

# Integration of Process Planning and Scheduling Functions for Batch Manufacturing

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## Abstract

*Process planning and scheduling are the two main functions in a batch manufacturing where the former is the input to the latter. 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 we propose a method that fills the gap between these two functions and integrates them dynamically. The system consists of three modules, i.e., the process planning module, scheduling module and the facilitator module. The process planning module is optimisation-based and the scheduling module is based on heuristic algorithms. The facilitator module acts as an integrator and provides feedback to the process planning module in the form of constraints on available resources, which have to be satisfied by the process plans. Here we present the overall approach of integration and the details of the proposed modules.*

**Keywords:** Process Planning, Scheduling, Integration, Batch Manufacturing.

## 1 Introduction

Process planning is the systematic determination of the methods by which a part can be manufactured competitively and economically in a given machining environment. Production scheduling involves the allocation of available manufacturing resources for producing quality products with minimum cost and ensuring timely delivery. If the process planning and scheduling activities are performed separately without any feedback then it gives rise to a number of problems [1]:

- (1) As process planners always assume that there are unlimited resources in the shop floor they repeatedly select desirable machines.
- (2) Process planning mainly concerns with the technological requirements, i.e., identifying the resources in the shop floor for accomplishing the operations of the jobs whereas the scheduling concerns with the timing and resource allocation.
- (3) As scheduling follows process planning it is restricted by fixed process plans that cannot be altered.
- (4) Even if the shop floor conditions are considered during the process planning stage the time delay between the planning phase and plan execution phase may lead to infeasible process plans.

To solve these problems the integration of process planning and scheduling has become essential. The integration will provide for the most effective use of production resources. It increases machine utilisation and reduces the number of late parts, total tardiness and mean flow time. The integration of these two functions has a number of benefits:

- (1) As the integrated system will consider both technical and production constraints simultaneously the resulting plan can be executed without frequent ad hoc changes on the shop floor.
- (2) Integration of process planning and scheduling will result in reduced production cost, production cycles can be shortened and it also increases the possibility to have balanced loading on machines.
- (3) The efficiency of information flow will be improved; there will be reduction in human error and different functions can be used flexibly.

Many methods have been reported for the integration of process planning and scheduling. Larsen and Alting [2] have identified three approaches of integration. Non-linear process planning generates and ranks all possible alternative plans for the part prior to production independent of the shop floor status. At the time of production, the scheduler selects the plan that best suits the present conditions of the shop. FLEXPLAN is an example of such a system [3].

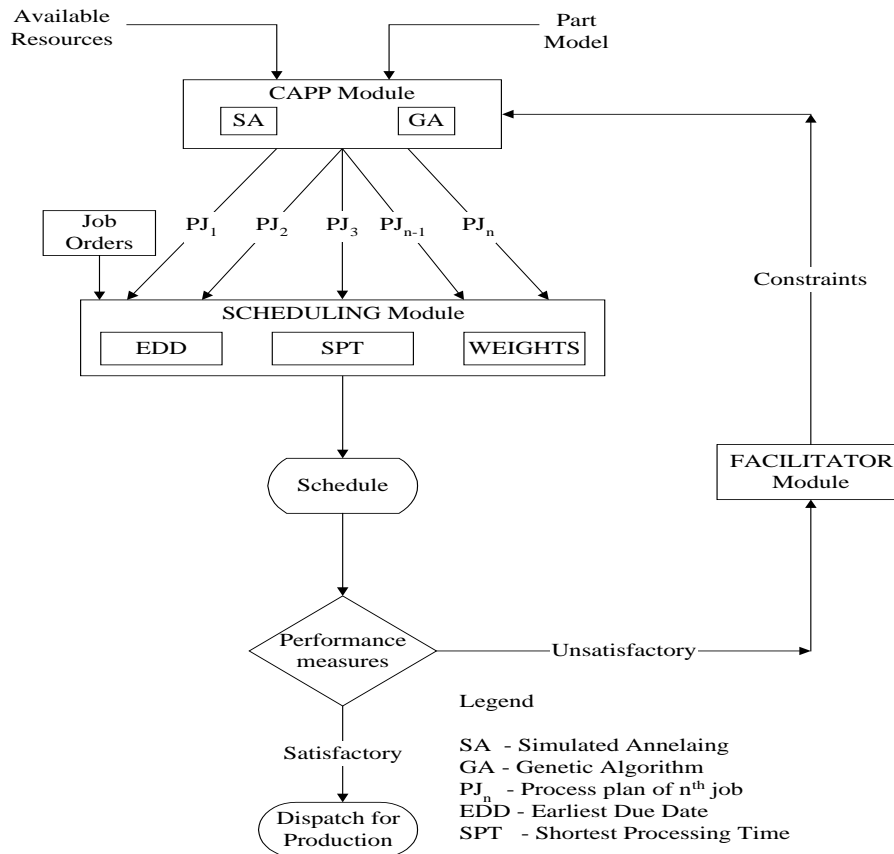
Closed-loop process planning, generates a plan for a job in the real-time at the time of production based on the feedback from the shop floor about the status of resources in the shop. Examples of such systems are RTCAPP [4] and DPP [5]. The problem with the two aforementioned methods is that a satisfactory schedule may not be achieved, e.g., bottleneck machine may be resulted, since machine utilization is not considered. The distributed process planning performs planning and scheduling activities simultaneously. IPPM [1] and IPPS [6] are examples of such systems. However, because of the problem complexity, this kind of approach is generally computational expensive [7].

