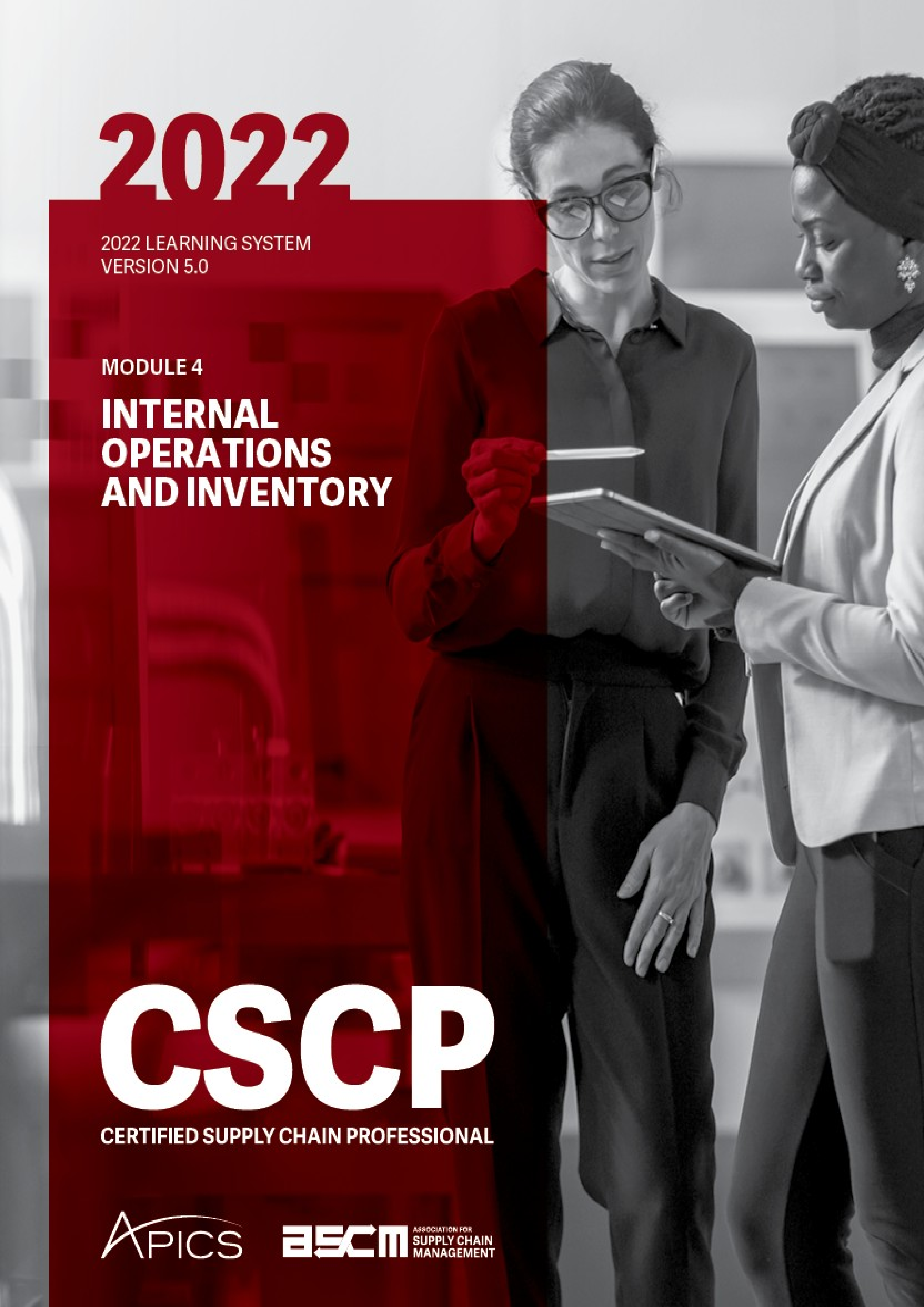

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MODULE 4

INTERNAL OPERATIONS AND INVENTORY

CSCP

CERTIFIED SUPPLY CHAIN PROFESSIONAL

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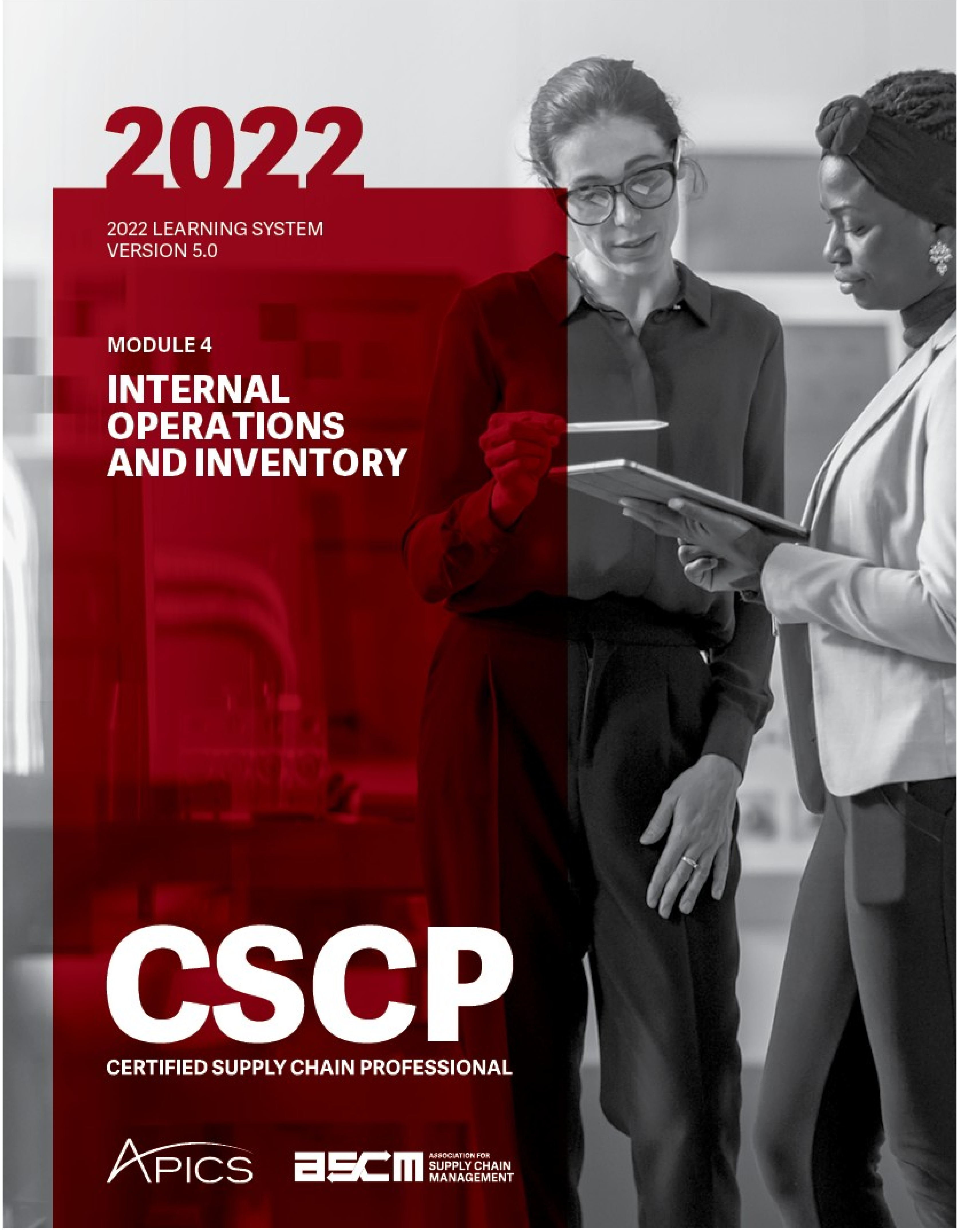

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APICS Certified Supply Chain Professional (CSCP) Learning System

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Module 4: Internal Operations and Inventory

This module addresses how products and services are produced and how the related inventories are managed and controlled.

The processes of master scheduling, material requirements planning, and various levels of capacity checks are discussed at a high level to start the module.

Since great inventory management can be a competitive advantage, the module then discusses how to align inventory requirements with demand, manage various types of inventory, set policies for how various classes of inventory will be replenished, audit actual inventory levels, and manage product disposition and obsolescence. Product traceability and chain of custody are hot topics in supply chain management today, both for regulatory compliance and for promoting internal supply chain efficiency. These subjects are discussed here from an internal communications perspective.

Another key area of discussion is measuring and assessing the performance of internal operations and inventory management, including financial performance.

The module concludes with a discussion of continuous improvement, total quality management, and many related tools, including general tools such as benchmarking, the seven basic tools of quality, the seven new tools, and systematic methodologies such as lean and six sigma.

Section A: Planning Operations

This section is designed to

- Describe the purpose and objectives of manufacturing planning and control and its major subset, master scheduling
- Identify master scheduling grid components, including the master production schedule, available-to-promise, and time fences
- Describe the steps to follow in creating a master production schedule
- Differentiate independent and dependent demand
- Describe the purposes of bills of material
- Define lead time, exploding, and offsetting
- Define push and pull distribution and distribution requirements planning (DRP) and explain the relative benefits of DRP.

Planning operations is how the supply side of operations keeps itself in balance with the demand side. The overall process is called manufacturing planning and control, which includes sales and operations planning, master scheduling, material requirements planning, and execution steps. Learning the logic of master scheduling and materials requirements planning in particular helps supply chain managers understand when this process is operating smoothly versus when it needs attention, such as to reduce frequent changes that cause expensive disruptions. Distribution requirements planning is also discussed here, which is how distribution networks directly link up with a master scheduling system.

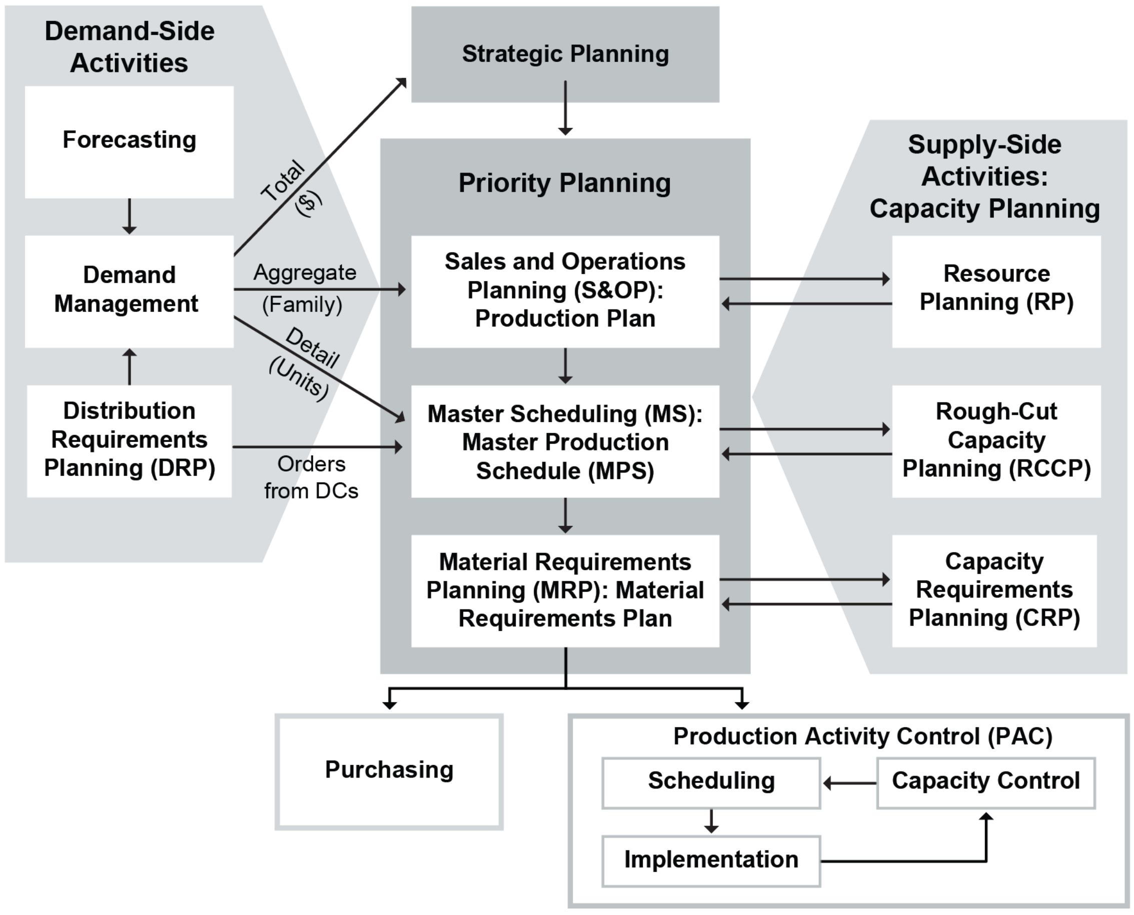
Topic 1: Planning Operations

From a supply side, supply chain managers are most concerned with the sales and operations planning (S&OP) process, because it is how they ensure that supply and demand are balanced so supply chain processes can be consistent. However, it is important to place this process into its overall context, so this is presented first. After that, a master scheduling tool called the master scheduling grid is presented, including a discussion of time fences. The process can also be used for allocation of supply because a projected available balance and an available-to-promise amount can be determined.

Planning Operations Road Map

The manufacturing planning and control process is used to plan operations. A high-level view of the process is shown in Exhibit 4-1.

Exhibit 4-1: Manufacturing Planning and Control



The collaborative process of sales and operations planning is used to generate the production plan at the level of aggregate supply and demand. It determines production volumes for product families rather than individual products. This process reconciles the needs of demand (activities on the left side of the exhibit) with the needs of supply (the various levels of capacity checks on the right).

Master scheduling (MS) is then used to create a master production schedule (MPS) that will commit the company to produce specific products on particular dates. The master scheduling process, therefore, has to disaggregate the product family data into numbers of individual products based on inventory levels, forecasts, demand plans, order backlogs, orders from distribution centers (DCs) as part of distribution requirements planning (DRP), and other considerations used to decide what you need to produce and how much of each item to produce.

From there, material requirements planning (MRP) automatically calculates all of the various materials that will be needed to produce the units that are scheduled. This could then result in purchasing or drawing materials from inventory. In addition to purchasing, production execution involves production activity control, which is the detailed planning and scheduling of shop floor equipment and resources.

Each planning stage includes a capacity check:

1. The aggregate production plan is checked against long-term capacity requirements using resource planning.
2. Rough-cut capacity planning at the master scheduling level verifies that the production targets are feasible
3. Capacity requirements planning at the MRP level checks capacity in detail.

4. Capacity control at the execution level validates that each job has the resources needed to run the job.

Capacity issues can result in efforts to increase capacity to the degree feasible or in the master scheduler revising the plan if the load exceeds available capacity.

The master scheduling process is typically facilitated by IT such as an enterprise resources planning (ERP) system, which creates a master scheduling grid for calculating production based on these data.

Master Scheduling Grid

The *APICS Dictionary,* 16th edition, defines the **master schedule** as

> a schedule format that includes time periods (dates), the forecast, customer orders, projected available balance, available-to-promise, and the master production schedule. It takes into account the forecast; the production plan; and other important considerations such as backlog, availability of material, availability of capacity, and management policies and goals.

The *Dictionary* defines a **master schedule item** as

> a part number selected to be planned by the master scheduler. The item is deemed critical in its impact on lower level components or resources such as skilled labor, key machines, or dollars. Therefore, the master scheduler, not the computer, maintains the plan for these items. A master schedule item may be an end item, a component, a pseudo number, or a planning bill of material.

The master scheduling grid calculates a projected available balance and available-to-promise amounts for demand prioritization purposes. It also calculates the master production schedule for operations purposes. See Exhibit 4-2.

Exhibit 4-2: Master Scheduling Grid

Period		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Forecast		20	22	21	25	24	23	21	21	25	25
Customer orders		19	17	15	11	9	5	2	1	0	0
Project available balance (PAB)	50	31	14	49	24	0	27	6	35	10	35
Available-to-promise (ATP)		14		15			43		49		
Master production schedule (MPS)				50			50		50		50

Demand Time Fence

Planning Time Fence

Source: APICS Master Planning of Resources, Version 3.1.

Master Scheduling Grid Line Items

The line items of the master scheduling grid are defined as follows.

Forecast

The forecast is the per-period demand plan for the individual end item. It is based on the forecast modified by the presumed effect of planned demand-influencing activities.

Customer Orders

According to the *Dictionary,* a **customer order** is

> an order from a customer for a particular product or a number of products. It is often referred to as an actual demand to distinguish it from a forecasted demand.

Projected Available Balance and Available-to-Promise

Projected available balance (PAB) and available-to-promise (ATP) are covered elsewhere, including details on how to calculate these items.

Master Production Schedule

The *Dictionary* defines the **master production schedule (MPS)** as

> a line on the master schedule grid that reflects the anticipated build schedule for those items assigned to the master scheduler. The master scheduler maintains this schedule, and in turn, it becomes a set of planning numbers that drives material requirements planning. It represents what the company plans to produce expressed in specific configurations, quantities, and dates.

MPS also takes into account **interplant demand ,** a “plant’s need for a part or product that is produced by another plant or division within the same organization” (*Dictionary*).

By providing firm production dates and numbers, the MPS serves as a contract between sales and operations. Putting numbers to the mutual obligations implied by the MPS “contract” offers benefits to both sides:

- For the sales force, the MPS provides assurance that they may make delivery commitments to customers based on the amount of product that will be available week by week.
- For operations, the commitment of the sales force to meet its numbers provides assurance that they can avoid problems resulting from overproduction or an excess of orders. Those problems include layoffs and unused plant capacity in the case of overproduction and the need to expand capacity rapidly and temporarily when orders exceed capacity.
- From the viewpoint of the company and the supply chain, the balance of supply and demand offers several potential benefits:
  - Low holding costs for inventory
  - Fewer stockouts that might back up customer orders, causing frustration and reduced loyalty
  - Efficient use of plant, labor, and equipment

Weekly Dates for Specific Products

Besides disaggregating the product families, master scheduling also determines weekly production dates based on the monthly projections in the production plan. Exhibit 4-3 shows what might happen to monthly S&OP numbers for a family of laser printers when the master scheduler disaggregates the projections into weekly production numbers for specific models.

Note that the exhibit shows production numbers only, not demand projections.

Exhibit 4-3: Disaggregation of Operations Plan Numbers into Weekly MPS

Months	July				August			
Aggregate production plan (S&OP) (Total production for family of laser printers)	1,000				1,200			
Weeks	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Master production schedule (Shows weekly production numbers for specific models within the product family)								
LX30—30-ppm	50	50	50	75	75	75	50	100
LX21—21-ppm	75	25	100	75	100	100	100	100
LX15—15-ppm	50	150	150	150	75	125	150	150

Time Fences in Master Scheduling

As defined in the *APICS Dictionary,* 16th edition, a **time fence** is "a policy or guideline established to note where various restrictions or changes in operating procedures take place." A time fence marks off a zone in which changes to production may not be made without escalation to the appropriate level such as the master scheduler or the master scheduler's supervisor.

There are two types of time fences: the demand time fence (DTF) and the planning time fence (PTF). The two time fences create three zones, as shown in Exhibit 4-4.

Exhibit 4-4: Time Fences and Zones in Master Scheduling Grid

		Frozen Zone			**Slushy Zone**					**Liquid Zone**	
Period		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Forecast		20	22	21	25	24	23	21	21	25	25
Customer orders		19	17	15	11	9	5	2	1	0	0
Project available balance (PAB)	50										
Available-to-promise (ATP)											
Master production schedule (MPS)											

Demand Time Fence (between periods 3 and 4)

Planning Time Fence (between periods 8 and 9)

Source: APICS Master Planning of Resources, Version 3.1.

- **Demand time fence/frozen zone.** In a frozen zone, capacity and materials are committed to specific orders. Orders are therefore “frozen” inside the fence. Any changes require the approval of senior management. Frozen time zones are bounded by a demand time fence like the one in Exhibit 4-4.

- **Planning time fence/slushy zone.** A zone marked off by a planning time fence is slushy rather than frozen. Capacity and materials are not as strongly committed as those inside a frozen zone. There is room to negotiate in a slushy zone in the form of tradeoffs, and the master scheduler makes these decisions.

- **Liquid zone.** In the liquid zone created by the remaining planning horizon after the planning time fence, all changes are permissible as long as they don’t violate the limits set in the production plan from sales and operations planning.

Time Fences for Material Requirements Planning

Time fences for material requirements planning (MRP)—basically, planning for components or subcomponents of a production unit—work similarly to those described for master scheduling, except that each planned component will have its own set of time fences. The purpose of using time fences in MRP is to ensure that materials needed for orders are committed to those orders and not used for other purposes. The planning time fence is usually set when the material is ordered or production is begun on the component; the demand time fence is usually set when the material is received or production of the component is complete.

Time fences in MRP help manage the end item’s cumulative lead time because the operation will have its requisite materials available when they are needed. **Cumulative lead time** is defined by the *APICS Dictionary,* 16th edition, as

> the longest planned length of time to accomplish the activity in question. It is found by reviewing the lead time for each bill of material path below the item; whichever path adds up to the greatest number defines cumulative lead time.

Complex products or services often have lengthy production or rollout cycles and thus multiple time fences. For example, a ship’s hull may have one set of time fences, its engines another, and the furnishings for the cabins could have another set much later in production than the first two.

Benefits of Time Fences

Time fences can help balance the need for a production system to maintain schedules and control costs against the need for it to be flexible. Costs for changes dramatically increase when nearing the final deadline of a time horizon. Rescheduling, additional setups, rerouting, expediting, overtime, and disrupted schedules for other items can all be direct costs of late changes, not to mention the toll it takes on the perceived reliability of the master production schedule and on customer service.

However, flexibility is needed because customers can cancel orders or request changes, equipment can experience failures or other capacity problems could occur, raw materials could be used at a higher rate than expected (e.g., scrap), or suppliers could fail to deliver goods on time.

Allocation of Supply

The *APICS Dictionary,* 16th edition, defines **allocation** as

> 1) The classification of resources or item quantities that have been assigned to specific orders but have not yet been released from the stockroom to production. It is an "uncashed" stockroom requisition. 2) A process used to distribute material in short supply.

Allocation of supply involves giving sales staff or downstream supply chain partners a view into the projected available balance and what is available-to-promise to customers. It includes finding ways to commit inventory and scheduled production to specific customer orders (intermediate customers or ultimate customers), including order promising by salespersons, without needing to move the items from inventory until they are needed for production. As per the second definition, allocation also refers to demand management and prioritization activities.

The master scheduling grid that is created during the master scheduling process includes the projected available balance and available-to-promise. Exhibit 4-5 shows a master scheduling grid with a planning horizon of 10 weeks, minimum order quantities of 50, and a safety stock level of zero units. (As defined in the *Dictionary,* the **planning horizon** is "the amount of time a plan extends into the future." It should be at least equal to the cumulative lead time for the product.)

Exhibit 4-5: Time Fences and Zones in Master Scheduling Grid

		Frozen Zone			Slushy Zone					Liquid Zone	
Period		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Forecast		20	22	21	25	24	23	21	21	25	25
Customer orders		19	17	15	11	9	5	2	1	0	0
Project available balance (PAB)	50										
Available-to-promise (ATP)											
Master production schedule (MPS)											

Demand Time Fence **Planning Time Fence**

Source: APICS Master Planning of Resources, Version 3.1.

Projected Available Balance

The **projected available balance (PAB)** is "an inventory balance projected into the future" (*Dictionary*). Whenever the PAB in a given period falls to a negative value or below the safety stock level, the master production schedule (MPS) must be reevaluated. Exhibit 4-6 shows an amount of 50 to the left of the PAB for period 1. This represents the available inventory at the start of this planning horizon.

The MPS logic calculates the PAB for all future periods based on the beginning inventory and the demand for each period. In its simplest form, the PAB is based on a calculation of

$$\text{Beginning Inventory} + \text{Any Additional Supply} - \text{Any Demand} = \text{Ending Inventory}$$

For the MPS, this is complicated by having a formula for the periods before the demand time fence and another for after the demand time fence.

Exhibit 4-6 uses the data from Exhibit 4-5 to complete the PAB. Prior to the demand time fence, the calculation is as follows (with an example from period 1 in the exhibit):

$$\begin{aligned} \text{PAB Prior to DTF} &= \text{Prior Period PAB} + \text{MPS} - \text{Customer Orders} \\ \text{Period 1 PAB} &= 50\text{ Units} + 0\text{ Units} - 19\text{ Units} = 31\text{ Units} \end{aligned}$$

After the DTF, the calculation is as follows (with an example from period 6):

$$\begin{aligned} \text{PAB After DTF} &= \text{Prior Period PAB} + \text{MPS} - \text{Greater of Forecast or Customer Orders} \\ \text{Period 6 PAB} &= 0\text{ Units} + 50\text{ Units} - 23\text{ Units} = 27\text{ Units} \end{aligned}$$

Exhibit 4-6: Projected Available Balance

		Frozen Zone			Slushy Zone					Liquid Zone	
Period		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Forecast		20	22	21	25	24	23	21	21	25	25
Customer orders		19	17	15	11	9	5	2	1	0	0
Project available balance (PAB)	50	31	14	49	24	0	27	6	35	10	35
Available-to-promise (ATP)											
Master production schedule (MPS)				50			50		50		50

Demand Time Fence **Planning Time Fence**

Source: APICS Master Planning of Resources, Version 3.1.

As you can see, prior to the DTF we are concerned only with the known component of demand (customer orders). After the DTF it is the greater of forecast or orders. Recall that, in the frozen zone, materials are committed to orders and orders are frozen. The MPS logic therefore considers that only orders we have in hand will consume the on-hand inventory. Beyond the DTF, we can expect to receive more orders than those already booked.

As noted, the MPS logic uses the PAB level to determine when additional product is needed and proposes an MPS activity. (The MPS has to be checked with the rough-cut capacity plan to verify that capacity is available.) In Exhibit 4-6, the MPS reflects a quantity of 50 units to make in period 3. This was developed by calculating the PAB for each period. Using the PAB formula, the first period that would go negative is period 3. (The calculation would result in –1 units in period 3 if no MPS activity had been proposed.) Therefore, production of 50 units (recall that the replenishment for this product is fixed at 50 units) is required in period 3. Calculations for the remaining periods proceed in the same manner. Note the PAB of zero in period 5. Many planners may feel that we need to have replenishment at this point for many valid reasons. Understand, however, that the basic MPS logic is for the PAB to go negative before ordering. In an actual software configuration, planners could make adjustments to system variables to include replenishment at this point, or they could set a safety stock level.

