circle and a transition (T) by a bar (certain authors represent a transition by a box) Places and transition are connected by arcs. The number of places and transitions are finite and not zero. An arc is a directed and connects either a place to a transition or a transition to a place.

The places are represented as P= $\{P_1,P_2,\ldots P_n\}$

The set of transitions is given as T= $\{T_1,T_2,\ldots..T_n\}$

Each place contains an integer (positive or zero) of tokens

4. Modelling of a Process planning with Petri nets

[9]The Petri net model is a modified and extended version described by Kiritsis and Porchet. This method has been proposed by Kiritsis D, K.-P. Neuendorf, P. Xirouchakis in the paper "Petri net techniques for process planning cost estimation" [10].

They are four types of process planning of cost

(i) Machining cost,

(ii) Moving a one part from one machine to another machine.

(iii) Changing a machine cost setup

(iv) Changing a machine tool cost

The cost of a machining depends on time machine is used to operation of a machining. The costs are generalized PP-nets incorporated by assigning to each transition of the PP-net. There are four methods are proposed.

Phase 1: Input data of a process planning

Phase 2: The operation and cost inputs i.e. machine, setup, tool and input of the cost operation the tool change, the machine also changed.

Phase 3: Creation of a PP-net

Phase 4: Compute generalized PP-net of the weighted minimal

In the graph of the PP-net of the test case part, the transitions are the arcs labelled and path are the process plan (i.e. transitions of a sequence) the graph starts from initially marking and finally end at a node. The final node is node having a token at P_{stop}. The estimated cost of every operation is given by a cost value assigned to every transition of the PP-net of the test case part. The machine cost, tool changes and setup is assigned corresponding machine, Petri net model tool, setup of the PP-net system as shown figure 1. The PPC system can be determined as the total values of the transitions and the corresponding path. The minimal weighted path of the graph of the PP-net of the test case part can be determine by analysis of a Petri net tool.

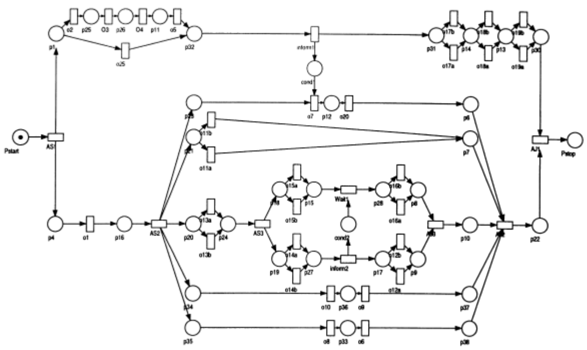


Figure 1. The PP-net of the test case part.

5. Scheduling using Genetic Algorithm

The scheduling algorithm has been developed in two modules .The first module is the input for the second module. In the first module, the output which is obtained from the process planning algorithm, the penalty cost and the due date are given as input to this algorithm .The second module retrieves this input and schedules the jobs on the machines. The output of the algorithm is:

1. A candidate table that gives the information about the number of operations that are performed on the job, the alternative machines which can be used for that particular operation, the processing times on each machine for each operation and the cost associated with each operation.
2. Minimum cost for the first and the last iterations with the best chromosomes associated with both process planning and scheduling.
3. A schedule table which gives the order in which the machines are scheduled with their processing times.
4. The start time and the completion time of each job n each machine.
5. Optimum combination of the scheduling cost and the process planning cost.

The first job on the list is first evaluated and assigned to the machine if the job precedence constraints and machine availability constraints are satisfied, i.e., if all the jobs that are to be done immediately before this job are done, and if the machine is available for setup. Once it is assigned, the start times and completion times are calculated based on the processing time of the machine. If the job cannot be assigned, it is put in a state of wait, and the next job is in the list is considered. This process is repeated for each list till all the jobs are allocated. Associated with each schedule is the scheduling cost depending on the completion time of the last job. Linear penalty function has been assigned for tardiness. Implementation of GA in scheduling Problem

The general procedure for genetic algorithms in optimization problems can be described as follows:

1. Design procedure for genetic encoding of the decision variables so that there is a one to one mapping between the genetic variable and the real value of the decision variables.
2. Define the probabilities of crossover and mutation, the population size and the maximum number of generations of solutions.
3. The objective function values can be evaluated
4. Reproduction, crossover and mutation are three operators applying to those solutions to generate a new population.
5. Chromosome is best solution of the optimization problem.

This logic is implemented for the scheduling of the machines. This has been illustrated on a simple 3x3 scheduling problem and can be extended over to any size of the problem. Advantage of this approach is that it covers maximum search space and the rate of convergence is high.

The disadvantage of this approach is that as the size of the jobs and machines goes on increasing the length of the chromosome increases and the computational time increases, which solely depends on the speed of the computer. Output of the scheduling algorithm

The work aims at minimizing the overall production cost, which includes both the manufacturing cost and the scheduling cost.

