Introduction to Materials Management is an introductory text written for students in community colleges and universities. It is used in technical programs, such as industrial engineering and manufacturing engineering; in business, operations and supply chain management programs; and by those already in industry, whether or not they are working in materials management.

This text has been widely adopted by colleges and universities not only in North America but also in many other parts of the world. The APICS organization recommends this text as a key reference for certification preparation for various CPIM examinations. In addition, the text is used by production and inventory control societies around the world, including South Africa, Australia, New Zealand, Germany, France, and Brazil, and by consultants who present in-house courses to their customers.

Introduction to Materials Management covers all the basics of supply chain management, manufacturing planning and control systems, purchasing, physical distribution, lean and quality management. The material, examples, questions, and problems lead the student logically through the text. The writing style is simple and user-friendly—both instructors and students who have used the book attest to this.

NEW TO THIS EDITION

- All chapters have been updated to reflect new techniques and technology
- Nine additional case studies have been added
- Several special topic boxes have been added relating chapter topics to nonmanufacturing settings such as service industries
- End-of-chapter problems have been revised, and some new ones added throughout the text
- Expansion of purpose and impact of strategic planning, including environmental and sustainability issues. Allows students to understand the importance of the field at a higher level, including impacts and benefits to society as a whole
- Additional information included on demand management
- Additional information included on lean production concepts and Theory of Constraints. Theory of Constraint provides an interesting and potentially effective alternative method to think about several of the concepts in the book, and can help students compare and contrast Theory of Constraint with non-Theory of Constraint approaches. (See Ch. 6)
- A brief introduction to Project Management has been added to Ch. 6 to provide students initial exposure to a skill today’s employers are looking for

In addition, we have retained several features from previous editions.

- Margin icons to note key concepts
- Key terms listed at the end of each chapter
- Example problems within the chapters
- Chapter summaries
- Questions and problems at the end of each chapter
- Full supplements package including Instructor’s Manual, Computerized Test Bank, PowerPoint, and Image Bank available for download
APPROACH AND ORGANIZATION

Materials management means different things to different people. In this textbook, materials management includes all activities in the flow of materials from the supplier to the consumer. Such activities include physical supply, operations planning and control, and physical distribution. Other terms sometimes used in this area are business logistics and supply chain management. Often, the emphasis in business logistics is on transportation and distribution systems with little concern for what occurs in the factory. Whereas some chapters in this text are devoted to transportation and distribution, emphasis is placed on operations planning and control.

Distribution and operations are managed by planning and controlling the flow of materials through them and by using the system’s resources to achieve a desired customer service level. These activities are the responsibility of materials management and affect every department in a manufacturing business. If the materials management system is not well designed and managed, the distribution and manufacturing system will be less effective and more costly. Anyone working in manufacturing or distribution should have a good basic understanding of the factors influencing materials flow. This text aims to provide that understanding and also includes chapters on quality management and lean production.

APICS defines the body of knowledge, concepts, and vocabulary used in production and inventory control. Establishing standard knowledge, concepts, and vocabulary is essential both for developing an understanding of production and inventory control and for making clear communication possible. Where applicable, the definitions and concepts in this text subscribe to APICS vocabulary and concepts.

The first six chapters of Introduction to Materials Management cover the basics of production planning and control. Chapter 7 discusses important factors in purchasing and supply chain; Chapter 8 discusses forecasting. Chapters 9, 10, and 11 look at the fundamentals of inventory management. Chapter 12 discusses physical inventory and warehouse management, and Chapter 13 examines the elements of distribution systems, including transportation, packaging, and material handling. Chapter 14 covers factors influencing product and process design. Chapter 15 looks at the philosophy and environment of lean production and explains how operations planning and control systems relate to lean production. Chapter 16 examines the elements of total quality management and six sigma quality approaches.

ONLINE INSTRUCTOR RESOURCES

To access supplementary materials online, instructors need to request an instructor access code. Go to www.pearsonhighered.com, click the Instructor Resource Center link, and then click Register Today for an instructor access code. Within 48 hours after registering you will receive a confirming e-mail including an instructor access code. Once you have received your code, go to the site and log on for full instructions on downloading the materials you wish to use.

List of Supplements

- Instructor’s Manual
- Computerized Test Bank
- PowerPoint
- Image Bank

ACKNOWLEDGMENTS

The period of time since the seventh edition of this book was published included the very unfortunate passing of two of the authors of the seventh edition—Tony Arnold and Lloyd Clive. Tony Arnold was responsible for the original vision and creation of the book many
years ago, and Lloyd Clive brought significant additional insights and knowledge in the creation of the last two revisions. Both of these gentlemen were well known and highly respected both by students and colleagues, and will be greatly missed.

The addition of Ann Gatewood as a new coauthor brings her extensive experience, knowledge, and insight to this eighth edition. However, this eighth edition continues to reflect the original vision of providing a clear and understandable introductory look at the field of Materials Management.

Help and encouragement have come from a number of valued sources, among them friends, colleagues, and students. We thank the many readers of the book who have provided comments and suggestions. We especially wish to thank members of the various APICS CPIM Committees who have provided specific guidance for the revision. Specifically, we would like to thank Andrea Prud’homme (The Ohio State University), Jim Caruso (Covidien), Frank Montabon (Iowa State University), and Mark Hardison (SIGA Technologies) for their significant insights and suggestions. In addition, we received several worthwhile suggestions from John Kanet (The University of Dayton) and Keith Launchbury (Keith Launchbury and Associates). Other academic reviewers include Vahid H Khiabani (Minnesota State University—Moorhead), Michael Gallaway (North Lake College), John Kros (East Carolina University), and Sunderesh Heragu (Oklahoma State University—Stillwater). Steve Chapman would also like to thank his wife Jeannine for her continued support and encouragement during the revision process.

Overall, this book is dedicated to those who have taught us the most—our colleagues and our students.

Stephen N. Chapman, Ph.D., CFPIM, Associate Professor Emeritus
Department of Business Management, Poole College of Management
North Carolina State University
Raleigh, North Carolina

Ann K. Gatewood, CFPIM, CIRM, CSCP
President, Gatewood Associates, LLC
Mooresville, North Carolina
CHAPTER SIX

PRODUCTION ACTIVITY CONTROL

INTRODUCTION

After all the planning and scheduling, it is time for the plans to be put into action. Production activity control (PAC) is responsible for executing the master production schedule (MPS) and the material requirements plan (MRP). At the same time, it must make good use of labor and machines, minimize work-in-process inventory, and maintain customer service.

The material requirements plan authorizes PAC:

■ To release work orders to the shop for manufacturing.
■ To manage work orders and make sure they are completed on time.
■ To be responsible for the immediate detailed planning of the flow of orders through manufacturing, carrying out the plan, and controlling the work as it progresses to completion.
■ To manage day-to-day activity and provide the necessary support.

Figure 6.1 shows the relationship between the planning system and PAC.

The activities of the PAC system can be classified into planning, implementation, and control functions.

![Figure 6.1](image-url) Priority planning and production activity control.
Planning

The flow of work through each of the work centers must be planned to meet delivery dates, which means production activity control must do the following:

■ Ensure that the required materials, tooling, personnel, and information are available to manufacture the components when needed.
■ Schedule start and completion dates for each shop order at each work center so the scheduled completion date of the order can be met. This will involve the planner in developing a load profile for the work centers.

Implementation

Once the plans are made, production activity control must put them into action by advising the shop floor what must be done. Instructions can be given by issuing a shop order with the relevant information, or by simply producing a schedule that shows product information, quantities, and dates. Production activity control will:

■ Gather the information needed by the shop floor to make the product.
■ Release orders to the shop floor as authorized by the material requirements plan. This is called dispatching.

Control

Once plans are made and shop orders released, the process must be monitored to learn what is actually happening. The results are compared to the plan to decide whether corrective action is necessary. Production activity control will do the following:

■ Rank the shop orders in desired priority sequence by work center and establish a dispatch list based on this information.
■ Track the actual performance of work orders and compare it to planned schedules. Where necessary, PAC must take corrective action by replanning, rescheduling, or adjusting capacity to meet final delivery requirements.
■ Monitor and control work-in-process, lead times, and work center queues.
■ Report work center efficiency, operation times, order quantities, and scrap.

The functions of planning, implementing, and controlling are shown in Figure 6.2.

![Figure 6.2: Schematic of a production control system.](image-url)
Manufacturing Systems

The particular type of production control system used varies from company to company, but all should perform the functions just mentioned. However, the relative importance of these functions will depend on the type of manufacturing process. Manufacturing processes can be conveniently organized into three categories:

1. Flow manufacturing.
2. Intermittent manufacturing.
3. Project manufacturing.

Flow manufacturing  Flow manufacturing is concerned with the production of high volume standard products. If the units are discrete (e.g., cars and appliances), the process is usually called repetitive manufacturing, and if the goods are made in a continuous flow (e.g., gasoline), the process is called continuous manufacturing. There are four major characteristics of flow manufacturing:

1. Routings are fixed, and work centers are arranged according to the routing. The time taken to perform work at one work center is almost the same as at any other work center in the line, enabling a constant flow.
2. Work centers are dedicated to producing a limited range of similar products. Machinery and tooling are especially designed to make the specific products.
3. Material flows from one workstation to another using some form of mechanical transfer. There is little buildup in work-in-process inventory, and throughput times are low.
4. Capacity is fixed by the line.

Production activity control concentrates on planning the flow of work and making sure that the right material is fed to the line as stated in the planned schedule. Since work flows from one workstation to another automatically, implementation and control are relatively simple.

Intermittent manufacturing  Intermittent manufacturing is characterized by many variations in product design, process requirements, and order quantities. This kind of manufacturing is characterized by the following:

1. Flow of work through the shop is varied and depends on the design of a particular product. As orders are processed, they may take more time at one workstation than at another. Thus, the work flow is not balanced.
2. Machinery and workers must be flexible enough to do the variety of work involved in intermittent manufacturing. Machinery and work centers are usually grouped according to the function they perform, for example, all lathes in one department.
3. Throughput times are generally long. Scheduling work to arrive just when needed is difficult, the time taken by an order at each work center varies, and work queues before work centers, causing long delays in processing. Work-in-process inventory is often large.
4. The capacity required depends on the particular mix of products being built and is sometimes difficult to predict.

Production activity control in intermittent manufacturing is complex. Because of the number of products made, the variety of routings, and scheduling problems, PAC is a major activity in this type of manufacturing. Planning and control are typically exercised using shop orders or detailed schedules for each batch being produced. Most of the discussion of PAC in this text assumes this kind of environment.
Project manufacturing  Project manufacturing usually involves the creation of one unit or a small number of units. Complex shipbuilding is an example. Because the design of a product is often carried out or modified as the project develops, there is close coordination between manufacturing, marketing, purchasing, and engineering.