Available-to-Promise

The *APICS Dictionary,* 16th edition, defines **available-to-promise (ATP)** as "the uncommitted portion of a company's inventory and planned production maintained in the master schedule to support customer order promising." The *Dictionary* defines **order promising** as "the process of making a delivery commitment (i.e., answering the question 'When can you ship?')."

The methods used to compute ATP are discrete ATP (or noncumulative), cumulative ATP with look-ahead, and cumulative ATP without look-ahead. For our example, we will use the noncumulative (discrete) method, because it is the base method that the other methods build upon. Noncumulative methods are used for products that have an expiration date, such as milk, vegetables, pharmaceuticals, or beer. Beer, for example, has a six-month time frame. The other methods account for unsold ATP from prior periods and backlogs in their calculations and are used for nonperishable items.

At the beginning of the planning horizon, the ATP amount includes inventory on hand plus the items scheduled to arrive in the form of an MPS receipt or scheduled receipts from a supplier. As customer orders come in and consume the uncommitted inventory, the number of available items goes down. When all the items have either been delivered or committed for delivery, nothing is left to promise.

Exhibit 4-7 uses the data from Exhibit 4-6 to complete the ATP row. ATP for the first period of the planning horizon is calculated as follows (with an example from period 1 of the exhibit):

First Period ATP = Inventory on Hand + MPS − Sum of Customer Orders Before Next MPS
Period 1 ATP = 50 Units + 0 Units − (19 Units + 17 Units) = 14 Units

Exhibit 4-7: Available-to-Promise

		Frozen Zone			Slushy Zone					Liquid Zone	
Period		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Forecast		20	22	21	25	24	23	21	21	25	25
Customer orders		19	17	15	11	9	5	2	1	0	0
Project available balance (PAB)	50	31	14	49	24	0	27	6	35	10	35
Available-to-promise (ATP)		14		15			43		49		50
Master production schedule (MPS)				50			50		50		50

Demand Time Fence (between periods 3 and 4)
Planning Time Fence (between periods 8 and 9)

Source: APICS Master Planning of Resources, Version 3.1.

For all other periods in which there is an MPS, the ATP does not include inventory on hand, so the formula is as follows (with an example from period 3 of the exhibit):

Following Period ATP = MPS − Sum of Customer Orders Before Next MPS
Period 3 ATP = 50 Units − (15 Units + 11 Units + 9 Units) = 15 Units

Commitment Decision Points

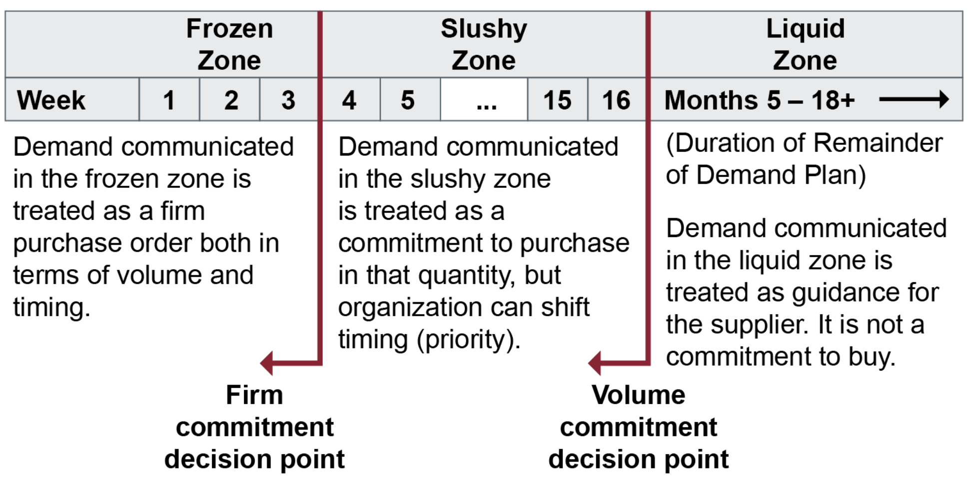
Two situations could frustrate buyer-supplier relationships when actual demand data and demand plans are shared:

- When the supplier apparently does not use the demand information and has not developed sufficient capacity (or maintains too much capacity) despite being given time and motivation make the necessary changes
- When the supplier builds sufficient capacity or inventory but the organization fails to order in that quantity because the plans overstate demand (or they understated demand and the supplier has insufficient capacity)

Since these problems affect both ends of the relationship, organizations that choose to collaborate should clearly set expectations and obligations in the form of a bilateral contract or trading partner agreement. Such agreements can specify how demand information will be communicated and what is expected of each organization in terms of building capacity or ordering what was requested. The agreement should specify development of formal processes to support the collaborative effort.

Such an agreement should specify when demand information represents a commitment to purchase goods or services and when it does not. This can be done using decision points similar to the time fences that were introduced previously. Exhibit 4-8 shows how decision points could be used to create three zones of purchase commitment so that sellers can feel comfortable committing to produce the requested orders on schedule.

Exhibit 4-8: Use of Decision Points to Create Purchase Commitment Zones



In this example, the organization negotiates two decision points with a supplier: a firm commitment decision point and a volume commitment decision point. The firm commitment decision point is set three weeks out, and this creates a frozen zone where the buyer commits to communicate purchase orders and makes firm requests for delivery timing on specific days. The buyer and the supplier negotiate a second decision point at 16 weeks out, a volume commitment decision point, which creates a slushy zone before the point and a liquid zone after the point. Within the slushy zone, demand that is communicated is treated as an agreement to specify weekly quantities to deliver. The buyer can rearrange priorities or change timing of orders but must buy the specified quantity of goods or services during those weeks. The liquid zone is used to communicate updates to the demand plan over whatever remains of the demand plan's planning horizon (five to 18 months in this example). Demand information communicated for these periods represents no contractual commitments for purchasing or production on the part of the buyer or the supplier.

If negotiations take this format, the subjects for negotiation will include where each decision point should be placed, based on the given industry, the supplier and buyer lead times, and the amount of flexibility or continuity each partner desires in the relationship. These negotiations should occur at the executive level with input from both organizations' supply and demand professionals. This will ensure that the plan encompasses all technical requirements for order timing while getting top support for the agreement.

This type of agreement allows the organizations to have a long-term focus and provides some amount of stability for the buyer and the supplier and perceived fairness for both parties.

Topic 2: Materials and Inventory

After finished goods are scheduled for production to satisfy demand, the necessary raw materials and components are calculated using material requirements planning (MRP). Also, inventory levels at specific locations are planned using distribution requirements planning (DRP). Besides discussing MRP and DRP, here we explain a number of manufacturing specifics: routing files, lot-for-lot or fixed order quantity replenishment, and offsetting.

Material Requirements Planning

Material requirements planning is defined in the *APICS Dictionary,* 16th edition, as

> a set of techniques that uses bill of material data, inventory data, and the master production schedule to calculate requirements for materials.

MRP plans dependent demand items—the raw materials and components needed to produce finished goods for consumers. The *Dictionary* defines **dependent demand** as

> demand that is directly related to or derived from the bill of material structure for other items or end products. Such demands are therefore calculated and need not and should not be forecast.

The *Dictionary* defines **independent demand** as

> the demand for an item that is unrelated to the demand for other items. Demand for finished goods, parts required for destructive testing, and service parts requirements are examples of independent demand.

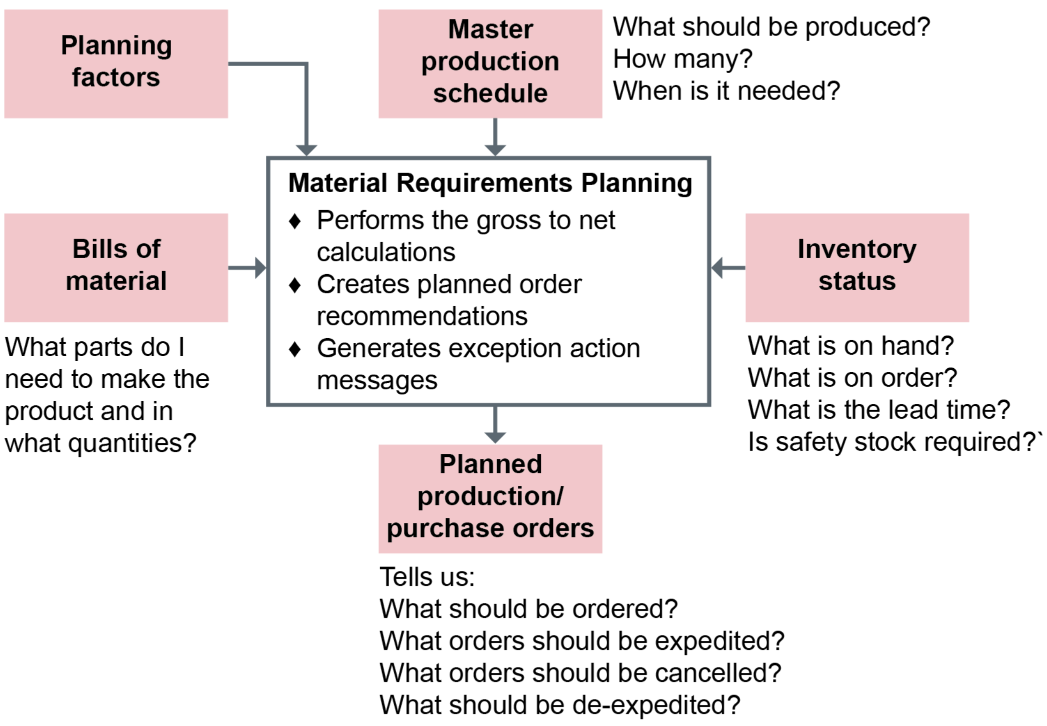
While independent demand is the subject of demand forecasts, dependent demand is not. Before you can talk about dependent demand for pockets and zippers and bolts of denim, there has to be independent consumer demand for jeans—or at least a demand plan based on a forecast. There can, however, be independent and dependent demand for the same item. For example, an item may be used as a component in finished production but also sold independently as a repair part or upgrade item. Auto parts stores stock replacement parts for independent sales to individuals and repair shops. Shelves in electronics stores contain numerous computer subsystems sold as upgrades. Those items are subject to independent sales and production forecasts. The same items are also ordered by manufacturers who base their orders for components on demand forecasts for the finished computers.

Dependent demand doesn't require estimation, only calculation. A scheduled demand for 1,000 pairs of blue jeans to be delivered in March to a major chain store creates a dependent demand for 1,000 right legs, 1,000 left legs, 2,000 front pockets, 1,000 zippers, 1,000 snaps, several thousand belt loops and rivets, and, further up the supply chain, bolts of denim, tons of cotton, kilograms of metal, and so on.

MRP plans all the orders that will get those materials to the right work centers or suppliers at the right times to get those blue jeans put together on the dates specified in the MPS.

Exhibit 4-9 illustrates the data inputs required for MRP and the resulting outputs.

Exhibit 4-9: Material Requirements Planning



MRP Inputs

As you can see from Exhibit 4-9, inputs to MRP include the master production schedule, inventory status, planning factors, and bills of material.

- The master production schedule lists planned or scheduled orders for end items—tables, computers, automobiles, finished clothing, etc. The *Dictionary* defines the following terms related to item orders.
  - **Planned orders** are

    > a suggested order quantity, release date, and due date created by the planning system's logic when it encounters net requirements in processing MRP. In some cases, it can also be created by a master scheduling module. Planned orders are created by the computer, exist only within the computer, and may be changed or deleted by the computer during subsequent processing if conditions change. Planned orders at one level will be exploded into gross requirements for components at the next level. Planned orders, along with released orders, serve as input to capacity requirements planning to show the total capacity requirements by work center in future time periods.

    Note that to be more precise, references to "the computer" in this and the next definition could be replaced by "MRP software."
  - **Firm planned orders (FPOs)** are

    > planned order[s] that can be frozen in quantity and time. The computer is not allowed to change [them] automatically; this is the responsibility of the planner in charge of the item that is being planned. This technique can aid planners working with MRP systems to respond to material and capacity problems by firming up selected planned orders. In addition, firm planned orders are the normal method of stating the master production schedule.

  - An **open order** (released order) is "a released manufacturing order or purchase order."
  - A **scheduled receipt** is "an open order that has an assigned due date."
- **Inventory status** is what materials are already available for use in manufacturing the finished goods and what finished goods exist now.
- **Planning factors** include safety stock concerns and lead times (how long it will take to get each component after it has been ordered; this is necessary for proper timing of orders).
- The **bill of material** (BOM) is a complete list of components and the quantities of each needed to make one unit of the end item—the "product tree." A BOM provides the basis for answering the questions "What do we need?" and "How many of them do we need?" In its simplest configuration, a bill of material is an ingredient list, enumerating quantities of every component required to

manufacture an item. It can also do a great deal more, such as enabling building modular components.

provides an example of a multilevel bill of material for a ½-horsepower electric motor.

Exhibit 4-10: Multilevel BOM for Electric Motor

Multilevel Bill of Material

Model: **JTE-5000**
Plant: **3000**
Validity Date: **9/13/XX**

Product Structure	Assembly	BOM Status	Short Text	Quantity
▼ **JTE-5000 3000 1 01**			**1 Motor, Electric 1/2 HP**	
▼ 0010 L JTE-4001	*		Stator Assembly	1
▼ JTE-4001 3000 1 01			1 Stator Assembly	
▼ 0010 L JTE-2002	*		Stator Leads	3
► JTE-2002 3000 1 01			1 Stator Leads	
0010 L JTE-1001			Terminal-Flag	1
0020 L JTE-1002			Wire-Stranded	1
▼ 0020 L JTE-3001	*		Stator Wire Coils	1
► JTE-3001 3000 1 01			1 Stator Wire Coils	
0010 L JTE-2001			Wire-Aluminum	25
▼ 0030 L JTE-3002	*		Stator Blank	60
► JTE-3002 3000 1 01			1 Stator Blank	
0010 L JTE-2003			Steel, Coiled	1
0020 L JTE-3004			Rotor Blank	1–
0040 L JTE-1004			Varnish	0.001
▼ 0020 L JTE-4002	*		Rotor Assembly	1
▼ JTE-4002 3000 1 01			1 Rotor Assembly	
▼ 0010 L JTE-3003	*		Shaft Rotor	1
► JTE-3003 3000 1 01			1 Shaft Rotor	
0020 L JTE-3004			Rotor Blank	60
0030 L JTE-3005			Aluminum	1
▼ 0030 L JTE-4003	*		End Bell-Top	1
▼ JTE-4003 3000 1 01			1 End Bell-Top	
0010 L JTE-3005			Aluminum	1
0020 L JTE-4004			End Bell-Bottom	1–
0040 L JTE-4004			End Bell-Bottom	1
0050 L JTE-4005			Screw-6", Motor Assembly	4

The *APICS Dictionary,* 16th edition, defines a **multilevel bill of material** as

> a display of all the components directly or indirectly used in a parent, together with the quantity required of each component. If a component is a subassembly, blend, intermediate, etc., all its components and all their components also will be exhibited, down to purchased parts and raw materials.

The *Dictionary* defines a **parent item** as "the item produced from one or more components," while a **component** is "the raw material, part, or subassembly that goes into a higher level assembly, compound, or other item; this term may also include packaging materials for finished items."

shows that the motor parent JTE-5000 3000 1 01 contains the following components, some of which are parents to other components:

- One stator assembly (part number 0010 L JTE-4001)
- One rotor assembly (part number 0020 L JTE-4002)
- One end bell-top (part number 0030 L JTE-4003)
- One end bell-bottom (part number 0040 L JTE-4004)
- Four six-inch screws (part number 0050 L JTE-4005)

The user can click the arrows to the left of the part numbers (far left of the screen) to reveal the parts needed to assemble those components. In the exhibit, the arrows pointing downward have already been clicked to reveal their components, while the arrows pointing to the right could still be clicked to drill further down into the details for each component. In this way a user can see the steady "explosion" of the parts tree for all the components of the BOM or keep the BOM at a high level as needed.

Another type of BOM is the modular (planning) bill that pertains to the construction of a module that is not a finished product but is a component for use in a product. In a mass customization situation, operations may focus on the creation of a number of modules for later assembly. The MRP in that case schedules orders for the materials used in constructing the modules. Companies can also use a configure-to-order process that presents modular options when the sales order is being entered.

MRP Outputs

With the information from the master production schedule and bill of material and on inventory status and planning factors, it is possible to develop a complete schedule for ordering (and delivering) all the components and materials necessary to create the items in the master schedule. The MRP process results in planned orders for making or buying all the components required. It typically includes the following specifications as defined in the *APICS Dictionary,* 16th edition:

- **Planned order receipts .** A planned order receipt (planned receipt) is "the quantity planned to be received at a future date as a result of a planned order release. Planned order receipts differ from scheduled receipts in that they have not been released."
- **Planned order releases .** A planned order release is "a row on an MRP table that is derived from planned order receipts by taking the planned receipt quantity and offsetting to the left by the appropriate lead time." Planned order releases may differ depending on whether the order needs to be manufactured or purchased.
- An **exception report .** This is "a report that lists or flags only those items that deviate from the plan."

When the planning system calculates net requirements in MRP, it generates a set of planned orders, which are subject to change until orders are either made into firm planned orders by the planner or are released to become open orders or scheduled receipts (if assigned a due date). A planned order receipt is the same as a scheduled receipt except that it is used for planned orders (i.e., not yet released) and so there is still some uncertainty whether the order will be released.

Note that when a family of related items is released as if it were one item, it is considered a joint replenishment system. According to the *Dictionary,* **joint replenishment** is a process of

> coordinating the lot sizing and order release decision for related items and treating them as a family of items. The objective is to achieve lower costs because of ordering, setup,

shipping, and quantity discount economies. This term applies equally to joint ordering (family contracts) and to composite part (group technology) fabrication scheduling.

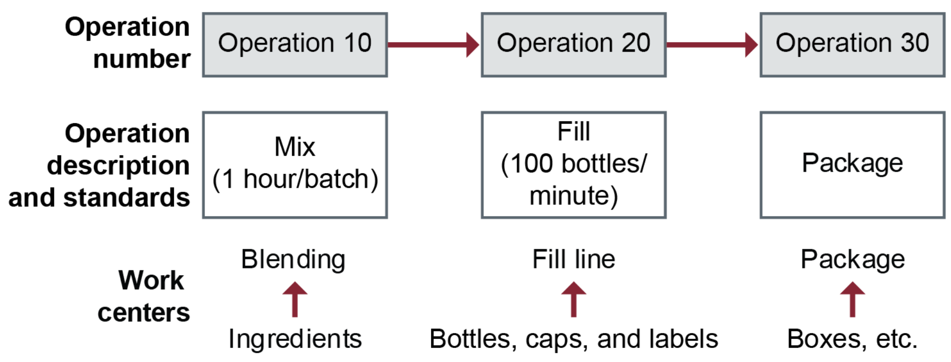
Manufacturing Specifics

Other aspects of manufacturing related to MRP are the routing file, lot-for-lot or fixed order quantity replenishment, and offsetting.

Routing File

When planning a trip, travelers can refer to route on a map. In manufacturing, we also look for the route, which is found in a routing file (router file or route sheet). The router maps the journey of a component from work center to work center, specifying all the operations it undergoes on the way to completion. It indicates each of the manufacturing steps required, the sequence of the steps, and the time required. There will be one entry for each operation. This can be very simple, such as the process shown in for an orange juice operation, or very complex, such as if the component travels around a global supply network with numerous partners. Note that this complexity would be broken down to be more palatable by having major part numbers each have their own set of routings.

Exhibit 4-11: Routing for Orange Juice



A **routing** for a product shows how it is manufactured in one or more operations. Each operation is identified by a sequence number and a description. The sequence number places the operations in the proper manufacturing sequence. The operations also identify where that process occurs and the standard setup and run times for the product. Tooling and testing requirements can also be included in the routing definition.

Lot-for-Lot or Fixed Order Quantity Replenishment

While inventory replenishment for independent demand may include some safety stock as a buffer against demand uncertainty, that sort of variability doesn’t affect dependent demand. There’s no buffer necessary, so any safety stock would only be a waste of money for storage space, handling, and production capacity. Also, using a fixed order quantity (FOQ) often makes sense for the production of end items because it can provide production efficiencies. However, if each dependent demand component were ordered in lots, this can result in a huge number of components accumulating that may not experience any demand for a long time. Therefore, a lot-for-lot replenishment technique is typically used for most dependent demand. In lot-for-lot replenishment, the exact number of components needed for production is the number that should be produced and delivered when needed.

When operations for filling dependent demand orders allow batch sizes to vary, lot-for-lot is the favored technique. However, an FOQ technique must be used rather than lot-for-lot for operations that require fixed batch sizes and order quantities (e.g., accommodating a fixed vat size for beer brewing).

Lot-for-lot scheduling depends upon the following essential information:

- Gross delivery required
- Projected amounts on hand for delivery
- Scheduled receipts (more potential deliverables)
- Net requirements (gross minus on-hand items and scheduled receipts)
- Lead time (so operations can be scheduled in time to meet the delivery date)

With that information, you can specify the date to release the order and the date it will be received. The example in assumes weekly deliveries and a one-week lead time.

Exhibit 4-12: Lot-for-Lot Scheduling

MRP Lot-Sizing Problem: Lot-for-Lot Technique											
Week		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Gross Requirements		35	30	40		10	40	30		30	55
Scheduled Receipts											
Projected on Hand	35	0	0	0	0	0	0	0	0	0	0
Net Requirements			30	40		10	40	30		30	55
Planned Order Receipts			30	40		10	40	30		30	55
Planned Order Releases		30	40		10	40	30		30	55	

Note in the exhibit that planned order releases (bottom row) are always equal to planned order receipts in the next column to the right and up one row. The orders released always equal the orders to be received—because in this example there is a one-week offset for lead time to produce the order.

In week 1, you will see that there is no net requirement even though the gross requirement is 35 units. That's because the week starts with 35 units projected on hand—enough inventory to fill the order without setting up for production. After that first week, gross and net requirements are equal because there is no more inventory on hand.

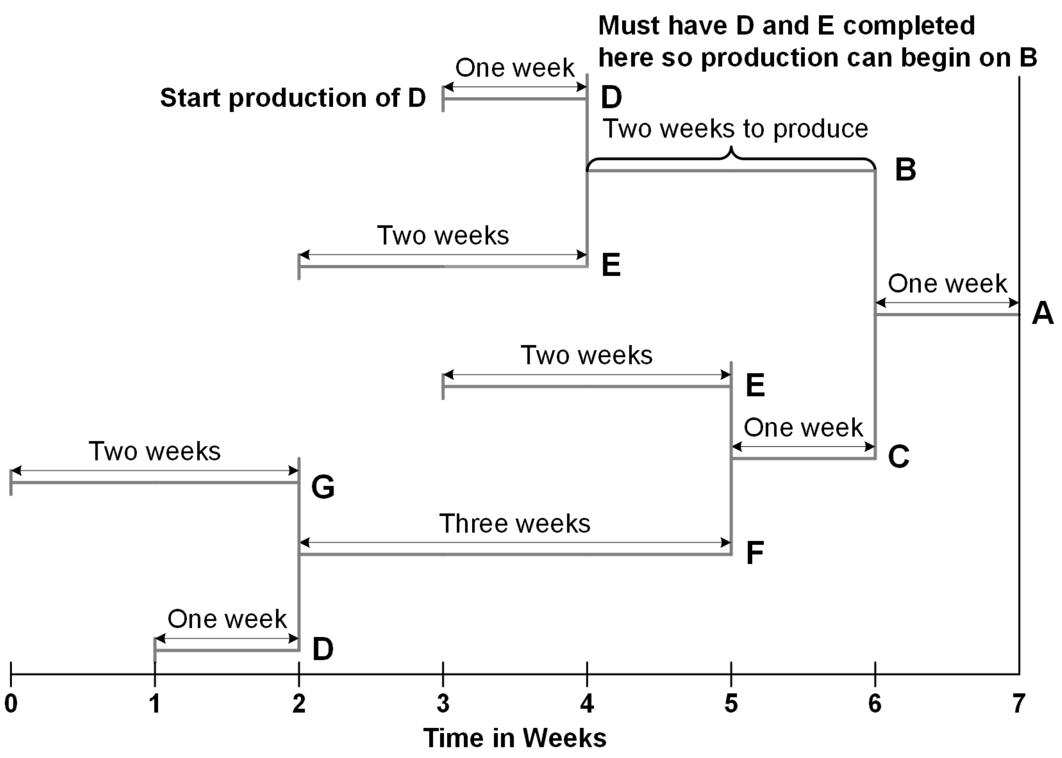
Offsetting

We just looked at a series of orders for one component. Scheduling the orders for all components for a product is more complicated. Why? Because the components are likely to have different lead times. If you want them all to arrive simultaneously at one work site or work center, you have to schedule different release dates based on the different lead times.

This process of counting backward from a due date to accommodate lead time is called offsetting. If you had a simple product with two components, product A with a lead time of one week and product B with a lead time of two weeks, you would release the order for A one week before the order receipt date and you would release B two weeks before the order receipt date.

Real products can be complex, of course, with the components themselves having components, and those components having components, and all of them having different lead times. As shown in , let's say product A is constructed from components B and C over a lead time of one week. Assume that component B has a lead time of two weeks and is itself constructed from components D and E, with lead times of one and two weeks respectively. Similarly, component C has a lead time of one week but is also assembled from components E and F with lead times of two and three weeks respectively. Finally, component F has to be constructed of components D and G, with lead times of one and two weeks.

Exhibit 4-13: Component Orders Offset by Lead Times for Simultaneous Arrival



Managing MRP

There is a degree of inflexibility built into MRP, because it uses fixed lead times. MRP has ease of replanning among its strong points, especially if you're using software that sorts out the impact that a change in one part of a schedule can have on the other parts. In the net change approach, only those parts of the MRP that require changes have to be altered. Regeneration of the entire plan is the more difficult alternative.

Feedback Loops and System Nervousness

Good supply chain planning contains numerous feedback loops so that one level of planning can test the assumptions of the previous level and ask for changes if the plan seems impracticable. Regular S&OP meetings are one place where feedback can be received and processed almost continuously. The MRP is also subject to change when events such as changes in design or the master production schedule make alterations seem necessary. The plan may be revised as often as daily to keep current with changing data.

