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ORIGINAL ARTICLE

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Integration of process planning and scheduling in a job shop environment

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Abstract Today's manufacturing systems are striving for an integrated manufacturing environment. To achieve truly computer-integrated manufacturing systems (CIMS), the integration of process planning and production scheduling is essential. This paper proposes a framework for integration of process planning with production scheduling in a job shop environment for axisymmetric components. Based on the design specifications of incoming parts, feasible process plans are generated taking into account the real time shop floor status and availability of machine tools. The scheduling strategy prioritizes the machine tools based on cost considerations.

Keywords Computer-aided process planning · Decision support system · Job shop environment · Production scheduling · Scheduling factor

1 Introduction

Process planning is a function in a manufacturing organization that selects the manufacturing processes and process parameters to be used to convert a part from its initial design to the final form. Computer-aided process planning (CAPP) has been recognized as a link between computer-aided design (CAD) and computer-aided manufacturing (CAM). In the past two decades, many efforts have been made in developing CAPP systems in which the focus was to integrate CAD and CAPP and little attention was given to integrate CAPP and CAM. To achieve true computer-integrated manufacturing (CIM) environment, process planning needs to be integrated with scheduling.

Process planning involves interpretation of part design data, selection of raw material, machining processes, cutting tools, sequencing of operations, determination of cutting parameters, and finally generation of process sheets. On the other hand, the purpose of production scheduling is to assign production tasks to various manufacturing resources with specific start and finish times [1]. Production scheduling begins with a process sheet, where process planning ends. Traditionally, process planning and scheduling have been performed sequentially, a process plan being generated before scheduling is performed. Although this method may be simple, it ignores the inherent relationship between process planning and scheduling. By assuming that scheduling takes over once the process plan is determined, the possible alternative schedules using alternative machines are ignored. Status of the job shop resources, specially the machines, is not considered during the process plan generation. This may lead to under- or over-utilization of certain machines. As a result, completion times of products may be delayed [2]. A large number of process plans perhaps cannot be executed, they may require considerable alterations or replanning. This shows the necessity of integrating process planning with scheduling [3]. The present work discusses an approach to integrate process planning with scheduling in a job shop environment for axisymmetric components. A brief review of literature published in this area is presented below.

2 Literature review

Torii et al. [4] proposed an on-line, real time work-in-process scheduler in a CAM system. Halevi and Weill [5] discussed 'Hal technology' to improve on-line scheduling in flexible manufacturing systems (FMS). Sundaram and Fu [6] proposed a method to minimize makespan and balance the load on machines. Iwata and Fukuda [7] proposed a dynamic process approach to decide the process plan and schedule simultaneously without alternate process plans. Khoshnevis and Chen [8] developed a heuristic algorithm that performs well in most circumstances, though it does not have a vision when it allocates features to the machine. Dong et al. [9] proposed an AI based feature extractor to extract product features according to the shop floor capabil-

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ities. Choobineh and Shivani [10] used fuzzy sets to model the subjectivity of process planners and vagueness of data. A real time scheduling algorithm was presented for assigning the features of parts to the most appropriate machine. Zhang [11] developed an integrated process planning model (IPPM) to extend the concept of distributed process planning and demonstrate the flexibility in allocation of resources. Villa and Rossetto [12] presented a decomposition approach integrating process planning with production planning. Liao et al. [13] developed an operation-machine index as a relative measure for selecting the best machine from the alternatives in the process planning stage to minimize mean flow time and number of tardy jobs. Brandimarte and Calderini [14] developed a two-phase hierarchical Tabu search for efficient planning and scheduling. Zijm [15] discussed a decomposition approach to integrate process planning and shop floor scheduling in small batch manufacturing. Lee et al. [16] described a shop floor control information architecture for interfacing process plans. Huang et al. [17] proposed a progressive approach based on distributed process-planning concept for integration of process planning and scheduling. Palmer [18] used simulated annealing for integrating process planning and scheduling. Usher and Fernandes [19] proposed an architecture for a CAPP system integrated with the scheduling system that reduced the workload when real time planning tasks were carried out. Kempenaers et al. [20] proposed a collaborative approach based on production constraints as a means to realize a feedback from scheduling to process planning. Gu et al. [21] described a bidding-based approach to integrate CAD, process planning and real time scheduling. Yang et al. [22] simulated the impact of multiple process plans on the performance of real time scheduling. Wang [23] proposed an integrated intelligent process planning system (IIPPS) for integration of process planning and scheduling activities. Weintraub et al. [24] developed a computationally efficient procedure for scheduling jobs in large scale manufacturing systems. Halevi [25] proposed a three stage relational CAPP system consisting of technology, transformation, and mathematics. Lee and Kim [26] proposed simulation based genetic algorithms to integrate process planning and scheduling. Chang and Chen [27] introduced a dynamic programming based process plan selection strategy, enabling an efficient solution of a stage-type network problem. Moon et al. [28] proposed an integrated process planning and scheduling (IPPS) model for a multi-plant supply chain. Zhang et al. [29] reported a method for integration of process planning and scheduling in a batch-manufacturing environment.