Project manufacturing or management uses many of the same techniques as production activity control, but also has some unique characteristics. Activities typically included in project management are:

- Initiating the project, which includes identifying the project requirements
- Planning the project, including the scope, schedule and tasks, budget, resources, and risks
- Executing the project by carrying out the tasks
- Monitoring and controlling the project tasks and resources, and communicating the status of the project to stakeholders
- Closing the project, which includes documenting the results, as well as any variances in time and costs

DATA REQUIREMENTS

To plan the processing of materials through manufacturing, PAC must have the following information:

- What and how much to produce.
- When parts are needed so the completion date can be met.
- What operations are required to make the product and how long the operations will take.
- What the available capacities of the various work centers are.

Production activity control must have a data or information system from which to work. Usually the data needed to answer these questions is organized into databases. The information contained in the databases are of two types: planning and control.

Planning Information

Four types of planning information are needed: item master, product structure, routing, and work center master.

Item master  There is one record in the item master database for each part number, containing all of the pertinent data related to the part. For PAC, this includes the following:

- Part number. A unique number assigned to a component.
- Part description.
- Manufacturing lead time. The normal time needed to make this part.
- Lot-size quantity. The quantity normally ordered at one time.

Product structure (bill of material)  The product structure (bill of material) contains a list of the single-level components and quantities needed to assemble a parent. It forms a basis for a pick list to be used by storeroom personnel to collect the parts required to make the assembly. There are a variety of ways of displaying a bill of material, including a single level bill of material, an indented bill of material, transient bill of material, matrix bill of material, and costed bill of material. In some industries, in particular the process industry, the bill of material is called a formula, recipe, or ingredients list.

Routing  The routing contains a record for each part manufactured. The routing consists of a series of operations required to make the item. For each product, a step-by-step set of instructions is provided describing how the product is made. It gives details of the following:

- The operations required to make the product and the sequence in which those operations are performed.
- A brief description of each operation.
- Equipment, tools, and accessories needed for each operation.
- Setup times, the standard time required for setting up the equipment for each operation.
- Run times, the standard time required to process one unit through each operation.
- Lead times for each operation.

**Work center master**  
The **work center master** collects all of the relevant data on a work center. For each work center, it gives details on the following:

- Work center number.
- Capacity.
- Number of shifts worked per week.
- Number of machine hours per shift.
- Number of labor hours per shift.
- Efficiency.
- Utilization.
- Queue time, the average time that a job waits at the work center before work is begun.
- Alternate work centers, work centers that may be used as alternatives.

**Control Information**
Control in intermittent manufacturing is exercised through shop orders and the data contained on these orders.

**Shop order master**  
Each active manufacturing order has a record in the **shop order master**. The purpose is to provide summarized data on each shop order, such as the following information:

- Shop order number, a unique number identifying the shop order.
- Order quantity.
- Quantity completed.
- Quantity scrapped.
- Quantity of material issued to the order.
- Due date, the date the order is expected to be finished.
- Priority, a value used to rank the order in relation to others.
- Balance due, the quantity not yet completed.
- Cost information.

The detailed records for each shop order contain records for each operation needed to make the item. Each record contains the following information:

- Operation number.
- Setup hours, planned and actual.
- Run hours, planned and actual.
- Quantity reported complete at that operation.
- Quantity reported scrapped at that operation.
- Due date or lead time remaining.

**ORDER PREPARATION**

Once authorization to process an order has been received, production activity control is responsible for planning and preparing its release to the shop floor. The order should be reviewed to be sure that the necessary tooling, material, and capacity are available. If they are not, the order cannot be completed and should not be released.
If MRP software is used, it will have checked the availability of material and pre-allocated it to a shop order so no further checking is necessary. If MRP software is not used, production activity control must manually check material availability of all the components necessary to produce the goods.

If a capacity requirements planning system has been used, necessary capacity should be available. However, at this stage, there may be some differences between planned capacity and what is actually available, due to product that is behind schedule, daily changes in workforce, and so forth. When capacity requirements planning is not used, it is necessary to determine if capacity is available before releasing orders.

Checking capacity availability is a two-step process. First, the order must be scheduled to see when the capacity is needed, and second, the load on work centers must be checked in that period.

SCHEDULING

The objective of scheduling is to meet delivery dates and to make the best use of manufacturing resources. It involves establishing start and finish dates for each operation required to complete an item. To develop a reliable schedule, the planner must have information on the routing, required and available capacity, competing jobs, and manufacturing lead times at each work center involved.

Manufacturing Lead Time

Manufacturing lead time is the time normally required to produce an item in a typical lot quantity. Typically, it consists of five elements:

1. **Queue time**, amount of time the job is waiting at a work center before operation begins.
2. **Setup time**, time required to prepare the work center for operation.
3. **Run time**, time needed to run the order through the operation.
4. **Wait time**, amount of time the job is at the work center before being moved to the next work center.
5. **Move time**, transit time between work centers.

The total manufacturing lead time will be the sum of order preparation and release plus the manufacturing lead time for each operation. Figure 6.3 shows the elements making up manufacturing lead time. Setup time and run time are straightforward, and determining them is the responsibility of the industrial engineering department. Queue, wait, and move times are under the control of manufacturing and PAC.

The largest of the five elements is queue time. Typically, in an intermittent manufacturing operation, it may account for 85–95% of the total lead time. Production activity control is responsible for managing the queue by regulating the flow of work into and out of work centers. If the number of orders waiting to be worked on (load) is reduced, so
is the queue time, the lead time, and work-in-process. Increasing capacity also reduces queue. Production activity control must manage both the input of orders to the production process and the available capacity to control queue and work-in-process.

A term that is closely related to manufacturing lead time is cycle time. *APICS Dictionary*, 14th edition defines *cycle time* as “the length of time from when material enters a production facility until it exits.” A synonym of cycle time is *throughput time*.

**Example Problem**

An order for 100 of a product is processed on work centers A and B. The setup time on A is 30 minutes, and run time is 10 minutes per piece. The setup time on B is 50 minutes, and the run time is 5 minutes per piece. Wait time between the two operations is 4 hours. The move time between A and B is 10 minutes. Wait time after operation B is 4 hours, and the move time into stores is 15 minutes. There is no queue at either workstation. Calculate the total manufacturing lead time for the order.

**Answer**

| Work center A operation time = \(30 + (100 \times 10)\) | 1030 minutes |
| Wait time | 240 minutes |
| Move time from A to B | 10 minutes |
| Work center B operation time = \(50 + (100 \times 5)\) | 550 minutes |
| Wait time | 240 minutes |
| Move time from B to stores | 15 minutes |
| Total manufacturing lead time | 2085 minutes |
| | = 34 hours, 45 minutes |

**Scheduling Techniques**

There are many techniques used to schedule shop orders through a plant, but all of them require an understanding of forward and backward scheduling as well as finite and infinite loading.

**Forward scheduling** assumes that material procurement and operation scheduling for a component start when the order is received, whatever the due date, and that operations are scheduled forward from this date. The first line in Figure 6.4 illustrates this method. The result is completion before the due date, which usually results in a buildup of inventory. This method is used to decide the earliest delivery date for a product.

Forward scheduling is used to calculate how long it will take to complete a task. The technique is used for purposes such as developing promise dates for customers or figuring out whether an order behind schedule can be caught up.

**FIGURE 6.4** Forward and backward scheduling: infinite loading.
Backward scheduling is illustrated by the second line in Figure 6.4. The last operation on the routing is scheduled first and is scheduled for completion at the due date. Previous operations are scheduled back from the last operation. This schedules items to be available as needed and uses the same logic as the MRP system. Work-in-process inventory is reduced, but because there is little slack time in the system, customer service may suffer.

Backward scheduling is used to determine when an order must be started. Backward scheduling is common in a make-to-stock environment because it reduces inventory.

Infinite loading is also illustrated in Figure 6.4. The assumption is made that the workstations in which operations 1, 2, and 3 are processed have capacity available when required. It does not consider the existence of other shop orders competing for capacity at these work centers. It assumes infinite capacity will be available. Figure 6.5 shows a load profile for infinite capacity. Notice the over- and underload.

Finite loading assumes there is a defined limit to available capacity at any workstation. If there is not enough capacity available at a workstation because of other shop orders, the order has to be scheduled in a different time period. Figure 6.6 illustrates the condition.

In the forward scheduling example shown in Figure 6.6, the first and second operations cannot be performed at their respective workstations when they should be because the required capacity is not available at the time required. These operations must be rescheduled to a later time period. Similarly, in the example of back scheduling, the second and first operations cannot be performed when they should be and must be rescheduled to an earlier time period. Figure 6.7 shows a load profile for finite loading. Notice the load is smoothed so there is no overload condition.

![Figure 6.5 Infinite load profile.](image1)

![Figure 6.6 Forward and backward scheduling. Finite loading.](image2)
Chapter 5 gives an example of backward scheduling as it relates to capacity requirements planning. The same process is used in PAC.

**Example Problem**

A company has an order for 50 brand X to be delivered on day 100. Draw a backward schedule based on the following:

a. Only one machine is assigned to each operation
b. The factory works one 8-hour shift 5 days a week
c. The parts move in one lot of 50.

<table>
<thead>
<tr>
<th>Part</th>
<th>Operation</th>
<th>Time (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>A</td>
<td>20</td>
<td>3</td>
</tr>
<tr>
<td>B</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>X</td>
<td>Assembly</td>
<td>5</td>
</tr>
</tbody>
</table>

**Answer**

In **operation overlapping**, the next operation is allowed to begin before the entire lot is completed on the previous operation. This reduces the total manufacturing lead times because the second operation starts before the first operation finishes all the parts in the order. Figure 6.8 shows schematically how it works and the potential reduction in lead time.

A concept used in operation overlapping is the difference between a process batch and a transfer batch. A **process batch** is the total lot size that has been released to production. A **transfer batch** is that quantity that moves from work center to work center. A process batch may consist of one or more transfer batches.

To perform operation overlapping, an order is divided into at least two lots. When the first lot is completed on operation A, it is transferred to operation B. As seen in Figure 6.8,
Chapter six

It is assumed that operation B cannot be set up until the first lot is received, but this is not always the case. While operation A continues with the second lot, operation B starts on the first lot. When operation A finishes the second lot, it is transferred to operation B. If the lots are sized properly, there will be no idle time at operation B. The manufacturing lead time is reduced by the overlap time and the elimination of queue time.

Operation overlapping is a method of expediting an order, but there are some costs involved. First, move costs are increased, especially if the overlapped operations are not close together. Second, it may increase the queue and lead times for other orders. Third, it does not increase capacity but potentially reduces it if the second operation is idle waiting for parts from the first operation.

The problem is deciding the size of the sublot. If the run time per piece on operation B is shorter than that on A, the first batch must be large enough to avoid idle time on operation B.