However, too frequent alteration of the plans can be extremely expensive and demoralizing to staff, such as purchasers and production schedulers. Frequent and often frantic adjustments to MRP are known as system nervousness. Each change can result in multiple components needing to be rescheduled or expedited. To avoid this consequence, managers should consider possible problems before allowing too many changes.

Time fences in the master schedule are one way to ease the system nervousness. They designate cutoff when automatic rescheduling is not allowed even if changes are made to the MRP—unless an exception order receives specific authorization.

Another way to mitigate excessive nervousness is pegging each component to its parent in the bill of material. The *APICS Dictionary,* 16th edition, defines **pegging** as follows:

> In MRP and MPS, the capability to identify for a given item the sources of its gross requirements and/or allocations. Pegging can be thought of as active where-used information.

When a pegged component is affected by a schedule change, someone can easily check to see what happened to its parent. It may turn out that the schedule change for the component was a mistake. Or, if there is an availability issue with a lower-level item, the planner can quickly check which end items will be affected and take countermeasures to minimize harm to the overall production schedule.

System nervousness is not always a mere annoyance to be suppressed. Nervousness can make an otherwise sound system costly and inefficient. Sometimes it's a symptom of excessive reprioritizing on the shop floor or in purchasing. This can underlie a variety of problems, such as quality issues or other conditions, and root causes should be sought to see if the nervousness is a result of problems in those areas.

Reconciling Just-in-Time or Lean with MRP

The fixed lead times in MRP can come into conflict with JIT's or lean's commitment to moving materials as fast as possible to reduce inventory costs. Two ways to reconcile MRP and JIT or lean are the small bucket or bucketless approach and balanced flow:

- **Small bucket or bucketless systems.** MRP typically uses a bucket system of timing orders. For instance, an MRP might schedule all the orders in week-long time buckets. Reducing the bucket size from a week to a day or even less speeds up the flow considerably by allowing material releases to stagger.

Some work centers don't use buckets for scheduling at all but attach dates to each item. In bucketless systems, orders can move through the work area on a JIT basis. As soon as an operation is complete, the item moves into inventory, reducing the quantity of scheduled receipts in the MRP system. Inventory balances are then reduced by backflushing, which means using the bill of material to deduct component quantities from inventory as soon as the unit has been completed.

- **Balanced flow.** Another way of combining JIT and MRP, called balanced flow, is used in repetitive work centers such as assembly lines. MRP takes care of the scheduling and planning for delivery of parts to the line in small lots. JIT pulls the materials through the facility with visual signals such as kanban cards or empty bins.

Evolution of MRP Software

Software to manage MRP has been evolving for a long time. Before MRP software existed, developing material requirements was a time-consuming and arduous task. With the software, planners were freed of the manual tasks and could dedicate more time to actual planning decisions. Early forays into MRP steadily evolved until MRP II (defined below) crossed the functional borderline out of manufacturing and into other areas. And beyond that, ERP (enterprise resources planning) software, starting basically as an extension of MRP II across all the functions of an enterprise, has now developed modules that link all business functions and even multiple supply chain partners.

Here are the highlights of MRP, closed-loop MRP, and MRP II—steps in the evolution of software from those first bills of material toward resource planning across the supply chain and linking of material planning with actual demand.

MRP Software

Material requirements planning software programs take information based on bills of material, component lead times, and incoming orders to schedule manufacturing dates.

One difficulty operations managers have experienced with MRP systems is the software's assumption that all work centers in the chain have infinite capacity. This assumption can result in the generation of impossible schedules.

Setting aside that problem, MRP systems provide very important benefits:

- They can improve on-time delivery percentages, thereby reducing component inventories and holding costs.
- They can free a scheduler to spend less time on scheduling tasks and more time on planning and exception resolution.

Closed-Loop MRP

Closed-loop MRP refines basic MRP because it incorporates feedback on available capacity. It calculates the impact of each order on the work center that is scheduled to complete the order, and, if it finds too little capacity at that center, it may send the order to another work center or site, outsource it, or change the order date.

Closed-loop MRP also leverages feedback from the execution functions to the planning functions to ensure that replanning occurs. Both status information (order status, inventory balances, etc.) and warning signals/exception messages (behind schedule, overloaded, etc.) are passed back to planning. This facilitates the maintenance of valid plans and schedules.

MRP II

Manufacturing resource planning (MRP II) is defined by the *APICS Dictionary,* 16th edition, as

> a method for the effective planning of all resources of a manufacturing company. Ideally, it addresses operational planning in units, financial planning in dollars, and has a simulation capability to answer what-if questions.

MRP II is the first upgrade of MRP to include other functions such as sales and finance. To recognize this advance in scope and power, it is generally called manufacturing resource planning, a term coined in 1979 by Oliver Wight, instead of material requirements planning. MRP II incorporates the following function upgrades:

- It includes financials—a separate functional area from manufacturing.
- It provides visibility of material and capacity requirements defined in an operations plan.
- It provides detailed activity information and translates activities to financial statements.
- It suggests ways to bring activities back into line with planned priorities.
- It integrates long-term planning (business planning and methodologies that evolved into S&OP) with operational planning.

Distribution Requirements Planning

Distribution requirements planning (DRP) is “the function of determining the need to replenish inventory at branch warehouses” (*APICS Dictionary,* 16th edition). DRP organizes inventory requirements so the organization has time to plan for when and how many goods will be required.

Pull versus Push Distribution

Before we look more closely at DRP, we’ll draw a distinction between systems that pull inventory through the distribution chain toward the retail end and systems that push inventory down the chain. In reality, most distribution chains include elements of both push and pull. The questions for supply chain managers are

- Which system is best adapted to the needs of the supply chain?
- Where should the line of demarcation between push and pull be located?

Note that manufacturing also uses push and pull to describe whether operations are pulled by actual demand (as in JIT) or pushed by forecast demand, but push versus pull manufacturing strategies are not necessarily related to push versus pull distribution strategies. For example, a JIT environment could operate based on actual demand pull and then perform centralized push distribution to get those orders to the correct customers.

In terms of distribution, the *Dictionary* defines a **push system** as "a system for replenishing field warehouse inventories where replenishment decision making is centralized, usually at the manufacturing site or central supply facility." This traditional approach to distribution replenishment pushes inventory through manufacturing to the company distribution centers. Determination of product requirements is done by a central planning organization and pushed out. Inventory is then in storage until a customer (distributor, wholesaler, retailer) pulls material to meet projected demand.

The *Dictionary* defines a **pull system** as "a system for replenishing field warehouse inventories where replenishment decisions are made at the field warehouse itself, not at the central warehouse or plant." The benefit of this decentralized inventory planning approach accrues mostly to the entity doing the ordering, because it is able to operate independently to balance its supply and demand requirements as it sees fit. This assumes that the company orders intelligently. At the retail end, for example, the company might be a hardware franchise with a history in the community and good forecasting instincts.

You might call this a system of serial autonomy, with each partner along the distribution chain making its own ordering decisions. As a system, however, it's not especially systematic. It doesn't take advantage of the essential strengths of supply chain management, which are collaboration and mutual decision making.

There are three particular drawbacks to the pull system:

- Orders are likely to increase as they travel up the chain (the bullwhip effect).
- The company doing the ordering knows nothing about the needs and plans of the other chain partners, who may have a greater need for the stock to meet customer service goals.
- The order doesn't take into account the supplier's situation.

Push systems solve some of these problems but with a tradeoff. The downstream partners receive shipments on schedules developed elsewhere in the network rather than when they order it. While this can be beneficial to the supply chain by providing systemwide coordination of inventory management, it is less likely than the pull system to be sensitive to local market conditions.

DRP is a hybrid system because it contains both push and pull elements. Hybrid systems are push-pull systems in which push distribution is pursued through centralized planning down to a particular supply chain level or echelon but pull distribution through decentralized planning is used after this point. For example, centralized planning could use information on demand from the retail end of the chain, aggregate this demand at the regional distribution centers (DCs), and push inventory to these DCs. The customers of these DCs, perhaps wholesalers and retailers, then order inventory from these DCs as they see fit. This very common replenishment strategy can increase centralized control by moving the point of push to pull down the chain or increase decentralized control by moving the point up the chain.

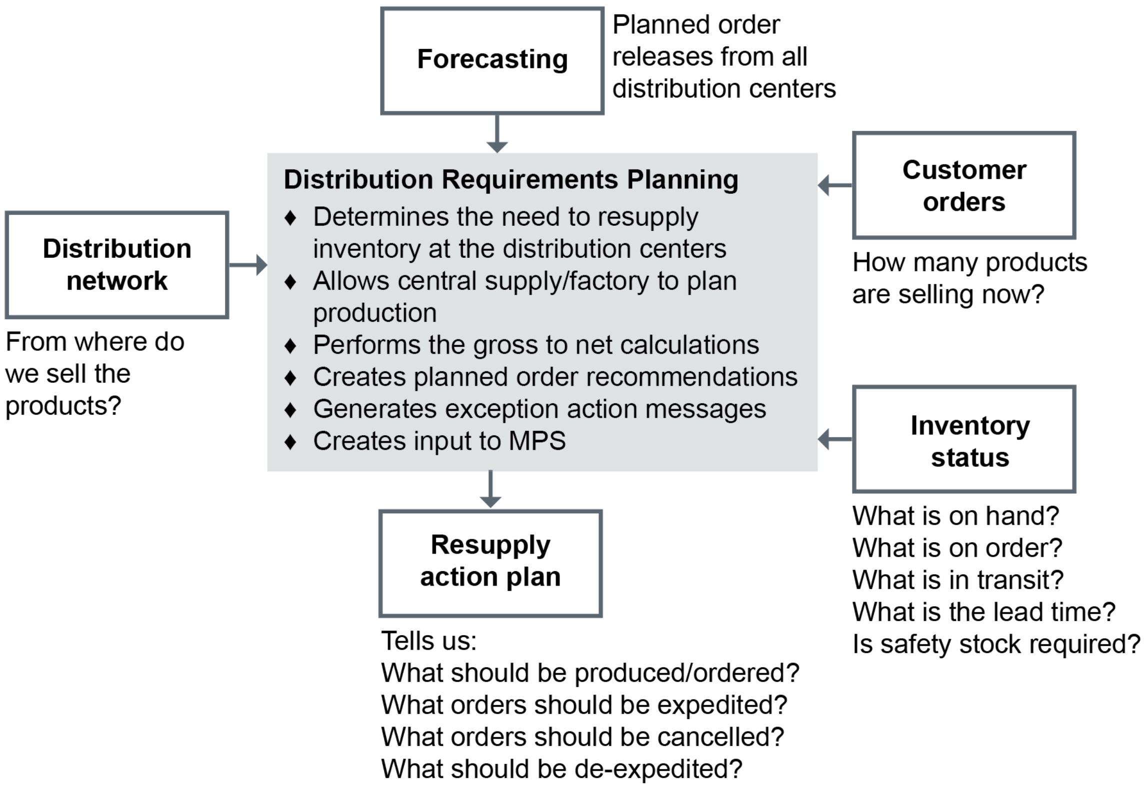
DRP Components

Distribution requirements planning combines the following inputs:

- Demand forecasts from distribution centers to determine the gross requirement
- Safety stock for customer service
- Accurate lead time information
- Overall knowledge of the distribution system (a mapping akin to a bill of material that shows how the distribution network is configured)

Exhibit 4-14 shows what goes into and comes out of a DRP system.

Exhibit 4-14: Distribution Requirements Planning Input/Output Diagram



DRP Logic

DRP system logic translates DC demand into forecasts for use in factory master scheduling. DRP logic typically uses time-phased netting of requirements (net requirements per period or bucket) rather than a decentralized order point (pull) system.

Exhibit 4-15 illustrates DRP logic using distribution centers A and B, a central supply location, and a master schedule grid for a factory.

Exhibit 4-15: Distribution Requirements Planning

DC A									
Week		1	2	3	4	5	6	7	8
Gross Requirements								300	
Scheduled Receipts									
Projected Available Balance	170	170	170	170	170	170	170	270	270
Net Requirements								200	
Planned Order Receipts								400	
Planned Order Releases							400		

DC B									
Week		1	2	3	4	5	6	7	8
Gross Requirements									500
Scheduled Receipts									
Projected Available Balance	200	200	200	200	200	200	200	200	200
Net Requirements									400
Planned Order Receipts									500
Planned Order Releases							500		

Central Supply									
Week		1	2	3	4	5	6	7	8
Gross Requirements							900		
Scheduled Receipts									
Projected Available Balance	500	500	500	500	500	500	200	200	200
Net Requirements							600		
Planned Order Receipts							600		
Planned Order Releases				600					

Master Schedule Grid						
Week	1	2	3	4	5	6
Gross Requirements			600			
Projected Available Balance	0	0	200	200	200	200
Master Production Schedule			800			

	Lot Size	Lead Time	Safety Stock
DC A	400	1 week	70
DC B	500	2 weeks	100
Central Supply	600	3 weeks	200
Master Schedule Grid	800	N/A	N/A

Source: APICS CPIM Basics of Supply Chain Management.

Planned order releases from DCs A and B are released to central supply according to each DC's demand requirements and lead times. In the exhibit, DC A and DC B release planned orders in week 6 for 400 and 500 units respectively. Central supply has a three-week lead time, a projected available balance of 500 units, and a lot size (order quantity) of 600 units. Therefore, to fill the planned order releases of 900 units, central supply releases a planned order for 600 units in week 3 (to account for the three-week lead time and lot size), which will leave a projected available balance of 200 units (equal to its safety stock requirement). Central supply's planned order release of 600 units becomes a gross requirement in the master schedule grid. This allows the distribution centers' time-phased requirements to be factored into the factory's master production schedule.

Benefits of Push and Pull Elements in DRP

Distribution requirements planning combines the coordinated planning and control offered by push systems with the responsiveness to local demand that characterizes pull systems.

Although orders originate downstream (that is, toward the retail end), they are evaluated at the supplying locations before being released to determine the actual need at the ordering location and the availability of goods at the sites receiving the order. This helps prevent shortages at supplying sites and overstock at ordering sites. In this way, DRP keeps inventory in balance around the network.

Because the hybrid DRP system combines information from both supplying and ordering locations, it can, in theory, provide more accurate allocations of stock than either straight pull or push systems, which take into account the needs of only the ordering or the supplying location. Because the DRP system is based on more accurate data and more thorough assessments of need and available supply, it should allow release of smaller, more frequent orders than straight pull or push arrangements. And this in turn provides the supply chain with the benefit of better customer service and lower inventory costs.

Section B: Capacity and Production Activity Control

This section is designed to

- Understand the role of planning, management, and control in relation to an organization's capacity
- Describe the levels of capacity checks: resource planning at the sales and operations planning level, rough-cut capacity planning at the master scheduling level, capacity requirements planning (CRP) at the material requirements planning level, and capacity control at the execution level
- Understand how long-term capacity can be increased by leading or lagging actual demand and in multiple steps or in one big step
- Enumerate the objectives of CRP
- Explain the purpose of production activity control and its activities
- Measure capacity using available time, utilization, and efficiency data to produce rated capacity
- Compare rated capacity to demonstrated capacity or capacity requirements
- Explore ways to improve production activity control such as by using the theory of constraints or kanbans.

A key way to balance supply with demand is to use capacity planning, management, and control. These are internal checks to create or verify capacity that are done over the long term for things that take a long time to change and over shorter and shorter time frames as we get closer to actual execution.

Production activity control is where actual production execution occurs, and this is also addressed in this section. Part of this process involves detailed capacity planning at the work center level, and this requires knowing how to measure rated capacity against demonstrated capacity and actual requirements.

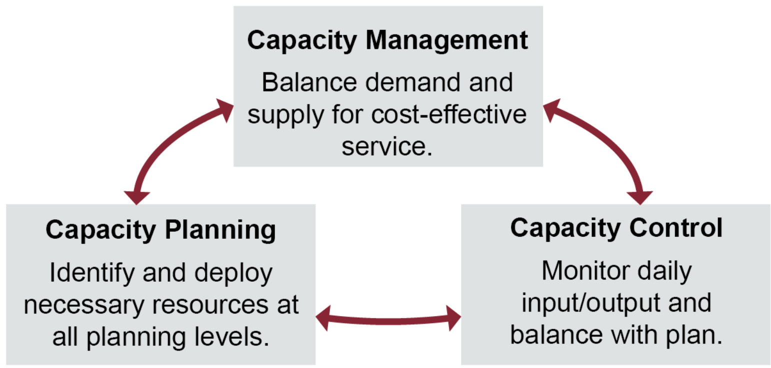
Topic 1: Capacity

Capacity is the primary constraint of supply, and it needs to be planned, managed, and controlled at multiple levels. After providing an overview of capacity, three levels of capacity checks are discussed: resource planning, rough-cut capacity planning, and capacity requirements planning.

Capacity Road Map

In order to satisfy significant shifts in demand or to roll out a new product or service, an organization must ensure that it will have the required capacity in time. For example, in a manufacturing setting, the organization must have the plants, equipment, production lines, and workers to produce the output dictated by the production plan within the time allowed. Capacity planning, capacity management, and capacity control are tools that help ensure success in the planning and execution of supply. These concepts are shown in Exhibit 4-16.

Exhibit 4-16: Capacity Management, Planning, and Control



- The *APICS Dictionary*, 16th edition, defines **capacity planning** as

> the process of determining the amount of capacity required to produce in the future. This process may be performed at an aggregate or product-line level (resource requirements planning), at the master scheduling level (rough-cut capacity planning), and at the material requirements planning level (capacity requirements planning).

Capacity planning involves identifying required resources and selecting the best method available to increase capacity when needed.

- According to the *Dictionary*, **capacity management** is

> the function of establishing, measuring, monitoring, and adjusting limits or levels of capacity in order to execute all manufacturing schedules (i.e., the production plan, master production schedule, material requirements plan, and dispatch list). Capacity management is executed at four levels:
>
> - Resource planning,
> - Rough-cut capacity planning,
> - Capacity requirements planning, and
> - Input/output control.

Maintaining proper capacity levels in the most efficient configuration possible enables serving customers in a cost-effective manner. The goal is to prevent an imbalance between supply and demand.

- The *Dictionary* defines **capacity control** as

> the process of measuring production output and comparing it with the capacity plan, determining if the variance exceeds pre-established limits, and taking corrective action to get back on plan if the limits are exceeded.

Capacity control takes place at the level of everyday activity, as a form of input/output control. It corrects imbalances that may begin at the single part or hour level before they become a bigger problem.

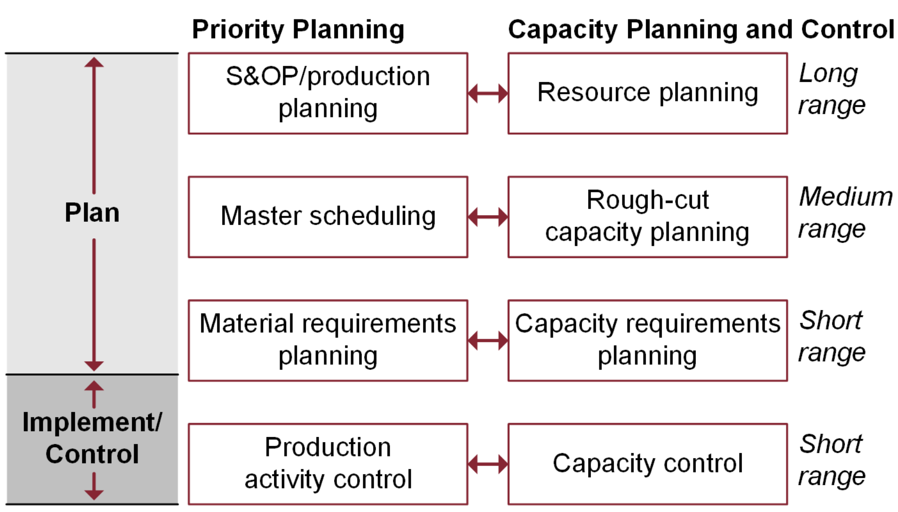
Attempts to balance capacity with load can result in too little capacity, too much capacity, or the correct amount of capacity.

- **Too little capacity.** If any site or work center in your supply network has too little capacity for the production goals assigned to it, demand at that point in the chain will exceed supply and you will have to either add capacity (if that is possible), shift work elsewhere, or endure stockouts, long backlogs, or backorders.
- **Too much capacity.** If an organization overbuilds or over-staffs a work center or plant, supply exceeds demand. If full capacity is used anyway, this results in high inventories. If capacity is reduced to actual demand levels, available labor hours, work centers, and warehouse space are wasted. Maintaining overcapacity means that some costs such as salaries, lease or interest payments, and insurance will remain at a high level, reducing profits or creating losses. When load and capacity are not in balance, the organization is inefficient. Serious oversupply can lead to enormous write-downs, plunging stock prices, bankruptcies, and layoffs.
- **Correct amount of capacity.** When organizations get capacity management right, supply and demand stay in balance, deadlines are met, orders are filled on time with quality items, overtime is minimal, and they are generally making optimal use of labor, equipment, and space. Continuous improvement practices can improve organizational performance, even as an organization continually works to maintain accurate levels of capacity.

Planning Horizons

Capacity planning begins with the sales and operations planning (S&OP)/production planning process and continues through production activity control (PAC). Exhibit 4-17 illustrates the levels of capacity planning as they correspond to the levels of manufacturing planning and control.

Exhibit 4-17: Planning Horizons



Capacity planning starts at a high level, looking at long-range activities. It continues all the way through short-range, daily activities.

Resource Planning

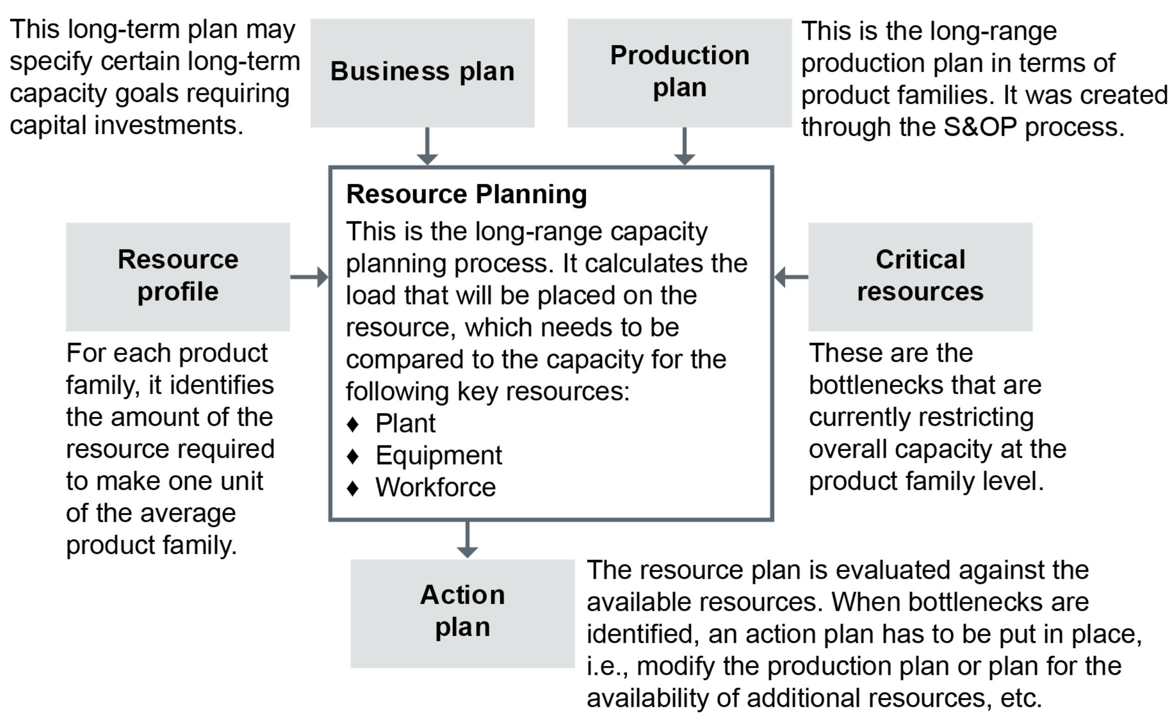
Resource planning (also called resource requirements planning) is capacity planning over the longest time frame. Resource planning results in a resource plan, which identifies the resources needed to meet production priorities one, two, or even five years into the future. The highest level of inputs are the strategic and business plans and their long-range demand forecasts, information that is used to plan long-term capital investments. This part of the resource plan is a long-range assessment of capacity requirements at an aggregate level. Another key input is the production plan (an outcome of sales and operations planning), which provides demand information for up to 18 months out or so. The resources that are needed—including plant, labor, and equipment—must be identified and acquired to create enough supply to match projected demand.

Resource planning might identify the number of labor hours required quarterly to meet operations goals. If those goals seem impossible to meet with realistic capacity projections, plans may have to be altered. If organizations don't already have the resources in the network to meet demand at this aggregate level, then they must make decisions about modifying capacity, modifying the production plan, or managing demand differently.

For the longer end of long-term capacity requirements, resource planning may involve generating business cases for capital expenditures such as infrastructure improvements, winning approval for them at the executive level, and producing project plans and performing project management to build or acquire the resources needed for long-term strategic business development. It can also involve strategic hiring and workforce training.

Exhibit 4-18 shows the part that capacity planning plays in relationship to resource planning (which interacts with the production plan from S&OP).

Exhibit 4-18: Capacity Planning at Level of Resource Plan



The *APICS Dictionary,* 16th edition, defines a **resource profile** as the standard hours of load placed on a resource by time period. Production lead-time data are taken into account to provide time-phased projections of the capacity requirements for individual production facilities.

Standard costing is a common tool used in capacity analysis because it enables estimating how much load is created by the demand for a given number of units of each family. Standard hours may be the cost driver for some operations. For example, assume that manufacturing an average laptop requires 0.75 standard hours of assembly time. If the production plan for the period calls for 100,000 units, then there is a planned load of 75,000 standard hours of assembly time. This load is then compared to the available capacity over the same period.

A resource profile can also use measures specific to a given operation, such as standard milliliters of a chemical, standard hours of drying time, or standard kilograms of raw material.