Most of the above discussed approaches fall short on two accounts. First, they fail to consider machine capacity and current status of the shop while generating a process plan. In some of the cases, generation of alternative process plans increases the search space, thereby increasing the time required to generate an optimal schedule and rendering it impractical to real time application. Second, they ignore cost considerations while assigning operations to various machines. It is imperative that expensive machines are assigned machining tasks more frequently in order to recover high initial costs and obtain economic benefits out of them. An integrated process planning and scheduling model for a job shop environment is proposed in this paper. It mainly addresses these two issues while integrating process planning with scheduling tasks.

3 The proposed integrated model

Integration between process planning and scheduling activities is achieved through two controlling modules – the process plan generator and scheduler. Activities within each module take place in different time periods as shown in Fig. 1. Process plan generation is executed as soon as the product design is finished, while scheduling is performed just before the manufacturing begins.

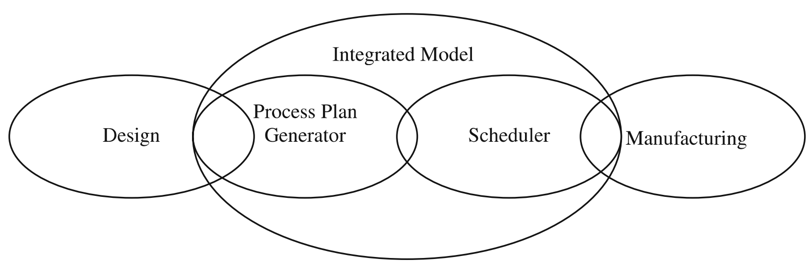
Architecture of the proposed model is shown in Fig. 2. Both controlling modules interact with a decision support system (DSS) in order to have easy access to decision models to support semi-structured or unstructured decision making tasks. The DSS interacts with various databases such as the tool-work material database, machining parameters database, unit power database, and machine tool database [30].

3.1 Process plan generator

The present study uses a generative approach for developing process plans for axisymmetric components in a job shop environment. The methodology developed to generate process plans and the allocation of the machine tool for a specific setup is explained through an illustrative example of a part shown in Fig. 3. The part is to be produced from a solid cylindrical stock of suitable dimensions. The process plan generator embodies the following tasks [31]:

1. Part data representation and feature interpretation – Geometrical and technical details of the component are assumed to be available in the form of an engineering drawing. Various features of the part along with their attributes are extracted

