CHAPTER – 1

INTRODUCTION

1.1 Introduction

Planning and scheduling are the most important activities involved in any manufacturing organization. The terms processplanning and scheduling are often used together, but they are two different activities with different objectives. Process Planning is concerned with what and how to do the manufacturing. Identifying the set of actions to be performed and the resources required to perform them is a part of process planning activity, whereas scheduling is concerned with when and who to do. On the other hand, it also deals with identifying a schedule from a large number of available alternatives. In some cases, it is difficult to decompose the planning and scheduling clearly, thus considering them together as a single activity. The objective of Computer-Aided Process Planning (CAPP) system is to bridge the gap between Computer Aided Design (CAD) system and Computer Aided Manufacturing (CAM) System.

Process planning plays an important key role in Computer Integrated Manufacturing (Alting and Zhang 1989). CAPP is the function that forms the link between design and manufacturing, thus providing a means for the translation of design requirements and specifications into a set of instructions describing how to manufacture the part. Traditionally, CAPP systems have operated under the assumptions that the shop-floor is idle and there are unlimited resources available. This separation from the reality of the shop-floor results in the CAPP system repeatedly selecting the most desirable machines for different parts, where these selected machines may be already in use. Thus when process plans for various parts are finally carried out, process bottlenecks may arise making the generated plans infeasible. Also, due to the time delay between the generation and actual execution of a plan, the conditions of the shop floor usually change to such a degree that the process plans generated are seldom followed. To overcome these problems a planning system is needed that integrates the process planning activities with scheduling such that the resulting plans are valid for the conditions that exist on the shop-floor at the time when an order is released.
New approach tends to integrate CAD, CAPP and CAM systems together, by using feature-based technology. Recently, a new trend towards integration is to utilize adaptive, dynamic and distribution process planning which results in production instructions for machining a part are generated dynamically and adaptively in accordance with changeable shop floor status. In other words, process plan information is generated in real-time in the shop floor based on current information of shop floor status.

Many manufacturing domains are already using computer and its peripherals. It has a considerable advantage particularly for a design and drafting, production control, machine control and so on in an effective manner. This technology is more efficient and has a tremendous advantage by enabling computers in different segments of the company and also to communicate and exchange information. Computer integrated manufacturing (CIM) may be defined as a manufacturing philosophy in which the functions of the organization, from product definition to the disposition of the final product, are designed and integrated to achieve clearly enunciated organizational goals, most efficiently and effectively.

In general, CIM is a strategy incorporating computers, for linking existing technology and people to optimize business activity by utilizing the computer to integrate the fragmented operations of manufacturing into a single, smoothly operating manufacturing system. This reduces total manufacturing costs and turnaround times, with improved quality.

CIM is a fully automated integrated system of CAD and CAM, linking CAPP. Many manufacturing entrepreneurs in CIM typically have concentrated their efforts in two areas: CAD, which applies the computer to the creation, modification, and evaluation of product design, and CAM, which applies the computer to the planning, control and operation of a production facilitating with CAPP. Material handling system devices like robots, Automated Guided Vehicles (AGV), Conveyors, Overhead cranes, Mono rails, automated trucks, and Automated Storage and Retrieval systems (AS/RS) etc., are integrated with computers which controls the entire production processes with or without partial human intervention. However, CIM is typically employed to a shorter level of total integration at the enterprise level.
Different researchers adopted different advanced techniques and approaches such as feature or solid model based design, object oriented programming, manufacturing databases, and advanced computing methods including expert system and Artificial Intelligence (AI). The decision logic in process planning may be based on decision trees, decision tables, heuristic methods, rule based decision trees, constraint-based methods, hard coded algorithms, and problem oriented languages. Because process planning is a NP-hard problem, some global search techniques must be applied.

1.2 Artificial Intelligence Systems

Artificial intelligence is an old dream and a fairly young discipline, which was developed since the late 1950’s as an interdisciplinary subject of computer and cognitive sciences aiming at computational models of human cognition. It is rather a marketing name for new programming methods to create reasoning systems.

