UNIT 15 COMPUTER AIDED TOOL SETUP PLANNING

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15.1 INTRODUCTION

Since the onset of the 1980s, manufacturing planning has been regarded by both academia and industry to be crucial in accomplishing the ultimate goal of unmanned and integrated factories of the future. Planning can be viewed as the activity of devising means to achieve desired goals under given constraints and limited resources. Hence manufacturing planning is the process of coordinating the various activities in the design and manufacturing processes.

Many computer-aided process planning (CAPP) systems that have been reported to date have their main objective of generating the machining sequences of features and to select the optimal machining operations. The objectives of process planning are as follows:

(a) select machining processes and tools to produce all the features on a workpiece,
(b) select machine tool(s) to perform these required operations,
(c) sequence these operations, taking into account features relations,
(d) generate set-ups,
(e) determine the various requirements for these set-ups,
(f) select machining parameters for the operations required,
(g) plan the tool paths, and
(h) generate the NC part program. Thus, setup planning is a part of the generic process planning framework.

The entire process planning domain for the machining environment have three dimensions, namely:

(a) operations planning,
(b) setup planning, and
(c) fixture planning.

The most important of these is setup planning because almost all the processes in machining depend upon setup, as illustrated in Figure 15.1.
Objectives
After completing this unit you should be able to understand

• setup planning in machining, and
• operation sequencing.

15.2 SETUP PLANNING FOR MACHINING

The setup process has been estimated to consume up to 60% of the production time on a CNC turning center, and greater than 60% for a CNC machining center. Thus, the reduction of the setup time and cost of a setup plan is a crucial task to achieve efficient production. Setup planning can be defined as a connecting link to integrate operations planning with fixture planning as both activities can be considered concurrently.

Many automated manufacturing systems operate in an environment that requires the production of a large variety of jobs in small batches, usually below 10. For these systems, the under-utilization of machines is predominant because of the need to stop the machine in order to set it up (tools and/or fixture) every time the next job type has to be produced. Consequently, setup time accounts for a substantial fraction of the total available machine time. Hence, minimizing the setup time has become a key objective in many automated manufacturing systems by selecting the optimal setup plan.

One of the key issues in determining the optimal setup is the problem of finding the minimal number of setups for the part types to be machined. To compare different process planning alternatives and to select the best one, it is essential to plan the processing of the workpieces so exploiting the resources in the most efficient way. Therefore, the setup planning by which a part is produced is undoubtedly one of the most difficult problems in the process-planning phase. By limiting the number of setups, the processing cycle time is reduced, because the number of pallet changes to produce a given amount of parts is minimized. This in turn allows for an improvement in working
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quality, since there are fewer errors and imprecisions due to the repositioning of the workpiece. Moreover, the determination of setup planning helps to define the configuration of the pallet fixture and therefore represents a cornerstone for optimal process planning determination.

With the advancement in technology, the problem of setup planning is somewhat mitigated. For instance, faster changeovers reduce the lead time. Also, smaller lots reduce the dependence on forecasts, inventory level of the shop floor and cycle time. The alternatives to reduce the setup events would be

- Buying one large flexible computer controlled machines with fast changeover times, for example, single stage multi-functional machining systems (where all the operations of a part are performed on the same machine). The main advantage of this system is its ability to combine many operations and processes, previously done on different machines in several stages, into a single stage. This saves transportation time and setup time.
- Installing several small dedicated machines capable of producing only one product and complete avoidance of changeover.
- Modifying the existing machine tools to create flexibility and fast changeover is yet another option.

15.2.1 Setup Time

Setup time or changeover time is the non-productive time required by a machine or a machining system because of switching from one product type to another.

The components of setup time are generally fixturing time, tool changing time, and time required for the preparation of the workplace. Minimizing the setup times has a profound effect on the manufacturing system performance as it leads to the increase in the flexibility, reduction in the work-in-process inventory, and reduces the economic batch size.

The setup time and thus the setup cost are incurred whenever a new batch is started on the machine. Therefore, in general large batch sizes reduce the number of events of tool changeovers and hence setup time and which reduces setup cost. However, large batch sizes on the other hand result in high inventory levels. The optimal tradeoff between these two objectives results in the economic batch size (EBS) that is the batch size for which the total cost, which is the sum of setup and inventory costs, is a minimum. The economic batch size \( Q \) is given by

\[
Q = \sqrt{\frac{2ScR}{I}}
\]  

where \( Sc = \) setup cost per batch,
\( R = \) demand rate for the item, and
\( I = \) inventory carrying cost per item per unit time.

From above equation it is clear that if setup time is reduced then EBS also reduces leading to smaller lot size.