Fig. 1. Domain of the integrated model



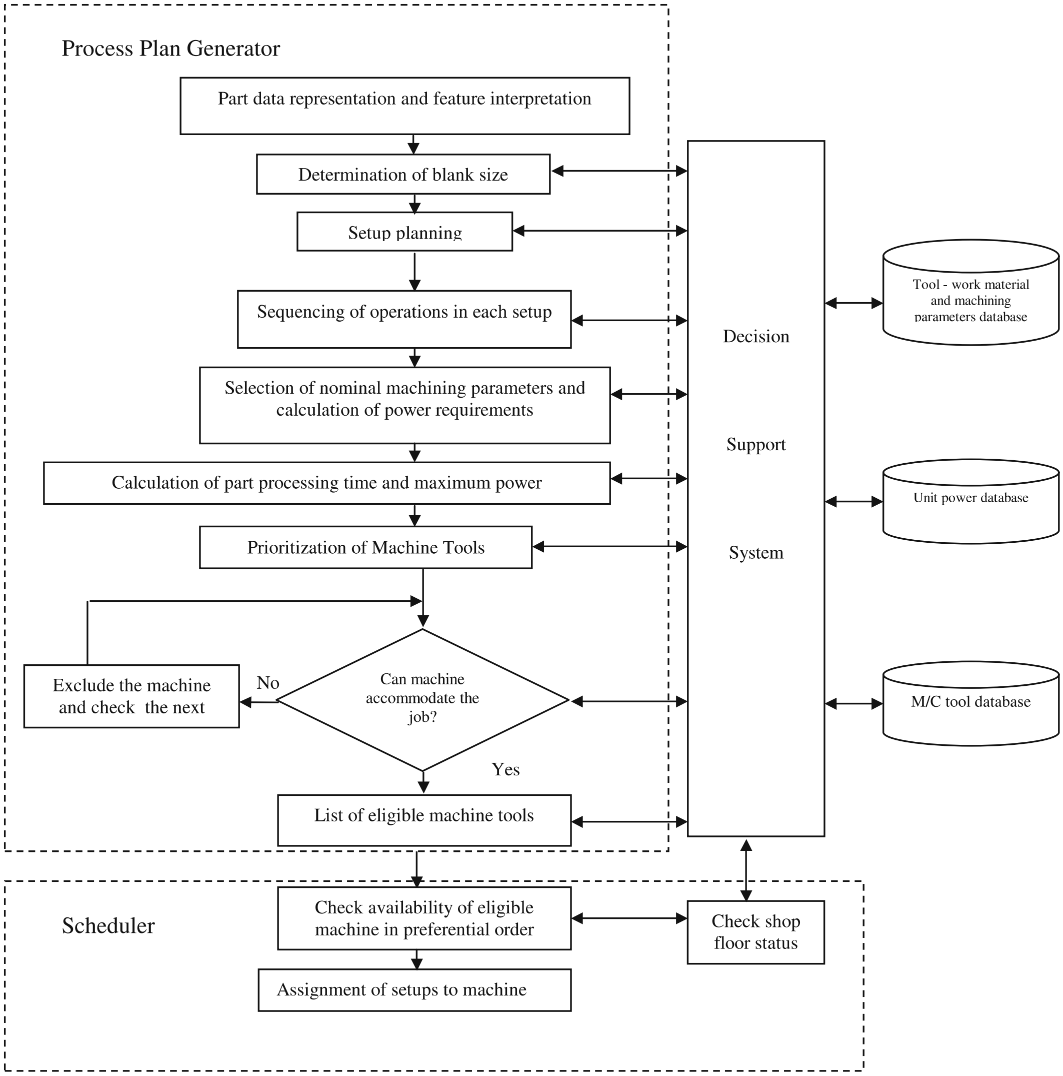


Fig. 2. Architecture of the integrated model

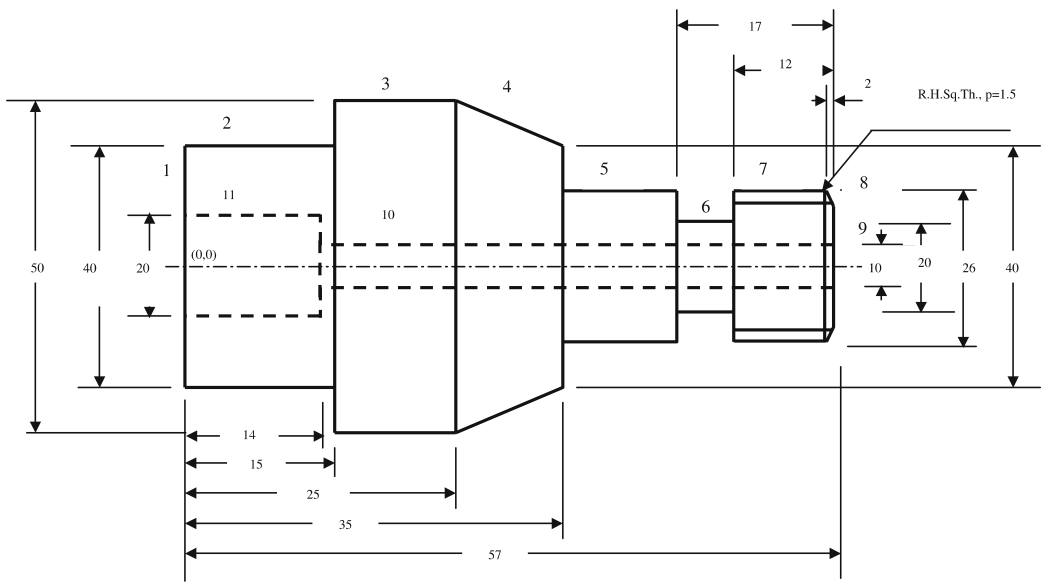


Fig. 3. Illustrative component drawing

Table 1. Feature modeling for the illustrative part

Feature	Type	Coordinates X_s	Y_s	X_e	Y_e	Remarks
1	External facing	0	10	0	20	
2	External turning	0	20	15	20	
3	External turning	15	25	25	25	
4	External tapering	25	25	35	20	
5	External turning	35	15	40	15	
6	External grooving	40	15	45	15	Form tool
7	External threading	45	15	55	15	Single start, R H Sq Th, pitch 1.5 mm
8	External chamfering	55	15	57	13	
9	External facing	57	13	57	05	
10	Internal boring	57	05	14	05	Preceded by 6 mm dia. drilling
11	Internal boring	14	10	0	10	Preceded by 6 mm dia. drilling

from the drawing in the form of external and internal features. A feature is defined here as a final part surface generated after machining operations. Data structure of a feature identifies its type, starting and ending X and Y coordinates, and additional information, if required. Feature modeling for the illustrative job is shown in Table 1.

2. Determination of blank size – Ferrous material rods are commercially available in standard diameters. This information is stored in a database [32]. A stock bar of 56 mm diameter and 67 mm length is selected for the illustrative job. The excess length allows for facing operations on both ends and clamping of the part.
3. Setup planning – A setup is defined as a group of features that can be machined during a single clamping of the part [33]. Reversing the part on the same machine or shifting the part from one machine to another can be treated as different setups. A setup is planned such that the maximum number of features can be synchronously machined with the minimum number of setups. It is considered as a basic element of a process plan. It helps to identify the part holding method and clamping span, and to group various features to be machined in the same clamping of the job. Tool approach direction and accessibility limits are considered while planning for setups. Only short parts that can be held using the 'chuck only' holding method have been considered in the present work. Setup planning involves establishing the tool accessibility limits of various features in each setup. The concept of a demarcation line [34] is used to segregate various features in different setups. Features of the illustrative component are grouped under two setups as follows: Setup 1: Features 1, 2, 11. Setup 2: Features 3, 4, 5, 6, 7, 8, 9, 10.