Computational Intelligence (CI) is the execution programming part of AI. CI relies on heuristic algorithms such as Fuzzy systems, Petrinets, Fuzzy Petrinets, Artificial Neural Networks (ANN’s), Evolutionary Computation Algorithms like GA, SA, Tabu Search, Swarm particle Optimization, Artificial Immune Systems etc. CI combines elements of learning, adaptation, evolution and fuzzy logic (rough sets) to create programs that are, in some sense, intelligent. The successful use of CI in many science and engineering areas reveals that CI techniques are applicable to process planning and scheduling problems.

AI programs can be divided into two different programs that are general and expert systems of intelligence. General systems are computer programs that attempt to simulate intelligence with no fixed limited class of problems. Consequently, programming a general system can be very difficult. Further, general systems are relatively impractical and so they are rare. In contrast, an expert system is a computer program geared towards solving one limited class of problems. Expert systems infer implications from a given knowledge base. This knowledge base may be static, pre-programmed, unchanging, dynamic and evolution. Dynamic rule bases may be better at representing intelligence since the evolution of the rule base reflects the program’s ability to “learn”. Programs that play chess generally use static rule bases, though some chess-playing programs use dynamic rules and adapt themselves to their
opponent. Most artificial intelligence applications, including law applications, are formulated as rule-based expert systems.

GA has been successfully applied to various optimization problems. The hybridization approaches, such as genetic-fuzzy, fuzzy-neural, genetic-simulated annealing etc., are aimed not only at exploiting the strong capabilities of the various tools, but also at solving manufacturing problems that are not amenable for modeling using traditional methods. The logical fuzzy inference is used as the computational method, where the system is developed in logical programming languages such as Prolog or other AI programming languages.

1.3 Need of the Manufacturing Activities Integration

The present market trend has shifted towards the integration of the enterprises, having mutual coordination and focusing on optimum production goal in response to the customer demand. Most of the time consumed by them is in the processing of the parts. In order to overcome these drawbacks, an effective process planning and scheduling model integration aiming to reduce the make span and delivery time, needs to be implemented. To conquer the inefficiency of not delivering the product within the due date, outsourcing strategy has been adapted. But its implementation needs to be economically feasible. In traditional approaches, process planning and scheduling were carried out in a sequential way. Scheduling will be conducted after the process plan had been generated. These approaches have become an obstacle to improve the productivity and responsiveness of manufacturing.

In manufacturing industry process planner plans the jobs individually. For each job, manufacturing resources on the shop floor are usually assigned on it without considering the competition for the resources from other jobs (Usher and Fernandez 1996). This may lead to the process planners favoring to select the desirable machines for each job repeatedly. Therefore, the generated process plans are somewhat unrealistic and cannot be readily executed on the shop floor for a group of jobs (Lee and Kim 2001). Accordingly, the resulting optimal process plans often become infeasible when they are carried out in practice at the later stage.
Scheduling plans are often determined after generating the process plans. Fixed process plans may drive scheduling plans to end up with severely unbalanced resource load and create superfluous bottlenecks. Even though process planners consider the restriction of the current resources on the shop floor, the constraints in the process-planning phase may have already changed owing to the time delay between the planning and execution phases which may lead to the infeasibility of the optimized process plans. Investigations have shown that 20–30% of the total production plans in a given period have to be modified to adapt to the dynamic change in a production environment (Kumar and Rajotia 2002 and 2003).

In most cases, both for process planning and scheduling, a single criterion optimization technique is used for determining the best solution. However, the real production environment is best represented by considering more than one criterion simultaneously (Kumar and Rajotia 2003). Furthermore, the process planning and scheduling may have conflicting objectives. Process planning emphasizes the technological requirements of a job, while scheduling involves the timing aspects and resources sharing all jobs. If there is no appropriate coordination, it may create conflicting problems.