Eq. (15.1) can be easily derived by noting that the total cost \( Tc \) is given by

\[
Tc = \frac{RS}{Q} + \frac{IQ}{2}
\]  

If the setup costs are zero, then the batch size becomes unity and hence cost effective.

The alternatives that may potentially reduce setup times may be :

(a) Separate the internal setup from the external setup;
(b) Convert as much as possible of the internal setup to the external setup; and
(c) Eliminate the adjustment process;
(d) Abolish the setup step itself.
15.2.2 Types of Setup Operations

Setup operations can be classified into two basic categories:

**Internal Setup Operations**

Internal setup operations activities that are carried out while the machine is non-operational, e.g., job loading if only one palette position is available and Tool Magazine Replenishment (TMR).

**External Setup Operations**

External setup operations activities that are carried out while the machine is operational, e.g., clamping parts onto a fixture, mounting a fixture onto a pallet, etc.

On the basis of above classification it is clear that effective setup reduction can be achieved only if internal setup operations are reduced or by any means the more and more internal setup operations are transformed into external setup operations.

15.2.3 The Various Problems in Setups

There are various problems which are addressed in literature pertaining to the setup planning. In this regard, problems such as tool allocation problem, tool magazine replenishment (TMR) problem and fixturing problem in production systems are reviewed in this section.

**The Tool Allocation Problem**

Machines have to stop each time the active tool needs to be switched with another tool from the tool magazine. Tool allocation problem is the problem that deals with the optimum arrangement of tools in the tool magazine in order to reduce the magazine’s indexing and tool search time. Due to technological advances and the use of fast tool delivery systems, a considerable reduction in tool switching time is now possible. Today, tool switching operations can be performed almost entirely without interfering with the machine’s operation (externally). As a result, tool magazine arrangement has become less of an issue. In contrast, tool allocation, in recent studies, refers to the issue of how to distribute the different tools among the different machines on the shop floor in order to improve the system’s efficiency and flexibility (machine redundancy and alternate routing), subject to tool availability or some other tooling cost constraint.

**The Tool Magazine Replenishment (TMR) Problem**

Due to advancement in technology, now machining centers are available that are equipped with large capacity tool magazines (120 or more tools slots), yet, a small-batch large-variety production setting may require an even greater number of tools to produce a given set of jobs. Therefore, machines need to stop each time a tool magazine replenishment, which is considered an internal setup, is required. A TMR is performed each time the tools needed to machine the next job are not all present in the tool magazine. Sequencing jobs that need a similar set of tools together, can potentially reduce the number of TMRs required, thereby reducing setup time and machine idle time. The time required for a TMR operation comprises two components:

(a) a fixed component that is related to the time it takes to stop the machine and prepare the tool magazine, and

(b) a variable component that is related to the number of tools that need to be replaced during the TMR. Also, optimal tool replenishment times are determined based on expected tool-life in order to prevent tool failure.

**Fixturing Problem in Production Systems**
Some of the studies that addressed fixture concentrated on the fixturing process itself. These studies focused on finding solutions for faster fixturing and clamping in order to reduce setup time. The system can be operated quickly and offers accuracy for refixturing a part in an exact repeatable location.

Indexers allow the machining centers to machine several faces of a work-piece without the need to re-fixturing the work-piece several times. This permits a considerable reduction in setup time.

The correct selection setup plan reduces the number of fixtures needed due to a better accommodation of jobs onto a single fixture. Minimizing the number of fixtures leads to a reduction in the number of setups and thus to a reduction in cost.

15.2.4 Two Viewpoints of Setup Planning

In general, the Computer Aided Process Planning (CAPP) systems perform functions such as selecting the least cost operation for each feature on a workpiece, determining the feeds, speeds, and processes for generating the individual feature, and sequencing the operations for generating these features.

Generally, setup planning has been associated with determining the groups of features and/or operations that can be machined together on a particular machine and/or fixture configuration, and the sequencing of these resultant groups. However, a distinction exists in the interpretation of setup planning by the operations planners and the fixture designers, as illustrated in Figure 15.2. Therefore, there are two viewpoints of setup planning. In fixture planning, setup planning is concerned with the grouping of features and the determination of the orientations of the workpiece for these groups; while in process planning, setup planning is concerned with the clustering of features into groups and the determination of a machining sequence of these clusters of features/operations.

The Machining Viewpoint

These systems, which essentially implement setup planning from the machining viewpoint, have factors and criteria used are the cutting tools for machining the features, tool cutting paths, dimensional and tolerance requirements, machining directions, etc. A setup is formed by grouping features that have the same approach direction, and considering the precedence relationships between the features due to constraints such as spatial and geometrical relationships.