4. Sequencing of operations in a setup – A precedence relationship is established between various operations in a setup, based on the general practice followed in industry. For similar features in the same setup, the sequence is based on the decreasing (for external features) and increasing (for internal features) order of feature diameters. The number of passes is determined allowing 1 mm depth of cut for finishing and a maximum 4 mm for roughing passes. Form tools are to be used for grooving, filleting, arcing, knurling, and threading features. Furthermore, various forms and geometries of threads have been included in the process plan generation. The drilling operation is a pre-requisite for the boring operation. A hole of diameter greater than 6 mm is assumed to be bored after drilling [30]. The sequence of operations in the two setups for the illustrative job is as follows: Setup 1: Feature sequence – 1, 2, 11. Setup 2: Feature sequence – 9, 3, 5, 4, 6, 8, 7, 10.
5. Machining parameters and power requirement – The process plan generator interacts with a tool-work material database and a machining parameter database to extract the values of nominal machining parameters (speed and feed) for appropriate combination of the type of cut (rough or finish) and depth of cut, for various combinations of job material and tool material. Another database is used to select the unit power required for machining various job materials [30]. Table 2 depicts the selected machining parameters and power required for machining the illustrative job.
6. Calculation of processing time and maximum power requirement – Machining time for each pass in a feature (and subsequently for each feature, and each setup) is determined based on the values of machining parameters selected in the previous step. Allowances for tool change and job setups are considered as 50% of the machining time. Thus, machining time of a feature = length * number of passes/(rpm * feed). Processing time of a feature = 1.5 * its machining time.
   Values of machining parameters are also used to calculate the material removal rate in each pass of an operation, which when multiplied by unit power gives the power required at the spindle for the operation. Considering 80% mechanical transmission system efficiency, the maximum power required at the motor is determined. This analysis helps in identifying the machine tool on which the job can be processed. Table 2 also shows the calculated values of processing time and power required at the motor for the illustrative component.
7. Prioritization of machine tools – The job shop is modeled as consisting of a number of machine tools, some of which may be identical. The capacity of a machine tool is specified in terms of the maximum diameter and length of the job that it can accommodate, and maximum rpm and power available at its spindle. It is assumed that all the machine tools are capable of producing the required tolerance and surface finish on the job. Cost attributes of a machine tool include its initial