Scheduling algorithm:

Module 1: input algorithm

Step 1: Initialize the size of job, operation and machine.
Step 2: Initialize the schedule table and the candidate table.
Step 3: Input the number of jobs, operations and machines.
Step 4: Input for the alternative process plans and for each job, processing time on each machine and the operating cost.
Step 5: Input the penalty cost and due time of the demand.
Step 6: Print the Candidate table with the number of operations, number of alternative machines, processing time on each machine and the operating cost.

Module 2: Schedule output Algorithm

Step 1: Read the input from the input.dat file, which stores the process planning output for each job i.e. number of operations, number of candidates for each operations, operating for time and machine ,penalty cost and due date of the demand. similarly for all the other jobs and operations.

Step 2: This function simple prints the input, which has been given to the input algorithm.

Step 3: To avoid printing of the garbage values, the 'initial' function initializes all the variables to zero.

Step 4: The size of the population is defined.

Step 5: The new chromosome function generates randomly the initial population such that the constraints are satisfied.

Step 6: Each chromosome is evaluated based on the fitness function, which is the cost function. This function evaluates for the manufacturing cost and the scheduling cost. Evaluation of the manufacturing cost is done based on the candidate machine selected. The scheduling cost is evaluated finding the make span time of given chromosome and it will estimate the time that will exceed the due date. This exceeding time is called the tardiness time from which we calculate the tardiness cost or the scheduling cost.

Step 7: After the evaluation of each chromosome the population is sorted in the ascending order of the cost.

Step 8: In the tournament selection approach, the minimum cost chromosome is kept undisturbed and is stored in a temporary location.

Step 9: Crossover is applied on the selected chromosomes of population depending upon the probability of crossover (P_c).

Step 10: Mutation is applied on the selected chromosomes depending upon the probability of mutation (P_m).

Step11: The newly generated off springs are replaced into the population pool and the fitness function of the newly created population is evaluated. The steps 6 to are repeated to achieve the objective function.

6. Implementation Via Example

In this section the applications of the developed system to real world test case. A job shop is considered in which ten machines are used namely, three milling machines, two drilling machines, three grinding machines ,one jig boring machine and one CNC machine. The layout of the machine is shown below. Three parts with similar manufacturing operations are considered for cost estimation using the PP-net. The drawings of the part are shown below.

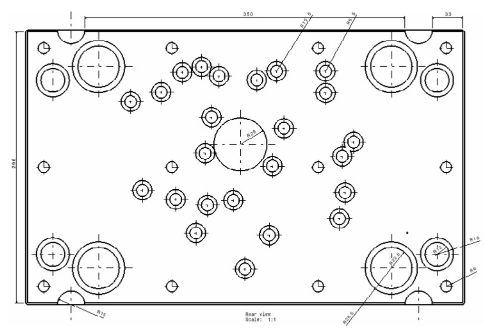
These are the sequence of steps of the process of cost estimation.

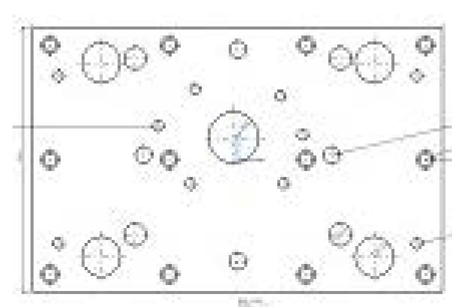
7. Model creation

The three parts are designed using the CATIA package. The CAD drawings are shown in the following figure. The parts are types of ejector plates in which mainly features present are holes and counter bores. The CAD drawings showing the dimensions of the parts are shown below.

8. Translation from VRML to PNML

These files are saved in VRML format for further process. The *VRML* can be viewed without any CAD package support on the web. The parts in the browser window are shown in figs. Using NIST *vrml2x3d* translator the VRML file is converted to *x3d* file. The *x3d* file can also be viewed with the help of the Octaga player on the web.





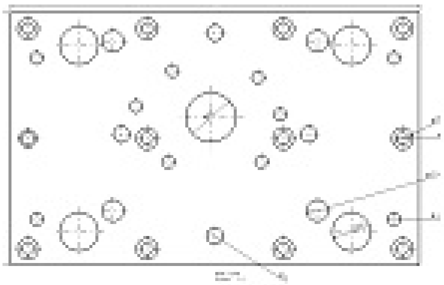


Figure 2. CAD Drawing of part 1,2 and 3.

9. Design of PP Net and Cost Analysis

Figure 3 shows the generalized PP-Nets for the parts shown in figure-2. The output obtained from petri net models for these parts are tabulated in table-1 based minimum time and cost.