The primary objective of these systems is to identify the operations and sequence them, together with the selection of tools and machining parameters. This assumption gives these systems an edge over other systems that perform computationally intensive fixture design and planning activities during setup planning. However, fixturing a setup is a time-intensive activity. Thus, this assumption limits the feasibility of the setup plans and the applicability of these systems, as the work-holding requirements and the availability of fixturing systems are not considered.

The Fixturing Viewpoint

The four main objectives in fixture design are to:

(a) position a workpiece, in relation to tools, in a desirable orientation,
hold the workpiece in the desired position and orientation against tool force,
restrict the deflection of the workpiece due to tools and holding forces on the workpiece, and
achieve the above three objectives without causing damage to existing machined surfaces.

From the fixturing viewpoint, setup planning groups features to be made, and determines the orientations to make these features in certain fixturing configurations. It includes the configuration, as well as the location of the fixturing components. A setup is thus a fixturing configuration for processing features using tools and fixturing elements. Several fixture planning systems have incorporated setup planning.

The fixturing viewpoint setup planning approach uses fixturing criteria and work-holding requirements of the workpieces for generating setups.

### 15.2.5 Factors and Constraints in Setup Planning

The objectives of setup planning are to

- identify groups of features that can be machined in a single setup,
- determine a desirable workpiece orientation for each setup,
- determine an appropriate fixturing method for each setup, and
- determine setup order for machining.

A set of features to be generated on a workpiece has explicit and implicit relations with each other and the features already present. These relations are formed due to factors and constraints such as

- the machining directions of features,
- the geometrical relationships of features,
- the datum and referencing requirements of features,
- processes, tools, and machines for workpiece manufacturing,
- intermediate states of the workpiece,
- the fixturing requirements of the features, and
- good manufacturing practices.

The constraints can be studied under the broad classifications as mentioned below.

**Geometrical Relationships**

The geometrical shape of the features present on the workpieces would stipulate some relationships with the features to be machined. Examples of geometrical relationships are the opening-to-face and the starting-from-face relationships between the features and the faces on the workpieces. These geometrical relationships between neighboring features are inherent in the design of a workpiece and the physical attributes of the machined surfaces. They cannot be violated since they physically limit the machining of surfaces or shape elements. Geometrical interactions of features are the main planning criterion for setup planning in systems.

**Design Specifications**

Dimensions and tolerances of a part are specified by a designer with regard to the functions of the part. The process planners and fixture designers have to follow the dimensional and geometrical tolerances of a part closely during the planning process. Machining difficulty depends on the specified tolerances, and closely
toleranced features have to be machined in one set-up. The systems reported by considering the tolerance specifications of a part is the main criterion in set-up planning.

**Fixturing Requirements**

A set-up plan must be designed in such a way that a part can be accurately held in a work-holding device. The plan should consider the stability of a part in the fixtures and ensure that there should be minimum deformation of the part under machining and clamping forces.

**Manufacturing Requirements of the Workpiece**

The analysis of the manufacturing requirements for processing the workpiece is the first steps in determining the setups. The manufacturing requirements are described in a data format. For instance, in STEP-NC the features of workpiece can be defined as manufacturing features and each needs a machining operation to be processed. The relationship between the machining features and machining operations is established. The information about the machining direction (Figure 15.3), that is the direction of the axis of the tool/cutter that produces the manufacturing feature is determined. Taking into account the machining direction, it is possible to estimate whether a given machining feature can be produced by a three, four or five axis machining centre when the workpiece is clamped in a definite position on the fixture. The various tolerances should be determined. The precedence constraints among machining operations should be determined.

![Figure 15.3 : Tool Machining Direction](image)

Prior executions of operations such as squaring up to prepare the workpiece for subsequent machining may require additional setups. In practice, rules-of-thumb and good manufacturing practices have been established to ensure an accurate, efficient, and economic production of workpieces. Other manufacturing rules are, for example, a face should not be followed by a hole with direction of the central axis is not parallel to the normal of the face, and a hole should not be followed by a face with normal vector is parallel to the direction of the central axis of the hole.

**Tool Accessibility**

To determine the potential setup it is necessary to make sure that related machining directions are within the reach of the tool mounted on the spindle by positioning the workpiece on the fixture correctly and exploiting the degree of freedom of the machine. The accessibility analysis used to determine the potential setups for the
workpiece entails as a first step of the generation of alternative orientations of the
workpiece on the fixture. Orientations of the workpiece on the fixture are
determined with regard to the degrees of freedom of the machine and aiming to
maximize the number of machining directions within the reach of the tool without
having to reposition the workpiece.