Table 2. Selected machining parameters

Feature	Type of cut (r–rough, f – finish)	Passes	Doc (mm)	Speed (m/min)	Speed (rpm)	Feed (mm/rev)	Processing time (min)	Power required at motor (kW)
Setup 1								
1	r	2	2.5	38	216	0.40	0.97	2.23
2	r	2	4,3	38	252	0.40	0.48	3.57
	f	1	1	46	348	0.18	0.36	0.49
11+	d (6 mm)	1	-	26	1380	0.13	0.48	0.27
	r	1	1	38	2016*	0.40	0.11	0.89
	f	1	2	46	1831	0.18	0.30	0.49
	r	1	4	38	1210	0.40	0.04	3.57*
	f	1	1	46	813	0.18	0.14	0.49
+ Feature number 10 gets generated as well								
Total Processing time in setup 1:2.88 min.								
Setup 2								
9	r	2	2.5	38	216	0.4	0.97	2.23
3	r	1	2	38	216	0.40	0.73	1.79
	f	1	1	46	281	0.18	1.25	0.49
5	r	3	4,1	38	355	0.4	0.86	0.90
	f	1	1	46	457	0.18	0.40	0.49
4	r	2	4	38	550	0.4	0.18	3.57*
	f	1	1	46	1046*	0.18	0.09	0.49
6	–	1	–	37	392	0.046	0.42	0.10
8	r	1	1.41	38	403	0.40	0.03	1.26
7	f	1	0.75	11	116	1.50	0.09	1.37
10	Feature already generated							
Total Processing time in setup 2: 5.02 min.								

* Maximum value

Table 3. Machine tool database

Machine tool	Max. job- -Diameter (mm)	Max. job- -Length (mm)	Max. rpm.	Max. power at motor (kW)	Cost of machine Initial (lakh Rs)	Cost of machine Operating (Rs/min)
1	150	550	3000	3.75	7.5	7.43
2	200	350	3500	5.5	10	8.74
3	250	460	3500	5.5	10	8.74
4	225	160	3000	5.5	12.5	9.13
5	225	300	5000	5.5	13	9.21
6	250	460	3500	7.5	12	10.12
7	250	470	4200	11	18	12.93
8	300	100	3500	15	20	15.38

cost and operating cost. Table 3 shows a database representing eight machine tools.

In order to assign various setups to different machine tools, a mechanism is developed to prioritize the machine tools based on cost considerations. For this purpose, a scheduling factor (μ) is defined as directly proportional to the initial cost of the machine tool (C), and inversely proportional to its operating cost (C_O) and the number of identical machine tools of a kind (N) [14, 35]. The relationship is as follows:

$$\mu = \frac{k_1 C}{k_2 C_O k_3 N}$$

Here, k_1, k_2, and k_3 are importance ratings given to respective parameters on a scale of 1–10 (1 - least important and 10 - most important). The scheduling factor has a higher value for a more expensive machine tool, since it is a common industrial practice to prefer the most expensive machinery first in order to utilize the company's investments more effectively. On the other hand, the scheduling factor favors a machine tool that has lower operating cost, or fewer numbers of identical types. Operating cost of the machine per unit time (C_O) is calculated as shown below [36]:

$$\begin{aligned} C_O = {} & \text{non productive cost } (C_N) + \\ & \text{cutting cost } (C_C) + \text{ tool cost } (C_T) \\ = {} & C_N + C_C + 0.4C_C \text{ (assuming } C_T \text{ to be 40\% of } C_C) \\ = {} & C_R T_N + 1.4 C_R T_C (C_R = \text{ cost rate,} \\ & T_C = \text{ processing time, } T_N = \text{non productive time)} \\ = {} & C_R(0.6T_C) + 1.4C_R T_C \\ & \text{(assuming } T_N \text{ to be 60\% of } T_C) \\ = {} & 2.0 C_R T_C \end{aligned}$$

Hence, operating cost per unit time $= 2.0C_R$. Further, cost rate is calculated as:

$C_R =$ labour cost rate (C_L)
+ overhead cost rate (C_{OH}) + depreciation rate (C_D)

The overhead cost rate depends on the power consumption in the machine tool. Depreciation is assumed to be charged on a straight-line basis. Substituting the relevant values of the parameters, the operating costs per unit time for various machine tools have been calculated and shown in Table 3. Further, using these values of initial cost, operating cost per unit time, and suitable values of other parameters (k_1, k_2, k_3, and N), the scheduling factor is computed for each machine tool. The machine tool with the highest value of the scheduling factor is ranked at the top, and so on. Table 4 gives these results. Thus, the priority list of the eight machine tools is: M_5, M_7, M_4, M_8, M_6, M_3, M_2, and M_1.

