

Scheduling with Processing Alternatives: An Approach to Minimize Makespan in a Multi-Product Manufacturing Industry

V Mahesh¹, Sandeep Dulluri²,
A Chennakesava Reddy³ and C S P Rao⁴

Traditionally, process planning and shop floor scheduling are viewed as separate and discrete manufacturing activities. Conflict arises between these two activities, as process planning is a technique-based, cost or quality-driven activity and scheduling is a mathematical due-date driven activity. This paper describes an approach in which process planning and shop floor scheduling are integrated in order to achieve a unified manufacturing aim. The integration of process planning and scheduling makes way for the effective use of production resources and creation of realistic process plans that can be readily executed with less modifications in a computer integrated manufacturing system. In this paper the problems behind planning and scheduling in complex process environments are analyzed and proposed to enhance the traditional schedulers by planning capabilities to solve these problems.

Introduction

Manufacturing process plans are usually defined by the sequence of operations a job has to go through to transform raw materials to a finished product. Restricting process plans are a sequence of operations that often over constrain the process plan beyond what the processing technology would require. If the strict ordering format in which operations are prescribed in conventional process plans are relaxed, then it can result in substantial reduction of lead time in manufacturing. Machine scheduling can take advantage of this fact by optimizing the job schedule and the order of operations in each job simultaneously. Although there is a strong relation between process planning and scheduling, conventionally the two functions have been studied independently (Lee and Kim, 2001).

¹ Associate Professor, Department of Mechanical Engineering, S R Engineering College, Warangal, India; and he is the corresponding author. E-mail: maheshbrutukuru@rediffmail.com

² Analyst, Investment Solutions R&D, HSBC, Bangalore, India. E-mail: dulluri@gmail.com

³ Professor, Department of Mechanical Engineering, JNTU, Ananthapur, India. E-mail: dr_acreddy@yahoo.com

⁴ Professor, Department of Mechanical Engineering, National Institute of Technology, Warangal, India. E-mail: csp_rao@rediffmail.com

In the most current Advanced Planning and Scheduling (APS) systems, the planning and scheduling components are implemented separately in different modules. The planning module is responsible for preparing plans, i.e., the sequences of activities to satisfy orders. The scheduling module schedules these activities, i.e., it assigns the activities to the resources and it determines the exact start and end times of the activities as well as other parameters of the activities. If the scheduler finds that it is not possible to schedule all the activities, then it backtracks to the planner to find another plan. Thus, the process plan and schedule are prepared for a static production environment with readily available manufacturing resources. This is an oversimplification, as manufacturing is dynamic in nature. Once a part is loaded to the manufacturing environment, it is inevitably subjected to unexpected production disturbances such as machine breakdowns, rush order arrivals and order cancellations. A process plan may become inefficient or infeasible due to changes (Wong *et al.*, 2006). To cope with the unexpected disturbances, it is necessary to revise the process plan and schedule dynamically.

The process of generating a new feasible schedule in response to unexpected disturbances is usually known as reactive scheduling or rescheduling (Aytug *et al.*, 2005). Rescheduling solutions are usually solved in real time to provide corrective measures to the manufacturing systems (Brucoleri *et al.*, 2003). The rescheduling solutions generally take the form of either generating an entirely new feasible schedule that is used until the next disruption occurs or modifies the existing schedule for the affected operations (Li *et al.*, 1993).

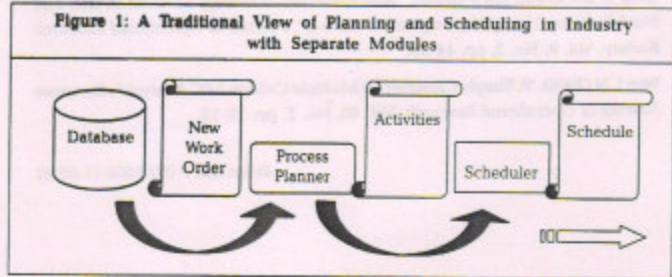
Many manufacturers now try to optimize the total system to cope with a global manufacturing. This is called supply chain. This optimizes not only the plant operations, but also all the activities from supplier to customer. As a result, manufacturing companies nowadays are migrating from separated planning process to more coordinated and integrated planning processes, to provide high quality products at lower costs (Chung and Yoonho, 2005).