**Example Problem**

Refer to the data given in the example problem in the section on manufacturing lead time. It is decided to overlap operations A and B by splitting the lot of 100 into two lots of 70 and 30. Wait time between A and B and between B and stores is eliminated. The move times remain the same. Setup on operation B cannot start until the first batch arrives. Calculate the manufacturing lead time. How much time has been saved?

**Answer**

<table>
<thead>
<tr>
<th>Description</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation time for A for lot of 70 = 30 + (70 x 10)</td>
<td>730 min</td>
</tr>
<tr>
<td>Move time between A and B</td>
<td>10 min</td>
</tr>
<tr>
<td>Operation time for B for lot of 100 = 50 + (100 x 5)</td>
<td>550 min</td>
</tr>
<tr>
<td>Move time from B to stores</td>
<td>15 min</td>
</tr>
<tr>
<td>Total manufacturing lead time</td>
<td>1305 min</td>
</tr>
<tr>
<td>Time saved</td>
<td>21 h, 45 min</td>
</tr>
</tbody>
</table>

**Operation Splitting**

**Operation splitting** is a second method of reducing manufacturing lead time. The order is split into two or more lots or transfer batches and run on two or more machines simultaneously. If the lot is split in two, the run-time component of lead time is effectively cut in half, although an additional setup is incurred. Figure 6.9 shows a schematic of operation splitting.
Operation splitting is practical when:

- Setup time is low compared to run time.
- A suitable work center is idle.
- It is possible for an operator to run more than one machine at a time.
- Duplicate tooling or equipment is available.

The last condition often exists when a machine cycles through its operation automatically, leaving the operator time to set up another machine. The time needed to unload and load must be shorter than the run time per piece. For example, if the unload/load time was two minutes and the run time was three minutes, the operator would have time to unload and load the first machine while the second was running.

**Example Problem**

A component made on a particular work center has a setup time of 100 minutes and a run time of 3 minutes per piece. An order for 500 is to be processed on 2 machines simultaneously. The machines can be set up at the same time. Calculate the elapsed operation time.

**Answer**

Elapsed operation time = 100 + 3 × 250 = 850 minutes
= 14 hours and 10 minutes

**LOAD LEVELING**

Load profiles were discussed in Chapter 5 in the section on capacity requirements planning. The load profile for a work center is constructed by calculating the standard hours of operation for each order in each time period and adding them together by time period. Figure 6.10 shows an example of a load report.

This report tells PAC what the load is on the work center. There is a capacity shortage in week 20 of 30 hours. This means there would be no point in releasing all of the planned orders that week. Perhaps some could be released in week 18 or 19, and perhaps some overtime could be worked to help reduce the capacity crunch.

<table>
<thead>
<tr>
<th>Work Center: 10</th>
<th>Available Time: 120 hours/week</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description: Lathes</td>
<td>Efficiency: 115%</td>
</tr>
<tr>
<td>Number of Machines: 3</td>
<td>Utilization 80%</td>
</tr>
<tr>
<td>Rated Capacity:</td>
<td>110 standard hours/week</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Week</th>
<th>18</th>
<th>19</th>
<th>20</th>
<th>21</th>
<th>22</th>
<th>23</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Released Load Planned Load</td>
<td>105</td>
<td>100</td>
<td>80</td>
<td>60</td>
<td>30</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total Load</td>
<td>105</td>
<td>100</td>
<td>140</td>
<td>80</td>
<td>130</td>
<td>80</td>
<td>665</td>
</tr>
<tr>
<td>Rated Capacity</td>
<td>110</td>
<td>110</td>
<td>110</td>
<td>110</td>
<td>110</td>
<td>660</td>
<td></td>
</tr>
<tr>
<td>(Over)/Under Capacity</td>
<td>5</td>
<td>10</td>
<td>(30)</td>
<td>0</td>
<td>(20)</td>
<td>30</td>
<td>(5)</td>
</tr>
</tbody>
</table>

**FIGURE 6.10** Work center load report.
SCHEDULING IN A NONMANUFACTURING SETTING

All industries deal with the issues of scheduling resources, and balancing demand and supply as well as available versus required capacity, can be a challenge. For example, in the transportation industry, fleets of trucks must be scheduled and routed to minimize the total cost while ensuring timely deliveries, minimal downtime, and the nonproductive time equated with vehicles returning empty.

In the health care industry, organizations must balance the available capacity of doctors, surgeons, nurses, technicians, operating rooms, hospital rooms, and so forth, with a dynamic capacity required by patients, emergency vehicles, and major traumas. While some of these may be planned, such as the scheduling of office visits and annual physicals, much of the load comes from unplanned events such as illnesses and natural disasters, and is difficult to predict. Many hospitals have begun forecasting the load by looking at past history of patient days by month to determine trends or seasonality in order to better plan capacity. Time studies can also be done to determine standards for activities such as lab work and surgical prep to better determine available capacity for specific resources.

The planning of resources is also critical in service industries such as retail, food, airlines, and so forth. Scheduling of service personnel often occurs at a weekly, daily, and hourly level based on predictions of when customers are most likely to need the service. The component of capacity in this case is human resources, but can also include equipment, tools, and time. Some industries, such as airlines and transportation, have to also deal with limitations of working hours for personnel, for example, not working more than a certain number of hours in a day.

Being able to adapt the level of work force in a service industry by cross-training employees, utilizing part-time workers, or adopting automation tools such as self-help kiosks, a company can optimize resources and increase capacity. Nonurgent tasks, such as cleaning and maintenance, can be performed during periods of low or no demand to utilize personnel. One popular food chain developed its own method of scheduling that included breaks, projections of how much food to prepare, and when to cut back on the production of its baked goods and begin offering samples to customers.

SCHEDULING BOTTLENECKS

In intermittent manufacturing, it is almost impossible to balance the available capacities of the various workstations with the demand for their capacity. As a result, some workstations are overloaded and some underloaded. The overloaded workstations are called bottlenecks and, by definition, are those workstations where the required capacity is greater than the available capacity. *APICS Dictionary*, 14th edition defines a bottleneck as “a facility, function, department, or resource whose capacity is less than the demand placed upon it.”

**Throughput** Throughput is the total volume of production passing through a facility. Bottlenecks control the throughput of all products processed by them, as total throughput cannot be more than can be processed through the bottleneck. If work centers feeding bottlenecks produce more than the bottleneck can process, excess work-in-process inventory is built up. Therefore, work should be scheduled through the bottleneck at the rate it can process the work. Work centers fed by bottlenecks have their throughput controlled by the bottleneck, and their schedules should be determined by that of the bottleneck.

**Example Problem**

Suppose a manufacturer makes wagons composed of a box body, a handle assembly, and two wheel assemblies. Demand for the wagons is 500 a week. The wheel assembly capacity is 1200 sets a week, the handle assembly capacity is 450 a week, and final assembly can produce 550 wagons a week.

a. What is the capacity of the factory?
b. What limits the throughput of the factory?
c. How many wheel assemblies should be made each week?
d. What is the utilization of the wheel assembly operation?
e. What happens if the wheel assembly utilization is increased to 100%?
**Answer**

a. 450 units a week.
b. Throughput is limited by the capacity of the handle assembly operation.
c. 900 wheel assemblies should be made each week. This matches the capacity of the handle assembly operation.
d. Utilization of the wheel assembly operation is \( \frac{900}{1200} = \frac{3}{4} \).
e. Excess inventory builds up.

The service sector also deals with throughput, such as the length of time a patient stays at a hospital, the number of times a restaurant turns tables during the dinner hour, or the amount of time a customer waits in line at a bank. One of the difficulties for service organizations is the variability in the time a service may take. The time it takes to wait on a customer at a bank, for example, may vary considerably, depending on the number and type of transactions.

**Bottleneck principles** Since bottlenecks control the throughput of a facility, some important principles should be noted:

1. **Utilization of a nonbottleneck resource is not determined by its potential but by another constraint in the process.** In the previous example problem, the utilization of the wheel assembly operation was determined by the handle assembly operation.
2. **Using a nonbottleneck resource 100% of the time does not produce 100% utilization.** If the wheel assembly operation was utilized 100% of the time, it would produce 1200 sets of wheels a week, 300 sets more than needed. Because of the buildup of inventory, this operation would eventually have to stop.
3. **The capacity of the facility depends on the capacity of the bottleneck.** If the handle assembly operation breaks down, the throughput of the factory is reduced.
4. **Time saved at a nonbottleneck does not save capacity elsewhere.** If the industrial engineering department increased the capacity of the wheel assembly operation to 1500 units a week, the extra capacity could not be utilized, and nothing would be gained.
5. **Capacity and priority must be considered together.** Suppose the wagon manufacturer made wagons with two styles of handles. During setup, nothing is produced, which reduces the capacity of the system. Since handle assembly is the bottleneck, every setup in this operation reduces the throughput of the system. Ideally, the company would run one style of handle for six months, then switch over to the second style. However, customers wanting the second style of handle might not be willing to wait six months. A compromise is needed whereby runs are as long as possible but priority (demand) is satisfied.
6. **Loads can, and should, be split.** Suppose the handle assembly operation (the bottleneck) produces one style of handle for two weeks, then switches to the second style. The batch size is 900 handles. Rather than waiting until the 900 are produced before moving them to the final assembly area, the manufacturer can move a day’s production (90) at a time. The process batch size (900) and the transfer batch size (90) are different. Thus, delivery to the final assembly is matched to usage, and work-in-process inventory is reduced.
7. **Focus should be on balancing the flow through the shop.** The key is total throughput that ends up in saleable goods.

**Managing bottlenecks** Since bottlenecks are so important to the throughput of a system, scheduling and controlling them is extremely important. The following must be done:

1. **Establish a time buffer before each bottleneck.** A time buffer is an inventory (queue) before each bottleneck. Because it is of the utmost importance to keep the bottleneck working, it must never be starved for material by disrupting the flow from feeding workstations. The time buffer should be only as long as the time of any expected delay caused by feeding workstations. In this way, the time buffer ensures that the bottleneck will not be shut down for lack of work and this queue will be held at a predetermined minimum quantity.
2. Control the rate of material feeding the bottleneck. A bottleneck must be fed at a rate equal to its capacity so the time buffer remains constant. The first operation in the sequence of operations is called a gateway operation. This operation and any other operations prior to the bottleneck control the work feeding the bottleneck and must operate at a rate equal to the output of the bottleneck so the time buffer queue is maintained.

3. Do everything to provide the needed bottleneck capacity. Anything that increases the capacity of the bottleneck increases the capacity of the process. Better utilization, fewer setups, and improved methods to reduce setup and run time are some methods for increasing capacity.

4. Adjust loads. This is similar to item 3 but puts emphasis on reducing the load on a bottleneck by using such things as alternate work centers and subcontracting. These may be more costly than using the bottleneck, but utilization of nonbottlenecks and throughput of the total facility are increased, which will result in more efficient operations, and a potential for increased sales and profits.