8. Eligibility of prioritized machine tools – The previous step prioritizes the machine tools according to the values of the scheduling factor. A setup of a job is to be assigned to a machine tool with the highest value of the scheduling factor, provided it can accommodate the job, and is available (not busy with another processing). For checking the job accommodability, the size of the job (length and diameter), maximum rpm, and power required in each setup are compared with the maximum respective capacities of each machine tool in the priority list, and another list of those machine tools that can accommodate the job is generated. Such machine tools become eligible to be assigned machining of individual setups. For the above illustration, the list of eligible machine tools for the two setups is as follows:
Setup 1: Machine tool – 5, 7, 4, 8, 6, 3, 2.
Setup 2: Machine tool – 5, 7, 4, 8, 6, 3, 2.
The eligibility lists for the two setups of a job may be different because of the power requirements of the individual setups.

3.2 Scheduler

In a manufacturing environment, production schedule provides the basis for making customer delivery promises, utilizing plant capacity effectively and attaining firm's objectives. The scheduler of the proposed model entails the following tasks:

1. Availability of eligible machine tools – A setup is assigned to that eligible machine tool which is available at the time of decision-making. If the first machine in the eligibility list is available, then the setup is assigned to it. Otherwise, the next machine in the eligibility list is considered. Thus it is quite likely that a setup may be started on a machine with a lower value of μ rather than joining the queue of machine with higher value of μ. If none of the eligible machines is available, then the job is kept waiting in a queue randomly in front of any eligible machine.
2. Assignment algorithm – The algorithm consists of the following steps:
   Step 1: Start with required inputs (job arrival time of the ith job (J_i), setup planning for the two setups including eligibility lists of machines).
   Step 2: Consider the first setup (J_iS_1) and the first machine in its eligible list.
   Step 3: If the machine is available, then assign the setup to this machine. else consider the next machine in the eligible list for assignment.
   Step 4: If no machine in the eligible list is available then place the setup in queue randomly in front of any eligible machine.
   Step 5: Repeat steps 2 to 4 for the arrival of next setup of either the same job or a new job, whichever comes earlier.

   Illustration
   An illustrative situation is shown in Table 5.
   Three jobs arrive in the shop for machining. Their arrival times, setup processing times and eligibility lists of machines for each setup are shown in the above table. The assignment of various setups of the three jobs is shown in the Gantt chart of Fig. 4.
   The illustrative job (J_1) arrives in the shop at time T_{now}, when machine M_5 is busy processing a previous job. The next machine in the eligibility list, M_7, is idle and is assigned the first setup (J_1S_1) to it. By the time $J_1S_1$is processed, another job (J_2) arrives. Since machines M_5 and M_7 are both busy at the time of its arrival, the next eligible machine M_6 is assigned the first setup of this job (J_2S_1). When J_1S_1 is complete, the second setup of job J_1 (J_1S_2) is again assigned to machine M_7 since M_5 is still busy. Job J_3 arrives in the shop to find machines M_5, M_7 and M_6 busy. Its first setup (J_3S_1) is assigned to