In this paper, the authors propose to combine both the planning and scheduling components into a single conceptual model. This model primarily performs a scheduling task and also has some planning capabilities.

Need for Integration of Process Planning and Scheduling

Process planning is a function within a manufacturing facility that selects the manufacturing processes and parameters to be used to convert a part of its initial form to a final form based on a pre-defined engineering drawing (Chang, 1990). A process plan contains the route, processes, process parameters, machines, and tools required for production. The process planning function involves some important activities like selection of machining operations, sequencing of machining operations, selection of machine tools, determining setup requirements and design of jigs and fixtures.

The information generated by process planning activities is used as the inputs of scheduling. Therefore, the process planning becomes an unavoidable constraint for scheduling. Figure 1 shows a traditional view of planning and scheduling in industry with separate modules.



The essential advantage of this integration is to eliminate the problems that arise as, process planning and scheduling are performed separately in the manufacturing system. These problems are:

- Process planners assume an ideal factory with unlimited resources on the shop floor. They plan for the most recommended alternative process. Thus, various process planners select desirable machines repeatedly. As scheduling follows the process planning, actual process plans when carried out result in queues at various workstations and thus these optimal process plans become infeasible.
- The throughput target of orders in a workshop often suffers from disruptions caused by bottleneck machines, non-availability of tools and personnel, or breakdown of machines and equipment. A readily generated schedule becomes invalid and has to be regenerated.
- The time delay between the planning and the execution phase may cause trouble. Due to the dynamic nature of a production environment, it is very likely that when a design is ready to be manufactured, the constraints that were used in generating the plan have already changed greatly, thus, rendering the plan suboptimal or totally invalid.
- Often process planning and scheduling have conflicting objectives. Process planning emphasizes the technological requirements of a task, while scheduling involves the timing aspects of it (Manish and Sunil, 2003).
- Without feedback from the shop, it is difficult to measure the quality of a process plan.

Without the integration of process planning and scheduling, a true Computer Integrated Manufacturing (CIM) system, which strives to integrate the various phases

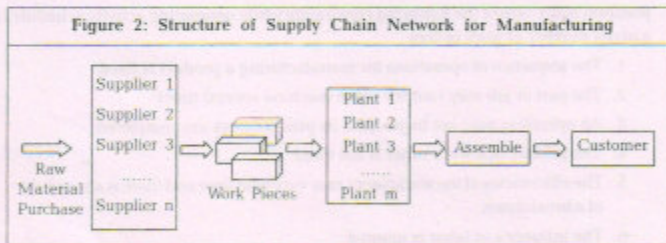
of manufacturing in a single comprehensive system will not effectively materialize (Torri *et al.*, 1983; and Hou and Wang, 1991).

Many methods have been reported for the integration of process planning and scheduling. Larsen and Alting (1990) have identified three approaches of integration. The first, nonlinear process planning, generates and ranks all possible alternative plans for the part, prior to production independent of shop floor status. Then, at the time of production, the scheduler works his way through the alternatives, until one is found which meets the current constraints of production. FLEXPLAN is one example of such a system (Tonshoff *et al.*, 1989). The second approach, closed loop process planning, generates a plan for a job in the real time at the time of production based on the feedback from the shop floor about the status of resources in the shop. Example system includes Real-Time Computer-Aided Process Planning (RTCAPP) (Khoshnevis, 1990) and Distributed Process Planning (DPP) (Tonshoff *et al.*, 1989). The problem with the two aforementioned methods is that a satisfactory schedule may not be achieved, e.g., bottleneck machine may be resulted, since the machine utilization is not considered. The last approach, distributed process planning involves performing planning and scheduling activities in parallel. Integrated Process Planning and Manufacturing (IPPM) (Zhang *et al.*, 1999) and later Integrated Process Planning and Scheduling (IPPS) (Huang *et al.*, 1995) are examples of such systems. However, as the problem complexity increases, this method may become a computational expense.

In this paper, the authors have made an attempt to address the integration issues of process planning and scheduling for a multi product manufacturing industry. The Heavy Machine Shop (HMS) of Bharath Heavy Electrical Limited (BHEL), Hyderabad, India is considered for the study and the scheduling module has been successfully developed. The following sections present the details of the issues concerned to the present problem.