5. Change the schedule. As discussed earlier, this should be done as a final resort, but may be necessary in order to provide accurate delivery promises.

Once the bottleneck is scheduled according to its available capacity and the market demand it must satisfy, the nonbottleneck resources can be scheduled. When a work order is completed at the bottleneck, it can be scheduled on subsequent operations.

Feeding operations have to protect the time buffer by scheduling backward from the bottleneck. If the time buffer is set at four days, the operation immediately preceding the bottleneck is scheduled to complete the required parts four days before they are scheduled to run on the bottleneck. Each preceding operation can be back scheduled in the same way so the parts are available as required for the next operation.

Any disturbances in the feeding operations are absorbed by the time buffer, and throughput is not affected. Also, work-in-process inventory is reduced. Since the queue is limited to the time buffer, lead times are reduced.

Bottlenecks occur in every process, including hospitals, banks, and restaurants. They must be managed, if possible, to retain customer loyalty. If the bottleneck is a result of not enough personnel, extra hours or additional shifts may be possible. However, in some cases, increasing capacity, such as adding extra hotel rooms or airline seats, cannot be easily accomplished.

One large airline determined that a bottleneck existed in the turnaround of an aircraft, which was limiting the number of flights available, and causing too much downtime of their limited resource—flight crews. From the arrival at the airport terminal, the time it took to disembark passengers, clean out the airplane, resupply the catering items, add fuel to the aircraft, unload and reload baggage, and get ready to board the next set of passengers, took a minimum of 45 minutes. They determined that there was also a direct correlation between aircraft turnaround efficiency and schedule punctuality. Through the use of technology, the staging of luggage carts, and a more robust communication system between the flight crews and ramp personnel, they were able to cut the time down to an average of 20 minutes. This also had a positive impact on the on-time departure percentage, which improved by 30%.

THEORY OF CONSTRAINTS AND DRUM-BUFFER-ROPE

The section on managing bottlenecks was developed based on the work of Eliyahu M. Goldratt in his Theory of Constraints. It has allowed many people to rethink their approaches to improving and managing their production processes. The fundamental concept behind the work is that every operation producing a product or service is a series of linked processes. Each process has a specific capacity to produce the given defined output for the operation, and in virtually every case, there is one process that limits or constrains the throughput from the entire operation. Refer to Figure 6.11 for an example of an operation producing product A.

The total operation is constrained by process 3 at a capacity of four per hour. No matter how much efficiency there is in the other processes and how many process improvements are made in processes 1, 2, and 4, it will never be possible to exceed the overall...
operational output of four per hour. Increased efficiency and utilization in processes 1 and 2 will only increase inventory, not sales.

Identifying the constraint in a process can actually be fairly simple. There is always a set of defined actions (processes) that are needed to create a finished product. When one process is discovered that is working to full capacity while inventory is growing behind the process waiting for the process, and processes downstream from that one process tend to have idle time with respect to their need to process the inventory, then the constraint has been identified. If all orders are scheduled and all raw material for those orders released, yet all processes in a production sequence have idle time for the required production, then sales is said to be the constraint.

**Manage the Constraint**

Several fundamental guidelines have been developed for understanding how to manage a constraining process or bottleneck, which were discussed in the section on Bottleneck Principles. These principles of balancing the overall flow, and maintaining steady work at the constraint, are critical to the Theory of Constraints.

**Improve the Process**

Once a constraint has been identified, there is a five-step process that is recommended to help improve the performance of the operation. The five steps are summarized as follows:

1. **Identify the constraint.** The entire process must be examined to determine which process limits the throughput. The concept does not limit this process examination to merely the operational processes. For example, in Figure 6.11, suppose the sales department was selling the output only at the rate of three per hour. In that case, sales would be the constraint and not process 3. It must be remembered that a constraint limits throughput, not inventory or production.

2. **Exploit the constraint.** Find methods to maximize the utilization of the constraint toward productive throughput. For example, in many operations all processes are shut down during lunchtime. If a process is a constraint, the operation should consider rotating lunch periods so that the constraint is never allowed to be idle.

3. **Subordinate everything to the constraint.** Effective utilization of the constraint is the most important issue. Everything else is secondary.

4. **Elevate the constraint.** This denotes finding ways to increase the available hours of the constraint, including getting more of it.

5. **Once the constraint is no longer a constraint, find a new one and repeat the steps.** As the effective utilization of the constraint increases, it may cease to be a constraint as another process becomes one. In that case the emphasis shifts to the new process constraint.

**Scheduling with the Theory of Constraints**

The scheduling system developed for the theory of constraints (TOC) has its own specific approach. It is often described as Drum-Buffer-Rope:

- **Drum.** The drum of the system refers to the “drumbeat” or pace of production. It represents the master schedule for the operation, which is focused around the pace of throughput as defined by the constraint. Note that once the pace of the constraint has been defined, it does no good to schedule more production than the constraint can handle. To do so will merely add in-process inventory and may actually decrease its effectiveness.
- **Buffer.** Since it is so important that the constraint never be “starved” for needed inventory, a time buffer is often established in front of the constraint. It is called a time buffer because it represents the amount of time that the inventory in the buffer protects the constraint from disruptions. In many systems there are actually three buffers: one for the constraint, one for assembly, and one for shipping. The constraint buffer often represents the processing time to protect the buffer from unexpected process variation. For example, a two-day time buffer would necessitate upstream operations to complete processing and have material in the buffer two days before actually needed. The initial time buffer used is often the total processing time from raw material release to reaching the constraint process. The assembly buffer often represents the time from raw material release to a process where components that do not go through the constraint process have to be assembled with components that do have to go through the constraint process. Finally, the buffer for shipping represents the processing time from the point the material leaves the constraint process to completion of the final product.

- **Rope.** The analogy is that the rope “pulls” production to the constraint for necessary processing. Although this may imply a reactive replenishment system, such as a reorder point, it can be done by a well-coordinated release of material into the system at the right time. The rope schedules release of raw material into production at a pace that maintains the buffer, ensures the constraint is not “starved” for material, and that excessive inventory does not build up. It is basically defined by the processing capability of the constraint process.

Even scheduling has its primary focus on effective management of the organization’s constraint to throughput and sales.

Four primary plant types are defined, and they are used to specify the flow of materials through a production process. They can therefore be helpful in understanding how to manage the operation using the theory of constraints. They include:

- **I-plant,** where one raw material is used to make one final product. Processing is usually done in a straight line.
- **A-plant,** where numerous subassemblies merge into a single final assembly.
- **V-plant,** where few raw materials can be made into several end products.
- **T-plant,** where multiple straight lines can split into several assemblies.

The theory of constraints also includes a process to help develop and implement change in an organization. The first step to this is to identify core conflicts, which are then validated by building what is called a *current reality tree*. After those undesirable effects are identified from the core conflicts, a *future reality tree* is developed, which will lay out a strategy to resolve the problems. The final major step in the process is to build a tactical objective map that will define a strategy to accomplish the future reality.

**Example Problem**

Parent X requires 1 each of component Y and Z. Both Y and Z are processed on work center 20, which has an available capacity of 40 hours. The setup time for component Y is 1 hour and the run time 0.3 hour per piece. For component Z, setup time is 2 hours and the run time is 0.20 hour per piece. Calculate the number of Ys and Zs that can be produced.

**Answer**

Let \( x \) = number of Ys and Zs to produce

\[
1 \text{me}_Y + 1 \text{me}_Z = 40 \text{ hours}
\]

\[
1 + 0.3x + 2 + 0.2x = 40 \text{ hours}
\]

\[
0.5x = 37 \text{ hours}
\]

\[
x = 74
\]

Therefore, work center 20 can produce 74 Ys and 74 Zs.

**Example Problem**

In this problem, parent A is made of one B and 2 Cs. As and Bs are both made on work station 1, which has a capacity of 40 hours per week. The Cs are made on work station 2, which also has a capacity of 40 hours per week.
Based on the above information, calculate the maximum number of As, Bs, and Cs that should be produced per week.

**Answer**

The number of Bs produced should equal the number of As produced to avoid overproduction. Therefore, the number of Bs can be expressed in a formula as the number of As.

Work station 1

\[
\text{Time}_A + \text{Time}_B = 40 \text{ hours}
\]

\[
2 + 0.1A + 2 + 0.2A = 40
\]

\[
0.3A = 36
\]

\[
A = 120
\]

Work station 1 has the capacity to produce enough As and Bs to make 120 As per week.

Work station 2

The number of Cs produced should be twice the number of As produced to avoid overproduction. Therefore, the number of Cs can be represented by \(2 \times A\).

\[
\text{Time}_C = 40 \text{ Hours}
\]

\[
1 + 2 \times 0.3A = 40
\]

\[
0.6A = 39
\]

\[
A = 65
\]

Work station 2 has the capacity to make enough Cs to support production of only 65 As per week, and in this case this is the constraint. To avoid overproduction, work center 1 should produce 65 As and 65 Bs per week. Work station 2 should produce 130 Cs per week (enough for 65 As).

In this example, work station 1 will have very low utilization. However, producing more than 65 Bs per week will only build inventory and work station 1 will be starved by work station 2, which has the capacity to produce only 130 Cs per week.

**IMPLEMENTATION**

Orders that have the necessary tooling, material, and capacity available have a good chance of being completed on time and can be released to the shop floor. Other orders that do not have all of the necessary elements should not be released because they only cause excess work-in-process inventory and may interrupt work on orders that can be completed. The process for releasing an order is shown in Figure 6.12.

Implementation is performed by issuing a shop order or schedule to manufacturing, which is the authorization for them to proceed with making the item. A shop packet that contains the shop order and whatever other information that is needed by manufacturing can be compiled. It may include any of the following:

- Shop order showing the shop order number, part number, name, description, and quantity.
- Engineering drawings.
- Bills of material.
- Route sheets showing the operations to be performed, equipment and accessories needed, materials to use, and setup and run times.
- Material issue tickets that authorize manufacturing to get the required material from stores. These are also used for charging the material against the shop order.
Tool requisitions authorizing manufacturing to withdraw necessary tooling from the tool crib.

Job tickets for each operation to be performed. As well as authorizing the individual operations to be performed, they also can function as part of a reporting system. The worker can log on and off the job using the job ticket, and it then becomes a record of that operation.

Move tickets that authorize and direct the movement of work between operations.

Many manufacturing companies today use a paperless system, which authorizes production via a production schedule, rather than the release of a shop order. The shop packet is replaced by access to the same information electronically. Online reporting of material movement and labor reporting are used in exchange for tickets.

**CONTROL**

Once work orders have been issued to manufacturing, their progress has to be controlled. To control progress, performance has to be measured and compared to what is planned. If what is actually happening (what is measured) varies significantly from what was planned, either the plans have to be changed or corrective action must be taken to bring performance back to plan.