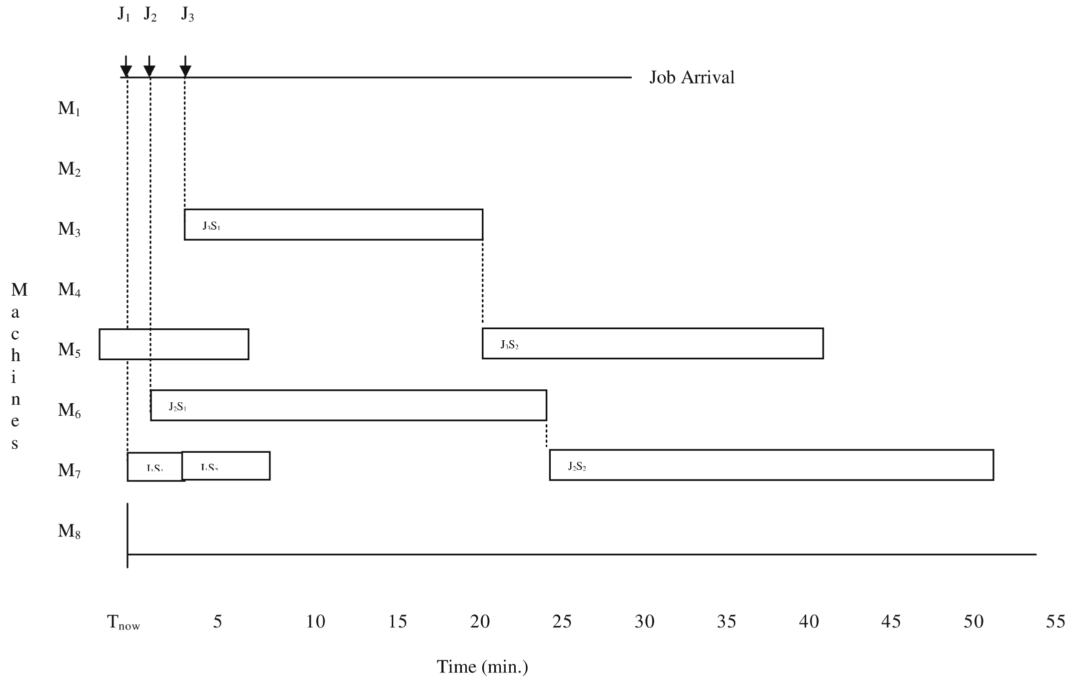
Table 4. Priority list of machine tools based on scheduling factor

Machine tool	Scheduling factor	Ranking
1	0.63	8
2	0.71	7
3	0.71	6
4	0.85	3
5	0.88	1
6	0.74	5
7	0.87	2
8	0.81	4

Table 5. Inputs for illustration of assignment of setups to various machines

Job number	Arrival time (min)	Setups	Processing time (min)	Eligibility list of machine tools
J_1	T_{now}	S1	2.88	5,7,4,8,6,3,2
		S2	5.02	5,7,4,8,6,3,2
J_2	$T_{now}+1.2$	S1	22.38	5,7,6,3,2
		S2	27.3	5,7,6,3,2
J_3	$T_{now}+3.0$	S1	16.92	5,7,6,3,2,1
		S2	20.88	5,7,6,3,2,1

Fig. 4. Gantt chart for the illustrative example



M_3, the next machine in the eligibility list. When this processing is complete, the second setup of this job (J_3S_2) is assigned to machine M_5, the first eligible machine. Similarly, when the first setup of the second job (J_2S_1) is complete, the second setup (J_2S_2) is assigned to machine M_7.

The assignment of setups is made in real time and takes care of the actual status of the machines in the shop. The model integrates the process planning phase with scheduling, and generates process plans that are operational in real time. Moreover, these process plans are economizing in nature, since they attempt to load the expensive machines preferentially in order to improve their utilization.

4 Conclusions

To improve the performance of CAPP systems, process planning needs to be integrated with scheduling. The integration of the two functions provides the most effective use of production resources and generates realistic process plans that can readily be executed without any change. An integrated process planning and scheduling model has been proposed in this paper.