Problem Definition

In a customized manufacturing environment, most jobs have a different sequence of operation steps and may have a set of alternate process plans. Figure 2 shows an example of the general structure of the network for customized manufacturing.



This kind of structure is common in heavy industries, e.g., turbine manufacturing and generator manufacturing. The production cycle in this chain, consists of three main units: with the supplier the raw materials are transformed into specified work pieces; with the manufacturers, machining processes—drilling, milling, boring and grinding are executed to remove pieces of the work pieces; and with the assembler, final products are produced. Among the units of supply chain in the above Figure, the manufacturer plays a vital role because it is a bottleneck unit. Therefore, the manufacturer unit is usually represented as a network of plants. Each plant includes several machines, which have different functions, processing time and capabilities. Hence, an actual optimization should be done considering the dynamic status of multiple plants chain (Chiung and Yoonho, 2005).

The Production Planning and Control (PPC) department of the user industry has to prepare scheduling of jobs on the high cost/critical equipment available on the shop floor under various constraints. From the time a customer places an order for a particular product, the order is uniquely identified and all the parts regarding the product are also identified. The shop floors and machines are also uniquely identified. The user industry manufactures several types of products like steam turbines, gas turbines, compressors and generators etc. Each customer order is identified by a unique number called Work Order Number (WONO). Each work order (i.e., product) consists of several subassemblies and they are identified by a unique number known as Product Group Main Assembly (PGMA). Further, each product group consists of individual parts identified by PART NO and the operation sequence of each part is identified by Operation Number (OPNO). The number of operations that are performed for each major component may range from 25 to 125. For example, the number of operations to be performed on an outer casing of a turbine is around 125 and for valve chest it is about 25. If there are 20 work orders to be scheduled in the next 6 months and each work order consists of about 600 to 800 parts and if a part recirculates (Pinado, 1995) a machine more than once for an operation, then it is very difficult to prepare the process plans for all of them and to schedule them on finite resources. The industry may have more than one workplace (machine) in a work center (group of machines) possessing similar processing capabilities. In general, work centers are identified by a number as WCNO and workplaces are identified as WPNO.

The size of the problem of scheduling is mathematically equivalent to N_j jobs to be scheduled on M_j machines, where,

$$N_j = \sum_{i=1}^{n_1} \sum_{j=1}^{n_2} \sum_{k=1}^{n_3} W O . P . N_j$$

$i = 1, 2, \dots, n_1$ (No. of work orders)

$j = 1, 2, \dots, n_2$ (No. of PGMAs)

$k = 1, 2, \dots, n_3$ (No. of Parts)

$WO_i = i^{\text{th}}$ work order

$P_j = j^{\text{th}}$ PGMA in i^{th} work order

$N_{jk} = k^{\text{th}}$ part in j^{th} PGMA of i^{th} work order

$$M_{ij} = \sum_{k=1}^{m_1} \sum_{l=1}^{m_2} \sum_{a=1}^{m_3} WC_l WP_{ij} M_{ijk}$$

$i = 1, 2, \dots, m_1$ (No. of work centers)

$j = 1, 2, \dots, m_2$ (No. of workplaces)

$k = 1, 2, \dots, m_3$ (No. of machines of type l)

$WC_l = l^{\text{th}}$ work order

$WP_{ij} = j^{\text{th}}$ PGMA in i^{th} work order

$M_{ijk} = k^{\text{th}}$ part in j^{th} PGMA of i^{th} work order

Process Planning Module

Process planning is the process of determining the sequence of individual manufacturing operations needed to produce a part, determining the machining parameters, tools and fixtures. The separation of planning and scheduling is natural; the planner generates the activities and the scheduler allocates these activities to available resources. However, there are also disadvantages of such decomposition and these drawbacks become even more evident in some problem areas like complex-process environments.

First, backtracking from the scheduler to the planner is required if the clash in the plan is found during scheduling or if the plan does not utilize the resources fully. Such backtracking is not desirable because it complicates the communication between modules (the scheduler should inform the planner about the reason of backtracking) and it decreases the overall efficiency of the system. To restrict the number of backtracks, we need a more informed planner, which means the planner that uses similar information about the resources like the scheduler.