Precedence Constraints

While finding the most optimal setup from the pool of alternative setups, the
precedence of the operations to be performed on a workpiece must be taken into
account. The precedence among the operations can be represented as edges of a
directed graph, usually indicated by the name of Process Graph. The sequence of
the setups found is one of the possible alternatives that satisfy precedence
constraints. Some times some added criteria are considered for putting setups in
order. For example, one of these criteria consists in placing, if possible, at the end
of the setup sequence, the ones which contain features requiring higher precision,
so that they are not damaged by operations carried out in subsequent setups.

15.2.6 Setup Planning and Product Design

Design evaluation of the part has to be performed concurrently with manufacturing
planning functions to achieve full integration between Computer Aided Design (CAD)
and Computer Aided Manufacturing (CAM). However, in most of the present systems,
parts are seldom evaluated during the design stage, but more towards prototyping and
manufacturing. Setup planning links up the various activities from design to production,
see Figure 15.4.

Error!

Figure 15.4 : Setup Planning – The Link between Design and Production

SAQ 1

(a) What is process planning?
(b) Explain the significance of setup planning in process planning.
(c) What is setup time and economic batch size (EBS)?
(d) What are the various types of setup operations?
(e) What are the various objectives and constraints in setup planning?

15.3 OPERATIONS SEQUENCING

Process planning involves the preparation of a plan that translates a set of design
requirements and specifications into technologically feasible instructions, which
describes the transformation of one or more components into final product. Computer
Aided Process Planning (CAPP) has been acknowledged as one of the most important tasks in the effort to link design (CAD – Computer Aided Design) and manufacturing (CAM – Computer Aided Manufacturing) in a CIM (Computer Integrated Manufacturing) environment. Due to the availability and use of large number of machines, machine tools, cutting tools, etc. within a shop floor, there is an intense requirement of an intelligent database system to assist in planning activities. The fact mentioned above is the main cause for the development of CAPP that assists process planners in technically analyzing processes and taking decisions. The major activities of process planning include: selection of machining operations; sequencing of machining operations; selection of cutting tools; determining setup requirements; calculation of cutting parameters; tool path planning and generation of NC part programs; and design of jigs and fixtures.

Sequencing of machine operations is considered as one of the most intricate and crucial tasks, as it takes into account the complexities involved in precedence relations, as well as the combinatorial nature of resulting solution space. The operation sequencing problem aims to determine the order to perform a set of selected operations that satisfies the precedence constraints along with the satisfaction of the optimization goals.

Pertaining to the intricacies involved in the formulation of an optimal process planning system, operation sequencing has been recognized as most complex and crucial task to be accomplished. The operation sequencing problem determines the preferred order to perform a set of selected operations that satisfies the precedence constraints along with the satisfaction of the optimization goals. In general, the problem is characterized by its combinatorial nature and complex precedence relations that makes it computationally complex.

The literature review of the past works in the field of operation sequencing unveils that several attempts have been made to solve operation sequencing problem in CAPP environment with varying approaches. Many researchers have focused on process planning optimizations, considering operation selection and sequencing in tandem. In the literature, operation sequencing problem has been addressed to achieve various objectives as per the need and requirement of the problem environment for instance, minimization of tool changeovers, to minimize the sum of machining cost and machining speed change costs. Three methods used so far, for implementing operation sequencing, are:

- use of production rules,
- precedence graphs with procedural algorithms for evaluation, and
- preferred sequences which are refined using production rules.

The operation sequencing problem has also been solved using various petrinet models that simplifies the problem structure and solution strategy for the problem.

The operation sequencing problem requires the prior knowledge of operations needed to manufacture a part; the precedence relations involved; the machines, tools and setups required.

**Precedence Constraints**

Precedence relations are the main restrictions in finding the optimal sequence. These represent a sequence of execution among various machining operations. The precedence constraints are imposed on various operations owing to the geometrical complexities and various technological requirements. These precedence constraints can be represented as tree structured graph in which a path from root to leaf nod represents a precedence relation. There may be various independent sub trees in a tree structured graph of operation sequences. This case is encountered when there are two or more operations having no preceding operations. To illustrate this, the machining features of a part are considered and their precedence constraints are also shown with the help of Figures 15.5, 15.6 and 15.7. To simplify the solution strategy and eliminate infeasible sequences the precedence directed graph is represented in Figure 15.7.
Example 15.1

In this section, an example of job sequencing is considered to show that how with different sequences the setup cost is reduced and how with respect to different objectives different sequence is produced.