Capacity Strategies

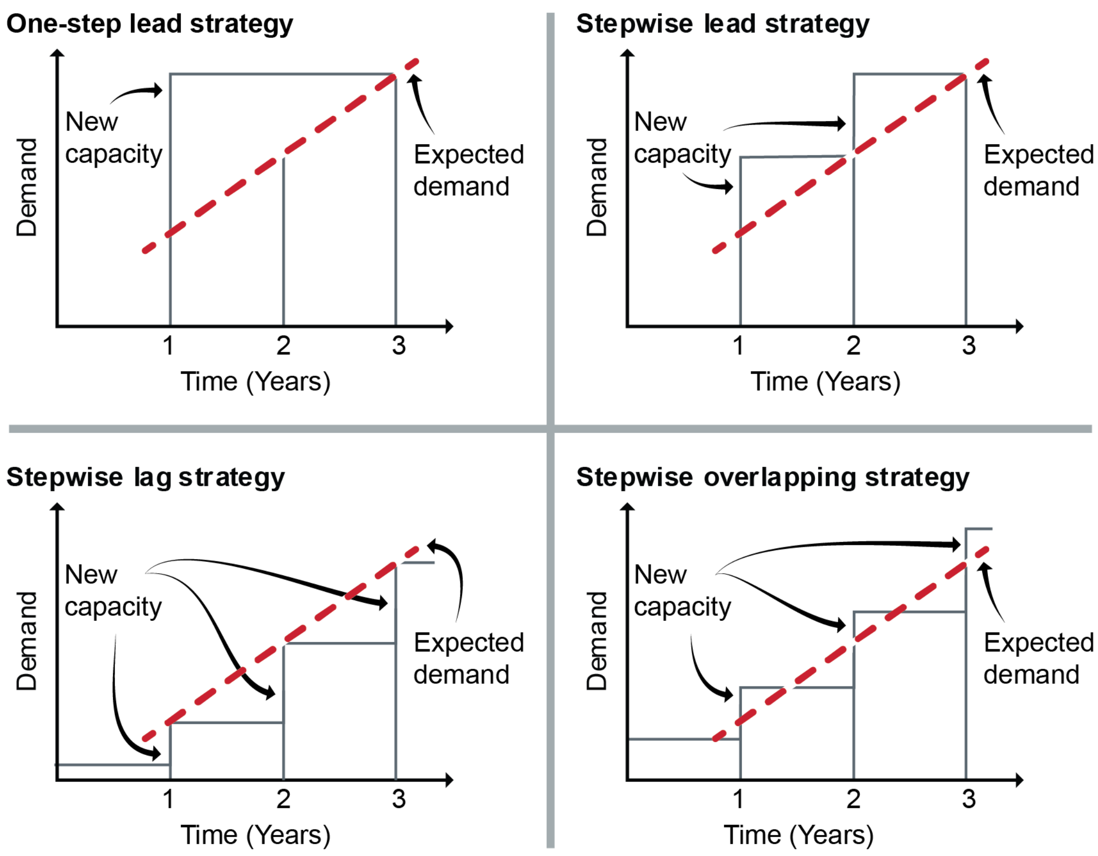
If an organization decides to increase capacity to match expected growth in demand, it can decide on the best strategy to stage the investments. For example, it may be necessary to build a new facility to accommodate types of work the organization isn't doing for current projects or to purchase expensive equipment. When the organization does so, it will develop excess capacity, and there will be a lag before demand catches up.

Organizations might instead decide that they have the basic capacity they need but some upgrades will be required. In that case, they may be able to stage the upgrades to match expected growth in demand, either staying a little ahead (leading), a little behind (lagging), or a little of each (so that demand and supply average out) as capacity is increased in stages to reach a future goal.

Exhibit 4-19 shows four ways to stage growth in capacity:

- One-step lead strategy: expanding all at once ahead of demand
- Stepwise lead strategy: expanding in steps ahead of demand
- Stepwise lag strategy: expanding in steps behind demand (to catch up, in other words)
- Stepwise overlapping strategy: expanding in steps that are sometimes ahead of and sometimes behind forecast demand

Exhibit 4-19: Four Ways to Stage Capacity Growth



No matter which strategy is employed to stage growth in capacity, they will all ultimately involve some form of resource management. The *Dictionary* defines **resource management** as follows:

> (1) The planning and validation of all organizational resources. (2) The effective identification, planning, scheduling, execution, and control of all organizational resources to produce a good or service that provides customer satisfaction and supports the organization's competitive edge and, ultimately, organizational goals. (3) An emerging field of study emphasizing the systems perspective, encompassing both the product and process life cycles, and focusing on the integration of organizational resources toward the effective realization of organizational goals.

Rough-Cut Capacity Planning

Rough-cut capacity planning (RCCP) is defined by the *APICS Dictionary,* 16th edition, as

> the process of converting the master production schedule into requirements for key resources, often including labor; machinery; warehouse space; suppliers' capabilities; and, in some cases, money. Comparison to available or demonstrated capacity is usually done for each key resource. This comparison assists the master scheduler in establishing a feasible master production schedule.

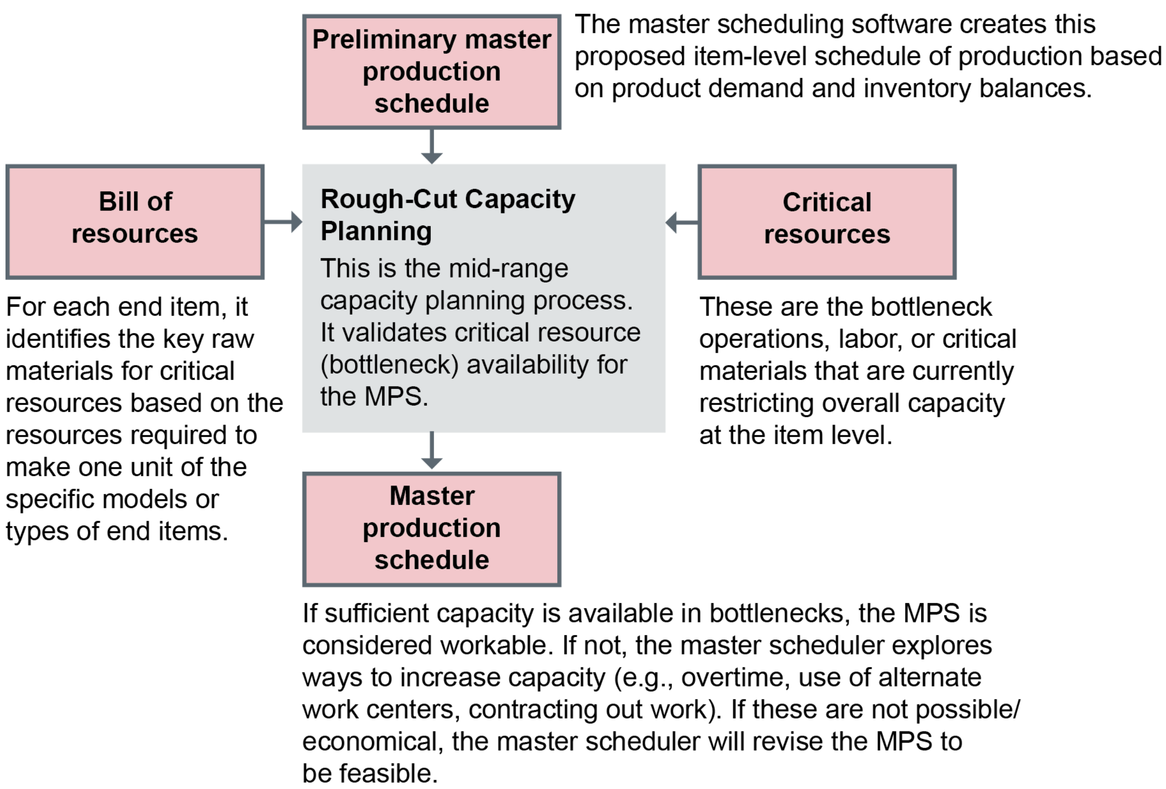
Rough-cut capacity planning takes a more detailed, medium-term look at production priorities as they are described in the master production schedule (MPS) and determines whether capacity is available to carry out the scheduled activities. If it does not appear that production targets are realistic within specified tolerances as agreed to by the S&OP policy, the plan goes back to the master scheduler for revision. The master scheduler can alter either the schedule or the capacity. Similarly, if there is too much capacity in the system, adjustments may be needed. The back-and-forth nature of rough-cut capacity planning is often facilitated by supply chain managers, who can represent various parties' interests.

Typically bottlenecks, gateway work centers, and critical suppliers are the only capacity checks that are done at this point. The *Dictionary* defines a **bottleneck** as "a facility, function, department, or resource whose capacity is less than the demand placed upon it." In other words, at this stage RCCP reviews key resources and bottleneck areas; it is not a review of every component of operational capacity. RCCP examines critical resources in the plants on the premise that if any bottleneck points can generate sufficient capacity (or key materials are sufficiently available), non-bottleneck capacities and materials are normally also sufficient.

An example of a bottleneck work center could include a situation in which an operation's throughput (rate of production) is constrained by a particular component's fixed oven-curing time. Speeding up production before or after this point would only increase work-in-process (WIP) inventory without increasing throughput. A steady supply of components should be ready to be cured (a buffer), but otherwise excess WIP inventory is unnecessary. (These concepts are part of the theory of constraints, discussed elsewhere.) While resource planning could be used to indicate a need for new ovens, the RCCP process works within current capacity limitations. These limits may be flexible, however. For example, the master scheduler could add a second shift to keep the ovens running longer each day. In this way, the rough-cut check is matched against bottleneck capacity and the load specified in the MPS. If there's a gap, the master scheduler must specify what is required to bridge it.

Exhibit 4-20 shows the part RCCP plays in capacity planning.

Exhibit 4-20: Capacity Planning at Level of Rough-Cut Capacity Planning



Similar to resource planning, RCCP has inputs for critical resources and standard resource capacities (bills of resources versus resource profiles). The difference is that for RCCP these inputs specify individual items rather than product families. According to the *Dictionary*, a **bill of resources (bill of capacity)** is

> a listing of the required capacity and key resources needed to manufacture one unit of a selected item. Rough-cut capacity planning uses these bills to calculate the approximate capacity requirements of the master production schedule. Resource planning may use a form of this bill.

Measuring Capacity

Capacity at a work center is measured using the standards that were set for sites and work centers (equipment and workers) to produce a product. Capacity may be measured in a variety of ways besides items per unit of time (widgets per hour). For example, hospital capacity is rated by number of beds. Additionally, some organizations rate a work center’s capacity only according to the standard hours of work time available. (100 workers at 40 hours per week is 4,000 hours of work time.) Capacity is never measured is in monetary units—euros, dollars, yen.

Goals of RCCP for Master Production Schedule Output

The output of the RCCP process is a workable master production schedule. An MPS is considered workable if the master scheduler has verified that

- Bottleneck capacity per item per time period is sufficient.
- The plan makes the best use of resources.
- Customer delivery promises can be kept.
- The plan is still economical given all excess costs that will be incurred, such as overtime.

Capacity Requirements Planning

Capacity requirements planning (CRP) determines in detail the amount of labor and machinery required to carry out production tasks specified in the material requirements plan (MRP), translating MRP orders (measured in units) into hours of work for each work center in each time period. CRP is the most detailed level of capacity planning. At this point in the process, planning looks at orders and work schedules to see how available capacity will or will not translate into the work center production necessary to meet demand.

The amount of work scheduled for a work center is determined by a system that reviews all of the work released to that center by MRP and MPS, adds up the standard hours required for each order, and compares it to capacity.

Another purpose of capacity requirements planning is to assign each facility, work center, and operation a load and perform load leveling. The *APICS Dictionary,* 16th edition, defines load and load leveling as follows.

Load : The amount of planned work scheduled for and actual work released to a facility, work center, or operation for a specific span of time.

Load leveling : Spreading orders out in time or rescheduling operations so that the amount of work to be done in sequential time periods tends to be distributed evenly and is achievable. Although both material and labor are ideally level loaded, specific businesses and industries may load to one or the other exclusively (e.g., service industries).

Steps in CRP

Four steps are required to determine the capacity available at a work center: check the open order file, planned order releases, the routing file, and the work center file.

Step 1: Check the Open Order File.

The open order file contains all active shop orders, with quantities, operations, and due dates. The open orders are recognized in the MRP grid on the “Scheduled receipts” line. Taken together, these orders tell you how much capacity is already scheduled at the work center. However, since manufacturing has already begun working on these orders, only the load of the remaining operations needs to be taken into account.

Step 2: Check Planned Order Releases.

The planned orders will be released on the release dates planned by MRP. Since these orders are not yet released, all operations still need to be performed and taken into account.

Step 3: Check the Routing File.

The routing file follows each component’s progress through the center or centers. The file may be electronic or a paper copy, and it contains the following for each component:

- Operations to be performed
- Sequence of operations
- Work centers
- Alternate work centers
- Tooling needed for each operation
- Standard times, including setup time for each piece as well as run time

Taken together, the routing file plus planned order releases provide the information necessary to calculate the amount of time in the schedule for any work center. The routing file includes information on the operation numbers and sequence, the operation descriptions with timing (e.g., mix: one hour/batch), the work centers, and other requirements. By adding the open orders and the planned order releases, the total commitment of time for the work center can be calculated.

Step 4: Check the Work Center File.

The work center file provides capacity information about the center, which includes a collection of people and/or machines engaged in one type of work. The file contains all the information needed to calculate the amount of manufacturing lead time to complete one order at the work center. At a minimum, the file will contain data on queue time, wait time, and move time.

These times, together with the setup and run times from the routing file, constitute the lead time for the component. Dividing the total time available during a scheduled period at the work center by the run time tells you how many units can be produced at the center in that period.

Lead times can be further broken down. The *Dictionary* defines **manufacturing lead time** as

> the total time required to manufacture an item, exclusive of lower level purchasing lead time. For make-to-order products, it is the length of time between the release of an order to the production process and shipment to the final customer. For make-to-stock products, it is the length of time between the release of an order to the production process and receipt into inventory. Included here are order preparation time, queue time, setup time, run time, move time, inspection time, and put-away time.

These manufacturing lead time components, along with wait time, can be summarized as follows:

- Order preparation time is the administrative time spent processing an order.
- Queue time is the time spent waiting for an operation to start. (It can be a significant percentage of manufacturing lead time.)
- Setup time is the time spent preparing work centers for different operations.
- Run time is the time spent performing an operation.
- Wait time is the time spent at a work center before going to the next center.
- Move time is the time spent physically moving items among work centers.
- Inspection time is the time spent on quality assurance.
- Put-away time is the time spent moving the item to its storage location. (It is part of move time.)

The work center file also contains data on work center efficiency and utilization.

Topic 2: Production Activity Control

Production activity control (PAC) is control of production execution, including related work center capacity checks. After introducing PAC, the specifics of how capacity is measured are addressed. The last area of discussion relates to how to continuously improve PAC.

Production Activity Control Road Map

Production activity control (PAC), of which capacity control is one part, consists of all those activities meant to ensure that actual production goes according to plan. Capacity control is the level of capacity planning that has the shortest horizon and takes place closest to the daily action of manufacturing. Within PAC, capacity control takes the form of input-output control and operations sequencing.

While it isn't the purpose of this course to go into the details of manufacturing activity, we cover the basic objectives of PAC and look at some control strategies that can help keep things running smoothly. If activities at each work center don't run smoothly, missed production schedules will affect the supply chain from one end to the other.

Control Objectives

PAC has four main objectives:

- Execute the master production schedule and the material requirements plan.
- Make the best use of resources.
- Minimize work-in-process (WIP).
- Maintain customer service.

Control Functions

Production activity control's functions can be put under three headings, as follows:

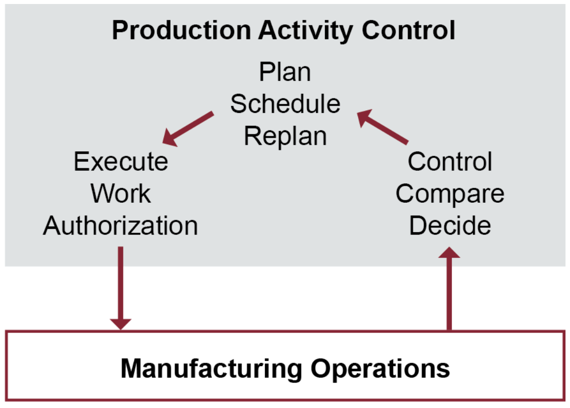
- **Plan.** Planning at this level means ensuring that resources are available and scheduling start and completion dates.

- **Execute.** Execution of the plan requires gathering relevant information for the shop order and releasing the orders.

- **Control.** Controlling the workflow requires
  - Establishing and maintaining order priority
  - Tracking actual performance (so you know where any problems are)
  - Monitoring and controlling work-in-process, lead times, run times, and queues
  - Reporting work center performance.

These three functions take place in a continuous loop (as shown in Exhibit 4-21), with the data gathering and analysis that takes place in the control function feeding information to the planning function to enable continuous improvement.

Exhibit 4-21: Planning, Executing, and Control



Source: CPIM Workbook.

Measuring Capacity

If we want to measure available capacity for a given period of time, we need to know three things:

- **Available time.** Available time is a product of hours of operation and numbers of workers or equipment in use during those hours. (For instance, four machines producing eight hours a day, five days per week, yield a weekly available time of 4 × 8 × 5 = 160 hours.)

- **Utilization.** The *APICS Dictionary,* 16th edition, defines **utilization** as “a measure (usually expressed as a percentage) of how intensively a resource is being used to produce a good or service.” Utilization is calculated as the percentage of available time that the work center is actually being used ([hours actually worked/available hours] x 100%). A work center with an available time of 120 hours per week that operates at 90 hours has a utilization rate of 75 percent [(90/120) x 100].

- **Efficiency.** The *Dictionary* defines **efficiency** as follows:

> A measurement (usually expressed as a percentage) of the actual output to the standard output expected. Efficiency measures how well something is performing relative to existing standards.

Efficiency can be calculated as

$$\text{Efficiency} = \frac{\text{Standard Hours of Work}}{\text{Hours Actually Worked}} \times 100\,\%$$

For example, a work center that produces 110 standard hours of work while operating for only 100 hours has an efficiency rate of 110 percent.

Standard hours or time (from standard costing) refers to the amount of time an average worker or piece of equipment is expected to need, following prescribed methods, to produce one unit of output. Standard time allows for ordinary delays and rest periods.

Note also that efficiency calculations may be used to determine bonus pay.

Productivity is one measure that can be derived from these metrics.

$$\text{Productivity} = \text{Utilization} \times \text{Efficiency}$$

This information can also be used to calculate rated capacity and capacity requirements.

Rated Capacity

Rated capacity for a work center is the available time multiplied by the utilization rate and the efficiency percentage:

$$\text{Rated Capacity} = \text{Available Time} \times \text{Utilization} \times \text{Efficiency}$$

If the work center has 160 hours of available time and its utilization rate is 85 percent with an efficiency rating of 90 percent, the available capacity would be 122.4 standard hours per week (160 x 0.85 x 0.90 = 122.4 standard hours). Note that rated capacity calculations result in standard hours.

Demonstrated Capacity

Another way of measuring capacity available determines the demonstrated capacity; you could consider this the practical counterpart of rated capacity. It is simply the average output measured over a period of time.

$$\text{Demonstrated Capacity} = \frac{\text{Output for n Periods}}{\text{n}}$$

For instance, let's say the work center rated above at 122.4 standard hours of available capacity had this performance during six consecutive weeks (n = 6):

Week 1	120.0
Week 2	118.5
Week 3	119.0
Week 4	123.0
Week 5	119.2
Week 6	122.5

Its demonstrated capacity would be the average of the weekly output for those six weeks, or 120.4 standard hours.

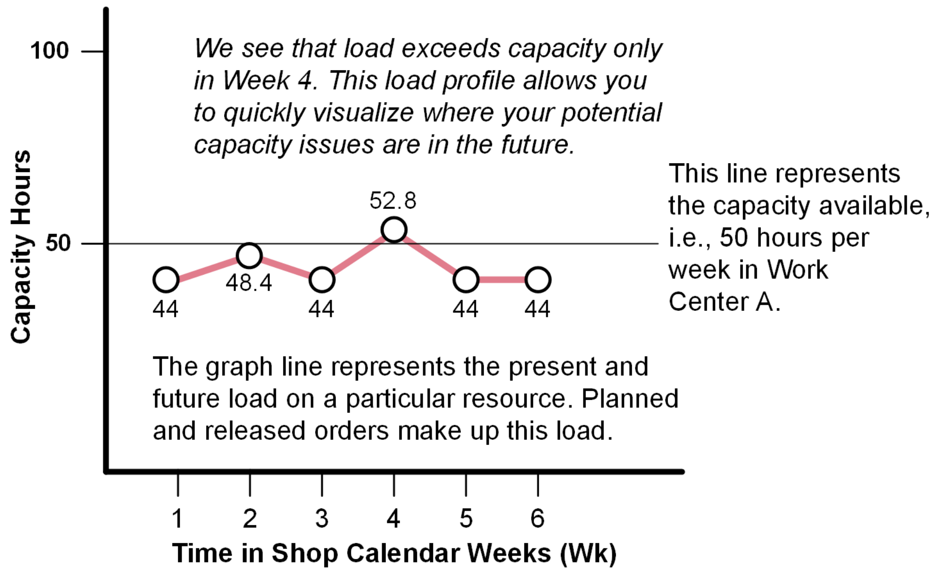
$$\text{Demonstrated Capacity} = \frac{120.0 + 118.5 + 119.0 + 123.0 + 119.2 + 122.5}{6} = \frac{722.2}{6} = 120.4$$

Capacity Requirements

Once you know the available capacity at a work center, you can compare it to the load. If you don't have the capacity at a work center to match or exceed the load, then there is a capacity constraint.

Exhibit 4-22 shows how a constraint might appear on a load profile tracking the capacity hours required in the first six weeks of the upcoming year. Week 4 turns out to be the week when the question "Can we do that?" is answered "No, we can't." The planner will have to talk to the work center manager about possible changes in available capacity—adding temporary labor, improving efficiency if possible, or producing extra goods early if the excess demand can be anticipated far enough in advance and there is available capacity earlier (as there is in this example).

Exhibit 4-22: Capacity Requirements



When Load and Capacity Are Out of Balance

If you find that there is more load than capacity or more capacity than load, you can choose to either change capacity, change the load, or change a combination of the two.

Change Capacity to Match the Load.

You can select one or a combination of the following means to alter the capacity:

- Add or reduce work hours. Use overtime hours to handle the extra load or undertime hours to reduce the cost of excess capacity.
- Hire or lay off workers. This is an inefficient way to handle a short-term problem (e.g., severance to outgoing employees or training new ones). Using temporary workers is an option if you have an agency that can provide workers with the requisite skills.
- Shift the workforce. If you have work centers that are over capacity and others that are under, you may be able to move workers with compatible skills. Job rotation techniques can prepare the workforce for this.
- Change the routings. Instead of moving workers around, reroute the work to take advantage of overutilized and underutilized stations.

Change the Load to Match Capacity.

It may be possible to reduce (or increase) the load to bridge a gap between load and capacity, but this can be done only if it doesn’t complicate matters too much at other work centers. You have a few possible tactics:

- Subcontract extra work to a third party (contracting out is not an increase of your capacity so it is a form of reducing load on your resources) or reduce subcontracting to increase internal load.

- Change lot sizes. **Lot size (order quantity)** is “the amount of a particular item that is ordered from the plant or a supplier or issued as a standard quantity to the production process” (*APICS Dictionary,* 16th edition).
- Change the schedule.

Continuous Improvement of Production Activity Control

In addition to carrying out production plans according to schedule, production activity control can engage in continuous improvement by adopting techniques associated with six sigma, kanban, lean manufacturing, and other tried and true systems.

Here are a few strategies employed to speed up manufacturing (and other) processes.

Concentrate on Constraints.

According to Goldratt’s theory of constraints, a production process is no faster than its slowest function, known as the constraint (or bottleneck). Capacity is limited by the constraint the way traffic flow is constrained by traffic jams. Cars headed into the jam can speed up without helping a bit; they just make the traffic queue longer, sooner.

So here are a few principles for handling the constraint in a system:

- Elevate the constraint, which means working to remove the constraint. For example, if you have only one machine to do a constrained task, buy another one. (Need would typically be identified in resource planning.)
- Put some inventory in a queue before the constraint as a time buffer. You want to make sure the constraint always has inventory so it never stops functioning, because that will make the system slow down even more.
- Control the rate of material feeding into the constraint. You want material coming in at the rate required to maintain the time buffer. Anything less depletes the buffer; anything more causes an expensive queue.
- Improve the flow at the constraint in any way possible, for instance, reduce setup time or increase utilization.
- Adjust loads to avoid the constraint when you can. (A lack of proactive planning soon enough to make a difference is itself a type of constraint.) There may be a cost tradeoff such as needing to use more expensive work centers, but this justifies itself if the added expense buys even more valuable throughput. **Throughput time** is “the length of time from when material enters a production facility until it exits” (*Dictionary*).
- Change the schedule—as a last resort.

Use Visual Signals.

The kanban system from Japan speeds up operations by pulling inventory through the work center instead of pushing it up to the next workstation where it sits in a queue. As defined in the *Dictionary,* **kanban** is

> a method of Just-in-Time production that uses standard containers or lot sizes with a single card attached to each. It is a pull system in which work centers signal with a card that they wish to withdraw parts from feeding operations or suppliers.