The user industry considered produces various types of turbines; the processing sequences of major parts of these turbines are mostly the same. The user industry maintains the history of process planning of all the work orders that were processed on the shop floor. Hence, whenever a new work order enters into the system, the process plan of it is developed by retrieving the information from an equivalent work order from the database. If a particular workplace required for the new work order is busy in processing the existing work orders within the time horizon considered, then possible alternatives (i.e., a workplace with similar capabilities) must be identified before generating the process plan for the new work order. This reduces the number of clashes to be resolved while scheduling. Thus, it minimizes the backtracking between

WONO	PGMA	Part No.	OPNO	WPNO	WCNO	Operation Time (min.)	Setup Time (min.)	Total Time (min.)
WONO1	30101	1001	2	9,863	1,032	900	40	940
WONO1	30101	1001	3	9,412	3,116	480	45	525
WONO1	30101	1001	4	4,828	3,116	2,100	60	2,160
WONO1	30101	1001	5	9,991	3,116	1,050	90	1,140
WONO1	30101	1001	6	4,828	3,116	1,600	60	1,660
WONO1	30101	1001	7	9,991	3,116	800	30	830
WONO1	30101	1001	8	9,421	3,116	200	20	220

the planner and the scheduler at the later stage. A typical structure of the process plan maintained in the database is as shown in the Table 1.

It is proposed to develop software system, which can address the integration of process planning and scheduling to represent a realistic manufacturing environment. The input can be accessed directly from the oracle database and the process plan for the new work order can be generated by the concept of equivalent work order. The selection of the process planning method has been done based on the nature of the problem. Here, we have chosen a retrieval method as the number of work orders are less and parts in each work order are more.

Scheduling Module

As the scheduling problem is of a larger size and the number of constraints involved is large, the schedule generation program follows a Heuristic procedure. Though some of the clashes were resolved while generating the process plan, still the clashes may exist while scheduling different work orders. This may be due to non-availability of the idle machines within the time horizon. The Heuristic procedure uses priority rule whenever there is a contention for the same machine by different parts of the same product or a different product. The authors have developed a multi-product scheduling system for the user industry earlier, which mainly concentrates on the scheduling aspect of various jobs on hand and on order (Mahesh et al., 2002). The scheduling program takes care of the following constraints while generating activity schedule for a given number of work orders:

1. The sequence of operations for manufacturing a product is fixed.
2. The part or job may visit the same machine several times.
3. An operation may not begin until its predecessors are completed.
4. The priority of a work order is not fixed.
5. The efficiencies of the workplaces may vary with time and there is a possibility of a breakdown.
6. The influence of labor is ignored.

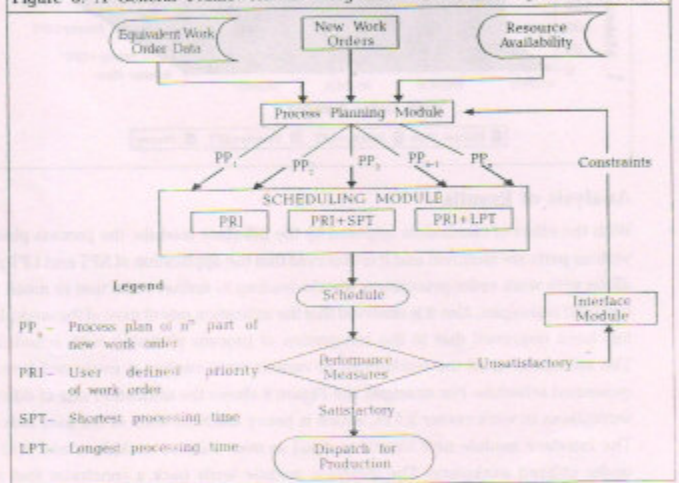
7. The industry works for two shifts in a day.