In this paper a new approach for dynamic integration of process planning and scheduling is developed (see Figure 1). The integration is achieved through a facilitator that provides feedback to the process planning module in the form of extra constraints based on the schedule performance measures. In this way, alternative process plans can be generated automatically that result in a better schedule.

## 2 Process Planning Module

Process planning involves a number of activities such as selection of process methods, machine and cutting tools, sequencing of operations satisfying the precedence relations and constraints.

The process planning module [8] is designed in such a way that 1) all the features are recognized automatically; 2) for each feature all possible process types that can accomplish the feature are determined; 3) the precedence relations and constraints among the required process types are determined; 4) for each process type all possible combinations of machines, tools, and tool access directions are determined; and 5) based on the optimisation criteria, two algorithms, based on simulated annealing and genetic algorithm, can be used to search for the optimal process plan. The optimization criteria used to evaluate a plan are machine cost, tool cost, machine change cost, set-up change cost, and tool change cost. These criteria may be used individually or together to suit the particular need of a job.



**Figure 1.** Proposed framework for integration.

The detailed description on this module can be found in Zhang et al. [8]. The process planning task is

essentially, to allocate each operation to unique set of machine and cutting tool with a unique position

(order) in the whole operation sequence subject to some constraints and object criteria. So the input to the process planning module are the design information, part model and the available resources in the company. The output of this module is the process plan for each job.

### 3 Scheduling Module

The scheduling module receives the process plans and orders of all the jobs. This module generates the schedule for a given time period using heuristic algorithms. The heuristics used for generating the schedule are Earliest Due Date (EDD), Shortest Processing Time (SPT), and Weights assigned to the jobs (WEIGHTS) [9].

Assumptions made while designing the scheduling module are:

- (1) A 24-hour workshop;
- (2) The processing time of an operation includes the set up time and also the machine change over time.
- (3) The influence of labour is ignored;
- (4) Each operation of a job is performed on a single machine; and
- (5) Jobs consist of ordered operation sequences.
- (6) An operation may not begin until its predecessors are complete.
- (7) A machine can process only one operation at a time.

#### 3.1 Inputs

The inputs to the scheduling module are process plans and job orders received, which includes:

- (1) The total number of jobs;
- (2) Specified due date for all jobs;
- (3) Weights assigned to the job (on a scale of 10);
- (4) The batch size;
- (5) The number of operations in each job;
- (6) Processing time and machine for each operation of the job; and
- (7) The scheduling period.

#### 3.2 Outputs

The outputs from the schedule are the tentative loading (start) and finishing (end) times of all operations of the jobs.

The schedule performance measures like machine utilisation, flow time and job tardiness are evaluated from the generated schedule. The company based on its needs can choose any one measure. If the chosen

performance measure is found to be satisfactory with respect to the criteria set by the company then the schedule is dispatched for production. If it is felt that the schedule needs improvement then it is input to the facilitator module for analysis and development of additional constraints to redo process planning and scheduling.

### 4 Facilitator Module

This module is incorporated 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 plan(s) have to follow. The constraints are developed based on the schedule performance measures.

The schedule performance measures considered include machine utilisation rate, flow time, and job tardiness. Heuristics and rules are incorporated in the facilitator for generating suggestions to regenerate process plans of the jobs. The suggestions can be further constraints on the employment of some machines and tools or some other resources in the shop, or a change of machine, tool or the optimization criteria. Here, heuristics based on machine utilization rate is given as an example.