The term **demand pull** is defined in the *Dictionary* as

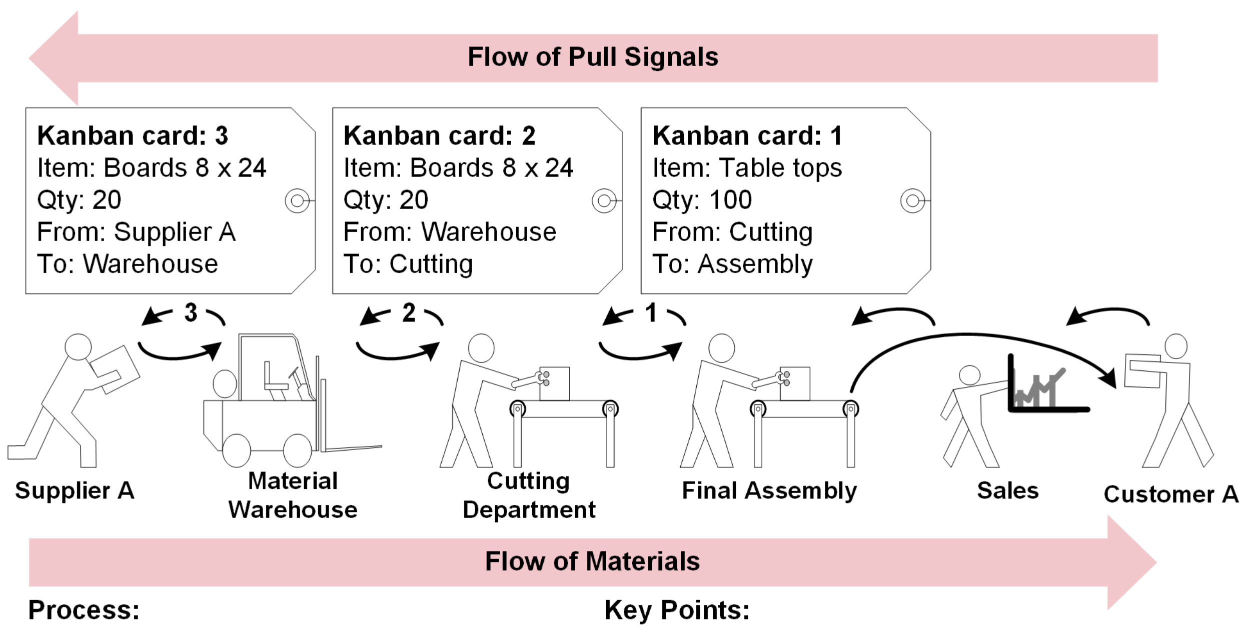
> the triggering of material movement to a work center only when that work center is ready to begin the next job. It in effect eliminates the queue from in front of a work center, but it can cause a queue at the end of a previous work center.

Kanban systems often use display cards as the visual signal to tell a workstation to begin operations. The idea is to keep the lot sizes as small as possible to optimize use of space and labor.

Many plants have adopted the system and modified it to use a signal other than a card. An empty space can do for a signal to begin operations. At Harley-Davidson, for instance, components are placed in special containers. An empty container signals the need for more parts.

Exhibit 4-23 illustrates a kanban system that pulls inventory all the way through the supply chain, from raw material to finished goods.

Exhibit 4-23: Kanban System with Visual Signals



Process:
1. Customer sends in an order for 100 tables.
2. Order is scheduled in the plant.
3. Assembly sends kanban card 1 to the previous department requesting 100 table tops.
4. Cutting department sends kanban card 2 to the warehouse requesting 20 8 x 24 boards.
5. Planning sends kanban card 3 to the supplier to send more 8 x 24 boards.

Key Points:
1. The kanban system is a pull system. Kanban means “display card” in Japanese.
2. It is a replenishment system that synchronizes the customer’s requirements through the plant and to the suppliers.
3. Production should start only when a kanban card has been issued.
4. The movement of kanban cards depends on the number of containers for each component and the timing of when to deliver the card to the upstream facility.

Develop Pull Partnerships and Learn to Be Lean.

Kanban's visual signals are one example of a pull system of production control. These systems, often part of lean or Just-in-Time systems, depend upon having supply partners who understand the vision and are willing and able to cooperate. Having a supplier who delivers small lots of inventory to your plants on an as-needed basis can help you save space and avoid slowdowns due to material shortages and can save on labor costs at the docks. but this level of coordination does require all parties have a high level of supply chain maturity.

Developing lean thinking focuses on taking only value-added steps and eliminating wasted efforts and resource waste. A simple example: Reduce the distance between work centers with the heaviest traffic. Fewer steps taken by many employees can add up to considerable savings of time and money. (Organizing the entire work site this way is called JIT layout.) Produce only what customer demand requires. Quality is in the eyes of the customer so they define what is value added and what isn't.

Section C: Inventory

This section is designed to

- Define inventory and inventory management
- Identify the main types of inventory
- Describe valid reasons for holding inventory
- Identify key performance indicators relevant to inventory management
- Describe the factors to be weighed when setting inventory policy
- Identify why inventory is managed in aggregate and at the item level
- Explain ABC analysis and how it shapes aggregate levels of inventory
- Differentiate between inventory cost categories
- Describe the effects of inventory on financial statements
- Describe how inventory can be given different values on the balance sheet based on how it is valued by accountants
- Understand the use of inventory turnover as an inventory control tool
- Explain how product traceability and chain-of-custody data assist with risk reduction and compliance
- Define centralized and decentralized inventory planning
- Discuss how locations of inventory can be optimized by echelon, number, and geographic location
- Explain assumptions and processes of lot-for-lot, fixed order quantity, and economic order quantity (EOQ) methods of determining order quantities
- Describe ordering systems, including order point, periodic review, min-max, time-phased order point, and demand-driven MRP
- Describe the functions and drawbacks of using safety stock and safety lead time
- Explain how and why inventory is tracked
- Distinguish between period and cycle counting
- Manage product disposition and obsolescence.

Inventory is an expensive asset when considered in the aggregate, and so it needs a great deal of attention from supply chain managers. After addressing inventory basics, this section looks at important policies that can help provide nuance to how inventory is managed, such as by using an ABC inventory analysis or managing product disposition and obsolescence. Supply chain managers will learn here how to present their inventory management improvements in financial terms. Since inventory across the entire supply chain is of interest to supply chain managers, methods of replenishment are addressed here at a high level along with other tools such as setting safety stock levels.

Topic 1: Inventory

Inventory is a major investment for many organizations, so it is important to know its forms, functions, and costs; how to plan and position it in the supply chain; how to manage it properly at both the aggregate and the item level; and how it is viewed by finance professionals and other stakeholders who use financial statements.

Inventory Road Map

The *APICS Dictionary,* 16th edition, defines **inventory** as

> those stocks or items used to support production (raw materials and work-in-process items), supporting activities (maintenance, repair, and operating supplies), and customer service (finished goods and spare parts).

Organizations that carry inventory do so because it is a necessary cost of doing business. However, since it is a cost, organizations are continually working to find the optimum levels of inventory—those that can maximize profits, production efficiency, and customer service. Inventory can also be seen as an investment that, if managed correctly, can be a strategic asset to the organization. For example, inventory can decouple demand and supply, so proper management of inventory can provide protection against variability in either.

Since using inventory to protect against variability costs money and consumes space, management may consider alternatives to carrying more inventory than desired, for example:

- Improved demand forecasting and/or use of actual demand orders
- Reduced variability in the quality, amount, and timing of supply deliveries
- Shorter production cycle times
- Careful maintenance of production equipment
- Keeping inventory in motion as much as possible rather than allowing it to wait in queues, in warehouses, and so on.

A basic understanding of inventory depends upon knowing the types of inventory and the functions performed by each type.

Types of Inventory

Inventory can be classified according to where along the supply chain it is being held. Classification of inventory type depends on the point of reference, meaning that a raw material supplier’s finished good becomes a manufacturer’s raw material upon transfer. Each type serves particular functions, all of them adding to the supply chain’s flexibility when maintained at optimum levels. The types are as follows:

- **Raw materials inventory** includes purchased parts, materials, or subassemblies to a production process that have been acquired but have not yet entered production.

- **Work-in-process (WIP) inventory** is defined in the *APICS Dictionary,* 16th edition, as

> goods in various stages of completion throughout the plant, including all material from raw material that has been released for initial processing up to completely processed material awaiting final inspection and acceptance as finished goods inventory.

In other words, work-in-process inventory is inventory to which value has been added, but it is not yet a finished good. WIP can also include subassemblies for a BOM that are held in inventory.

- **Finished goods inventory** includes the finished, ready-to-use products waiting to be purchased by the customer.
- **In-transit inventory (distribution inventory)** is "inventory in the transportation network and the distribution system, including the flow through intermediate stocking points" (*Dictionary*). Some amount of inventory of each other type is in transit at any given time due to the never-ending cycle of production and replenishment; an example is inventory on containerships for international shipments. Counting only the inventory that is currently in stock could be omitting a significant percentage of total inventory. In-transit inventory is measured by the average annual inventory in transit, which is a function of transit time in days and annual demand. Reducing this cost requires finding ways to reduce transit time, because less volume needs to be in transit at a given time.
- **MRO (maintenance/repair/operating supplies) inventory** includes spare parts, lubricants, hand tools, and cleaning supplies that are needed to maintain production but are not in the final product. Because of this, MRO is expensed rather than being an asset on the balance sheet like the other types of inventory. Maintaining reliable production requires keeping an inventory of supplies for both routine maintenance and emergency repairs. Attention to production machinery and MRO forecasting can reduce equipment costs and downtime.

MRO inventory has its own inventory management challenges. It is often kept in multiple dispersed locations at a facility, making it hard to accurately account for its accumulation or use. This creates risks of obsolescence, unnecessary purchasing of items already in stock, and unnoticed pilferage. Purchase requisitions are often the only trigger to order more MRO inventory, but their frequency and small order size make these an administrative burden. Organizations could realize significant benefits from investing management time in optimizing the size of this inventory investment, the number of suppliers being used, the controls over MRO inventory, or the MRO ordering process. Many organizations rely on corporate credit cards for small-value MRO items. Some organizations partner with full-service distributors to create an online requisition system. Given enough volume, a distributor may keep an employee on site to help the organization avoid stocking so much MRO inventory because they can offer fast replenishment. Another improvement example is to centralize MRO inventory storage.

Functions of Inventory

Inventory can be seen as both an asset and a liability. The following functions, or purposes, of inventory answer the question "Why have inventory in the supply chain?"

- **Cycle stock or lot-size inventory.** The *APICS Dictionary,* 16th edition, defines **cycle stock** as inventory that "depletes gradually as customer orders are received and is replenished cyclically when supplier orders are received." These available-for-sale or sold goods constitute the main function of inventory. When referring to aggregate inventory in the supply chain, cycle stock may be called pipeline inventory. Cycle stock is called lot-size inventory when the inventory is purchased or manufactured in quantities greater than needed, such as to receive quantity or full truck discounts or to match batch sizes for production.

- **Anticipation inventory** is "additional inventory above basic pipeline stock to cover projected trends of increasing sales, planned sales promotion programs, seasonal fluctuations, plant shutdowns, and vacations" (*Dictionary*). It is intended to cover the demand projected in the organization's demand plan. The demand plan will include anticipation of demand peaks and valleys due to promotions or changes in seasonal demand. In a level production strategy, anticipation inventory may require building additional inventory before it is needed in order to cover the anticipated increased demand later in the year.

- **Buffer inventory** includes materials maintained to keep throughput steady at work centers. The *Dictionary* defines a **buffer** as

  > a quantity of materials awaiting further processing. It can refer to raw materials, semifinished stores or hold points, or a work backlog that is purposely maintained behind a work center.

  The term is also related to the theory of constraints. Some organizations dynamically adjust their buffer sizes as a control lever to manage constraints and keep throughput a priority so it can remain as high as possible.

- **Safety stock (fluctuation inventory)** is defined in the *Dictionary* as follows:

  > 1) In general, a quantity of stock planned to be in inventory to protect against fluctuations in demand or supply. 2) In the context of master production scheduling, the additional inventory and capacity planned as protection against forecast errors and short-term changes in the backlog. Overplanning can be used to create safety stock.

  Safety stock is inventory held to protect against miscalculations of timing or quantity. It is used to reduce variability in demand and/or supply. If a supplier goes bankrupt suddenly, for instance, safety stock can be used to continue production while looking for a replacement supplier. Safety stock helps meet customer service targets and reduces stockout costs. Use of safety stock to satisfy unplanned demand should be considered normal to a point. Inventory policy can be used to set an acceptable frequency for use of safety stock; increased frequency of use over this target is an exception indicating that there may not be enough planned cycle stock. Decreased frequency of use or non-use under this target may indicate that there may be too much safety stock.

Note: When the delivery times fluctuate, safety stock may be used for A and B items (fast and medium-fast movers) in the ABC inventory method. However, when applied to C items (slow movers), inventory will increase too much because the inventory is rarely needed. In this case, safety lead time should be used.

- **Hedge inventory.** Hedge inventory is not a commonly used term, but many organizations do practice hedging when it comes to inventory. Hedging involves managing risk by building, buying, or contractually guaranteeing additional inventory at a set price if supply could be threatened or prices could rise. These decisions involve speculating on events such as the weather, the economy, labor strikes, civil strife, or political actions.

A key concept related to buffer inventory and safety stock is decoupling. **Decoupling** is defined in the *Dictionary* as

> creating independence between supply and use of material. Commonly denotes providing inventory between operations so that fluctuations in the production rate of the supplying operation do not constrain production or use rates of the next operation.

Decoupling allows supply and demand functions to operate at differing, independent rates. Holding a supply of raw materials inventory, for example, decouples the manufacturer from its suppliers. The sawmill operator wants to have a ready supply of trees to turn into dimensional lumber. The furniture manufacturer wants enough dimensional lumber to process.

Since many products are produced in batches when there are competing uses for the same work centers, decoupling also allows scheduling use of a work center so that some production may occur earlier than needed to avoid bottlenecks in overall production. While this adds to inventory build-up because some WIP inventory will be ready for the next work center before it is needed, it is an example of the need to optimize the overall flow of inventory in production. While decoupling is often necessary, supply chain managers look for ways to achieve the same goals without the holding costs by reducing variability in quality, quantity, or delivery time.

Inventory Costs

A number of specific costs are associated with inventory. It is important to understand up front that these costs are interrelated and a decrease in one cost could result in an increase in a different cost. Inventory managers set order amounts and timing to reduce acquisition, carrying, and ordering costs without sacrificing customer service. This process is needed in each part of the supply chain. The retailer and the distributor order more finished goods, the manufacturer orders more components and supplies, the supplier orders its own materials and supplies, and so on. An order schedule can help coordinate these flows.

Acquisition Costs

The *APICS Dictionary,* 16th edition, defines **acquisition cost** as

> the cost required to obtain one or more units of an item. It is order quantity times unit cost.

Acquisition cost is also referred to as product cost or purchase price.

Landed Costs

According to the *Dictionary,* **landed costs** include "the product cost plus the costs of logistics, such as warehousing, transportation, and handling fees." Landed costs for purchased inventory are the sum of all direct costs, including the price paid (i.e., acquisition cost), transportation to the site, customs, and insurance. Landed costs for internally sourced inventory include direct labor, direct materials, and factory overhead costs.

Carrying Costs

Carrying cost (also called holding cost) is "a percentage of the dollar value of inventory per unit of time (generally one year)" (*Dictionary*). It is a variable cost that increases as the level of inventory increases. Carrying costs may be as high as 40 percent of the value of the inventory and are unlikely to be less than 15 percent. They include all the expenses involved in housing the inventory, such as the following:

- **Storage costs.** Storage costs include allocations for rent, operating cost, taxes, material-handling costs, lease payments for equipment, depreciation, power costs, and operating costs. These material, labor, and overhead costs for storing and moving inventory are allocated to individual SKUs (stock keeping units) based on their volume (called cube), weight, or density. Large, dense, or difficult-to-handle goods have higher storage costs.

- **Capital costs.** Inventory requires financing, and capital costs refer to the return expected by creditors and investors because the money could be invested elsewhere (called opportunity cost). Companies acquire financing from debt or equity sources. Debt sources include borrowing arrangements that charge interest and require repayment; equity sources include money from investors (who get an ownership stake in the organization) plus retained earnings (past profits). The relative proportion or weight of each of these sources is called the weighted average cost of capital (WACC). WACC can be used as a required percentage return on inventory sales that must be exceeded.

- **Risk costs.** Risk is related to the sensitivity of the inventory to loss of value, such as its perishability, speed of obsolescence, or likelihood of theft. Risk costs include the cost of insurance, inventory value reductions, and inventory write-offs. Subjective quantifications of risk can be added to inventory, such as a two percent per day decline in inventory value due to obsolescence. In this example, inventory remaining in stock for more than 50 days is considered valueless.

Ordering Costs

The *Dictionary* defines **ordering costs** as follows:

> Used in calculating order quantities, the costs that increase as the number of orders placed increases. It includes costs related to the clerical work of preparing, releasing, monitoring, and receiving orders, the physical handling of goods, inspections, and setup costs, as applicable.

Ordering costs are all those costs that do not vary due to quantities ordered but vary only by the frequency of ordering.

Ordering costs include costs incurred when ordering inventory and setup costs resulting from the process of preparing to go into production to fill the order. For purchased materials, ordering costs include all the costs associated with the purchasing process. Use of electronic forms and payment transfers can reduce these ordering costs; less frequent ordering can also reduce these costs but at the price of additional inventory holding costs. Setup costs include labor for cleaning machinery and making any necessary adjustments or modifications. This requires shutting down the machines, but it is sometimes possible to reduce the shutdown time by doing some preparation work off the work site while the machines are still processing previous orders.

Backorder, Lost Sale, and Lost Customer Costs

The cost of backorders, lost sales, and lost customers are costs related to customer service. A **backorder** (also known as a stockout) is "an unfilled customer order or commitment…an immediate (or past due) demand against an item whose inventory is insufficient to satisfy the demand" (*Dictionary*). The cost of backorders, lost sales, and lost customers can be difficult to quantify financially but can be measured using various means such as percentage of orders shipped on schedule, which can help quantify the safety stock investment needed for a particular item at a particular location to keep this risk at acceptable levels.

Capacity Variance Costs

Capacity variance costs are the costs of changing capacity beyond a "normal" range, including the costs of overtime, additional shifts, layoffs, or plant closings. Capacity variance costs can be minimized by production leveling strategies (producing a consistent amount throughout the year), but this strategy increases inventory holding costs during periods of low demand.

Inventory Planning

According to the *APICS Dictionary,* 16th edition, **inventory planning** is

> the activities and techniques of determining the desired levels of items, whether raw materials, work in process, or finished products including order quantities and safety stock levels.

Inventory planning can be centralized or decentralized or a hybrid of the two.

- In centralized inventory planning, inventory is pushed out to later stages in the supply chain by the lead organization or channel master. Later stages such as distribution centers have no say in what they receive, but the central system usually attempts to replace inventory that is sold and to plan for seasonal effects or other trends. Centralized planning can minimize overall inventory levels but may respond slowly to local demand.
- Decentralized inventory planning involves each supply chain stage determining its own inventory requirements and placing orders independently, so there is no coordination expense.
- Hybrid systems use centralized planning up to a certain point in the supply chain (such as the distribution centers), followed by decentralized inventory planning at all later points.

Decentralized inventory planning can lead to the bullwhip effect and other problems, especially if actual customer demand isn't available to all stages of the supply chain. Therefore, centralized or hybrid planning has grown in popularity.

Inventory planning has two major components: where to locate inventory and the desired levels of items at each selected location.

Locations of Inventory

Where should inventory be located? Inventory should be located in any place in the distribution network structure where it can serve a valid purpose as a buffer between stages of the supply chain, reduce overall costs, and meet customer service goals.

Warehouses, Distribution Centers, in Transit

Inventory can be stored in warehouses and in retail locations.

The *APICS Dictionary,* 16th edition, defines **warehouses** as

> facilities used to store inventory. Decisions driving warehouse management include site selection, number of facilities in the system, layout, and methods of receiving, storing, and retrieving goods.

Distribution centers are a type of warehouse. According to the *Dictionary*, a **distribution center** is "a location used to store inventory." Inventory can also be located in transit.

Echelons

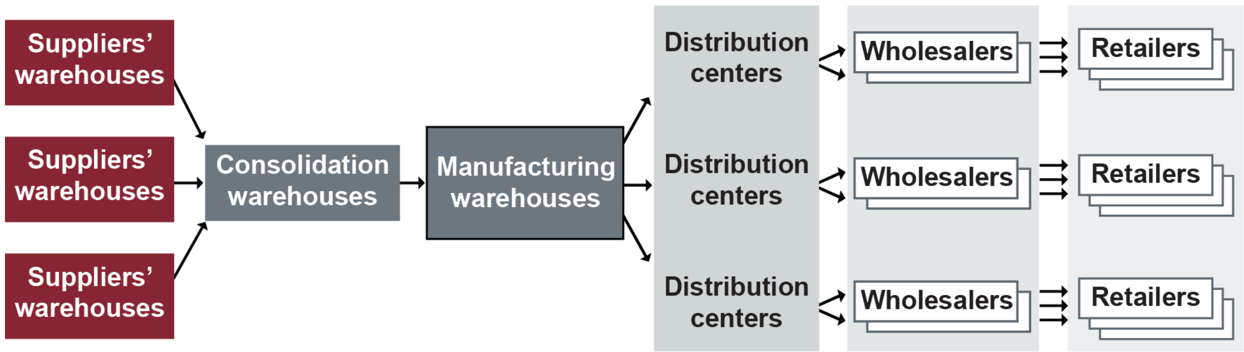
How can these inventory locations be optimized to minimize total inventory and maximize customer service? Treating each stage of inventory handling as an echelon is a good way to start understanding how to manage inventory locations. According to the *Dictionary*, an **echelon** is

> a level of supply chain nodes. For example, a supply chain with two independent factory warehouses and nine wholesale warehouses delivering product to 350 retail stores is a

supply chain with three echelons between the factory and the end customer. One echelon consists of the two independent factory warehouses, one echelon consists of the nine wholesale warehouses, and one echelon consists of the 350 retail stores. Each echelon adds operating expense, holds inventory, adds to the cycle time, and expects to make a profit.

illustrates the possible locations of inventory by these supply chain nodes.

Exhibit 4-24: Locations of Inventory by Echelon



Echelons can be helpful in planning the locations of inventory because organizations can decide how many echelons to have. Some organizations will not have as many as others, since each adds to material, labor, overhead, and inventory costs. Consolidation warehouses could be omitted entirely. A direct-to-customer business model would not contain any wholesalers or retailers. The same could be true for any other echelon.

The organization performs strategic network design to determine the optimum number of echelons, followed by analysis of the number and geographic location of specific sites. Usually this analysis makes use of network modeling, operations research, and decision support systems to calculate the lowest total cost of ownership of all storage locations, handling costs, and transportation costs for a selected level of customer service.

Each echelon can provide particular benefits, such as the following:

- Suppliers' warehouses provide a buffer against manufacturing orders.
- Consolidation warehouses lower transportation costs by grouping shipments from multiple sources into fewer shipments to a manufacturer/assembler.
- Manufacturing warehouses provide a buffer for manufacturing processes as raw materials and WIP and for later echelons as finished goods. That is, the buffer provides decoupling between these supply chain nodes.
- Distribution centers provide a buffer for later echelons. When they serve as break-bulk warehouses, they lower transportation costs by receiving large shipments (economy of scale) while shipping out individual orders. They can also serve as consolidation warehouses by grouping shipments from multiple vendors into fewer shipments to a wholesaler or retailer.
- Wholesalers may provide buffering, consolidation, or break-bulk services.
- Retailers provide immediate access to inventory and possibly other services.

Consolidation and break-bulking not only reduce transportation costs but can reduce inventory, especially slow-moving inventory, since it can be shipped in smaller quantities when consolidated with other inventory.

In addition to buffering, consolidation, and break-bulking, storage locations can provide three other benefits:

- Sorting (cross-docking, assembly, and mixing)
- Seasonal storage (produce inventory year-round; sell in one season)
- Reverse logistics (sites for returns, remanufacturing, repair, remarketing, and disposal or recycling)

Echelons can also be used to aggregate inventory for centralized inventory planning purposes—if inventory planning decisions can be made for the entire supply chain and/or decision makers have access to visibility of inventory information at each location. Hybrid systems can use this policy up to the point where centralized planning ends and may rely on visibility after that.

Echelon inventory policy considers inventory at a particular point to include all inventory at that echelon and at all later points in the supply chain, including all transit inventory after the given point. The benefit of thinking in this way is that the demand from all lower points can be aggregated for more accurate calculation of order quantities and order levels. At each lower echelon, this process can be repeated and will be more and more detailed.

Levels of Inventory

In addition to determining the number and location of warehouses, supply chain managers oversee the stocking of warehouses with an optimal level of inventory. They also establish transportation links that ensure timely arrival at and departure from warehouses.

In the ideal network, raw materials, components, and other resources might never be at rest in a warehouse. Instead, they would always be in motion until arriving, just in time, at each location along the supply chain. One reason this ideal state is difficult, or impossible, to achieve is the fluctuation in demand all along the supply chain, beginning with the ultimate customer. Unpredictable demand, along with other factors such as accidents and adverse weather conditions, means that maintaining some levels of inventory at various locations along the supply chain is generally necessary. The supply chain manager's challenge in the area of inventory level planning, therefore, involves assessing future demand as accurately as possible and keeping inventory as low as possible without disruptions in delivery to customers.

Inventory level planning requires demand management and forecasting, distribution requirements planning systems, warehouse management systems, and transportation management systems, as discussed elsewhere.

Inventory Management

The *APICS Dictionary,* 16th edition, defines **inventory management** as “the branch of business management concerned with planning and controlling inventories.” Inventory management is required at any organization that carries inventory. This role involves planning and controlling inventory from a supply chain perspective and an internal process perspective.

The supply chain perspective of inventory management is concerned with the inflows and outflows at each stage, from the ordering of raw materials to customer handoff of finished goods. Therefore this area can benefit strongly from inventory visibility and supply chain collaboration. **Inventory visibility** is “the extent to which inventory information is shared within a firm and with supply chain partners” (*Dictionary*).

Inventory management is also integrally connected to production management, so the second perspective of inventory management is an enterprisewide view of inventory processing. Inventory feeds into production and/or is a result of production, so planners, master planners, and production schedulers coordinate with each other at each level of production planning refinement.

Inventory management may be the responsibility or concern of many different competing interests at an organization, as shown in Exhibit 4-25.

Exhibit 4-25: Inventory Management Roles

Purchasing and materials management	Adequate raw materials at low inventory cost
Manufacturing and finance	Efficient and low-cost production balanced against low inventory cost
Sales and marketing	Sufficient inventory to meet customer delivery requests and service levels

Inventory is managed as an overall strategic concern (in aggregate) and at the individual item level. Each method is necessary. Together these two methods provide inventory managers with sufficient information to meet both strategic and operational requirements. Inventory policy may be set at both the aggregate and item levels, so it is discussed first.

Inventory Policy

Inventory policy is a way of formalizing the results of strategic inventory decisions so that they can be implemented consistently. Inventory policy codifies both broad and specific inventory management decisions. On a broad level, inventory policy could specify centralized or decentralized inventory planning and/or warehousing, frequency of communications and coordination, or a geographical inventory positioning strategy such as postponement. On a more specific level, inventory policy can specify rules for order quantities, order timing, when to act on exceptions to rules, and amounts of specific items to purchase versus produce.