8. Change in material availability dates.

The scheduling system is developed as per the requirements specified by the user industry. It is a priority based dynamic scheduling with resource optimization and minimization of mean flow time and makespan. Any number of work orders can be considered for scheduling. The clash between the work orders waiting to be processed on the same workplace is resolved based on the priorities of the work orders. There is a provision for changing the priority assigned to work order at any stage of processing. The workplace efficiencies are also taken into consideration, so as to make the system work with real time machine data. The material availability dates can be modified as per the requirement and rescheduling done, as per the modified material availability date considering the priorities and clashes. The workplace efficiency can be changed keeping in view the working conditions of the machine prevailing on that date. This helps for the maximization of the utilization of the available work centers/workplaces, hence the makespan obtained will be optimal. This system facilitates the user to tell the near optimal delivery date of any new work order which is expected to arrive in the near future. Component wise schedules with the starting and ending dates are provided.

The integrated process planning and scheduling system used Oracle as the database management tool; Shortest Processing Time (SPT), Longest Processing Time (LPT) and priority heuristics as schedule generation tools and visual basic for Graphical User Interface (GUI's) and overall management of the software. It is observed that the

Figure 3: A General Framework for Integrated Process Planning and Scheduling



application of SPT and LPT rules along with work order priorities is always leading to reduction in mean flow time and makespan.

The various integrated modules shown in Figure 3 shall take care of the overall management of the software.

Interface Module

This module acts as an integrator of process planning and scheduling. It facilitates the integration by providing feedback to the process planning module in the form of constraints that the process plans have to follow. The constraints are developed based on the schedule of performance measures. The schedule performance measures considered include machine utilization rate, job tardiness and makespan. The facilitator module suggests the process planning module to regenerate the process plans for the parts based on the schedule performance criteria.

For example, the utilization of each machine in the shop is deduced from the generated schedule. The machines that are overutilized and under-utilized are identified. From the group of over-utilized machines, the most over-utilized machine is taken and the jobs on this machine are listed. The time taken for processing of each job on the machine is found out. The job, which is processed on the machine for the maximum time is identified. This job is chosen for modification and a specific constraint is fired, e.g., an alternate machine should be found for performing the operation of the job in place of an already selected machine. Thus, a suggestion is given to the process planning module that the operation of the job is to be performed on some other machine, if alternatives with similar capabilities are available. Process planning module takes these constraints into consideration and regenerates the process plan for the affected jobs. These modified process plans are input to the scheduling module and the reschedule is carried out.

The schedule performance measures for the newly generated schedule are evaluated. If they are found to be satisfactory according to the set objectives, the schedule is accepted and dispatched to the shop floor for production. If the performance of the schedule needs further improvement, then the interface module generates new set of constraints to be fed to the process planning module.

The algorithm used for scheduling with processing alternatives consists of the following sequence of steps:

- Step 1: The details of the new work order, its priority, start date, and equivalent work order are given as input.
- Step 2: Process planning module retrieves the existing process plan of the equivalent work order from the master database and add the entire data of new work order to the current database.
- Step 3: If a particular workplace required for the new work order is busy within the time horizon considered, then possible alternative (i.e., a workplace with similar capabilities) is identified before generating the process plan for the new work order.
- Step 4: If the alternative workplace is not available, then work orders, which are in contention for the same workplace, are identified.

- Step 5: The clash between the work orders waiting to be processed in the same workplace is resolved initially based on the priorities of work orders.
- Step 6: The schedules generated are further improved by applying heuristics like SPT and LPT to the existing schedules generated based on dynamic priorities, i.e., if parts with same priority are contending for the same workplace, then they are loaded on to the workplaces based on SPT/LPT.
- Step 7: The schedule performance measures like machine utilization and makespan are evaluated. If the performance is not satisfactory, the over-utilized workplace and a job which is taking maximum processing time on it are identified.
- Step 8: A constraint is fired by the interface module, suggesting the process planning module to change the process plan of the job by identifying alternative workplaces. These modified process plans are input to the scheduling module and the reschedule is carried out followed by Step 7. The constraints are fired till the results cannot be improved further. The scheduling results obtained by the three priority rules before and after integration of process planning and scheduling modules are presented in Tables 2 and 3, and Figures 4 and 5 respectively.