To overcome these problems, there is an increasing need for deep research and application of Integrated Process Planning and Scheduling (IPPS) system. The IPPS introduces significant improvements to increase the efficiency of manufacturing system greatly through eliminating or reducing scheduling conflicts, reducing flow-time and work-in-process, improving production resources utilizing and adapting to irregular shop floor disturbances (Lee and Kim 2001). Through the integration of these two systems, IPPS can provide better process plans and schedules than the traditional manufacturing systems which improve the productivity of the manufacturing.

1.4 Importance and applications of AI

For the past three decades, there have been considerable advances in Computer Aided Engineering (CAE) tools that employ leading-edge artificial intelligence techniques and can be used with CAD/CAM tools to reduce design costs. The current AI applications, that can prove beneficial in the design and planning stages of
manufacturing, can assist in solving scheduling and control problems, and can be used in manufacturing integration. The applications are the following:

- Application of Machine Learning to Industrial Planning and Decision Making.
- Geometric Reasoning Using Feature Algebra.
- Backward Assembly Planning Symmetry Groups in Solid Model-Based Assembly Planning.
- Interactive Problem Solving for Production Planning.
- An Abstraction-Based Search and Learning Approach for Effective Scheduling.
- ADDYMS: Architecture for Distributed Dynamic Manufacturing Scheduling.
- Architecture for Real Time Distributed Scheduling.
- Teamwork among Intelligent Agents.
- Exploiting Local Flexibility during execution of pre-computed schedules.
- Symbolic representation and planning for Robot Control Systems in manufacturing.
- Architecture for integrating enterprise automation.
- An Intelligent agent framework for enterprise integration.
- Integrated Software System for Intelligent Manufacturing.
- Enterprise Management Network Architecture.
- Design and Manufacturing: Integration through Quality.

1.5 Problems with traditional Process Planning and Scheduling

Traditional construction planning is built up on the basis of a conversion model, where each activity is a conversion process that converts input resources into a final or an intermediate product. The conversion process can be divided into sub processes. Planning at different levels is responsible for identifying the activities and then organizing them in the most efficient way to achieve certain objectives subject to
some constraints. This conversion model has been supported by many conventional scheduling tools, such as the Critical Path Method (CPM). Some implicit assumptions in these scheduling techniques are as follows.

1) Each process or sub process is conducted and managed independently.
2) Scheduling activities is subject to certain constraints, such as precedence relationships between activities, resource availability profile, and client’s constraints, etc.
3) Preparation for doing an activity has always been adequately made before the activity’s scheduled time.
4) Each activity is to be duly accomplished.

Traditional scheduling tools do well in project-level planning, which is not concerned with details of resource delivery and information acquisition. However, they are not easily amenable to producing robust look-ahead and commitment schedules. Present CPM-based scheduling tools are not able to track the availability of required resources or information for each activity. This is acceptable if the above assumptions are true. Unfortunately, in practice what happens is hardly consistent with what was estimated at the planning stage. Work flow tends to be fragile and easily deviates from the original sequence. Although field crews make their own efforts to reduce such inconsistencies, the chance of success is remote unless the root cause of the problem has been identified. The conversion model is incomplete, if not erroneous, for it neglects the physical flow between activities. Construction should be viewed accordingly as a combination of flows and conversions. This view is supported by the new Lean construction philosophy (Koskela 1992). Conversions represent value-adding activities that directly contribute to the accomplishment of certain products. Flows contain hidden activities that either facilitate the conversions (e.g., necessary preparation for the work), or are simply waste (e.g., waiting for the missing resources/information to be available). The task of construction management, therefore, is not only to make each conversion process efficient but also to compress the flow between conversions to reduce waste. As traditional scheduling tools are poor in identifying and managing hidden activities in flow, it is clear that new tools should be developed to make construction process more transparent and efficient, and hence manageable.
1.6 Issues in the Integration of Process Planning and Scheduling