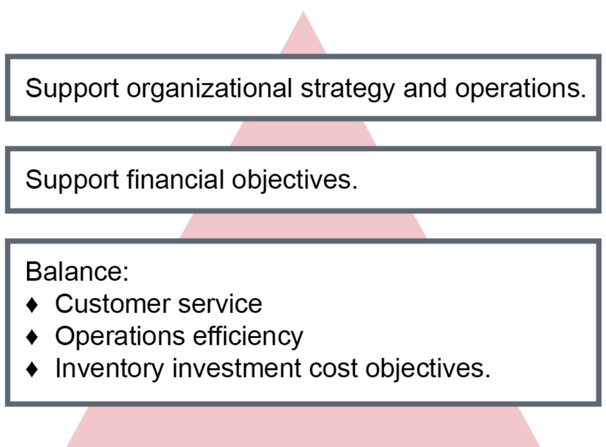
Organizations weigh a number of factors when setting an inventory policy:

- **Customer demand.** Customer demand is known in advance of production and/or is forecasted. Inventory policy must compensate for demand forecast variability.
- **Planning horizon.** The duration of the planning horizon affects necessary inventory levels; long-term plans may provide time to change system capacity.
- **Replenishment lead time.** The time required to replenish stock at various locations in the supply chain is a key inventory policy input, especially for long or highly variable lead times.
- **Product variety.** Similar products may compete for budget allocations or retail shelf space and thus need interconnected inventory policies. Product families are planned together in part as a way to reduce the impact of product variety on planning. An excess of variety can produce far too many SKUs (stock keeping units), which results in a significant increase in inventory holding costs for make-to-stock products.
- **Inventory costs.** Inventory costs include order costs (production and transportation) and inventory carrying costs.
- **Customer service requirements.** Inventory policy specifies a level of safety stock per item and location that balances minimizing failure to fill customer orders within an acceptable time (e.g., stockouts) against increasing inventory costs.

Aggregate Inventory Management

Aggregate inventory management is primarily concerned with the financial impact of inventories, which means getting to an optimal level of inventory that can produce the greatest overall profit for the organization and the supply chain. The objectives of aggregate inventory management are shown in Exhibit 4-26.

Exhibit 4-26: Objectives of Aggregate Inventory Management



Inventory is aggregated, or grouped, prior to analysis not only because the large number of individual items in some organizations would be impractical to analyze individually but also because, when forecasting supply and demand patterns, aggregate-level forecasts are more accurate than item-level forecasts. (Aggregation reduces the variability in data.) Note that aggregation is performed only to the level that the groupings provide effective analysis.

Aggregate inventory management can be used to
- Determine the types of inventory to hold
- Optimize the flow of inventory and provide suitable buffers between stages
- Match supply with demand
- Set inventory objectives and inventory policy
- Calculate inventory costs by category
- Perform sales and operations planning (including production planning), demand management, and resource planning.

Aggregating inventory helps inventory managers determine the costs and benefits of a particular group of inventory. Inventory can be aggregated by
- Demand pattern (e.g., women's running shoes versus men's running shoes)
- Production process (e.g., men's and women's running shoes produced on the same production line)
- Stage of production flow (e.g., raw materials, finished goods)
- Product or SKU family or type (e.g., finished goods with similar functions but variations in models, packaging, colors, or styles)
- Distribution pattern (e.g., products that originate at the same source and/or are to be delivered to the same location or customer zone)
- Relative value to the organization (e.g., ABC inventory classification).

Let's take a closer look at ABC inventory classification.

ABC Inventory Classification

ABC classification , also known as ABC analysis, is defined by the *APICS Dictionary,* 16th edition, as follows:

> The classification of a group of items in decreasing order of annual dollar volume (price [more typically standard cost] multiplied by projected volume) or other criteria. This array is then split into three classes, called A, B, and C. The A group usually represents 10% to 20% by number of items and 50% to 70% by projected dollar volume. The next grouping, B, usually represents about 20% of the items and about 20% of the dollar volume. The C class contains 60% to 70% of the items and represents about 10% to 30% of the dollar volume. The ABC principle states that effort and money can be saved through applying looser controls to the low-dollar-volume class items than will be applied to high-dollar-volume class items.

ABC classification is often based upon the monetary value of inventory, which is usually a standard cost. The A grouping has the greatest value and qualifies for the most careful treatment and highest level of controls.

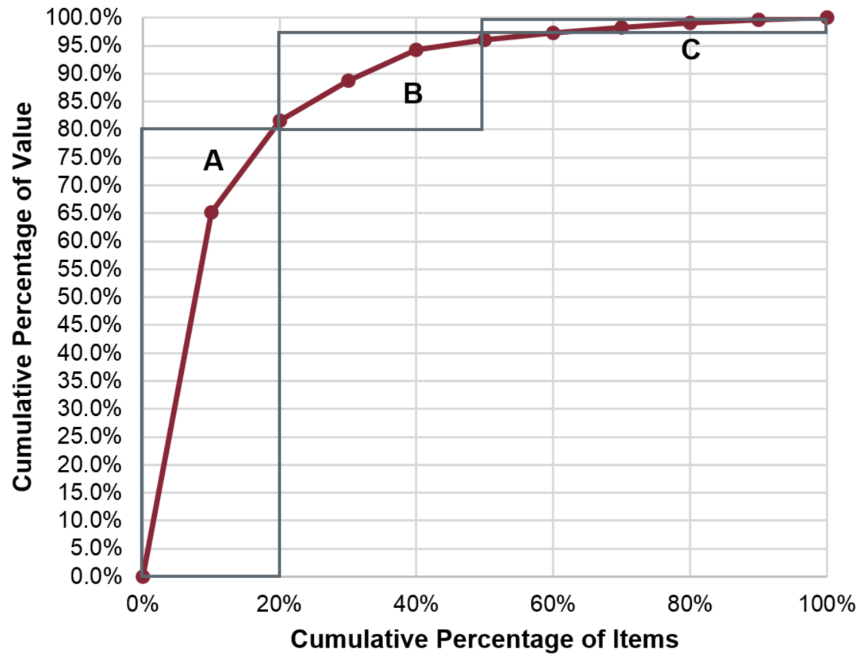
Dividing inventory into A, B, and C groupings is an application of the Pareto principle, which asserts that in any population (customers, inventory items, etc.), a small percentage of the population (about 20 percent) will be responsible for a large portion of the group's impact (about 80 percent). It is a general rule, of course, but it often proves to be meaningful enough as an estimate that it is worth applying.

The ABC application of Pareto analysis, or the 80/20 rule, reads this way:

- The **Class A** inventory items are those with the highest value in terms of annualized monetary volume. A classic Pareto analysis would determine that 80 percent of the inventory's monetary value would reside in 20 percent of the part numbers in the inventory. (The prior definition lists alternate values.)
- The **Class B** inventory items are those with the next highest value in terms of annualized monetary volume. Approximately 15 percent of the inventory's monetary value would reside in 30 percent of the part numbers in the inventory.
- The **Class C** inventory items are those with the lowest value in terms of annualized monetary volume. Approximately 5 percent of the inventory's monetary value would reside in 50 percent of the part numbers in the inventory.

shows an ABC classification that uses an 80/15/5 split.

Exhibit 4-27: ABC Classification in Inventory Management



Annual monetary volume is just one criterion used to assess value. Class A items could be high-profit-margin goods or lower-margin goods that have high turnover. Other considerations, such as quality concerns or anticipated upgrades, may suggest altering the classes.

Some organizations further refine this type of classification system. For example, one organization found that one percent of their items accounted for 50 percent of their annual monetary volume, so they made an additional class and called their system an ABCD inventory classification to highlight this inventory’s importance.

An ABC inventory classification might be used as a foundation for any of the following policies:
- Putting more time, effort, and money into cultivating relationships with the suppliers of the A items (and none into working with C suppliers)
- Warehousing the A items in the most secure part of the facilities, taking more care in transporting them, providing quick access to fast-turnover goods, etc.
- Conducting more rigorous demand forecasts for A items than for other items
- Prioritizing cycle counting activities (Note that enterprise resources planning systems usually segregate ABC systems for the purpose of counting. Using ABC as an inventory policy may require using a different identification data field.)

There are also various other methods for aggregate inventory classification according to specific criteria, for example, individual cost or utility value.

Item Inventory Management

Item inventory management is used in short-term operational decision making. Management specifies rules to follow for individual inventory items using inventory policy and/or information technology systems. These rules specify
- When to order inventory
- How to determine order size
- Relative importance of each inventory item
- Inventory control procedures for individual items.

The goal of item inventory management is to enable planners to translate strategic inventory goals into measurable results: proper production and distribution of each product or SKU. While sales and operations planning plans production at the family (aggregate) level, master scheduling plans inventory production at the item level (involving generation of the item-level master production schedule). Item inventory management is also necessary at retail locations, which must anticipate demand for inventory both at the aggregate and item level to ensure that individual items are available for purchase. Item inventory management is implemented through inventory planning, inventory models, and inventory control.

Effects of Inventory on Financial Statements

In addition to inventory describing the things the company owns that are available for sale or that are used in the production of things available for sale, inventory can be viewed as all the money currently tied up in the supply chain. What is critical to know is this: As much as 40 to 50 percent of a supply chain's invested working capital can be tied up in inventory.

While inventory can be seen as the buffer that hides the flaws in the supply chain, it can also be seen as the lubricant that keeps a supply chain flexible. A flexible supply chain is able to respond quickly to internal or external (market) changes, such as fluctuations in demand. Therefore, inventory management is an integral supply chain management role because it strongly affects the company's cash flows and financial position.

The goal of the supply chain professional is to efficiently manage the company's inventory level and cost while maintaining and improving customer satisfaction. If a company has fast delivery and strong customer satisfaction because it keeps a large inventory, it can also face financial failure because of all the cash tied up in inventory. On the other hand, if a company does a great job at reducing its inventory and associated costs down to next to nothing, it may run the risk of being unable to deliver the requested products. This may cause customers to take their business elsewhere. Balancing cost, inventory level, and customer service is vital. A key way to do this without going too high or too low in terms of overall inventory is to keep the inventory moving and the cash flow turning over—in other words, having a relatively high inventory turnover ratio (the number of times per year that cash is invested into inventory and returned in the form of revenue) and a relatively short cash-to-cash cycle time (this includes the effect of accounts payable and accounts receivable).

Use of the financial statements is an exercise in inventory management at the aggregate level to determine if the flow of materials through the various inventory classifications is efficient and effective enough to maximize profits. Discussions surrounding the financial impacts of inventory are generally framed around reducing inventory, reducing inventory costs, or increasing inventory turnover or cash-to-cash cycle time.

Balance Sheet

The balance sheet, or statement of financial position, has two major sections that have to be in balance as per the accounting equation:

$$\text{Assets} = \text{Liabilities} + \text{Owner's Equity}$$

Exhibit 4-28 displays a balance sheet. Inventory is a current asset that is broken down in this example by raw materials, work-in-process (WIP) inventory, and finished goods inventory. Note that most externally available balance sheets will list only total inventory (but breakdowns could be listed in a supporting schedule), while internal reports made for management purposes often have more details such as these.

Exhibit 4-28: Sample Balance Sheet Showing Two Years of Results

BALANCE SHEETS December 31,	In Millions (000,000) Year 2	Year 1
Assets		
Current Assets		
Cash and Cash Equivalents	$96.5	$56.3
Inventory		
Raw Materials Inventory	10.0	11.4
WIP Inventory	16.6	18.0
Finished Goods Inventory	33.3	31.0
Total Inventory	59.9	60.4
Prepaid Expenses	-	-
Accounts Receivable	48.4	44.3
Total Current Assets	**204.9**	**161.1**
Fixed Assets		
Gross Property, Plant, and Equipment	70.0	60.0
Less: Accumulated Depreciation	12.1	7.5
Net Property, Plant, and Equipment	57.9	52.5
Total Assets	**$262.8**	**$213.6**
Liabilities		
Current Liabilities		
Accounts Payable	20.0	19.6
Short-Term Notes Payable	7.5	6.0
Total Current Liabilities	27.5	25.6
Long Term Liabilities		
Long-Term Debt	60.0	60.0
Total Liabilities	**87.5**	**85.6**
Owners' Equity		
Common Stock (Par Value)	11.0	10.0
Additional Paid-In Capital	66.0	54.0
Retained Earnings	98.3	64.0
Total Owners' Equity	175.3	128.0
Total Liabilities and Owners' Equity	**$262.8**	**$213.6**

Statement of financial value at a point in time (end of year)

Unsold inventory on the books at the given date is a current asset on the balance sheet.

Direct materials, direct labor, and overhead costs of these assets will become an expense on the income statment when sold.

Average Inventory = (59.9 + 60.4)/2 = 60.2

Inventory as Asset

Raw materials, WIP, and finished goods are carried as current assets on the balance sheet. MRO (maintenance/repair/operating) inventory is a period expense; it is expensed on the income statement during the period in which it is purchased. The balance sheet items do not impact the income statement until the inventory is sold, reduced to fair market value, or written off (when inventory becomes obsolete).

While it sounds good that inventory is an asset, what this means to finance is that more liabilities are needed to finance those assets. Also, some amount of the organization's current assets will be less liquid than others. (Liquidity is how quickly assets can be converted into cash.) Therefore, optimum inventory holdings are those that equal projected sales in the organization's demand plan (plus an optimal amount of safety stock), because inventory that is projected to be sold soon is considered more liquid while inventory in excess of the demand plan is less liquid.

Risks of Carrying Too Much Inventory

The value of the inventory on the balance sheet includes the costs involved in producing the inventory. However, when the inventory is sold, the portion of inventory value that comprises direct materials (the raw materials), direct labor, and factory overhead will become an expense on the income statement that offsets revenue and reduces cash (an asset). In other words, inventory is an asset on the balance sheet until it is sold, at which point only its profit margin contributes to net income.

Unnecessary inventory can also magnify quality issues. If a defect or other quality issue is discovered, more inventory with the same defect will magnify the quality issue and quality costs for scrap, repair, and/or replacement.

An additional risk of carrying too much inventory is the risk of obsolescence or spoilage. As a general rule, the longer the inventory remains on the books, the more likely it will not be sold and will have to be written down to fair market value (what the market will currently pay) or written off completely. Inventory that has to be written off requires physical removal of the items and financial recording of the direct materials, direct labor, and factory overhead as an expense without any offsetting revenue. Note that there are strict accounting rules for inventory write-offs that organizations will need to follow. Accountants will often create an inventory reserve account to reduce the value of inventory in anticipation of write-offs.

Finding Average Inventory on Balance Sheet

A calculation of average inventory for a period of time is frequently used in managing inventory. With today's software systems, average inventory can easily be determined at any time. However, to quickly estimate average inventory levels one can add the inventory value at the start of a period to the value at the end of the period and divide by two.

As an example, using the data in the balance sheet shown in Exhibit 4-28, we can calculate the average inventory for year 2 as follows (amounts in thousands):

$$\text{Average Inventory} = \frac{\text{US\$59.9} + \text{US\$60.4}}{2} = \text{US\$60.2}$$

Average inventory (however your organization calculates it) is used in performance measures and calculations for inventory space requirements.

Financial and Managerial Accounting Value of Inventory

How is the value of inventory on the balance sheet calculated? Inventory valuation is a financial accounting process that follows specific rules based on the age distribution of inventory. Various financial accounting methods can cause the accounting value of inventory over time to be more or less in alignment with its actual market value—first-in, first-out (FIFO); last-in, first-out (LIFO); weighted average cost; or specific identification. Also, inventory can be valued for managerial accounting purposes using standard costing. Standard costing applies the standard cost to inventory valuation; any variances from actual costs are adjusted at the period end and would be reflected in the financial statements. These accounting methods are addressed elsewhere.

Other reasons that the reported level of inventory on the balance sheet could differ from the actual market value is that this reported amount may include inventory that is reserved, obsolete, damaged, or otherwise unsalable. Some of this obsolete or damaged inventory will be written off as it becomes clear that it cannot be sold.

Since changes to inventory levels can affect the accounting values of inventory and financing needed to sustain the inventory, supply chain managers should consult with financial managers with enough advance notice so the organization can determine how to change inventory levels while keeping the organization solvent and in good standing with creditors and investors.

Income Statement

An income statement, such as the one shown in Exhibit 4-29, reflects the cumulative, dynamic relationship of earnings to expenses over a given period of time.

Exhibit 4-29: Sample Income Statement Showing Two Years of Results

INCOME STATEMENTS	**In Millions (000,000s) except per share amts.**	
For the Years Ending (Profit or loss over a period of time)	**Year 2**	**Year 1**
Revenue (Sales)	**$302.6**	**$276.9**
Less: Cost of Goods Sold (COGS)		
Direct Labor	38.3	37.6
Direct Materials	101.5	99.7
Factory Overhead	26.6	26.1
Less: Total Cost of Goods Sold (COGS)	166.4	163.4
Gross Profit	**136.2**	**113.5**
Less: Operating Expenses		
Selling Expenses	30.3	24.9
General and Administrative	27.2	22.2
Lease Expense	12.1	8.3
Less: Total Operating Expenses	69.6	55.4
Less: Depreciation	4.6	4.0
Less: Interest Expense	3.9	3.9
Net Income (Profit) Before Taxes	**58.1**	**50.3**
Less: Income Taxes	16.3	14.1
Net Income (Profit)	**$41.8**	**$36.2**
Net Income (as a Pct. of Revenue)	14%	13%
Net Income Per Share-Basic	**$3.95**	**$3.78**

Product expenses: these expenses are booked when the related units of inventory are sold.

Period expenses: these expenses are recorded in the period in which they are incurred.

Managers, investors, and creditors use the income statement to determine whether the company has made or lost money during some period of time, such as a quarter or a year. An income statement measures profitability in more than one way. Gross profit is determined by subtracting cost of goods sold (COGS) from revenues. COGS includes inventory costs of direct labor, direct materials, and factory overhead for all goods that sold that year. Reducing elements in COGS can therefore directly increase gross profit.

Reducing these costs is more effective in increasing profits than increasing revenues through an increase in sales volume, because variable costs increase as revenues increase. By reducing costs, you are effectively increasing the profit margin on inventory without having to raise prices.

This shows that increasing sales cannot produce higher profits as quickly as lowering costs. It also shows that lowering variable costs in the supply chain can strongly impact profits.

COGS is an expense that is matched to the revenue being generated. Strategies that build inventory far in advance of actual sales can defer accounting for expenses that make up COGS until that inventory is sold. However, supply chain managers should understand that operating expenses (see Exhibit 4-29) are expensed on a periodic basis. These immediately booked expenses could cause problems with maintaining financial ratios at the proper levels. However, the actual cash outflows for both the product (depending on payment terms) and period costs would occur as the inventory is being built up (e.g., salaries, utilities, maintenance), so cash flow could be an issue without proper advance planning for the inventory build-up on the part of finance.

Statement of Cash Flows

Exhibit 4-30 is the statement of cash flows. Remember that a company does not want all of its capital tied up in inventory. Insufficient cash can result in expensive borrowing or cause an organization to fail quickly if it cannot raise funds. Note that a net increase in inventory lowers the cash position, while a net decrease in inventory increases the cash position. (The parentheses show which actions reduce cash.)

Exhibit 4-30: Sample Statement of Cash Flows Showing Two Years of Results

CASH FLOW STATEMENTS	In Millions (000,000)	
Year	Year 2	Year 1
Operating Section		
After-Tax Net Income	$41.8	$36.2
Depreciation Add-Back	4.6	4.0
(Increase)/Decrease in Inventory	0.5	(8.6)
(Increase)/Decrease in Accounts Receivable	(4.1)	(4.1)
Increase/(Decrease) in Accounts Payable	0.4	1.8
Cash Flow from Operations	**43.2**	**29.3**
Investing Section		
Capex Spend (Capital Expenditures)	(10.0)	(10.0)
Cash Flow from Operations and Investment	**33.2**	**19.3**
Financing Section		
Additional Equity Capital	13.0	7.0
Less Dividends Paid	(7.5)	(5.0)
Increase/(Decrease) in Long-Term Debt	-	-
Increase/(Decrease) in Short-Term Notes	1.5	(1.5)
Cash Flow from Operations, Investments, and Financing	**40.2**	**19.8**
Beginning Cash Balance	56.3	36.5
Ending Cash Balance	**$96.5**	**$56.3**

A viable firm needs positive cash flow from operations in most years.

Change in cash balance over a period of time

Increase in inventory or accounts receivable reduces cash; a decrease will grow cash on hand.

Increase in accounts payable increases cash, while a decrease reduces cash.

Investments in extra capacity reduce cash.

Extra cash from financing means more debt or equity investments were issued; reduced cash means debt was paid down or dividends were paid to owners.

Net Income
+/– Change in (Δ) Operating
+/– Δ Investing
+/– Δ Financing
+ Beginning Cash
= Ending Cash

Changes to Inventory Affect Cash Flows

Inventory can strongly affect cash flows, which, in turn, can affect covenants with lenders (contractual agreements that may include lender requirements that the borrower maintain certain financial ratios at certain levels). Even a reduction in inventory can create one-time adjustments for finance that impact reporting. However, once the adjustments are made, the long-term financial impact of inventory reductions is usually positive.

For example, consider a situation in which a supply chain manager discovers that some types of inventory at the organization are not selling and have been held for too long. The manager suggests that reducing these types of inventory will allow the organization to reduce inventory by €60 million (m). However, the organization's chief financial officer raises a major concern. The organization's bank has a financial covenant on its loans that requires the organization to maintain a ratio of 2:1 between owners' equity and liabilities (twice as much in equity). If inventory is reduced by €60m, in the best case, cash would increase by a few million euros and, in the worst case, the organization would have to pay to scrap the inventory. Assuming that the transaction could be completed with no net change in income, in order to keep the balance sheet in balance, owners' equity (retained earnings) would be lowered by the same €60m. To maintain the financial covenant, the organization would need to decrease its liabilities by half as much, or €30m. These requirements could put a large burden on cash flow. Failure to maintain the covenant would place the organization in technical default, and its debts could become immediately due and payable. The result is that the organization is unable to perform the change immediately. The supply chain manager learns the value of consulting with finance prior to making suggestions for a major change in inventory so that finance can determine ways to accommodate the change while keeping the company solvent. The financial officer recommends that to prevent such a situation from recurring the organization should make financial reservations for obsolete stock, which would help the finance department understand how to prepare for the inventory write-off.

Topic 2: Replenishment Strategies

Replenishment strategies help control inventory levels at various supply chain echelons by providing guidance on how much to order and when to order resupply. Setting levels of safety stock or safety lead time in ways that balance customer service levels against inventory costs is another area requiring inventory control.

Inventory Control and Replenishment

The *APICS Dictionary,* 16th edition, defines **inventory control** as "the activities and techniques of maintaining the desired levels of items, whether raw materials, work in process, or finished products." Inventory control determines how much to order and when (how often) to order. Setting proper levels of safety stock or safety lead times is an additional type of inventory control.

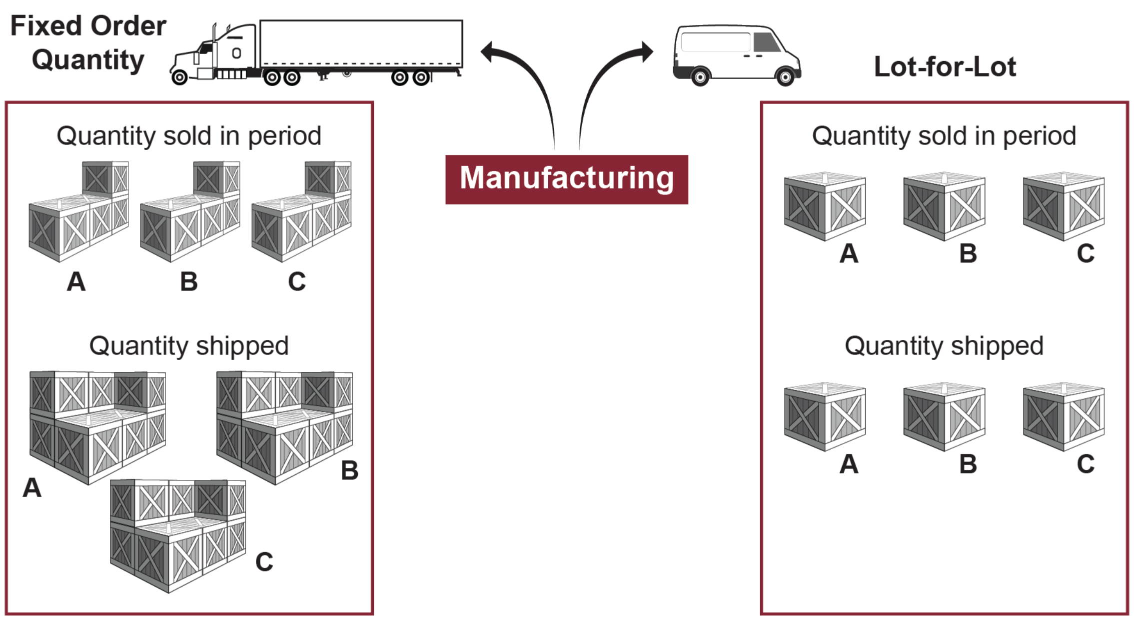
Inventory control aims to determine order amounts and timing with an objective of reducing carrying, ordering, and setup costs—without sacrificing customer service goals. Remember, an order schedule is necessary for managers all along the supply chain—the retailer and the distributor order more finished goods, the manufacturer orders more components and supplies, the supplier orders its own materials and supplies, and so on.

Determining Order Quantities

Ordering can be haphazard or disciplined, but there are enough unknowns in real life that managers will need to review their ordering model regularly. Since a haphazard system amounts to little more than guesswork, any disciplined method will be an improvement over that. Two models managers can use to determine how much to order are lot-for-lot and fixed order quantity (FOQ). These models are used with independent demand forecasts. The models were generally designed to be used with decentralized inventory planning, but they can be adapted for use in centralized planning (or echelon inventory policies could be used).

Exhibit 4-31 shows the relationship between these two ordering types.

Exhibit 4-31: Lot-for-Lot versus Fixed Order Quantity (FOQ)



The **lot-for-lot** ordering technique is defined by the *Dictionary* as

> a lot-sizing technique that generates planned orders in quantities equal to the net requirements in each period.

That is, organizations order no more and no less inventory than is needed. In this ordering system, the quantity ordered will differ in each period depending upon the current requirements.