Table 2: Comparative Results of Three Priority Rules Before Integration

Work Order Number	Release Date (Days)	Makespan (in Days)		
		Priority	Priority and SPT	Priority and LPT
WONO1	0	190	196	184
WONO2	20	192	180	175
WONO3	35	190	169	200
WONO4	102	261	256	254
WONO5	58	252	209	216
WONO6	63	239	220	223
WONO7	123	301	277	268
WONO8	96	261	252	255

Figure 4: Graphical Comparison of Makespan with Three Priority Rules Before Integration

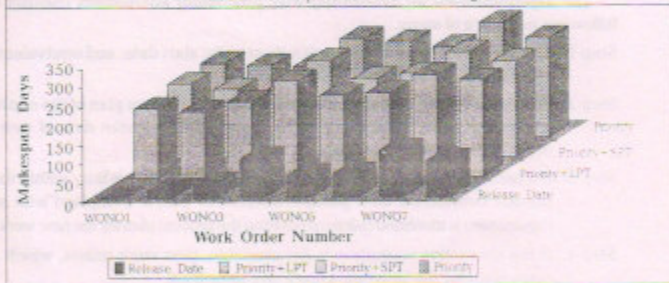
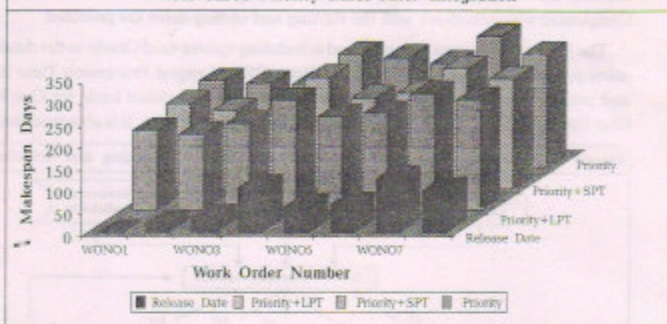


Table 3: Comparative Results of Three Priority Rules After Integration

Work Order Number	Release Date	Makespan (in Days)		
		Priority	Priority and SPT	Priority and LPT
WONO1	0	190	183	178
WONO2	20	185	178	170
WONO3	35	185	168	196
WONO4	102	258	254	240
WONO5	58	247	192	201
WONO6	63	233	200	216
WONO7	123	290	261	250
WONO8	96	252	245	244

Figure 5: Graphical Comparison of Makespan with Three Priority Rules After Integration

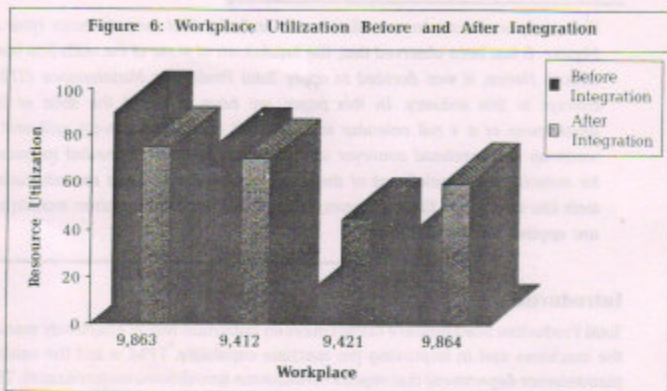


Analysis of Results

With the effect of constraints imposed by the interface module, the process plans of various parts are modified and it is observed that the application of SPT and LPT rules along with work order priorities is always leading to further reduction in mean flow time and makespan. Also it is observed that the utilization rate of most of the workplaces has been improved due to the integration of process planning with scheduling. The utilization of all the workplaces in various work centers is evaluated from the generated schedule. For example, the Figure 6 shows the utilization rate of different workplaces in work center 3,116, which is heavy machine shop of the user industry. The interface module now identifies, 9863 as over-utilized workplace and 9,421 as under-utilized workplace. The interface module feeds back a constraint that if an

alternative workplace is available for accomplishing the operations of the job, which is taking maximum time on 9,863, then the alternative must be used. It also gives a suggestion that if workplace 9,421 (least utilized workplace in the shop) is one of the alternatives for 9,863, then 9,421 could be used instead of 9,863.

From Figure 6, it is found that after feedback, the utilization of workplace 9863 is reduced, whereas the under utilized workplace 9421 is better utilized. Similarly, the utilization of other workplaces may also be normalized so as to achieve the performance measures.