In today’s highly turbulent environment, manufacturing enterprises are striving hard to compete with each other. Present era has enforced them to realize the importance of organized planning. The challenges to handle the varying lot sizes, reduced lead time, increased product variety has left the enterprises with no other alternatives than to modify their strategies as per shifting market trend. Therefore, enterprises are aiming to meet their customer expectations in more efficient manner by shifting their old manufacturing and planning strategies with the modern day approaches. One of the major concerns that the enterprises are targeting these days is to deliver the products within the due dates and reduce the lead time as much as possible to counteract the fluctuations in demand. In order to meet these objectives industries are motivated towards the integrated process planning and scheduling approaches. Since, the traditional way of treating process planning and scheduling results in deadlocks, incompetent resource utilization and inefficient scheduling. Hence integrating them simultaneously overcomes the drawbacks inherited in it. Integration of process planning and scheduling activities in shop floor allows a manufacturing enterprise to focus on its core competencies, eliminate its investment in non-core activities, control the specialized expertise of its partners, and to build strategic flexibility along with, reduction of manufacturing cost, capital investment, and uncertainty by the risk pooling effect leading to the performance optimization of the enterprises.

Current practice of separate process planning and production scheduling has been recognized by many researchers. A summary of common features are enlisted by researchers as follows (Ham and Lu 1988; ElMaraghy and ElMaraghy 1993; Larsen and Alting 1992; Lenderink and Kals 1993; Liao et al. 1994; Tonshoff et al. 1989 and Zhang 1993):

- Scheduling strictly follows the process planning, and is unable to change the fixed process plan.
- Process planning assumes a 100% idle factory with unlimited capacity of various resources.
Focusing on technical considerations, process planning always selects certain "good" machines.

Changes of machine tools are conducted intuitively and opportunistically by foremen on the shop floor with insufficient or incomplete knowledge on process planning.

The consequences of the above-mentioned practice are as follows.

(i) Certain machines are always congested while others are kept idle.
(ii) Neither process plans nor production schedules are followed well on the shop floor.
(iii) Selecting machine tool based only on technical considerations may lead to suboptimal selection.

Because of the immense problems created in current practice of separated planning, integration of process planning and production scheduling has posed a great challenge to contemporary manufacturing planning research. Planning in manufacturing framework is vital in achieving the ultimate goal of unmanned and integrated factories in future (Ham and Lu 1988). Process planning which serves as a linking element in perspective CIM must be integrated itself with product design and production scheduling. While the research issue of integrating process planning and product design has drawn great attention, the issue of integrating process planning with production scheduling has not yet been recognized by both academic and industry communities. Although some research has been reported on this topic, more serious issues need to be addressed in this current research endeavor.

There is a lack of fundamental analysis encompassing technical and nontechnical factors for manufacturing systems. "Without a clear structure, it is difficult to develop planning systems that are modular enough to incorporate local constraints" (Ham and Lu 1988). A clear structure is based on a thorough systems analysis.

More concrete models must be devised to support the integration philosophy. Most of the past researches either focus on high level system architectures which need concrete models or focus on local level optimization algorithms with many assumptions which are not realistic at the current stage.
Integrated planning requires integrated goals (objectives), integrated constraints, integrated methodologies, and integrated procedures. New techniques such as object-oriented modeling technique which can combine the functional integration and data integration need to be introduced.

1.7 Computer Integrated Manufacturing (CIM) Environment

CIM environment provides a complete automation of all possible manufacturing activities or tasks, with all processes working under computer control systems linked together within the enterprise level. Its technologies are as follows:

- Computer Aided Design (CAD)
- Computer Aided Manufacturing (CAM)
- Computer Aided Process Planning (CAPP)
- Computer Numerical Control of machine tools (CNC)
- Direct Numerical Control of machine tools (DNC)
- Distributed Numerical Control of machine tools (Distributed NC)
- Flexible Manufacturing Systems (FMS)
- Automated Storage and Retrieval Systems (AS/RS)
- Automated Guided Vehicles (AGV)
- Robotics and automated conveyors
- Computerized Scheduling and Production Control systems
- Business oriented integrated database management systems