The objectives of production activity control are to meet delivery dates and to make the best use of company resources. To meet delivery dates, a company must control the progress of orders on the shop floor, which means controlling the lead time for orders. As discussed previously in this chapter, the largest component of lead time is queue. If queue can be controlled, delivery dates can usually be met. Intermittent operations have many different products and order quantities and many different routings, each requiring different capacities. In this environment, it is almost impossible to balance the load over all the workstations. Queue exists because of this erratic input and output.

**FIGURE 6.12** Order release process.
To control queue and meet delivery commitments, production activity control must:

- Control the work going into and coming out of a work center. This is generally called **input/output control**.
- Set the correct priority of orders to run at each work center, which is referred to as **dispatching**.

### Input/Output Control

Production activity control must balance the flow of work to and from different work centers. This is to ensure that queue, work-in-process, and lead times are controlled. The input/output control system is a method of managing queues and work-in-process lead times by monitoring and controlling the input to, and output from, a facility. It is designed to balance the input rate in hours with the output rate so these will be controlled.

The input rate is controlled by the release of orders to the shop floor. If the rate of input is increased, queue, work-in-process, and lead times increase. The output rate is controlled by increasing or decreasing the capacity of a work center. Capacity change is a problem for manufacturing, but can be attained by overtime or undertime, shifting workers, and so forth. Figure 6.13 shows the idea graphically.

#### Input/output report

To control input and output, a plan must be devised, along with a method for comparing what actually occurs against what was planned. This information is shown on an **input/output report**. Figure 6.14 shows an example of such a report. The values are in standard hours.

**Cumulative variance** is the difference between the total planned for a given period and the actual total for that period. It is calculated as follows:

\[
\text{Cumulative variance} = \text{previous cumulative variance} + \text{actual} - \text{planned}
\]

\[
\text{Cumulative input variance week 2} = -4 + 32 - 32 = -4
\]

Backlog is the same as queue and expresses the work to be done in hours. It is calculated as follows:

\[
\text{Planned backlog for period 1} = \text{previous backlog} + \text{planned input} - \text{planned output}
\]

\[
= 32 + 38 - 40
\]

\[
= 30 \text{ hours}
\]

The report shows that the plan was to maintain a level output in each period and to reduce the queue and lead time by 10 hours, but input and output were lower than expected.

---

**FIGURE 6.13** Input/output control.
Work Center: 201
Capacity per Period: 40 standard hours

<table>
<thead>
<tr>
<th>Period</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planned Input</td>
<td>38</td>
<td>32</td>
<td>36</td>
<td>40</td>
<td>44</td>
<td>190</td>
</tr>
<tr>
<td>Actual Input</td>
<td>34</td>
<td>32</td>
<td>32</td>
<td>42</td>
<td>40</td>
<td>180</td>
</tr>
<tr>
<td>Cumulative Variance</td>
<td>-4</td>
<td>-4</td>
<td>-8</td>
<td>-6</td>
<td>-10</td>
<td>-10</td>
</tr>
</tbody>
</table>

| Planned Output | 40    | 40    | 40    | 40    | 40    | 200   |
| Actual Output  | 32    | 36    | 44    | 44    | 36    | 192   |
| Cumulative Variance | -8    | -12   | -8    | -4    | -8    | -8    |

| Planned Backlog | 32    | 30    | 22    | 18    | 18    | 22    |
| Actual Backlog  | 32    | 34    | 30    | 18    | 16    | 20    |

**FIGURE 6.14** Input/output report.

Planned and actual inputs monitor the flow of work coming to the work center. Planned and actual outputs monitor the performance of the work center. Planned and actual backlogs monitor the queue and lead time performance.

**Example Problem**

Complete the following input/output report for weeks 1 and 2.

<table>
<thead>
<tr>
<th>Week</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planned Input</td>
<td>45</td>
<td>40</td>
</tr>
<tr>
<td>Actual Input</td>
<td>42</td>
<td>46</td>
</tr>
<tr>
<td>Cumulative Variance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planned Output</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Actual Output</td>
<td>42</td>
<td>44</td>
</tr>
<tr>
<td>Cumulative Variance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planned Backlog</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Actual Backlog</td>
<td>30</td>
<td></td>
</tr>
</tbody>
</table>

**Answer**

Cumulative input variance week 1 = 42 – 45 = -3
Cumulative input variance week 2 = -3 + 46 – 40 = 3
Cumulative output variance week 1 = 42 – 40 = 2
Cumulative output variance week 2 = 2 + 44 – 40 = 6
Production Activity Control  153

Planned backlog week 1 = 30 + 45 - 40 = 35
Planned backlog week 2 = 35 + 40 - 40 = 35
Actual backlog week 1 = 30 + 42 - 42 = 30
Actual backlog week 2 = 30 + 46 - 44 = 32

Operation Sequencing

*APICS Dictionary, 14th edition* defines operation sequencing as “a technique for short-term planning of actual jobs to be run in each work center based on capacity (i.e., existing workforce and machine availability) and priorities.” Priority, in this case, is the sequence in which jobs at a work center should be worked on.

The material requirements plan establishes proper need dates and quantities for orders. Over time, these dates and quantities change for a variety of reasons. Customers may require different delivery quantities or dates. Deliveries of component parts, either from suppliers or internally, may not be met. Scrap, shortages, and overages may occur. In addition, multiple orders may have the same due date, or be scheduled to run on a particular work center the same day, but need to be sequenced. Control of priorities is exercised through dispatching.

**Dispatching**  Dispatching is the function of selecting and sequencing available jobs to be run at individual work centers. The dispatch list is the instrument of priority control. It is a listing by operation of all the jobs available to be run at a work center with the job listed in priority sequence. It normally includes the following information and is updated and published at least daily:

- Plant, department, and work center.
- Part number, shop order number, operation number, and operation description of jobs at the work center.
- Standard hours.
- Priority information.
- Jobs coming to the work center.

Figure 6.15 shows an example of a daily dispatch list.

**Dispatching rules**  The ranking of jobs for the dispatch list is created through the application of dispatching or priority rules. There are many rules, some attempting to reduce work-in-process inventory, others attempting to minimize the number of late

<table>
<thead>
<tr>
<th>WORK CENTER: 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated Capacity: 16 standard hours per day</td>
</tr>
<tr>
<td>Shop Date: 250</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Order Number</th>
<th>Part Number</th>
<th>Order Quantity</th>
<th>Setup Hours</th>
<th>Run Hours</th>
<th>Total Hours</th>
<th>Quantity Completed</th>
<th>Load Remaining</th>
<th>Operation</th>
<th>Dates</th>
</tr>
</thead>
<tbody>
<tr>
<td>123</td>
<td>6554</td>
<td>100</td>
<td>1.5</td>
<td>15</td>
<td>16.5</td>
<td>50</td>
<td>8</td>
<td>249</td>
<td>250</td>
</tr>
<tr>
<td>121</td>
<td>7345</td>
<td>50</td>
<td>0.5</td>
<td>30</td>
<td>30.5</td>
<td>10</td>
<td>24</td>
<td>249</td>
<td>251</td>
</tr>
<tr>
<td>142</td>
<td>2687</td>
<td>500</td>
<td>0.2</td>
<td>75</td>
<td>75.2</td>
<td>0</td>
<td>75</td>
<td>250</td>
<td>259</td>
</tr>
</tbody>
</table>

Total Available Load in Standard Hours 107

Jobs Coming

<table>
<thead>
<tr>
<th>Order Number</th>
<th>Part Number</th>
<th>Order Quantity</th>
<th>Setup Hours</th>
<th>Run Hours</th>
<th>Total Hours</th>
<th>Quantity Completed</th>
<th>Load Remaining</th>
<th>Operation</th>
<th>Dates</th>
</tr>
</thead>
<tbody>
<tr>
<td>145</td>
<td>7745</td>
<td>200</td>
<td>0.7</td>
<td>20</td>
<td>20.7</td>
<td>0</td>
<td>20.7</td>
<td>251</td>
<td>253</td>
</tr>
<tr>
<td>135</td>
<td>2832</td>
<td>20</td>
<td>1.2</td>
<td>1.0</td>
<td>2.7</td>
<td>0</td>
<td>2.7</td>
<td>253</td>
<td>254</td>
</tr>
</tbody>
</table>

Total Future Load in Standard Hours 23.4

**Figure 6.15**  Dispatch list (based on 2 machines working one 8-hour shift per day).
orders or maximize the output of the work center. None is perfect or will satisfy all objectives. Some commonly used rules are:

- **First come, first served (FCFS).** Jobs are performed in the sequence in which they are received. This rule ignores due dates and processing time.
- **Earliest job due date (EDD).** Jobs are performed according to their due dates. Due dates are considered, but processing time is not.
- **Earliest operation due date (ODD).** Jobs are performed according to their operation due dates. Due dates and processing time are taken into account. In addition, the operation due date is easily understood on the shop floor.
- **Shortest process time (SPT).** Jobs are sequenced according to their process time. This rule ignores due dates, but it maximizes the number of jobs processed. Orders with long process times tend to be delayed.

Figure 6.16 illustrates how these sequencing rules work. Notice that each rule usually produces a different sequence.

**Critical ratio (CR).** Critical ratio considers due dates and process time, and is an index of the relative priority of an order to other orders at a work center. It is based on the ratio of time remaining to work remaining and is expressed as:

$$ CR = \frac{\text{due date} - \text{present date}}{\text{lead time remaining}} = \frac{\text{actual time remaining}}{\text{lead time remaining}} $$

Lead time remaining includes all elements of manufacturing lead time that have not yet been processed and expresses the amount of time the job normally takes to complete.

If the actual time remaining is less than the lead time remaining, it implies there is not sufficient time to complete the job and the job is behind schedule. Similarly, if lead time remaining and actual time remaining are the same, the job is on schedule. If the actual time remaining is greater than the lead time remaining, the job is ahead of schedule. If the actual time remaining is less than 1, the job is late already. The following table summarizes these facts and relates them to the critical ratio:

<table>
<thead>
<tr>
<th>CR less than 1 (actual time less than lead time).</th>
<th>CR equal to 1 (actual time equal to lead time).</th>
<th>CR greater than 1 (actual time greater than lead time).</th>
<th>CR zero or less (today’s date greater than due date).</th>
<th>Order is behind schedule.</th>
<th>Order is on schedule.</th>
<th>Order is ahead of schedule.</th>
<th>Order is already late.</th>
</tr>
</thead>
</table>

Using the critical ratio dispatching rule, orders are listed in order of their critical ratio with the lowest one first. The critical ratio of an order may change as the actual time remaining and lead time remaining change.