Conclusion

In the conventional approach where the scheduling function is isolated from process planning, the selection of process is an important decision making problem owing to the presence of multiple alternative plans. In this paper, a new approach for the integration of process planning and scheduling is proposed by making use of the scheduling performance measures and the flexibility of the in-house developed process planning module. In the proposed system, process planning and scheduling maintain their own identity but at the same time interact dynamically with each other for obtaining better results. By implementing the proposed methodology in the industry, the resources can be better utilized, the bottleneck problems of the shop floor can be reduced and consequently the throughput of the parts significantly increases. ♦

References

1. Aytug H, Lawley M A, McKay K, Mohan S and Uzsoy R (2005). "Executing Production Schedules in the Face of Uncertainties: A Review and Some Future Directions", *European Journal of Operational Research*, Vol. 161, pp. 86-110.

2. Bruccoleri M, Amico M and Perrone V (2003), "Distributed Intelligent Control of Exceptions in Reconfigurable Manufacturing Systems", *International Journal of Production Research*, Vol. 41, No. 7, pp. 1393-1412.
3. Chang T C (1990), "Expert Process Planning for Manufacturing", Englewood, Prentice Hall, New Jersey.
4. Chiung Moon and Yoonho Seo (2005), "Evolutionary Algorithm for Advanced Process Planning and Scheduling in a Multi-Plant", *Computers & Industrial Engineering*, Vol. 48, pp. 311-325.
5. Hou T H and Wang H P (1991), "Integration of a CAPP System and an FMS", *Comput. Ind. Eng.*, Vol. 20, No. 2, pp. 231-242.
6. Huang S H, Zhang H C and Smith M L (1995), "A Progressive Approach for the Integration of Process Planning and Scheduling", *IIE Transactions*, Vol. 27, pp. 456-464.
7. Koshnevis B and Chen Q (1990), "Integration of Process Planning and Scheduling Functions", *Journal of Intelligent Manufacturing*, Vol. 1, pp. 165-176.
8. Larsen N E and Alting L (1990), "Simultaneous Engineering within Process and Production Planning", *Pacific Conference on Manufacturing*, pp. 1024-1031, Australia.
9. Lee H and Kim S S (2001), "Integration of Process Planning and Scheduling Using Simulation Based Genetic Algorithms", *International Journal of Advanced Manufacturing Technology*, Vol. 18, pp. 586-590.
10. Li R K, Shyu Y T and Adiga S (1993), "A Heuristic Rescheduling Algorithm for Computer-Based Production Scheduling Systems", *International Journal of Production Research*, Vol. 31, pp. 1815-1826.
11. Mahesh V, Siva Rama Krishna L, Sandeep D and Rao C S P (2002), "Design and Development of a Database Oriented Scheduling System for a Multi Product Manufacturing Industry", pp. 542-546, *International Conference on Responsive Manufacturing*, Gaziantep, Turkey.
12. Manish K and Sunil Rajotia (2003), "Integration of Scheduling with Computer Aided Process Planning", *Journal of Materials Processing Technology*, Vol. 66, No. 43, pp. 1-4.
13. Pinedo M (1995), *Scheduling: Theory, Algorithms & Systems*, Prentice Hall Publications.
14. Tonshoff H K, Beckendroff U and Anders N (1989), "FLEXPLAN—A Concept for Intelligent Process Planning and Scheduling", pp. 88-106, *Proceedings of CIRP International Workshop on Computer Aided Process Planning (CAPP)*, Hannover.

15. Torri J, Ohtuski N and Suzuki M (1983), "Development of On-Line, Real Time, Scheduling Methods for a Computer Aided Manufacturing Systems", *Ann. CIRP*, Vol. 32, p. 1.
16. Wong T N, Leung C W, Mak K L and Fung R Y K (2006), "An Agent-Based Negotiation Approach to Integrate Process Planning and Scheduling", *International Journal of Production Research*, Vol. 44, No.7, pp. 1331-1351.
17. Zhang Y F, Ma G H and Nee A Y C (1999), "Modeling Process Planning Problem in a Optimization Perspective", *Proceeding of the IEEE International Conference on Robotics and Automation*, Vol. 3, pp. 1764-1769.

Reference # 07J-2008-11-03-01