CAD/CAM is very essential to reduce cycle times in an organization. CAPP emerges as a key factor in CAD/CAM integration because it is the link between CAD and CAM. CAD techniques make use of Group Technology (GT) to create similar geometries for quick retrieval electronic files thus replacing the drawing rooms. CAD/CAM integrated system provides design and drafting, planning and scheduling, and fabrication capabilities. CAD provides the electronic part images, and CAM provides the facility to guide the cutting tool to perform the desired operation. Advanced software programs can analyze and test designs before a prototype is made. Finite element analysis programs allow engineers to predict stress points on a part, and the effects of loading. Generative, variant and semi-generative process planning is advanced CAPP methods in integration of CAD/CAM modules.
1.8 The back bone of CIM technologies

The key elements in any CIM technologies are information management and communication systems, material management and control systems, process management and control, and integration. The information management and communication systems are the computers that link the various developments and decision making activities to each other. The second area involves material flow control. The third area is process control and this includes downloading of the appropriate inputs or process instructions and monitoring the process itself. Finally, the systems are integrated using computers (Kellso 1989). If CIM solution is practical, there must be common operating plans for all affected departments, with an integrated system using a common database.

1.9 Manufacturing process planning

Manufacturing process planning system is an increasingly important part of the interface between the design and manufacturing engineering processes. The CAPP system is developed while the manufacturing method is being determined, and is used and revised throughout the life of the production system. CAPP includes the hardware systems involved in the process, the personnel operating these hardware systems, and data stored about current and past production. Some CAPP systems automate the manufacturing process by making real-time decisions based on the model of the part, sensors in the assembly hardware, or other sources. Together, the CAPP system components will determine how to efficiently manufacture the product (Bose 1999). Previously, this process planning was performed by a manufacturing engineer. Assembly manufacturing also used CAPP systems to improve part flow, reduce assembly errors, and increase the general efficiency of operations. The development of CAD and CAM systems brought CAPP into the manufacturing industry.

Early CAPP systems improved the manufacturing efficiency for new parts that had slight variations in their design from previous or similar current models. “Group Technology” theory utilizes the fact that parts with similar designs will have similar process plans. Therefore these simple “Variant” methods only consider the variations in the parts and then modify manufacturing instructions based on these variations. It is important to note that these CAPP systems are created based on previous
manufacturing methods for the product, and worked from a fixed set of process plans. This CAPP system selects one detailed input instruction set, and outputs one simple, similar instruction set for the manufacturing hardware. In contrast, “Generative” type CAPP systems create customized process plans for each new part based on the manufacturing hardware, product details, and other information sources. The generative process plan contains function variables that change for every part based on the CAPP system’s information sources (Cay and Chassapis 1989). The system inserts values into its guiding functions to generate the process plan. This functional process plan incorporates the machine hardware and software. Variant CAPP systems also incorporate machine details, but only at the time when the CAPP system is created. This means that generative CAPP systems are able to adapt and reconfigure to changing manufacturing needs, making them more flexible.

1.10 Scheduling activities in shop floor

Scheduling is the process to allocate the operations to time intervals on the production machines. A scheduling problem can be classified into different types based on four parameters (Conway et al. 1990) job arrival patterns, number of machines in the shop, flow patterns in the shop and the criteria by which the schedule is to be evaluated.

Among various scheduling types, job shop scheduling is one of the most important scheduling types. Job shop Scheduling Problem (JSP) can be defined as (French 1982) given a set of $n$ jobs, which are to be processed on $m$ machines with defined technological constraints for each job, find a sequence in which jobs pass between machines such that it satisfies the technological constraints and it is optimal with respect to some performance criteria (Tan and Khoshnevis 2000). The JSP is one of the hardest combinatorial optimization problems. It is widely acknowledged as one of the most difficult number of populations -complete problems (Garey et al. 1976). JSP has been studied by a significant number of researchers.

Many optimization algorithms and approximation algorithms have been proposed. The optimization algorithms, which are mainly based on the branch and bound scheme such as Carlier and Pinson (1989 and 1994), and Brucker et al. (1994) have been successfully applied in solving the small instances. However, they could
not solve instances larger than 250 operations in a reasonable time. On the other hand, approximation algorithms, which include priority dispatch, shifting bottleneck approach, meta-heuristic methods and so on, provide quite good alternatives for the JSP.