In the process plan generation stage, the planning module searches for the optimal plan for each job assuming that all the resources are available. This may lead to over-utilisation or under-utilisation of a particular machine, which is not desirable. In order to avoid such problems the facilitator module generates appropriate constraints in terms of the usage of a particular machine and the planning of a particular job.

The utilisation of each machine in the shop is deduced from the generated schedule. The machines that are over-utilised and under-utilised, are identified. From the group of over-utilised machines the most over-utilised machine is taken and the jobs on this machine are listed. The time taken for the 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 may be due to a large batch size or long processing time of the operation. This job is chosen for modification and a specific constraint is fired, e.g., an alternative machine should be found for performing the operation of the job in place of the already selected machine. This means that the job is to be removed from the present machine and the process planning module is given the suggestion that the operation of the job is to be performed on some other

machine if alternatives with the same capabilities are available. Although the plan generated for the chosen job may not be as good as the one before, this will help resolve the overloading by distributing the load evenly among different machines in the shop.

These constraints are taken into account by the process planning module to regenerate the process plans for the affected jobs. Once the process plans are regenerated they are input to the scheduling module and rescheduling 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 facilitator module generates a new set of constraints to be fed back to the process planning module.

The cycle of regenerating process plans, rescheduling and generation of new constraints by the facilitator continues until a schedule with satisfactory performance measures is achieved.

## 5 Case Study

To illustrate the approach presented, a small job shop with 4 machines and 6 jobs is considered over a scheduling period of 20 days. The process plans for all the jobs are generated and are input to the scheduling module along with the job orders. The input is given in Table 1.

**Table 1.** Schedule input data.

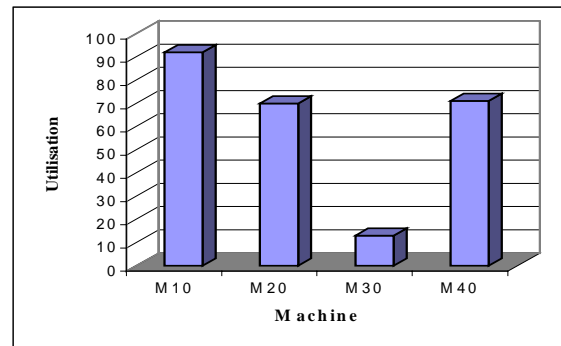
Job No	Batch size	Job weight	No. of ops	Opn time	M/C	Due Date
J24	50	9	2	3	M10	30.08.1999
				1	M40	
J34	60	10	3	2	M20	05.09.1999
				1	M40	
				2	M10	
J44	45	9	2	3	M20	28.08.1999
				1	M10	
J54	30	7	2	1	M20	23.08.1999
				2	M30	
J64	50	8	3	2	M40	06.09.1999
				3	M10	
				1	M20	
J74	65	9	2	2	M40	27.08.1999
				1	M10	

In this case, the SPT algorithm is used for scheduling. The schedule generated is presented in Table 2.

**Table 2.** Schedule generated using SPT algorithm.

Job no	Mc no	Start Time		End Time	
		Hours	Date	Hours	Date
J54	M20	00	17.8.1999	06	18.08.1999
	M30	06	18.08.1999	18	20.08.1999
J44	M20	06	18.08.1999	21	23.08.1999
	M10	21	23.08.1999	18	25.08.1999
J74	M40	00	17.08.1999	10	22.08.1999
	M10	18	25.08.1999	11	28.08.1999
J24	M10	00	17.08.1999	06	23.08.1999
	M40	06	23.08.1999	08	25.08.1999
J64	M40	08	25.08.1999	12	29.08.1999
	M10	12	29.08.1999	18	04.09.1999
	M20	18	04.09.1999	20	06.09.1999
J34	M20	21	23.08.1999	21	28.08.1999
	M40	12	29.08.1999	00	01.09.1999
	M10	18	04.09.1999	18	09.09.1999

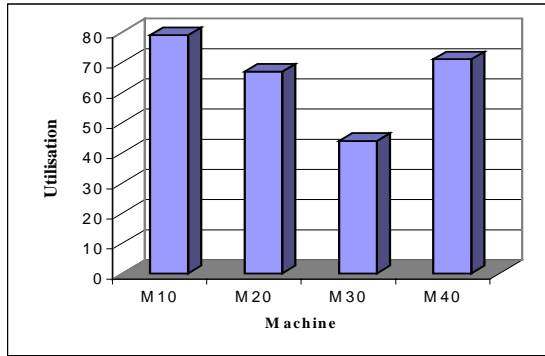
The utilisation of all the machines in the shop is evaluated from the generated schedule. Figure 2 shows the utilisation rate of the different machines.