To show this, consider an example of a machining system where all the operations of a job are performed on a single machine. In this regard, the effect of tool magazine capacity and part type variety on setup events, are considered. The model assumes each job type requires a dedicated fixture and only one fixture of each type exists in the system. As a result, a re-fixturing operation is needed each time for identical jobs (same tools and fixture requirements) and is sequenced one after the other. Every time if identical jobs are sequenced in succession, a re-fixturing operation (RF) is required during which the current job is released...
from the fixture and next job which requires the same fixture is re-fixtured. Therefore, to avoid this, identical jobs should not be sequenced consecutively. However, this approach may lead to increase in the number of instances in which tool magazine needs to be replenished as in this approach more number of tool variety is needed in the tool slot.

Now let us take a simple job sequencing example. Three job types A – C are to be produced using the above mentioned machining system. The maximum number of tools that can be placed in the tool magazine is 50. Also, assume that cost of re-fixturing and a TMR is $10 and $20 respectively. The job production data is presented in Table 15.1.

<table>
<thead>
<tr>
<th>Job</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity</td>
<td>3</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Tool Needed</td>
<td>20</td>
<td>21</td>
<td>18</td>
</tr>
</tbody>
</table>

The maximum capacity of the tool magazine is 35 and in this example the total number of tools required to produce the jobs is 59 (> 35). Therefore, at least one tool replenishment is necessary, irrespective of what job sequence is chosen. Now, two sequences are presented and the setup cost is calculated. One sequence is as shown below.

The setup cost (TMR+RF) in this case would be $30.

The setup cost (TMR+RF) in this case would be $20.

Therefore, with change in sequencing of the jobs the setup cost changes. The sequence for which the setup cost is least is the optimal sequence, which can be found out by formulating certain methodology.

Following are certain corollaries which can be drawn from the example.

(a) Increasing the tool magazine capacity will cause a decrease in the number of TMRs.

(b) Increasing the tool magazine capacity may lead to lower RF costs.

(c) As the variety of part types increases, it is more likely that additional TMRs would be needed.

(d) An increase in the part type variety is more likely to cause a reduction in the number of Re-fixturing.

SAQ 2

Explain the terms operations sequencing and precedence constraints, account for the following:

(a) Increasing the tool magazine capacity will cause a decrease in the number of TMRs.

(b) Increasing the tool magazine capacity may lead to lower RF costs.

(c) As the variety of part types increases, it is more likely that additional TMRs may occur.
15.4 SUMMARY

In this chapter, setup planning for machining and operations sequencing is elaborately discussed. Planning can be viewed as the activity of devising means to achieve desired goals under given constraints and limited resources. Setup planning is a part of the generic process planning framework. It represents a cornerstone for optimal process planning determination. Due to the technological advancement, one can get several alternatives to reduce the setup events. Setup time or changeover time is the non-productive time required by a machining system because of switching from one product type to another. The optimal tradeoff results in the economic batch size (EBS) that is the batch size for which the total cost, which is the sum of setup and inventory costs, is minimum.

Setup operations can be classified into two basic categories: Internal setup operations and External setup operations. There are various problems which are addressed in literature pertaining to the setup planning. In this regard, problems such as tool allocation problem, tool magazine replenishment (TMR) problem and fixturing problem in production systems are reviewed in this chapter. Because of the distinction in the interpretation of setup planning by the operations planners and the fixture designers, therefore, there are two viewpoints of setup planning: the machining viewpoint and fixture viewpoint.

The machining viewpoint setup planning approach uses the criteria such as cutting tools for machining the features, tool cutting paths, dimensional and tolerance requirements, machining directions, etc. whereas, the fixturing viewpoint setup planning approach uses fixturing criteria and work-holding requirements of the workpieces for generating setups.

The main objective of setup planning is to minimize setup costs while satisfying the constraints such as Geometrical Relationships, Design Specifications, Fixturing Requirements, Manufacturing requirements of the workpiece, Tool accessibility, and Precedence constraints. Setup planning links up the various activities from design to production.

Sequencing of machine operations is considered as one of the most intricate and crucial tasks, as it takes into account the complexities involved in precedence relations. Three methods used so far, for implementing operation sequencing, are: use of production rules, precedence graphs with procedural algorithms for evaluation and pruning, and preferred sequences which are refined using production rules. Precedence relations are the main restrictions in finding the optimal sequence. A simple example illustrates shows that how with different sequences different cost is incurred. Various corollaries are drawn form the considered example.

15.5 KEY WORDS

Setup Time : Setup time or changeover time is the non-productive time required by a machine or a machining system because of switching from one product type to another.