<table>
<thead>
<tr>
<th>Job</th>
<th>Process Time (days)</th>
<th>Arrival Date</th>
<th>Due Date</th>
<th>Operation Due Date</th>
<th>Sequencing Rule</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>4</td>
<td>223</td>
<td>245</td>
<td>233</td>
<td>2 4 1 3</td>
</tr>
<tr>
<td>B</td>
<td>1</td>
<td>224</td>
<td>242</td>
<td>239</td>
<td>3 2 2 1</td>
</tr>
<tr>
<td>C</td>
<td>5</td>
<td>231</td>
<td>240</td>
<td>240</td>
<td>4 1 3 4</td>
</tr>
<tr>
<td>D</td>
<td>2</td>
<td>219</td>
<td>243</td>
<td>242</td>
<td>1 3 4 2</td>
</tr>
</tbody>
</table>

**FIGURE 6.16** Application of sequencing rules.
Example Problem

Today's date is 175. Orders A, B, and C have the following due dates and lead time remaining. Calculate the actual time remaining and the critical ratio for each.

<table>
<thead>
<tr>
<th>Order</th>
<th>Due Date</th>
<th>Lead Time Remaining (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>185</td>
<td>20</td>
</tr>
<tr>
<td>B</td>
<td>195</td>
<td>20</td>
</tr>
<tr>
<td>C</td>
<td>205</td>
<td>20</td>
</tr>
</tbody>
</table>

**Answer**

Order A has a due date of 185, and today is day 175. There are 10 actual days remaining. Since the lead time remaining is 20 days,

\[
\text{Critical ratio} = \frac{10}{20} = 0.5
\]

Similarly, the actual time remaining and the critical ratios are calculated for orders B and C. The following table gives the results:

<table>
<thead>
<tr>
<th>Order</th>
<th>Due Date</th>
<th>Lead Time Remaining (days)</th>
<th>Actual Time Remaining (days)</th>
<th>CR</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>185</td>
<td>20</td>
<td>10</td>
<td>0.5</td>
</tr>
<tr>
<td>B</td>
<td>195</td>
<td>20</td>
<td>20</td>
<td>1.0</td>
</tr>
<tr>
<td>C</td>
<td>205</td>
<td>20</td>
<td>30</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Order A has less actual time remaining than lead time remaining, so the CR is less than 1. It is, therefore, behind schedule. Order B has a CR of 1 and is exactly on schedule. Order C has a CR of 1.5—greater than 1—and is ahead of schedule.

An additional principle sometimes used for sequencing is **slack time**. Slack time is the result of adding up the remaining setup and run times for an order, and subtracting that from the time remaining. The job with the least slack would be scheduled first. Slack time can also be divided by the number of remaining operations, which is called **slack per operation**, where the job with the smallest value would be the priority.

Dispatching rules should be simple to use and easy to understand. As shown in Figure 6.16, each rule produces a different sequence and has its own advantages and disadvantages. Whichever rule is selected, it should be consistent with the objectives of the planning system.

**PRODUCTION REPORTING**

Production reporting provides feedback of what is actually happening on the plant floor. It allows PAC to maintain valid records of on-hand and on-order balances, job status, shortages, scrap, material shortages, and so on. Production activity control needs this information to establish proper priorities and to answer questions regarding deliveries, shortages, and the status of orders. Manufacturing management needs this information to make decisions about plant operations. Payroll needs this information to calculate employees' pay.

Data must be collected, sorted, and reported. The particular data collected depends upon the needs of the various departments. The methods of data collection vary. Sometimes the operator reports the start and completion of an operation, order, movement, and so on, using an online system directly reporting events as they occur. In other cases, the operator, supervisor, or timekeeper reports this information on an operation reporting form included in the shop packet. Information about inventory withdrawals and receipts must be reported as well.

Once the data is collected and recorded, appropriate reports are produced. Types of information needed for the various reports include:

- Order status.
- Weekly input/output by department or work center.
Chapter six

- Exception reports on such things as scrap, rework, and late shop orders.
- Inventory status.
- Performance summaries on order status, work center and department efficiencies, and so on.

PRODUCT TRACKING

Production control is often responsible for product tracking or lot traceability. This is the process of tracking parts and materials back to their origins. It has a very practical application in the matching of colors in fabrics and paint ensuring the consumer that different units of the product match in color at the time of manufacturing and during the product’s lifetime. Traceability may also be legislated in industries such as food, pharmaceutical, or aerospace to ensure the safety of the product. Should a product prove unsafe, it is possible for the manufacturer to trace back to find the source of all materials and recall all finished products that used that particular lot. This is a very meticulous process with information collected along with other supply chain information, often by production activity control personnel.

MEASUREMENT SYSTEMS

As mentioned previously, to control progress, as well as adjust plans, performance has to be measured and compared to what is planned. In the area of production activity control, there are many types of performance measurement systems available. The primary purpose of these measurements is to provide an objective means of evaluating performance, and to take corrective action if necessary. It is also important to make sure whatever type of measurement is used, it is aligned with the overall performance measurement of the organization.

In addition to those already discussed in this text, such as utilization, efficiency, productivity, demonstrated capacity, and input/output control, some of the more common measurements used are as follows:

- **Actual vs. planned lead time**: A comparison of the actual throughput time to the stated lead time.
- **Percent orders completed on time**: Percentage of orders completed on the due date, rather than early or late
- **Performance to schedule**: A measure of the quantity and date produced as compared to the master schedule.

Measurement systems will be discussed further in Chapters 15 and 16.

SUMMARY

Production activity control is concerned with converting the material requirements plan into action, reporting the results achieved, and when required, revising the plans and actions to meet the required results. Order release, dispatching, and progress reporting are the three primary functions. To accomplish the plans, PAC must establish detailed schedules for each order, set priorities for work to be done at each work center, and keep them current. Production activity control is also responsible for managing the queue and lead times. Nonmanufacturing industries must also control capacity and inventory in order to monitor progress, manage resources, and derive appropriate schedules.

The theory of constraints modifies the approach to PAC since it views a production facility, the suppliers, and the market as a series of interdependent functions. TOC attempts to optimize the constraints (bottlenecks) in a system as they affect the overall throughput. As a result, traditional lot sizing rules should be modified to increase the throughput of the entire process and not just the individual work centers. Drum-buffer-rope describes how the TOC works by setting an overall pace of material flow, ensuring
bottlenecks never run out of material, and linking the output of one work center to another. Measurement systems are used by PAC to monitor and control progress, meet delivery dates, utilize labor and equipment efficiently, and keep inventory levels down.

**KEY TERMS**

| Backward scheduling | Manufacturing lead time |
| Bill of material | Move time |
| Bottlenecks | Operation overlapping |
| Continuous manufacturing | Process batch |
| Critical ratio (CR) | Product batch |
| Cumulative variance | Product structure |
| Cycle time | Product tracking |
| Dispatching | Repetitive manufacturing |
| Drum-Buffer-Rope | Routing |
| Earliest job due date | Run time |
| Earliest operation due date | Setup time |
| Finite loading | Shop order master |
| First come, first served | Slack per operation |
| Flow manufacturing | Slack time |
| Forward scheduling | Shortest process time |
| Gateway operation | Throughput |
| Infinite loading | Transfer batch |
| Input/output control | Work center master |
| Input/output report | Work center master |
| Intermittent manufacturing | Work center master |
| Item master | Work center master |
| Load profile | Work center master |

**QUESTIONS**

1. What is the responsibility of production activity control?
2. What are the major functions of planning, implementation, and control?
3. What are the major characteristics of flow, intermittent, and project manufacturing?
4. Why is production activity control more complex in intermittent manufacturing?
5. To plan the flow of materials through manufacturing, what four things must production activity control know? Where will information on each be obtained?
6. What are the four types of planning data used in production activity control? What information does each contain?
7. What information is used for controlling production?
8. What should production activity control check before releasing a shop order?
9. What is manufacturing lead time? Name and describe each of its elements.
10. Describe forward and backward scheduling. Why is backward scheduling preferred?
11. Describe infinite and finite loading.
12. What is operation overlapping? What is its purpose?
13. What is operation splitting? What is its purpose?
14. What information does a load report contain? Why is it useful to production activity control?
15. What is a bottleneck operation?

16. What is the definition of throughput?

17. What are the seven bottleneck principles discussed in the text?

18. What are the five things discussed in the text that are important in managing bottlenecks?

19. What is a shop order? What kind of information does it usually contain?

20. What two things must be done to control queue and meet delivery commitments?

21. What is an input/output control system designed to do? How is input controlled? How is output controlled?

22. What is dispatching? What is a dispatch list?

23. Describe each of the following dispatching rules giving their advantages and disadvantages.
   a. First come, first served.
   b. Earliest due date.
   c. Earliest operation due date.
   d. Shortest processing time.
   e. Critical ratio.

24. If the time remaining to complete a job is 10 days and the lead time remaining is 12 days, what is the critical ratio? Is the order ahead of schedule, on schedule, or behind schedule?

25. Would critical ratio be better utilized as a static ratio or a dynamic ratio, and why?

26. What is the purpose of production reporting? Why is it needed?

27. A student of production inventory management has decided to apply critical ratio to his homework assignments. Describe what is happening if his critical ratio for various assignments is:
   a. negative.
   b. zero.
   c. between zero and 1.
   d. greater than 1.

28. Bottlenecks exist in many business processes that serve the public and are usually indicated by lineups. Choose a business that experiences lineups and identify the constraints in the system. Give specific examples of each of the seven bottleneck principles that apply to that business. Suggest a way to increase the throughput of the bottleneck and describe the benefits to the business and to the customers.

29. What is lot traceability? Why is it important to safety related products?

30. Choose a service industry and describe the scheduling and bottleneck issues that must be controlled in order to maintain customer service.

31. Provide an explanation of Drum-Buffer-Rope and give an example of how it would be used.

**PROBLEMS**

6.1. Shop order 7777 is for 600 of part 8900. From the routing file, it is found that operation 20 is done on work center 300. The setup time is 3.5 hours, and run time is 0.233 hours per piece. What is the required capacity on work center 300 for shop order 7777?

   **Answer.** 143.3 standard hours

6.2. An order for 100 of a product is processed on work centers A and B. The setup time on A is 50 minutes, and run time is 5 minutes per piece. The setup time on B is 60 minutes, and the run time is 5 minutes per piece. Wait time between the two operations is 5 hours. The move time between A and B is 40 minutes. Wait time after operation B is 5 hours, and the move time into stores is 3 hours. Queue at work center A is 25 hours and at B is 35 hours. Calculate the total manufacturing lead time for the order.

   **Answer.** 92 hours and 10 minutes

6.3. In problem 6.2, what percentage of the time is the order actually running?

   **Answer.** 18.08%

6.4. An order for 50 of a product is processed on work centers A and B. The setup time on A is 45 minutes, and run time is 5 minutes per piece. The setup time on B is 30 minutes,
and the run time is 4 minutes per piece. Wait time between the two operations is 8 hours. The move time between A and B is 60 minutes. Wait time after operation B is 8 hours, and the move time into stores is 2 hours. Queue at work center A is 40 hours and at B is 35 hours. Calculate the total manufacturing lead time for the order.