**Figure 2.** Machine utilisation before feedback.

From the machine utilisation chart, Figure 2, the facilitator identifies M10 as the most over-utilised machine. All jobs except J54 use this machine. Jobs J64 and J24 use M10 for a maximum time of 150 hours each. The facilitator feeds back a constraint to the process planning module that if an alternative machine is available for accomplishing operation 2 of job J64 then the alternative is to be used. It also gives a suggestion that if M30 (least utilised machine in the shop) is one of the alternatives for M10 then M30 could be used instead of M10.

Here M30 has the capability to do the operation 2 of J64. So the process planning module now replaces M10 with M30. After this modification rescheduling is done and now the utilisation of the machines in the shop is given in Figure 3.



**Figure 3.** Machine utilisation after feedback.

From Figure 3, it is found that after feedback the load on the machine M10 is reduced. It is also found that the under-utilised machine M30 is better utilised and due dates of almost all jobs are met. For the same case, if the facilitator gives a suggestion to replace M10 with M30 for operation 1 of J24, it is found that the utilisation of the machines is improved but the due dates performance is not as good as the previously effected change.

Here for simplicity we have illustrated just one change to the process plan and the results of a single iteration. In some situations there will be many modifications to the process plan as many constraints and suggestions will be generated by the facilitator module. The effect of such changes will be reflected in the schedule each time we make a change. Thus we continue to iterate and modify the process plans according to the constraints generated by the facilitator until a schedule with satisfactory performance is achieved.

## 6 Conclusions

This paper presents an approach for the integration of process planning and scheduling by making use of the schedule performance measures and the flexibility of an in-house developed process planning module. Here process planning and scheduling maintain their identity but at the same time interact dynamically with each other for obtaining better outputs. To the authors' best knowledge, achieving a satisfactory schedule in batch manufacturing through automatic process plan modification is not addressed by any of the earlier methods of integration. As we strive for the improvement of the schedule the resources in the shop

are better utilised, due dates of jobs are met and the overall cost involved is also reduced. Thus the proposed approach integrates process planning and scheduling by considering and processing their needs simultaneously. The facilitator module, which plays an important role in the integration, is to be further improved by the addition of expert knowledge for providing more useful and effective feedback to the process planning module.

## References

1. Zhang H.C., IPPM – a prototype to integrate process planning and job shop scheduling functions, *Annals of CIRP*, 42(1), pp. 513-518, 1993.
2. Larsen N.E., Alting L., Simultaneous engineering within process and production planning, *Pacific Conference on Manufacturing*, Australia, pp. 1024-1031, 1990.
3. Tonshoff H.K., Beckendroff U., Anders N., FLEXPLAN – A concept for intelligent process planning and scheduling, *Proceedings of CIRP International workshop on Computer Aided Process Planning (CAPP)*, Hannover, pp. 88-106, 21-22 September 1989.
4. Koshnevis B., Chen Q., Integration of process planning and scheduling functions, *Journal of Intelligent Manufacturing*, 1, pp. 165-176, 1990.
5. Iwata K., Fukuda J., A new proposal of dynamic process planning in machine shop, *Proceedings of CIRP International workshop on Computer Aided Process Planning (CAPP)*, Hannover, pp. 73-83, 21-22 September 1989.
6. Huang S.H., Zhang H.C., Smith M.L., A progressive approach for the integration of process planning and scheduling, *Institute of Industrial Engineers (IIE) Transactions*, 27, pp. 456-464, 1995.
7. Gindy N.N., Saad S.M., Yue Y., Manufacturing responsiveness through integrated process planning and scheduling, *International Journal of Production Research*, 37(11), pp. 2399-2418, 1999.
8. Zhang Y.F., Ma G.H., Nee A.Y.C., Modeling process planning problem in a optimization perspective, *Proceedings of the 1999 IEEE International Conference on Robotics and Automation*, 3, pp.1764-1769, 1999.
9. Baker K.R., *Introduction to Sequencing and Scheduling*, Wiley Publications, 1974.