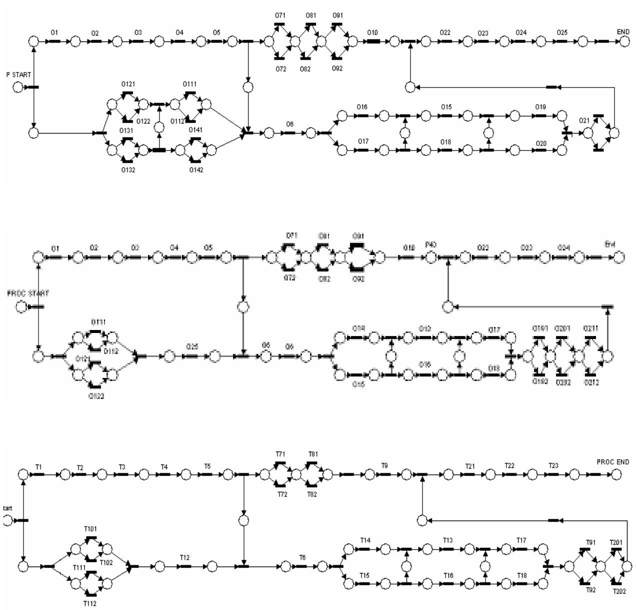


Figure 3. The Generalized PP-Nets for part 1, 2 and 3.

Table 1. Minimum time and cost paths for part 1,2 & 3

PART-1	
Min Processing time	**Min Processing Cost**
100.process_start	100.process_start
2.facing_0	1.front_facing
3.facing_90	2.facing_0
4.facing_180	3.facing_90
5.facing_270	4.facing_180
1.front_facing	5.facing_
131.chamfer1	132.chamfer2
121.thickness_mill1	121.thickness_mill1
112.lxw_mill2	141.grind_frnt_back1
141.grind_frnt_back1	111.lxw_mill1
6.facing_back	6. facing_back
17.cbore_36	17.cbore_36
16.cbore_44	16.cbore_44
18.bore_13	18.bore_13
15.bore_58	15.bore_58
19.bore_12	19.bore_12
20.slots	20.slots
72.drill2_51	71.drill1_51
81.drill1_38	82.drill2_38
92.drill2_19	91.drill1_19
10.grinding1	10.grinding1
212.m12_drill2	211.m12_ drill1
22.grind_final	22.grind_final
23.mill_45	23.mill_45
24.mill_21	24.mill_21
25.cmill_36	25.cmill_36
1400.process_stop	1400.process_stop
PART-2	
Min Processing time	**Min Processing Cost**
100.process_start	100.process_start
121.chamfer1	1.front_facing
111.thickness_mill1	2.facing_0
25.grinding2	3.facing_90
1.front_facing	4.facing_180
2.facing_0	5.facing_270
3.facing_90	111.thickness_mill1
4.facing_180	122.chamfer2
5.facing_270	25.grinding1
6.facing_back	6.facing_back
14.bore_45	15.cbore_11
15.cbore_11	16.cbore_15
16.cbore_15	14.bore_45
13.bore_60	13.bore_60
17.bore_25	17.bore_25
18.bore_20	18.bore_20
192.cboref2_15	191.cboref1_15
201.boref1_25	201.boref1_25
211.boref1_20	211.boref1_20
71.drill1_15	71.drill1_15
81.drill1_20	82.drill2_20
91.drill1_25	91.drill1_25
22.final_grndg	22.final_grndg
23.cncmill_45	23.cncmill_45
24.cncmill_12	24.cncmill_12
1400.end_process	1400.end_process
PART-3	
Min Processing time	**Min Processing Cost**
100.process_start	100.process_start
1.front_facing	1.front_facing
2.facing_0	2.facing_0
3.facing_90	3.facing_90

4.facing_180	4.facing_180
5.facing_270	5.facing_270
111.chamfer1	101.thickness_mill1
101.thickness_mill1	112.chamfer2
12.grinding2	12.grinding2
6.facing_back	6.facing_back
15.cbore_11	14.bore_45
14.bore_45	14.bore_45
16.cbore_15	16.cbore_1
13.bore_60	13.bore_60
17.bore_25	17.bore_25
18.bore_20	18.bore_20
192.cboref2_15	191.cboref1_15
201.boref1_25	202.boref2_25
71.drill1_15	71.drill1_15
82.drill2_20	82.drill2_20
9.grinding1	9.grinding1_192
21.final_grndg	21.final_grndg
22.cncmill_45	22.cncmill_45
23.cncmill_15	23.cncmill_15
1400.end_process	1400.end_process
100.process_start	100.process_start

10. Scheduling using GA

A ‘C’ program is written in which the input includes the operations on the machines with the process time and cost. First the input is given through *input.dat* file which gives the processing time, the number of the machine and the cost of operation on the machine. Alternate operations are also given if present. The output of the program is the process plan with lowest cost of processing. These process plans are further considered for scheduling.