Common uses for lot-for-lot include Just-in-Time manufacturing environments and ordering A items in the ABC inventory classification system. Lot-for-lot in retail environments is called consumption-driven replacement.

According to the *Dictionary*, **fixed order quantity** is

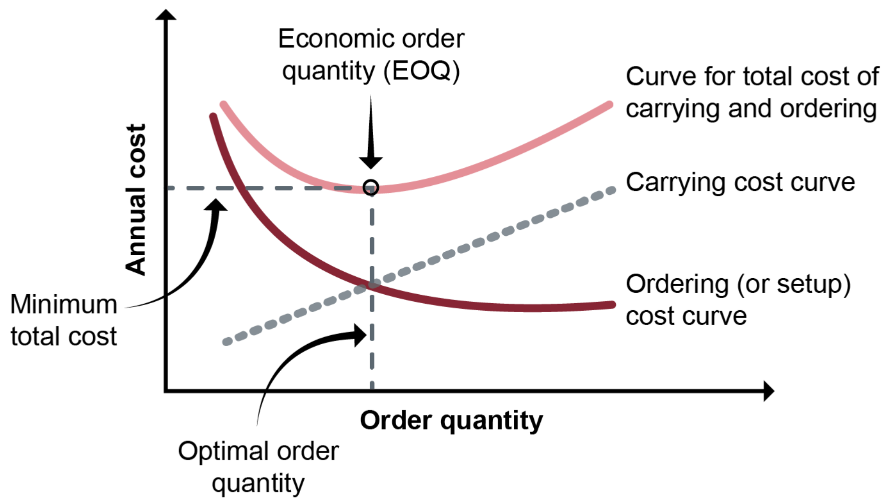
> a lot-sizing technique in MRP or inventory management that will always cause planned or actual orders to be generated for a predetermined fixed quantity, or multiples thereof, if net requirements for the period exceed the fixed order quantity.

The fixed amount may be determined by the amount in a box or on a pallet or the need to fill shipping containers to achieve full container discounts. A fixed order quantity can be delivered on a fixed schedule, or a variable schedule can be based on inventory levels. While this method is straightforward and inexpensive, it won't produce satisfactory results unless customer demand is very stable over the long term. One improvement that can be made to the method is to use an economic order quantity.

Economic Order Quantity (EOQ)

Economic order quantity (EOQ) is a refinement of FOQ that determines the most cost-effective fixed order size when replenishing inventory. The EOQ is the order size with the lowest total cost for carrying plus ordering (or setup) costs. Carrying costs tend to go up with larger order quantities, while ordering costs go down due to fewer orders being placed. In , the EOQ is the lowest point on the total cost curve.

Exhibit 4-32: Determining the Economic Order Quantity



You can see some general quantity-cost relationships from the graph:

- The total costs tend to drop until they reach a minimum, and then they start rising again. So there is an incentive to increase order quantity—but only to a point.
- The minimum total cost occurs where carrying and ordering costs are equal—just above where the cost lines intersect.
- If you shift the costs in either curve such as by reducing the costs per order (as lean manufacturing works to do) or the inventory carrying costs (e.g., taller warehouse racks for more storage), the EOQ will also shift.

The formula for EOQ is as follows:

$$\text{Carrying Costs} = \text{Ordering Costs}$$

$$\frac{Q \times i \times c}{2} = \frac{A \times S}{Q}$$

Solving for Q results:

$$\text{EOQ} = \sqrt{\frac{2 \times A \times S}{i \times c}}$$

Where:

Q = Order quantity in units

i = Annual carrying cost rate as percentage

c = Unit cost in dollars

A = Annual usage in units

S = Ordering costs in dollars per order

The first equation above shows the carrying cost formula set as equal to the ordering cost formula, which would be true at the point of intersection in the graph. When the costs are equal, solving for Q results in the EOQ formula as shown above.

EOQ is a simple model and so depends upon the following set of assumptions:

- Demand is constant and known.

- Lead time is constant and known. (The same amount of time always elapses between order placement and arrival.)
- The items ordered arrive all at once, not in stages.
- There are no quantity discounts.
- The variable costs in the calculation model are limited to carrying costs and ordering costs (whereas in reality other variable costs exist).
- There will be no stockouts if you place orders on schedule.

The beauty of the EOQ model is that even if there are considerable variations in the cost figures, the economic order quantity tends to vary within a fairly small range. Therefore, while the model's assumptions will no doubt be violated in the real world, the EOQ model is still considered useful. Supply chains with significant volatility may need to create a more complex model or frequently recalculate EOQ.

Ordering Systems (Determining When to Order)

In addition to picking an order quantity, an ordering system determines when orders should be placed. The *APICS Dictionary,* 16th edition, defines **inventory ordering systems** as "inventory models for the replenishment of inventory."

Inventory control models differ for independent versus dependent demand. Ways to determine when to order independent demand inventory include the order point, periodic review, min-max, time-phased order point, and demand-driven material requirements planning (DDMRP) systems. Material requirements planning (discussed elsewhere) is used for dependent demand, but DDMRP could also be used in conjunction with MRP. DDMRP highlights the strategic positioning of inventory (acting as a decoupling point) in a bill of material or a supply chain.

Order Point System

An order point system determines the inventory level, or point, at which a reorder must be placed. The order point is the point at which we have enough inventory to cover anticipated demand that will be consumed during the replenishment process.

This point is our demand during the lead time plus safety stock:

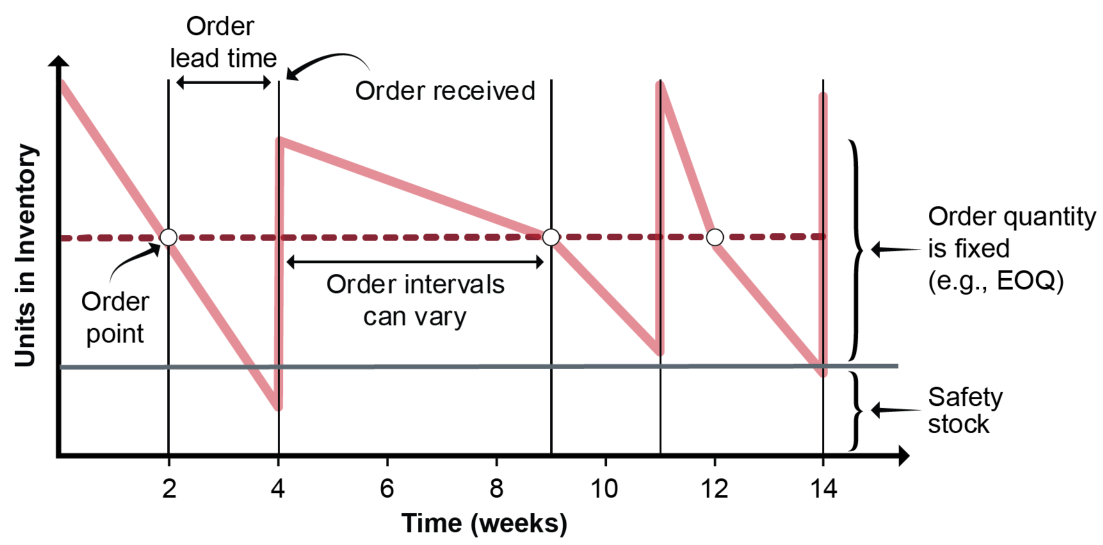
$$\text{Order Point} = \text{Demand During Lead Time} + \text{Safety Stock}$$

For example, if demand during the lead time averages 100 units a week, lead time is two weeks, and safety stock is 50 units, then the order point is when inventory falls to 250 units:

$$\text{Order Point} = (100\text{ Units per Week} \times 2\text{ Week}) + 50\text{ Units} = 250\text{ Units}$$

The sawtooth diagram in illustrates an order point system.

Exhibit 4-33: Inventory Level Fluctuations in Order Point System



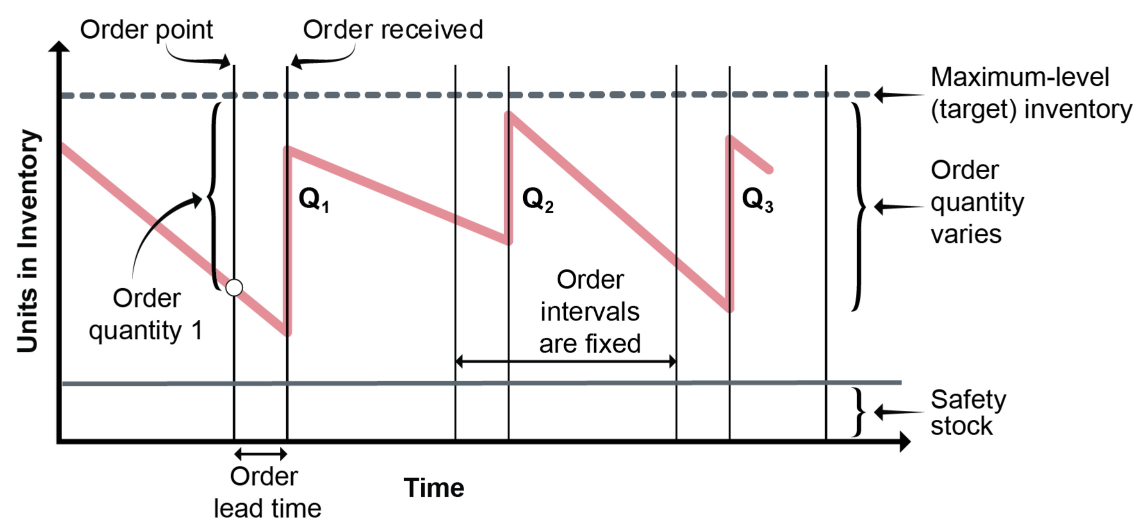
In an order point system, the time between replenishment orders is not fixed but varies based on the actual demand during the reorder cycle. Since the order point is based on the average demand during the lead time, if either the average demand or the lead time changes, the order point should also be changed or the level of safety stock will automatically change. A system based on average demand means that, at maximum demand, stockouts could occur, so some amount of safety stock is useful.

Periodic Review System

In a periodic review system, order intervals are fixed, such as each week, month, or quarter, and order quantities (shown as Q1, Q2, and Q3 in) vary. The method sets a base stock level, or maximum level of inventory, based on what is needed to maintain effective and continuous operations. This is the inventory target, or “order-up-to” level. The inventory position is reviewed each period, and order size is just enough to raise the inventory position to the base stock (target) level.

shows how the sawtooth diagram has fixed-width “teeth” that vary in height according to the amount ordered.

Exhibit 4-34: Inventory Level Fluctuations in Periodic Review System



The quantity in stock plus the quantity ordered must be enough to prevent stockouts, which means non–safety stock inventory has to last until the next review period plus the lead time required for the next shipment. The quantity ordered is the maximum amount less the quantity of inventory on hand at the order period:

$$
\begin{aligned}
\text{Maximum-Level Inventory} &= D(T+L)+SS \\
\text{Order Quantity} &= \text{Maximum-Level Inventory} - \text{Inventory On Hand} \\
\text{Where:} & \\
D &= \text{Demand per unit of time} \\
T &= \text{Time interval between ordering periods} \\
L &= \text{Lead time duration} \\
SS &= \text{Safety Stock}
\end{aligned}
$$

For example, if average demand is 50 units per week and there are 5 working days, demand per day is 10 units/day. Assume that orders are placed every 10 working days and lead time duration is 3 days. If safety stock should be 4 days' supply, at 10/units per day this would be 40 units. If there are 42 units on hand at the order point, then the maximum-level inventory and order quantity are calculated as follows:

$$
\begin{aligned}
\text{Maximum-Level Inventory} &= 10\,\text{Units per Day}(10\,\text{Day}+3\,\text{Days}) + 40\,\text{Units} \\
&= 170\,\text{Units} \\
\text{Order Quantity} &= 170\,\text{Units} - 42\,\text{Units} = 128\,\text{Units}
\end{aligned}
$$

Periodic review systems are useful for supermarkets or retailers with many items to sell because it keeps inventory tracking cost down and helps fill truckload assortments, assuming that the assortments can all be shipped from the same source such as a consolidation warehouse.

Min-Max System

With a min-max system, both order timing and order amount are allowed to vary. Orders are submitted after inventory has fallen below the minimum point, but inventory isn't allowed to go over a maximum. If, for example, the minimum is 300 items, the maximum is 1,000 items, and the periodic review reveals that inventory has dropped to 275 items, it would be time to place an order for 725 items. (This assumes that the order would arrive immediately—i.e., no lead time.)

Time-Phased Order Point System (TPOP)

The *APICS Dictionary,* 16th edition, defines a **time-phased order point (TPOP)** system as

> MRP-like time planning logic for independent demand items, where gross requirements come from a forecast, not via explosion. This technique can be used to plan distribution center inventories as well as to plan for service (repair) parts, because MRP logic can readily handle items with dependent demand, independent demand, or a combination of both. Time-phased order point is an approach that uses time periods, thus allowing for lumpy withdrawals instead of average demand. When used in distribution environments, the planned order releases are input to the master schedule dependent demands.

Rather than waiting until inventory drops below the order point, a TPOP system will check whether the item will fall below the order point during the order horizon. When used for a shop floor warehouse, it checks not only available inventory but also planned deliveries during the order horizon and the planned reorder point. If the available plus planned inventory is below the reorder point, a replenishment order is placed. “Lumpy withdrawals” in the above definition refers to situations such as promotions that create demand variability that order point systems have trouble adapting to because they are based on average demand.

Time-phased order point systems are useful for parts maintained in low volumes, slow movers, irregular demand items, and large parts. The shop floor warehouse needs visibility to its own inventory levels so it can allocate parts for assembly orders from the warehouse and backflush these orders against the shop floor warehouse.

Note that when a time-phased order point system is used for independent demand items at distribution centers, it is called distribution requirements planning.

Demand-Driven MRP System

Demand-driven material requirements planning (DDMRP) is a relatively new type of ordering system that can be used for dependent and independent demand items at any point in the supply chain. Note that DDMRP is part of a larger process called demand-driven planning (DDP); DDMRP is its ordering system. DDMRP strategically positions inventory to achieve all the benefits of modern supply chain management (reduce inventory, customer lead times, and the bullwhip effect; increase customer service and utilization) without needing to rely on safety stocks. Instead, DDMRP determines how to shrink total lead times by creating buffer inventories of key components with longer lead times.

DDMRP dynamically determines the best places to position inventory and dynamically adjusts the size of the buffer inventories to maximize return on investment for the inventory. To do this, it performs daily reviews that account for how long customers will wait for their orders, whether faster lead time would generate new sales, and whether certain inventory positions would leave the organization with more options for dynamic lead time compression. To minimize risk, it also factors in information on the item’s supply variability and demand variability and the need to maintain buffer inventories before any bottleneck work centers as per the theory of constraints.

Further information can be obtained at www.demanddriveninstitute.com. Another resource is *Demand Driven Material Requirements Planning (DDMRP), Version 3,* by Ptak and Smith.

Safety Stock and Safety Lead Time

Safety stock is extra inventory each partner along the supply chain may keep to reduce risks of unpredicted supply and demand fluctuations during the lead time. Safety lead time is ordering supplies earlier than needed as a measure of security against unpredicted manufacturing and transportation lead time fluctuations. For slow-moving items, safety lead times are preferred, because using safety stock will result in a larger overall inventory investment.

Safety Stock

The *APICS Dictionary,* 16th edition, defines **safety stock** as follows:

> 1) In general, a quantity of stock planned to be in inventory to protect against fluctuations in demand or supply. 2) In the context of master production scheduling, the additional inventory and capacity planned as protection against forecast errors and short-term changes in the backlog. Overplanning can be used to create safety stock.

Safety stock is there to be used, but always needing it typically means that cycle stock levels are not high enough while never needing it means too much cycle stock is being maintained. (The latter is usually the more expensive problem.) Organizations usually set a target frequency at which safety stock can be accessed, such as once per month. Needing to use safety stock at a given location more or less frequently than this target or never using safety stock at a location would trigger an exception needing review.

The amount of necessary safety stock or buffer stock depends upon several variables:

- **Frequency of ordering.** Stockout risk is highest at the time of replenishment because of the uncertainty of order receipt. If you need to replenish only once a year, you have one point of vulnerability, while replenishing weekly creates 52 potential stockout situations. Therefore, more frequent ordering typically requires higher levels of safety stock. However, infrequent ordering involves larger orders and average inventory levels at a high cost (except for very inexpensive items).
- **Variability of demand during lead time.** High variability of demand means high sales might occur while waiting for an order.
- **Length of lead time.** Longer waits have more chance for variability.
- **Accuracy of forecasting.** Higher confidence in the demand forecast reduces the need for safety stock.
- **Organizational, regulatory, or industry requirements.** Some organizations simply have to keep a minimum level of safety stock. For example, medical and pharmaceutical companies need to keep high levels of some safety stocks to address the risk of a pandemic.

There are three basic methods for determining the amount of safety stock to maintain:

- **Fixed amount.** Using experience or intuition to set or periodically review a fixed amount for a location's safety stock may be acceptable for stable demand items.
- **Coverage.** A coverage method sets safety stock for a given period at the level of inventory requested in the demand plan. If the demand plan forecasts a need for 10 units a day, safety stock for 30 days is 300 units. The advantage of coverage is that the safety stock will adjust itself based on the average (seasonal) demand.

- **Statistical.** A statistical safety stock calculation involves calculating a normal distribution (bell curve) of the variation in demand with average demand at the center. The standard deviations (sigmas) show analysts how high or low demand can get from the center. Safety stock is set to match the maximum variation in demand at a desired customer service level; it can be based on the most probable scenario or increased for less and less probable scenarios (1 sigma, 2 sigma, etc.).

Safety stock can enhance the customer service level by increasing availability or enabling meeting quoted lead times. A certain amount of safety stock is beneficial to the supply chain because it helps decouple supply from demand.

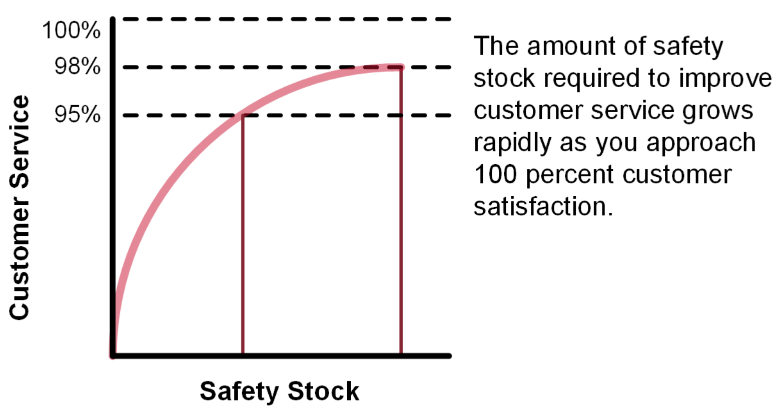
- If demand shoots up unexpectedly, warehouse safety stock can be shipped to the retailer. Retailer safety stock may also be in the back room or on shelves.

- If supply is suddenly lacking, you have that inventory in the pipeline to keep filling orders until the flow of supply resumes.

The prudent manager will look for ways to balance the costs related to holding safety stock and expenses related to stockouts—such as the cost of lost customers, needing to rapidly ramp up production, or needing to pay for expensive special deliveries. While the costs of stockouts are difficult to project accurately, management should set an acceptable cost level for stockouts and predetermine methods for dealing with them. The total cost of carrying safety stock plus the cost of stockouts should be tracked and minimized together.

While it may be tempting to shoot for 100 percent order fulfillment, Exhibit 4-35 shows how it takes a very large increase in safety stock to approach perfection. It shows that moving from 95 percent order completion to 98 percent requires a very large jump in safety stock, whereas relatively little safety stock was required to achieve 95 percent. (These are typical numbers, but they are not the same for all businesses.)

Exhibit 4-35: Safety Stock Increases Versus Order Fulfillment



Some companies have found a way to reduce inventory—not just safety stock—almost to zero while actually improving customer service on at least some measures. Dell Computer is a prime example. Dell is able to deliver custom computers rapidly. If, like Dell, a business can essentially source and make or assemble a product to order and deliver it within a reasonable time, it may eliminate its inventory while enhancing its reputation and customer loyalty. (A company may achieve these goals by shifting inventory back up the supply chain to its suppliers, in which case it's possible that nothing has been gained for the supply chain as a whole.)

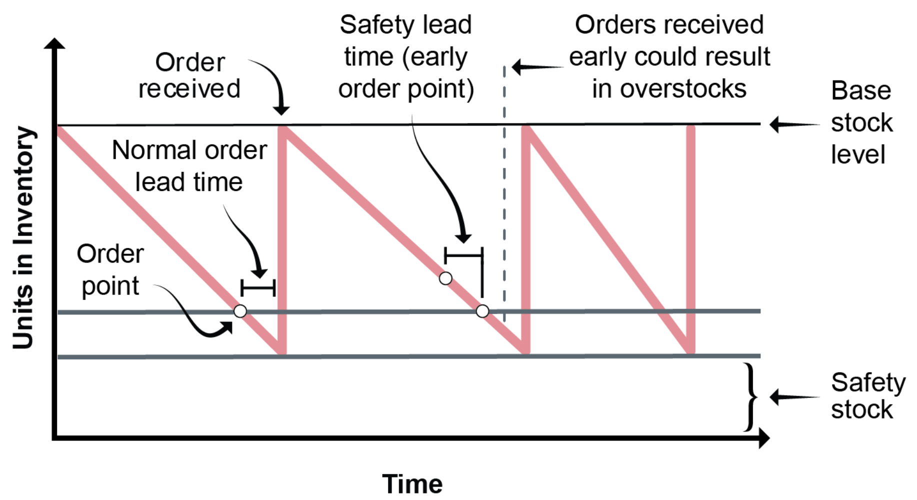
Safety Lead Time

The *Dictionary* defines **safety lead time** as

> an element of time added to normal lead time to protect against fluctuations in lead time so that an order can be completed before its real need date. When used, the MRP system, in offsetting for lead time, will plan both order release and order completion for earlier dates than it would otherwise.

When order lead times vary significantly or are lengthy, the longer wait increases the chances that a stockout could occur. Some organizations solve these risks by placing orders early (or late if orders consistently arrive too early). The safety lead time is the amount of time the order is placed ahead of the normal order point. Exhibit 4-36 shows how safety lead time could be used in an order point system.

Exhibit 4-36: Use of Safety Lead Time in Order Point System



In order point systems that can vary the timing of orders, the amount of safety lead time used can be hard to determine, for example, when studying ordering patterns of retailers. Reducing unnecessary safety lead time can reduce the bullwhip effect.

Safety lead times also require performing the same balancing act between ordering too soon and having overstocks and ordering too late and risking stockouts. For example, materials shipped overseas often have lead times of 60 days or more. Ordering too soon can result in a serious overstock because orders arrive by the container load. However, delays from weather, labor unrest, or other factors could cause a serious stockout (also due to the large order size).

Topic 3: Traceability, Accuracy, and Disposition

Product traceability helps provide a chain of custody and component origin information. Configuration management helps document product characteristics and control changes. Inventory accuracy is important for financial records and supply chain efficiency. Periodic or cycle counting can be used. Inventory that faces obsolescence or is returned may need to go through a decision process regarding its final disposition.

Product Traceability and Configuration Management

Product traceability refers to the ability to provide a chain of custody for a product and its components or ingredients. Traceability tracks a product's source materials and the finished good itself by their national origin and production facility, through each point of distribution, possibly to the specific final customer.

The *APICS Dictionary,* 16th edition, defines a **configuration management system** as "formal procedures to identify and document the physical characteristics of a product or project, control changes, and support an audit to verify conformance." Configuration management can ensure that product engineering specifications or product versions are properly maintained and distributed to the necessary parties so everyone is working from the same version. Product traceability and configuration management software exists, and one feature is often a change control system with related approvals.

Product traceability and configuration management

- Reduce the size of product recalls to just those items affected rather than having to expand the recall (and customer anxieties)
- Differentiate goods when region-specific bans on goods are put in place in response to contamination or food-borne disease epidemic risks
- Assist compliance audits, such as when verifying a claim that milk is free from bovine growth hormones as advertised
- Provide evidence that conflict minerals were not used
- Help with compliance with free trade zone agreements and labels such as "Made in the U.S.A." (All or virtually all components must be U.S.-sourced.)
- Assist with customs inspections
- Help establish a chain of custody for sensitive goods such as pharmaceuticals as they move between countries and supply chain points so that each stage and the specific parties involved in the journey can be on record. Blockchain is being used to ensure that these records can be securely created at multiple points in the supply chain, and it can even track things like temperature records for a cold chain. An auditable chain of custody is important to control counterfeits, to detect pilferage, and to prove safety compliance (e.g., compliance with U.S. Food and Drug Administration regulations).

Product traceability and configuration management also affect trade agreements such as free trade zones. These agreements provide special benefits for goods originating within the trade zone country but have limits on the number of components or ingredients that can come from outside the zone. Tracing the national origins of product components may be necessary.

Traceability and configuration management are enabled by technology systems such as some types of bar codes, radio frequency identification (RFID), global positioning systems (GPS), blockchain, and information systems such as transportation management systems (TMS) and warehouse management systems (WMS).

Assessing Inventory Accuracy

The *APICS Dictionary,* 16th edition, defines **physical inventory** as follows:

> (1) The actual inventory itself. (2) The determination of inventory quantity by actual count. Can be taken on a continuous, periodic, or annual basis.

No amount of forecast accuracy, ABC analysis, secure storage, or automated ordering adds up to successful inventory management without an accurate, current count of the physical inventory on hand. If you don't know how much you have, you don't know how much or when you should order. It is also vital to be able to accurately represent the amount of inventory on financial statements for compliance reasons.

The *Dictionary* defines **inventory accuracy** as follows:

> When the on-hand quantity is within an allowed tolerance of the recorded balance. This important metric usually is measured as the percent of items with inventory levels that fall within tolerance. Target values usually are 95 percent to 99 percent, depending on the value of the item. For logistical operations (location management) purposes, it is sometimes measured as the number of storage locations with errors divided by the total number of storage locations.

If inventory is inaccurate, it requires an inventory adjustment. The *Dictionary* defines **inventory adjustment** as

> a change made to an inventory record to correct the balance, to bring it in line with actual physical inventory balances. The adjustment either increases or decreases the item record on-hand balance.

There are two general approaches to keeping accurate inventory records, the results of which are used to make inventory adjustments when errors are found: periodic counts of all items and continuous cycle counts of specific items. Cycle counting is often preferred, but periodic counting still has its place.