6.5. In problem 6.4, what percentage of time is the order actually running?

6.6. Amalgamated Skyhooks, Inc., has an order for 200 Model SKY3 Skyhooks for delivery on day 200. The Skyhook consists of three parts. Components B and C form subassembly A. Subassembly A and component D form the final assembly. Following are the work centers and times for each operation. Using a piece of graph paper, draw a backward schedule based on the following. When must component C be started to meet the delivery date?

- Only one machine is assigned to each operation.
- The factory works one 8-hour shift, 5 days a week.
- All parts move in one lot of 200.

<table>
<thead>
<tr>
<th>Part</th>
<th>Operation</th>
<th>Standard Time (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>7</td>
</tr>
<tr>
<td>B</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>7</td>
</tr>
<tr>
<td>C</td>
<td>10</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>5</td>
</tr>
<tr>
<td>Subassembly A</td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>Final Assembly SKY3</td>
<td></td>
<td>5</td>
</tr>
</tbody>
</table>

**Answer.** Day 171

6.7. International Door Slammers has an order to deliver 500 door slammers on day 130. Draw up a backward schedule under the following conditions:

- Only one machine is assigned to each operation.
- Schedule one 8-hour shift per day for 5 days per week.
- All parts are to move in one lot of 500 pieces.
- Allow 8 hours between operations for queue and move times.

A slammer consists of three parts. Purchased components C and D form subassembly A. Subassembly A and component B form the final assembly. Part B is machined in three operations. No special tooling is required except for part B, operation 20. It takes 24 hours to make the tooling. Material is available for all parts. Standard times for the lot of 500 are as follows:

<table>
<thead>
<tr>
<th>Part</th>
<th>Operation</th>
<th>Standard Time (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>6</td>
</tr>
<tr>
<td>Subassembly A</td>
<td></td>
<td>18</td>
</tr>
<tr>
<td>Final assembly</td>
<td></td>
<td>5</td>
</tr>
</tbody>
</table>

6.8. An order for 100 of a product is processed on operation A and operation B. The setup time on A is 50 minutes, and the run time per piece is 9 minutes. The setup time on B is 30 minutes, and the run time is 6 minutes per piece. It takes 20 minutes to move a lot between A and B. Since this is a rush order, it is given top priority (president’s edict) and is run as soon as it arrives at either workstation.
It is decided to overlap the two operations and to split the lot of 100 into two lots of 60 and 40. When the first lot is finished on operation A, it is moved to operation B where it is set up and run. Meanwhile, operation A completes the balance of the 100 units (40) and sends the units over to operation B. These 40 units should arrive as operation B is completing the first batch of 60; thus, operation B can continue without interruption until all 100 are completed.

a. Calculate the total manufacturing lead time for operation A and for B without overlapping.

b. Calculate the manufacturing lead time if the operations are overlapped. How much time is saved?

Answer.

a. Total manufacturing lead time = 1600 minutes

b. Total manufacturing lead time = 1240 minutes

Saving in lead time = 360 minutes

6.9. An order for 250 bell ringers is processed on work centers 10 and 20. The setup and run times are as follows. It is decided to overlap the lot on the two work centers and to split the lot into two lots of 100 and 150. Move time between operations is 30 minutes. Work center 20 cannot be set up until the first lot arrives. Calculate the saving in manufacturing lead time.

Setup on A = 50 minutes
Run time on A = 5 minutes per piece
Setup on B = 100 minutes
Run time on B = 7 minutes per piece

6.10. An order for 100 of a product is processed on operation A. The setup time is 50 minutes, and the run time per piece is 9 minutes. Since this is a rush order, it is to be split into two lots of 50 each and run on two machines in the work center. The machines can be set up simultaneously.

a. Calculate the manufacturing lead time if the 100 units are run on one machine.

b. Calculate the manufacturing lead time when run on two machines simultaneously.

c. Calculate the reduction in lead time.

Answer.

a. 950 minutes

b. 500 minutes

c. 450 minutes

6.11. What would be the reduction in manufacturing lead time if the second machine could not be set up until the setup was completed on the first machine?

6.12. An order for 100 of a product is run on work center 40. The setup time is 4 hours, and the run time is 3 minutes per piece. Since the order is a rush and there are two machines in the work center, it is decided to split the order and run it on both machines. Calculate the manufacturing lead time before and after splitting.

6.13. In problem 6.12, what would be the manufacturing lead time if the second machine could not be set up until the setup on the first machine was completed? Would there be any reduction in manufacturing lead time?

6.14. Complete the following input/output report. What are the planned and actual backlogs at the end of period?

<table>
<thead>
<tr>
<th>Period</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planned Input</td>
<td>35</td>
<td>38</td>
<td>36</td>
<td>39</td>
<td></td>
</tr>
<tr>
<td>Actual Input</td>
<td>33</td>
<td>33</td>
<td>31</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>Cumulative Variance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Period</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>--------</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Planned Input</td>
<td>78</td>
<td>78</td>
<td>78</td>
<td>78</td>
<td>78</td>
</tr>
<tr>
<td>Actual Input</td>
<td>84</td>
<td>80</td>
<td>78</td>
<td>82</td>
<td>80</td>
</tr>
<tr>
<td>Cumulative Variance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Answer.** Planned backlog = 20 units. Actual backlog = 18 units

6.15. Complete the following input/output report. What is the actual backlog at the end of period 5?

<table>
<thead>
<tr>
<th>Process</th>
<th>Time (days)</th>
<th>Arrival Date</th>
<th>Due Date</th>
<th>Operation Due Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Job</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>5</td>
<td>123</td>
<td>142</td>
<td>132</td>
</tr>
<tr>
<td>B</td>
<td>2</td>
<td>124</td>
<td>144</td>
<td>131</td>
</tr>
<tr>
<td>C</td>
<td>3</td>
<td>131</td>
<td>140</td>
<td>129</td>
</tr>
<tr>
<td>D</td>
<td>6</td>
<td>132</td>
<td>146</td>
<td>135</td>
</tr>
</tbody>
</table>

**Sequencing Rule**

<table>
<thead>
<tr>
<th>Job</th>
<th>Process Time (days)</th>
<th>Arrival Date</th>
<th>Due Date</th>
<th>Operation Due Date</th>
<th>FCFS</th>
<th>EDD</th>
<th>ODD</th>
<th>SPT</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>5</td>
<td>123</td>
<td>142</td>
<td>132</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>2</td>
<td>124</td>
<td>144</td>
<td>131</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>3</td>
<td>131</td>
<td>140</td>
<td>129</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>6</td>
<td>132</td>
<td>146</td>
<td>135</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
6.17. Jobs A, B, and C are in queue at work center 10 before being completed on work center 20. The following information pertains to the jobs and the work centers. For this problem, there is no move time. Today is day 1. If the jobs are scheduled by the earliest due date, can they be completed on time?

<table>
<thead>
<tr>
<th>Job</th>
<th>Process Time (days)</th>
<th>Due Date</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Work Center 10</td>
<td>Work Center 20</td>
</tr>
<tr>
<td>A</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>B</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>C</td>
<td>9</td>
<td>4</td>
</tr>
</tbody>
</table>

6.18. Calculate the critical ratios for the following orders and establish in what order they should be run. Today’s date is 75.

<table>
<thead>
<tr>
<th>Order</th>
<th>Due Date</th>
<th>Lead Time Remaining (days)</th>
<th>Actual Time Remaining (days)</th>
<th>CR</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>89</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>95</td>
<td>25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>100</td>
<td>20</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

CASE STUDY 6.1

Johnston Products

No matter how many times Justin Wang, the master scheduler for Johnston Products, tried, he couldn’t seem to get it through people’s minds. They kept trying to “front load” the production schedule by attempting to catch up with production they failed to make the previous week, and the problem appeared to be getting worse. It seemed to happen every week, and the only way Justin could get things back to a realistic position was to completely reconstruct the entire master schedule—usually about every three weeks.

Last month could serve as an example. The first week of the month Justin had scheduled production equal to 320 standard hours in the assembly area. The assembly area managed to complete only 291 hours that week because of some equipment maintenance and a few unexpected part shortages. The assembly supervisor then had the workers complete the remaining 29 hours from week 1 at the start of week 2. Since week 2 already had 330 standard hours scheduled, the additional 29 hours really put them in a position of attempting to complete 359 hours. The workers actually completed 302 hours in week 2, leaving...
57 hours to front load into week 3, and so forth. Usually by the time Justin came to his three-week review of the master schedule, it was not uncommon for the assembly area to be more than 100 standard hours behind schedule.

Clearly, something needed to be done. Justin decided to review some of the areas that could be causing the problem:

1. **Job standards** Although it had been at least four years since any job standards had been reviewed or changed, Jason felt the standards could not be the problem—quite the opposite. His operations course had taught him about the concept of the learning curve, implying that if anything the standard times for the jobs should be too high, allowing the average worker to complete even more production per hour than that implied by the job standard.

2. **Utilization** The general manager was very insistent on high utilization of the area. He felt that it would help control costs, and consequently used utilization as a major performance measure for the assembly area. The problem was that customer service was also extremely important. With the problems Justin was having with the master schedule, it was difficult to promise order delivery accurately, and equally difficult to deliver the product on time once the order promise was made.

3. **The workers** In an effort to control costs, the hourly wage for the workers was not very high. This caused a turnover in the workforce of almost 70% per year. In spite of this, the facility was located in an area where replacement workers were fairly easy to hire. They were assigned to the production area after they had a minimum of one week's worth of training on the equipment. In the meantime, the company filled vacant positions with temporary workers brought in by a local temporary employment service.

4. **Engineering changes** The design of virtually all the products was changing, with the average product changing with respect to some aspect of the design about every two months. Usually this resulted in an improvement to the products, however, so Justin quickly dismissed the changes as a problem. There were also some engineering changes on the equipment, but in general little in the way of process change had been made. The setup time for a batch of a specific design had remained at about 15 minutes. That forced a batch size of about 50 to 300 units, depending on the design. The equipment was getting rather old, however, forcing regular maintenance as well as causing an occasional breakdown. Each piece of equipment generally required about three hours of maintenance per week.

Since the computer had done most of his calculations in the past, Justin decided to check to see if the computer was the source of the problem. He gathered information to conduct a manual calculation on a week when there were eight people assigned to the assembly area (one person for each of eight machines) for one shift per day. With no overtime, that would allow 320 hours of production.