The outputs for the process plan algorithm are given below for the three parts.

Table 2. Output of Process Plan Algorithm of Part-1

PART-1		
Machine	Processing Cost	Processing Time
M1	105	180
M2	150	120
M4	75	90
M2	105	60
M3	115	90
M7	75	120
M9	215	360
M5	120	140
M8	90	60
M10	520	270

Due time =1600 min & Penalty cost = Rs. 4.00

Table 2. Output of Process Plan Algorithm of Part-2

PART-2		
Machine	Processing Cost	Processing Time
M1	105	180
M5	100	80
M4	40	40
M6	75	90
M2	115	90
M7	80	120
M9	275	240
M4	180	210
M8	90	60
M10	200	90

Due time =1200 min & Penalty cost = Rs. 2.00

Table 3. Output of Process Plan Algorithm of Part-3

PART-3		
Machine	Processing Cost	Processing Time
M1	105	180
M4	45	60
M5	50	50
M6	65	90
M2	50	50
M3	60	50
M7	70	120
M9	120	180
M4	60	90
M5	65	100
M8	80	60
M10	250	120

Due time =1200 min & Penalty cost = Rs. 3.00

The output of the process plan algorithm for the three parts is given as the input for the scheduling algorithm. The results of the scheduling algorithm are shown below. The output gives the schedule table for each part on the machines and the time of operation on the respective machine in the prescribed sequence. The process planning cost and the scheduling cost for the parts.

These are the final results obtained:

Total Process Planning cost = (1570.00+1260.00+1020.00) = Rs.3850.00/-

Tardiness or Scheduling cost = (1000.00+0.00+660.00) = Rs.1660/-

Table 5. Schedule Table for the three parts

Schedule Table with Start Time and Completion Time of the operations						Process planning cost (Rs)	Scheduling cost (Rs)
1 360→540	4 540→660	6 660→750	2 750→810	3 810→900		1570.00	1000.00
7 900→1020	9 1020→1380	5 1380→1520	8 1520→1580	10 1580→1850			
1 0→180	5 180→260	4 260→300	6 300→390	2 390→480	7 480→600	1260.00	0.00
9 600→840	4 840→1050	8 1050→1110	10 1110→1200				
1 180→360	4 360→420	5 420→470	6 470→560	2 560→610	3 610→660	1020.00	660.00
7 660→780	9 840→1020	4 1050→1140	5 140→1240	8 1240→1300	10 300→1420		

Total Cost = (Total Process planning cost (including the setup cost (assumed as 1000/-)) + Tardiness Cost)

= 3850+1000+1660

= Rs. 6510/-

Table-5 gives the Schedule Table for the three Parts considered for the problem. It gives the start and completion times of the Parts on the machines in a sequence in accordance to the operation precedence. The Process Planning cost and the Tardiness cost are given as output from the algorithm. Figure 4 gives the Gantt chart for the machines for the scheduling of the three parts considered for the analysis.

Manufacturing cost optimization is the major concern for the manufacturing industries which is the subject of interest in this work. Process planning and scheduling are traditionally regarded as separate tasks which are performed sequentially. Many attempts have been made to integrate these two functions and much success has been attained. This paper is a novel approach towards the integration of CAPP and scheduling.

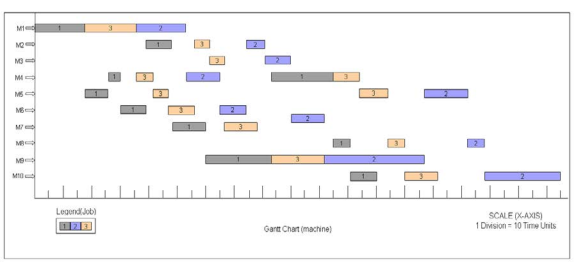


Figure 4. Gantt chart for the scheduling of three parts on ten machines.

11. Conclusion

1. A Petri net technique for process planning cost estimation is presented. The technique is based on a new Petri net model (PP-net: Process planning net) that allows the modeling of partial process plans. With this technique, operations machines, setups and tool changes are represented in single transitions of the generalized PP-net.

2. The optimal process plans for three parts are developed using this technique with the help of INA analyser (A Petri net tool for analysis).The models are analyzed for minimum time and minimum cost.

3. GA is used for developing Process planning algorithm that establishes the optimal sequence of operations satisfying the precedence constraints and generates the sequence of machines for the optimal sequence of operations.

4. The so obtained process plans are given are input to the Scheduling algorithm which establishes the optimal schedule of the jobs on the machines, in the shop floor such that the production cost is minimized.

5. The Gantt chart shows the allocation of the jobs on the machines and the operation times (start time and completion time) on each machine.

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