Approximation algorithms were first developed on the basis of dispatching rules, which were very fast, but the quality of solutions that they provided usually leave plenty of room for improvement. A more elaborate algorithm, which could produce considerably better approximations at a higher computational cost, is the shifting bottleneck approach proposed by Adams et al. (1988).

More recently, the meta-heuristic methods, such as Genetic Algorithm (GA) (Croce et al. 1995), Simulated Annealing (SA) (Van et al. 1992) and Tabu Search (TS) (Taillard 1994; Nowicki and Smutnicki 1996; Zhang et al. 2007 and 2008), could provide the high-quality solutions with reasonable computing time and captured the attention of many researchers. The relevant researches had been summarized in Vaessens et al. (1996), Blazewicz et al. (1996) and Jain and Meeran (1999).

1.11 Integration of process planning and scheduling activities

Technical challenges effectively support the integrated process-planning and production-scheduling decisions in a complex and dynamic environment. From a pure process planning perspective, the number of orders that require the generation of new process plans and production of new tools, and the sheer variety of parts and machines (and their various characteristics) present a significant challenge. As in other large machine shops, production scheduling in this environment is not an easy task. Major scheduling challenges include the presence of multiple sources of uncertainty, both internal (e.g., machine breakdowns) and external (e.g., new order arrivals, delays in tool production and raw-material delivery), the difficulty in accurately accounting for the finite capacity of a large number of resources operating according to complex constraints, and the need to take into account the multiple resource requirements of various operations (e.g., tools, NC programs, raw materials, human operators). While considerable progress has been made with respect to software technologies for process planning and finite-capacity production scheduling, very little attention has been given to issues of integration. Except for a few
attempts, often in the context of small manufacturing environments, process-planning and production-scheduling activities are typically handled independently, and are carried out in a rigid, sequential manner with very little communication. Process alternatives are traded off strictly from the standpoint of engineering considerations, and plans are developed without consideration of the current ability of the shop to implement them in a cost-effective manner. Likewise, production scheduling is performed under fixed process assumptions and without regard to the opportunities that process alternatives can provide for acceleration of production flows. Only under extreme and ad-hoc circumstances (e.g., under pressure from shop floor expediters of late orders) are process-planning alternatives revisited. This lack of coordination leads to unnecessarily long order lead times and increased production costs and inefficiencies, and severely restricts the ability to effectively coordinate local operations with those at supplier/customer sites, whether internal (e.g., a tool shop) or external (e.g., raw-material suppliers). Huang et al. identify three distinct approaches to integrate process planning and production scheduling,

1. Non-Linear Process Planning, which generates all possible process plans ahead of time (i.e., based on static considerations) and dynamically selects between these alternatives at execution time. This is the approach taken in the FLEXPLAN system (Tonshoff et al. 1989).

2. Closed-Loop Process Planning, also referred to as real-time or dynamic process planning (Iwata and Fukuda 1989, Tonshoff et al. 1989) where process planning attempts to take into account dynamic resource availability information.

3. Distributed Process Planning, which reduces the complexity of the closed-loop approach by subdividing integrated process-planning and production-scheduling decisions into multiple, more localized, decision phases.

In practice, none of these approaches totally dominates the other two, as different manufacturing environments generally entail different levels of complexity and different operational requirements (e.g., different real-time requirements). In fact, the decision flows assumed in earlier work are rather restrictive and cannot accommodate some of the complexities of environments.

Even with the support of sophisticated state-of-the-art Computer Aided Process Planning and Scheduling techniques, process planning and production scheduling
remain highly interactive processes, where the user has to be able to evaluate alternative decisions based on experience and knowledge that is not easily amenable to computer modeling rather than committing to a pre-specified decision flow. The resulting shell provides a customizable framework capable of supporting a wide range of integrated process-planning and production-scheduling decision flows, including all three of the approaches identified in as well as a number of more complex hybrids.

1.12 Summary

The practical problems and related issues encounter with traditional process planning and scheduling activities are discussed. And also the benefits of Artificial Intelligencetechniques, Integration of process planning and scheduling system are elaborately discussed.