<table>
<thead>
<tr>
<th>Product</th>
<th>Batch Size</th>
<th>Standard Assembly Time (minutes per item)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A174</td>
<td>50</td>
<td>17</td>
</tr>
<tr>
<td>G820</td>
<td>100</td>
<td>9</td>
</tr>
<tr>
<td>H221</td>
<td>50</td>
<td>19.5</td>
</tr>
<tr>
<td>B327</td>
<td>200</td>
<td>11.7</td>
</tr>
<tr>
<td>C803</td>
<td>100</td>
<td>21.2</td>
</tr>
<tr>
<td>P932</td>
<td>300</td>
<td>14.1</td>
</tr>
<tr>
<td>F732</td>
<td>200</td>
<td>15.8</td>
</tr>
<tr>
<td>J513</td>
<td>150</td>
<td>17.3</td>
</tr>
<tr>
<td>L683</td>
<td>150</td>
<td>12.8</td>
</tr>
</tbody>
</table>
Assignment

1. With this information, Justin calculated the total standard time required to be within the 320 hours available. Is he correct? Calculate the time required and check the accuracy of his calculation.

2. List the areas you think are causing trouble in this facility.

3. Develop a plan to deal with the situation and try to get the production schedule back under control under the constraints listed.

CASE STUDY 6.2

Crofts Printing Company

John Burton was not a happy man. He was a supervisor for the Crofts Printing Company, having been recently promoted from lead printer. While he felt very comfortable with his knowledge and success in the printing business, this managerial position was starting to wear on him. He was determined not to let it get him down, however, as he felt he surely had the knowledge, experience, and respect of the workers. He had been asking Jason Crofts for months for a chance at management, and he certainly wasn’t about to let it get the better of him.

His current problem had to do with scheduling. Since he had become supervisor the sales people always asked him about an order before they promised delivery to a customer. He thought that would be quite simple; after all, who knew more about the printing business than he did? Based on his knowledge of the processes and what was already in progress, he gave what he thought were reasonable, even conservative, estimates of promise dates. Unfortunately, his track record was not too good. There had been many late deliveries since his managerial appointment, and nobody in the organization was too happy about it.

At first he thought it must be the other workers. “They’re just jealous about my selection as supervisor and want to make me look bad” was his initial reaction. Henry Hurley, another long-time machine operator, was John’s best friend. One afternoon over a beer, John asked Henry about the problem in a confidential discussion. Henry said he was sure that John had been trying to get it right but somehow it didn’t seem to be going well. Henry assured John that the workers were trying their best. In fact, according to Henry, the workers had been putting in extra effort. They viewed John’s promotion as a positive sign that there was a possible future for them in management as well. John’s failure would have been, in fact, greatly discouraging to most of the workers.

John then thought he might be the problem when it came to giving estimates. The sales people would almost always contact him about a possible job to ask him when it should be promised to the customer. His great knowledge of the printing business allowed him, he thought, to quickly come to a good estimate. Perhaps he was not as good at estimating as he thought. To check this out, he looked at most of the jobs done during the last couple of weeks. In almost every case, the work recorded against a job was almost exactly what he had estimated. What little error existed was certainly not large enough to cause the problem.

John trusted Henry and believed his account of the situation, and his analysis of the estimates convinced him the problem wasn’t there. If it wasn’t the workers and wasn’t the estimates then what could it be? He must do something. Jason Crofts was a patient man, but there was a limit. He was worried about alienating his best customers, and at the same time knew he must be concerned about efficiency as a way to control cost.

John decided there was a need to take drastic action to ease the situation, or at least to find out what the cause was. On a Friday he scheduled overtime for Saturday to finish all jobs in progress. On Monday, therefore, he could start with a clean slate. There were several jobs already promised, but not yet started. He figured that on Monday he could start with all new jobs and really figure out the source of his problem.

The jobs were all promised within four days, but he figured there should be no problem. He had three operations, and most of the jobs went through all three, but not all jobs needed all operations. He had one worker assigned to each operation. Over the next four days that represented 96 hours of available work time (3 operations × 4 days × 8 hours
per day), he had eight jobs promised. The total estimated time for all eight jobs was only 88 hours, giving him a buffer of 8 hours over the next four days. To make sure there would be no problem, he decided there would be no new jobs even scheduled to start during those four days, with the only exception being if any operation completed all the necessary work for all eight jobs before the end of the four days, they could start another. In any case, he wanted to make sure that if necessary, all 96 hours would be reserved for just the 88 hours of scheduled work.

John had learned that a good priority rule to use was the critical ratio rule, primarily because it took into account both the customer due date and the amount of processing time for a job. He therefore used that rule to prioritize the jobs. The following table shows the eight jobs, together with processing time estimates and due dates. All due dates are at the end of the day indicated. Processing times for all jobs at all three operations are in hours.

<table>
<thead>
<tr>
<th>Job</th>
<th>Operation 1</th>
<th>Operation 2</th>
<th>Operation 3</th>
<th>Total Time</th>
<th>Day Due</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>5 hours</td>
<td>3 hours</td>
<td>4 hours</td>
<td>12 hours</td>
<td>Tuesday</td>
</tr>
<tr>
<td>B</td>
<td>0</td>
<td>6</td>
<td>2</td>
<td>8</td>
<td>Wednesday</td>
</tr>
<tr>
<td>C</td>
<td>4</td>
<td>2</td>
<td>5</td>
<td>11</td>
<td>Tuesday</td>
</tr>
<tr>
<td>D</td>
<td>7</td>
<td>0</td>
<td>3</td>
<td>10</td>
<td>Thursday</td>
</tr>
<tr>
<td>E</td>
<td>2</td>
<td>8</td>
<td>0</td>
<td>10</td>
<td>Thursday</td>
</tr>
<tr>
<td>F</td>
<td>0</td>
<td>6</td>
<td>3</td>
<td>9</td>
<td>Thursday</td>
</tr>
<tr>
<td>G</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>10</td>
<td>Thursday</td>
</tr>
<tr>
<td>H</td>
<td>6</td>
<td>5</td>
<td>6</td>
<td>17</td>
<td>Thursday</td>
</tr>
</tbody>
</table>

Assignment
1. Using the critical ratio rule, establish the priority for the eight jobs.
2. Use a chart to load the operation according to the priority rule established. In other words, load the most important job in all three work centers, then the next most important, and so forth. This is the method that John used.
3. Analyze John’s approach and try to determine if he has a problem, and if he does determine the source of the problem.
4. Try to provide a solution to John that will ease the problem, and perhaps eliminate it.

CASE STUDY 6.3

Melrose Products
Jim Hartough was not in a good mood. He worked his way through the ranks when supervisors did supervision and workers did what they were told. He was now faced with the fact that the new president of Melrose products was one of these “touchy-feely” types that was pushing for self-directed work teams. As the manufacturing manager, Jim was ultimately responsible to not only meet production needs, but also to do so in the most efficient and cost-effective manner possible. To him, that meant specific allocation of work. It had always worked that way and he saw nothing new to tell him it shouldn’t continue to do so.

Part of the problem, Jim realized, was that the business environment was changing. Changes in the product design were becoming more frequent and the customers were expecting more service. While they were still sensitive to price (the competition had not disappeared), they wanted quick delivery, high quality, and the product designed more specifically to their need. To Jim, that meant putting more pressure on those “lazy, pampered engineers” to make better designs as well as additional pressure on those “bums on the factory floor” to meet production needs. With better designs, he
could more easily allocate the work to his workforce to meet the customer demands. He felt he had truly kept up with the times—the customer was king. The fact that the customer expected more meant little more than how to get them what they wanted from production. It was merely a case of making sure everyone delivered on the job the way they were supposed to.

While Mr. Melrose had avoided the need to become a public company and had managed to keep unions out, he had still apparently gone soft, at least according to Jim. He had recently appointed Cindy Lopez as the new president, passing over Jim. She not only had an MBA (Jim had always thought the real business learning was done “on the firing line”), but also had never even been a supervisor. She had come from, of all places, the human resources department! That department had never done anything for him other than send him a bunch of worthless people. Some of those people had, in his mind, no chance of ever becoming useful. As far as he was concerned, the only real value of a human resources department was to keep the government idiotic bureaucrats off their backs.

So, now Jim was in the position to try to “change with the times,” as Cindy had said. She wanted to gradually move the company toward flexible self-directed work teams. Jim, of course, felt that all the workers really wanted was to get their paycheck and party on Friday and Saturday nights, and could care less about having any say in the product or the customer. How was he ever going to get anything done with someone so naive in charge?

The Current Situation

Cindy had suggested that Jim start the process of changing to teams by looking at the K-line. The K-line of product was a fairly standard product that had recently undergone heavy competitive pressure in the form of delivery speed and design enhancements. Melrose had been gradually losing market share in the K-line. Jim had responded, before the naming of Cindy as president, by putting additional pressure on workers to be more efficient and reducing their task times. As Jim said, “there’s always some slack time we can squeeze out of any process if we really put our minds to it.”

They are using carefully developed time standards, much as Jim learned in his Industrial Engineering courses. He feels they are quite good, including a liberal 10% allowance. Since the K-line is a fairly standard product, Jim not only uses the time standard to develop cost figures for labor, but also uses those cost figures to allocate overhead.

There are currently seven labor tasks to make one of the K-line products.

<table>
<thead>
<tr>
<th>Task</th>
<th>Standard Time (Min.)</th>
<th>Estimated Labor Cost/Minute</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7.5</td>
<td>$0.24</td>
</tr>
<tr>
<td>2</td>
<td>2.3</td>
<td>$0.22</td>
</tr>
<tr>
<td>3</td>
<td>4.7</td>
<td>$0.28</td>
</tr>
<tr>
<td>4</td>
<td>5.1</td>
<td>$0.29</td>
</tr>
<tr>
<td>5</td>
<td>17.8</td>
<td>$0.26</td>
</tr>
<tr>
<td>6</td>
<td>19.1</td>
<td>$0.18</td>
</tr>
<tr>
<td>7</td>
<td>8.4</td>
<td>$0.25</td>
</tr>
</tbody>
</table>

The overhead allocation is currently at 230% of direct labor. Material costs are $9.35 per unit. They currently have enough labor to produce 20 of the K-line per shift. Each shift has one supervisor costing about $24 per hour, accounted for in the overhead account.

From this information, Jim was being asked to develop teams, and without direct supervision. From his standpoint, the effort was doomed to failure. Jim, however, always considered himself a “company man” and would do what he could to make it happen.
Assignment
1. What is the standard cost of the K-line product?
2. What specific steps would you undertake to make the self-directed teams? How, specifically, would you deal with the cost and time standard issues?
3. Do you agree with Cindy? Do you agree with Jim? Is there some other alternative approach that might be better in this situation? Explain.
4. What do you do with the supervisor in this situation? Be specific in your approach.
5. How do you deal with Jim? Develop a specific plan to deal with a situation such as the one described.
6. Are self-directed work teams the answer? Where should or shouldn’t they be used. Discuss the pros and cons of such teams and where, or where not, they should be used, and how they would be used in this situation, if appropriate.