References

1. Chryssolouris G, Chan S (1985) An integrated approach to process planning and scheduling. Ann CIRP 34(1):413–417
2. Morad N, Zalzala A (1999) Genetic algorithms in integrated process planning and scheduling. J Intell Manuf 10:169–179
3. Alting L, Zhang HC (1993) Computerized manufacturing process planning systems. Chapman & Hall, New York
4. Torii T, Ohtsuki N, Suzuki M (1983) Development of on-line, real time, scheduling method for a computer aided manufacturing system. Ann CIRP 32(1):379–383
5. Halevi G, Weill R (1984) On line scheduling for flexible manufacturing systems. Ann CIRP 33(1):331–333
6. Sundaram RM, Fu SS (1988) Process planning and scheduling - A method of integration for productivity improvement. Comput Ind Eng 15(1-4):296–301
7. Iwata K, Fukuda Y (1989) Design of decision making engine in knowledge assisted process planning system. Proc IFAC information control problems in manufacturing technology, Madrid, Spain, pp 85–90
8. Khoshnevis B, Chen Q, (1990) Integration of process planning and scheduling functions. J Intell Manuf 1:165–176
9. Dong J, Jo HH, Parsaei HR (1992) A feature based dynamic process planning and scheduling. Comput Ind Eng 23(1–4):141–144
10. Choobineh F, Shivani M (1992) Dynamic process planning and scheduling algorithm. Proc 1992 Japan–USA Symposium on Flexible Automation, Part 1(of 2), San Francisco, CA, USA, pp 13–15
11. Zhang HC (1993) IPPM - A prototype to integrate process planning and job shop scheduling functions. Ann CIRP 42(1):513–518
12. Villa A, Rossetto S (1993) Methodology for integrated process-production planning: IFIP Trans B: Comput Appl Technol, B-13, pp 267–273
13. Liao TW, Coates ER, Aghazadeh F, Mann L, Guha N (1993) Modification of CAPP systems for CAPP/scheduling integration. Comput Ind Eng 25(1-4):203–206
14. Brandimarte P, Calderini M (1995) A hierarchical bicriterion approach to integrate process plan selection and job shop scheduling. Int J Prod Res 33(1):161–181
15. Zijm WHM (1995) The integration of process planning and shop floor scheduling in small batch part manufacturing. Ann CIRP 44(1):429–432
16. Lee S, Wysk RA, Smith JS (1995) Process planning interface for a shop floor control architecture for computer integrated manufacturing. Int J Prod Res 33(9):2415–2436
17. Huang SH, Zhang HC, Smith ML (1995) A progressive approach for integration of process planning and scheduling. IIE Trans 27:456–464
18. Palmer GJ (1996) A simulated annealing approach to integrated production scheduling. J Intell Manuf 7:163–176
19. Usher JM, Fernandes KJ (1996) A two-phased approach to dynamic process planning. Comput Ind Eng 31(1-2):173–176

20. Kempenaers J, Pinte J, Detand J, Kruth JP (1996) A collaborative process planning and scheduling system. Adv Eng Softw 25:3–8
21. Gu P, Balasubramanian S, Norrie DH (1997) Bidding-based process planning & scheduling in a multi-agent system. Comput Ind Eng 32(2):477–496
22. Yang Z, Qiao L, Jiang I (1998) Improving the performance of part dispatching based on multiple process plans using graph theory. Int J Prod Res 36(7):1987–2003
23. Wang K (1998) An integrated intelligent process planning system (IIPPS) for machining. J Intell Manuf 9:503–514
24. Weintraub A, Cormier D, Hodgson T, King R, Wilson J, Zozom A (1999) Scheduling with alternatives: a link between process planning and scheduling. IIE Trans 31:1093–1102
25. Halevi G (1999) Relational CAPP (computer aided process planning) system. Int J Manuf Sci Prod 2(4):171–187
26. Lee H, Kim SS (2001) Integration of process planning and scheduling using simulation based genetic algorithms. Int J Adv Manuf Technol 18:586–590
27. Chang HC, Chen FF (2002) A dynamic programming based process planning selection strategy considering utilization of machines. Int J Adv Manuf Technol 19:97–105
28. Moon C, Kim J, Hur S (2002) Integrated process planning and scheduling with minimizing total tardiness in multi-plants supply chain. Comput Ind Eng 43:331–349
29. Zhang YF, Saravanan AN, Fuh JYH (2003) Integration of process planning and scheduling by exploring the flexibility of process planning. Int J Prod Res 41(3):611–628
30. ASM (1997) ASM metals handbook – machining 9th edn., vol 16, Materials Park, OH, USA
31. Kumar M, Rajotia S (2005) Development of a generative CAPP system for axisymmetric components for a job shop environment. Int J Adv Manuf Technol, DOI: 10.1007/s00170-004-2135-2
32. Mahadeven K, Reddy KB (1983) Design data handbook for mechanical engineers. CBS Publishers & Distributors, Delhi
33. Chang TC (1990) Expert process planning for manufacturing. Prentice Hall, Englewood, NJ
34. Hinduja S, Huang H (1989) Automatic determination of work holding parameters for turned components. Proc Inst Mech Eng 203(B2):101–112
35. Kumar M, Rajotia S (2003) Integration of scheduling with computer aided process planning. J Mater Process Technol 138:297–300
36. Lal GK (1994) Introduction to machining sciences. New Age International Publishers, New Delhi