- **Periodic counting.** Periodic counting involves shutting down the facility once a year and sending a large group of employees or temps into the area to count every item and calculate the dollar value of the items on the shelves. It's disruptive, expensive, and prone to inaccuracy because of the low expertise of the counters. (They may do it only once a year, after all.) However, for facilities that lack the control and advanced technology found in many up-to-date warehouses, periodic counting may be the only way to get the job done.

- **Cycle counting .** Cycle counting is defined in the *Dictionary* as

> an inventory accuracy audit technique where inventory is counted on a cyclic schedule rather than once a year...The key purpose of cycle counting is to identify items in error, thus triggering research, identification, and elimination of the cause of the errors.

Cycle counting is a more reliable method to determine the value of the items in storage and to facilitate the cost-effective, timely ordering needed for the most reliable customer service.

Here's how it works:

- Some items are counted every day to verify records and record any inaccuracies.
- All items are counted a set number of times per year. A items are counted most frequently—perhaps once a month, while B and C items are counted less often.

Smart rules are used in deciding when to count. Before a replacement order arrives, existing inventory is low and is easy to count. The same is true when inventory is zero. If the system says it is negative, it must be an error.

This continuous, limited counting doesn't require the facility or retail location to shut down for the count, so there is little or no disruption of ordinary business. Unlike the once-a-year count, cycle counting allows timely detection and correction of problems. It is much easier to find inventory error root causes when issues are found in real time. Attempting to problem-solve for transaction errors that occurred months ago is much more difficult. Cycle counting also eliminates the need for annual inventory adjustments.

Exhibit 4-37 provides an example of cycle counting. For this scenario, assume that a fictitious company, King Hospital Supplies, has an inventory of 10,000 items, of which there are 1,000 A items, 3,500 B items, and 5,500 C items. Cycle counting policy is to count A items once per month (20 working days), B items once per quarter (60 working days), and C items every six months (120 working days). Counts are distributed evenly over the year.

Exhibit 4-37: Cycle Counting Example

Item Class	Quantity	Cycle Counting Policy	Number of Items Counted per Day
A	1,000	Each month (20 days)	1,000/20 = 50/day
B	3,500	Each quarter (60 days)	3,500/60 = 58/day
C	5,500	Semiannually (120 days)	5,500/120 = 46/day
			154/day

The design and control of the warehouse is the beginning of accurate record keeping. Here are a few points to consider about keeping a secure storage space that makes tracking and counting inventory easier:

- **Keep it secure.** Small employee thefts add up, and, of course, large-scale vandalism or theft can wipe out inventory overnight. Limit access to the stockroom and keep it under observation. Keep a special high-security area as needed.
- **Keep it neat.** There should be a place for everything, and everything should always be in its place. In a busy environment, this can be a major challenge, but counting is much easier if areas are consistently used for the same type of items. Random systems can be secure if the record locators are kept accurate.
- **Make labels easily visible and put them on everything.** Labels can be designed for both fast visual identification and for automatic identification, such as using bar codes or radio frequency identification (RFID).
- **Use bins and space arrangements that make counting easy.** If storage bins and containers are limited to a certain number of items, you can estimate at a glance and count by groups instead of individual items.
- **Treat A, B, and C items appropriately depending on their classification.** A items require tighter control on security and reordering. You don't want to lose them or run out of them.
- **Make technology your friend.** Counting is something machines do better than people. With bar codes/RFID, readers, and real-time updates, you can keep a running tally of what goes into a facility, what goes out, what remains, how much should be on hand, and when you need to submit an order.

Product End of Life, Returns, and Disposition

The *APICS Dictionary*, 16th edition, defines **end-of-life management** as follows.

> Planning for the phase-out of one product and the phase-in of a new product to avoid both the excessive inventory of and an out-of-stock situation with the old product before the replacement product is available.

An end-of-life plan is needed for the point at which a product is no longer profitable due to lack of demand caused by obsolescence, market saturation, or supply/manufacturing issues such as rising costs (also affected by the level of competition). These plans need senior management support, consensus, and approval. A best practice is to standardize the process so that important details such as communications will be timely and professional. An end-of-life plan can include the following steps:

- Determine an end-of-sales strategy and schedule. At the appropriate time, communicate the strategy and schedule to suppliers, supply chain customers, end customers, and other stakeholders. Often the end of sales is a closely guarded secret until the time of official communication, because it can ruin sales of the old product. Customers will wait for the new product, and this can result in unsold inventory. The strategy may provide time to sell off remaining inventory (including in the distribution network), sell it in bulk to a third party, reuse components, recycle products, or responsibly dispose of them. Marketing may reduce prices or provide upgrade incentives and support.
- Determine an end-of-service strategy and schedule, including customer service, technical support, repairs, and/or service parts. This will need to be communicated well in advance. Service could remain profitable for an extended period, or, as an investment in customer loyalty, there could be a strategic decision to provide support for the expected life of the final products sold. Service parts might be outsourced or the designs sold to other organizations. Less-expensive forms of service could be substituted.
- Determine changes to manufacturing equipment or spaces that will no longer be needed, such as selling the equipment, retooling it for a new product introduction, or reallocating space. The product manufacturing rights and equipment could also be sold to a third party.
- Incorporate end-of-life plans, such as plans for backward compatibility or the timing of the introduction of new products, into new product introduction plans.
- Manage programs to accept products back at the end of their lives. Such programs could be based on regulatory requirements, be voluntary for sustainability, or enable recovery of rare materials such as gold.
- Perform risk and crisis management such as for product recalls, lawsuits, or unhappy customers.

Supply chain management professionals can provide valuable input or analysis for end-of-life plans. This includes reviewing minimum order quantity requirements, other contractual requirements, lifetime sales quantities and timing, and obsolescence timing.

Products in decline can delay their end-of-life date by cutting costs, often at the expense of customer service. However, other costs might increase as suppliers also work to cut costs, since components may also be in decline. Supply chain management professionals therefore need to review minimum order quantity (MOQ) requirements from suppliers and for customers. Suppliers may increase their MOQ in order to cut their manufacturing and supply chain costs, and this will lower the organization’s ordering cost but increase inventory carrying costs. Suppliers could instead lower the MOQ to promote sales if customers are no longer willing to buy in bulk. The organization can also alter its MOQs for customers for the same reasons. The net changes in costs will need to be analyzed for their impact on profitability.

Contractual promises may have been made to suppliers to buy their components or materials or for them to provide products and/or support to customers for a particular period, such as for a warranty period. It is important to review exit clauses to determine if there are ways to end a product per a desired time frame.

Reviewing lifetime sales quantities and timing involves estimating how many more units customers will purchase or can be convinced to purchase as a product is in decline/nearing obsolescence. The purpose is to help determine the timing of how many more units of the old product to produce and when to stop production. If the product has a direct replacement, the replacement needs to be available at that time. (This could be a new product or an existing one that could be a substitute and may be subject to increased demand.) Lifetime sales quantities are also used to estimate the quantities of components such as spare parts that will be needed to repair the existing products in use during their remaining useful life.

Often, customers need to calculate a “lifetime buy quantity” for equipment they own. This is the quantity of spare parts that the customer will need to purchase now in order to maintain a product to the end of its life cycle. It is used when spare parts for the product are being discontinued.

The timing of end of sales will not necessarily be obvious. Managers and salespersons will be invested in the status quo. Reviewing lifetime sales history can help provide information on where a product is in its life cycle. Historical sales trend data and sales pipeline information from the sales organization can be used to help reach consensus regarding a product’s end-of-sales point. The information can also be used for product life cycle analysis for future products that are similar. Note that this is the basic process used in a **life cycle analysis**, defined in the *Dictionary* as follows.

> A quantitative forecasting technique based on applying past patterns of demand data covering introduction, growth, maturity, saturation, and decline of similar products to a new product family.

Obsolescence can be planned or market-based. Planned obsolescence is part of a new product introduction strategy to release a replacement product and market it as an essential upgrade. Market-based obsolescence is based on a steady or sudden drop in demand, often due to competitor actions. Reviewing obsolescence timing involves forecasting when a product should or must reach its end-of-sales point. It is also important to ensure that material requirements planning components are planned accordingly as part of the end-of-sales plan, including:

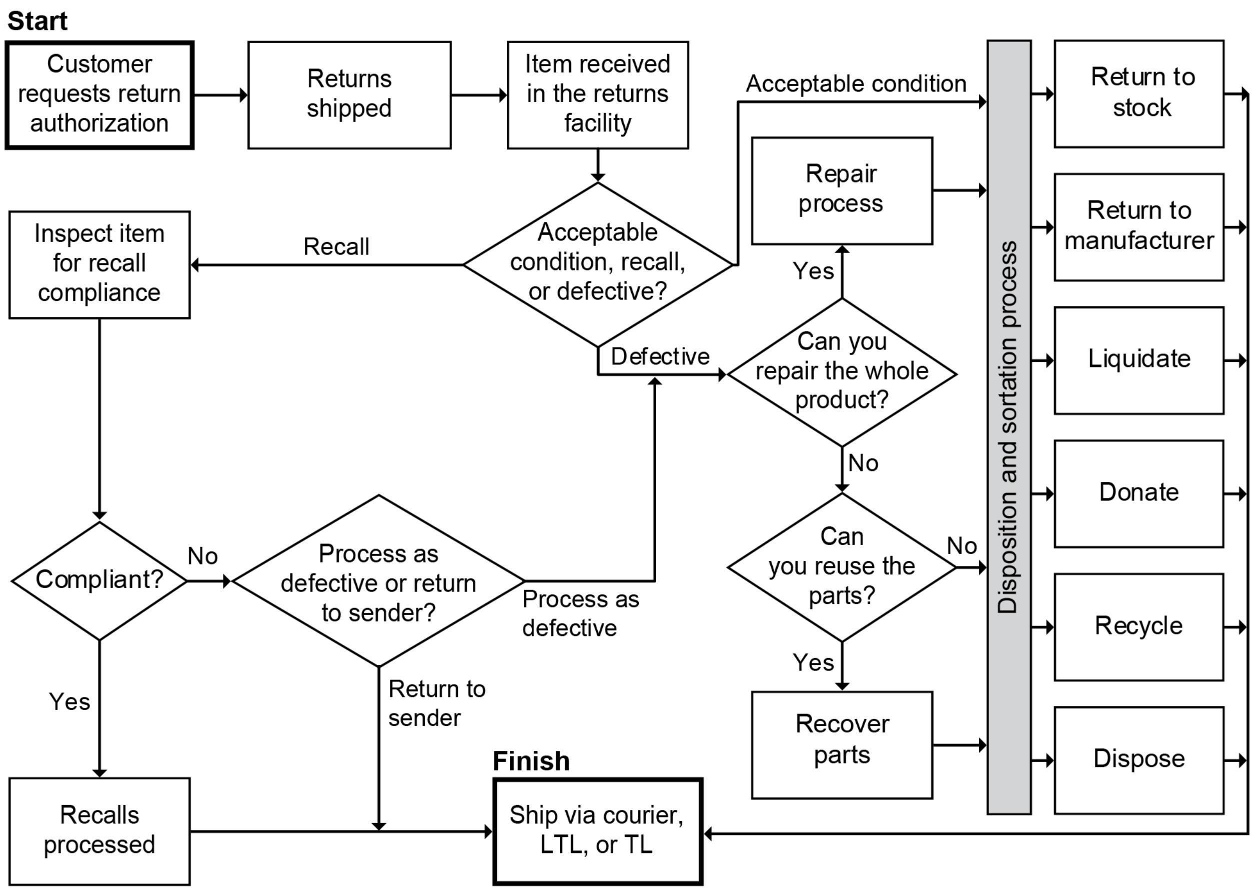
- Managing and updating effectivity dates (effective date of new engineering specifications)
- Removing safety stocks and buffers
- Reducing lot sizes
- Forecasting amounts of excess or obsolete inventory and making plans for their disposition.

Products that have been determined to be obsolete or expired or are otherwise unsaleable can be handled in a way similar way to product returns in that they might be returned up the supply chain if this is possible, or they could be donated, recycled, or disposed of. Disposal may have associated costs, especially for items with hazardous materials. The following returns process lists these and other possible methods for disposition.

Product Returns and Disposition Process

When handling returns, an organization must first assess and categorize returned items, based on their condition and status. To do so, returned products are first centralized in a single location. Then disposition takes place. Disposition is the process of determining the appropriate disposal category for each returned item or for items that are no longer saleable. Returned products would use the entire flowchart seen in Exhibit 4-38, while products that are to be disposed of internally could use portions of this process, such as, "Can you reuse the parts?"

Exhibit 4-38: Disposition of Returned Products



Adapted from © "Reverse Logistics Process Flow," Greve-Davis. Used with permission.

The disposition of each item is an important decision, since about 80 percent of the value of the reverse logistics process depends on matching the product with the best disposition option. Making wise decisions regarding internal products to be disposed of can likewise result in greater or lesser costs and could help with other goals such as sustainability. The exhibit shows six options for how a returned item can be handled. (Internal items to be disposed cannot use the first option.)

- Return to stock (e.g., an unsold item still in its original package or a sold item that is unused)
- Return to manufacturer or producer (e.g., refillable beverage and liquor bottles, packing crates, or items that are contractually allowed to be returned after authorization for an allowed return reason)

- Liquidate (sell to a secondary seller or market)
- Donate (e.g., to a charitable organization as a tax write-off)
- Recycle
- Dispose (e.g., bury in landfill, incinerate)

Any revenue earned from liquidations or tax benefits from donation can be tracked along with related disposition expenses. This information then results in either a net gain or a net loss from the disposition. The accounting department will then use this information when writing off the inventory.

Section D: Performance and Continuous Improvement

This section is designed to

- Define continuous improvement and its role in total quality management
- Describe the key aspects of continuous improvement
- Identify the stages in the continuous improvement model
- Explain the rationale for adopting continuous improvement
- Describe continuous improvement philosophies and how they can enhance the competitiveness of a supply chain
- Describe and distinguish between the approaches to benchmarking: competitive, best-in-class, and process
- Identify the seven basic tools of quality and the seven new tools and discuss their uses in continuous improvement initiatives
- Explain major approaches to continuous improvement: lean, Just-in-Time, six sigma, and the theory of constraints.

Operations are complex and can easily start out or become inefficient or ineffective over time, so it is vital to learn how to use continuous improvement philosophies and tools to keep the overall supply chain running smoothly.

Topic 1: Operations, Inventory, and Financial Performance

Operations, inventory, and financial performance metrics help ensure that operations goes according to plan, inventory levels stay efficient while being effective at meeting customer service goals, and financial performance is acceptable. Metrics also indicate when plans are not being met so course adjustments can be made. Metrics and key performance indicators (KPIs) are discussed first from a big-picture perspective.

Metrics and KPIs Road Map

Here we address the nature of metrics and key performance indicators.

Metrics

So how are improvements measured? It depends on what is being measured. As the saying goes, “You get what you measure.” While there is no guarantee of achieving a goal a company or team decides to measure, it’s very likely that it won’t achieve what it fails to measure.

Regardless of the initiative, decision makers need to determine their objectives first. Then they define what criteria need to be achieved for the initiative to be considered a success. While not all of these criteria will be directly measurable, many will be, and others might be approximated. The metrics that are selected determine how progress will (and will not) be measured. After selecting the appropriate set of metrics, managers then need to set challenging but feasible targets for them. A best practice is to set goals in consultation with the persons who will be doing the work. The next step in the process is ensuring that the measurements are made. The measurements then need to be consolidated, analyzed, and reported. The level of summary needs to be just right so as to highlight the key action areas promptly. Summary at too high a level may not enable getting down to the root causes of an issue, such as a customer quality claim. Reports that have the ability to drill down to the details are one way of providing both a summary and actionable information. Or one level of management may be focused on the details and another on the bigger picture.

A good measurement process helps motivate the persons being measured to achieve the desired goals if there is sufficient communication and buy-in. Once the objectives, metrics, targets, and reporting requirements have been set or revised, they need to be communicated throughout the extended enterprise along with the benefits of achieving them. Getting everyone to use a consistent set of metrics helps everyone share the same vision of what success looks like.

Note that metrics rely on sufficient, accurate, and regularly or automatically collected data. Data are crucial as a basis for executive decisions at the highest level and operations at the most minute level. For example, without customer data, what customers value is a mystery, so you can’t design processes with any assurance that you are targeting their needs. Without accurate financial data, it will be impossible to know the contribution of process improvements toward improving the bottom line.

Key Performance Indicators

Strategic attributes of supply chains may include velocity, visibility, variability, collaboration, trust, customer focus, flexibility, security (risk management), compliance with regulations, reverse supply chain efficiency, and environmental excellence. Any of these attributes could be woven into strategy, expanded into specific objectives, and subjected to measurement.

For the most important strategic goals of an organization or group, a small set of key performance indicators can be developed to promote the success of that strategy.

As defined in the *APICS Dictionary,* 16th edition, a **key performance indicator (KPI)** is

> a financial or nonfinancial measure that is used to define and assess progress toward specific organizational goals and typically is tied to an organization's strategy and business stakeholders. A KPI should not be contradictory to other departmental or strategic business unit performance measures. A metric used to measure the overall performance or state-of-affairs. SCOR level 1 metrics are considered KPIs.

How does a team determine which key performance indicators are appropriate for a particular initiative and which are not because they would dilute the key metrics, make analysis less decisive, or add measurement expense without much benefit? The key is to predetermine what a reasonable number of key performance indicators would be (such as no more than 20) and then ensure that each one chosen can be clearly linked back to one or more specific strategic objectives.

Here are some guidelines for working with KPIs:

- Understand that while all KPIs are metrics, not all metrics are KPIs.
- Establish a set of KPIs using a balanced scorecard approach and determine baselines for each indicator.
- Limit the KPIs to a workable number.
- Be sure to include the four general areas of the balanced scorecard: business process improvement (which you should have covered in the design of your initiative), customer considerations, financial impact, and growth and learning. Growth and learning can be crucial to the success of supply chain process improvements.
- Establish baseline measures for each KPI and set targets (using benchmarks as you did for process improvement).
- Be sure the change has a measurable, positive effect on customers and your bottom line.
- Monitor the performance of the KPIs.

If an improvement initiative is supposed to increase the velocity with which information flows from the end customer back through the supply chain, we could develop technology-related objectives, assess the current state of the system, and identify metrics to measure progress toward a velocity goal. The KPI might be a measure of the actual velocity of communications. Perhaps demand data are aggregated monthly and communicated in face-to-face S&OP meetings. The goal could be to substitute the status quo with direct transfer of data from the point-of-sale via scanners, bar codes, and the internet. Enabling objectives might be put in place (buying equipment, training staff, and so on), but the KPI would be a measure of velocity. This KPI would be a true supply chain metric, because the process it measures crosses tiers. Since higher information velocity could result in tradeoffs, we would also need to track customer satisfaction and financial impact. Does the faster communication and sharing of demand data pay off in terms of customer service and profitability? A KPI for variability might be the extent of the bullwhip effect.

In addition to the commonly used KPIs of profitability and customer satisfaction, supply chain managers have developed many others:

- For sourcing—price performance, quality, delivery metrics, responsiveness, innovation, sustainability, supply chain and inventory integration, and internal customer satisfaction
- For new product introductions—internal failure rate, scrap, external failure rate, warranties, returns, and introduction lead time

- For merchandising products—market share, volume growth, and total supply chain inventory turns (aggregate inventory across the supply chain)
- For replenishment—order fill rate, on-time delivery, forecast accuracy, and order fulfillment lead time

The key point about KPIs is that they have to be applied to supply chain processes that directly enable the organizational and supply chain strategies. A great supply chain KPI must go beyond internal silos and possibly external organizations. KPIs that measure activity within only one internal silo will not promote collaborative behavior. Inventory holding costs at one warehouse, cost containment on one leg of a cross-country shipment, or increased production at one plant are all too disconnected to provide useful information on whether the action benefits the supply chain as a whole.

Operations and Inventory Performance Measures

Operations metrics include those related to efficiency, utilization, throughput, inventory, and operating expenses. Inventory metrics reduce ordering and holding costs while maintaining customer service.

Operations Key Performance Indicators

The *APICS Dictionary,* 16th edition, defines **operational performance measurements** as follows

> 1) In traditional management, performance measurements related to machine, worker, or department efficiency or utilization. These performance measurements are usually poorly correlated with organizational performance. 2) In theory of constraints, performance measurements that link causally to organizational performance measurements. Throughput, inventory, and operating expense are examples.

Some key operational measures include the following:

- Percentage of master production schedule completed as scheduled
- Number of time fence violations (i.e., late and expensive replanning)
- Production yield (standard or maximum yield versus actual yield due to scrap, waste, or other shrinkage)
- Quality metrics
- Inventory turnover broken down by raw material turns, work-in-process turns, etc.

Operational measures may include SCOR metrics as discussed elsewhere. Other operational measures include measuring capacity using efficiency and utilization metrics, and these are also addressed elsewhere. Including inventory measurements as part of operational metrics helps counterbalance metrics that promote high utilization, because increasing utilization will increase inventory unless there is sufficient demand for that inventory.

Inventory Management Key Performance Indicators

From the supply chain management perspective, there are two KPIs for inventory:

- Reduction of inventory costs related to holding, ordering, and transporting materials, supplies, and finished goods at various points along the supply chain
- Achievement of customer service targets related to the quality, availability, and on-time delivery of products and services (which may depend upon availability of supplies)

Since inventory represents such a large investment, improving inventory management promises a significant boost in return on investment. Keeping too little inventory in the system can result in frustratingly long lead times, broken orders, lost customers, and lower market share. On the other hand, too much inventory could have a negative financial impact and increases the risk of holding distressed goods. Goods that are held too long may face a reduction in inventory value, write-offs, or disposal costs. In some industries, the obsolescence or spoilage rate is quite rapid.

The tightrope you walk with inventory management is to reduce the cost of holding and transporting goods while meeting or exceeding customer service goals. Setting and regularly updating an inventory policy is one way organizations perform this balancing act, because it keeps the aggregate and item levels at specific locations from growing too large. Metrics related to process improvements can reduce the costs per inventory movement or transaction.

Methods of Tracking Inventory

Tracking is necessary to keep inventory secure and accounted for. **Inventory shrinkage** is defined in the *APICS Dictionary,* 16th edition, as

> Reductions of actual quantities of items in stock, in process or in transit. The loss may be caused by scrap, theft, deterioration, evaporation, and so forth.

Inventory tracking can help minimize the losses from pilferage or misplacement because an organized system makes it difficult for items to be misplaced or stolen. A tracking system can also identify damaged or obsolete goods so that inventory can be properly valued. Finally, tracking inventory is necessary for accounting since inventory is an asset that must be recorded accurately. A proper inventory tracking process assists with keeping accurate counts of inventory.

Most organizations track inventory through the use of a warehouse management system while in storage and a transportation management system while in transit.

Any inventory tracking system will have certain steps:

1. **Identify the item.** Items are identified through the **stock keeping unit (SKU) .** The *Dictionary* defines a SKU as follows:

   > 1) An inventory item. For example, a shirt in six colors and five sizes would represent 30 different SKUs. 2) In a distribution system, an item at a particular geographic location. For example, one product stocked at the plant and at six different distribution centers would represent seven SKUs.

Items are also identified by association with a purchase order, which indicates expected quantity and location.
2. **Verify the quantity.** Inbound and outbound items must be physically counted and verified against the purchase order.
3. **Obtain an order to make a move, or request a move and obtain approval.** A transaction record is initiated when either of these occurs.
4. **Execute the inventory movement.** Inventory is moved between locations.
5. **Create a record of the transaction completion.** The transaction record is finalized after material movement, unless done electronically using tools such as radio frequency identification (RFID) that occur simultaneously with the material movement.

Inventory tracking systems plus inventory audit results will provide two metrics: record on hand (ROH), which is the amount the tracking system indicates should be present, and the physical on hand (POH), which is the result of a physical count. When the POH is less than the ROH due to shrinkage, there will need to be an inventory record adjustment so that inventory replenishment systems are using correct data. Failures in this area could result in items being sold even though they or a necessary component for their manufacture to order is not actually available.

Financial Measures

It is important to determine how supply chain financial information is reflected in overall financial reporting. Exhibit 4-39 explores how the plan, source, make, deliver, and return processes impact financial statement elements on the balance sheet (statement of financial position) and income statement. This information can be useful when showing how supply chain management activities create year-over-year financial improvements in specific areas.

Exhibit 4-39: Financial Statement Elements Impacted by Each Supply Chain Process

Process	Balance Sheet Elements	Income Statement Elements
Plan	• Raw materials inventory • Accounts payable • Cash • Debt	• Cost of goods sold
Source	• Property, plant, and equipment • Accounts payable • Cash • Debt	• Depreciation • Taxes

Process	Balance Sheet Elements	Income Statement Elements
Make	• Raw materials and work-in-process (WIP) inventory • Accounts payable • Accrued expenses • Wages payable • Cash	• Cost of goods sold • Wages • Utilities
Deliver	• Raw materials (for warehousing only), WIP, and finished goods inventory • Accounts payable • Accounts receivable (for order management only) • Accrued expenses • Warranty reserves (for order management only) • Wages payable • Commissions payable (for order management only) • Cash	• Net sales (for order management only) • Cost of goods sold • Marketing and selling expenses and commissions (for order management only) • Wages • Utilities (for warehousing only)
Return	• Accounts payable • Accounts receivable • Inventory reserves • Warranty reserves • Commissions payable • Cash	• Net sales

The selected supply chain financial, operational, and customer-oriented metrics should support and validate these end results, which could be useful for proving that the organization has an adequate system of internal measurements as is required in the U.S. by the Sarbanes-Oxley Act (SOX).

Topic 2: Continuous Improvement

Here we define and describe the purpose of continuous improvement along with a foundational quality system called total quality management. After looking at why a supply chain manager needs to learn about these tools, we describe a continuous improvement process. Some broad continuous improvement tools such as root cause analysis and benchmarking are discussed, and benchmarking gets a deeper dive.

Continuous Improvement and Total Quality Road Map

Continuous improvement (CI) , as defined in the *APICS Dictionary,* 16th edition, is

> the act of making incremental, regular improvements and upgrades to a process or product in the search for excellence.

Note how CI can be applied to processes or products. When applied to processes, it is called **continuous process improvement (CPI) ,** which the *Dictionary* defines as a "never-ending effort to expose and eliminate root causes of problems: small-step improvement as opposed to big-step improvement." Improving people's skills can be considered an important aspect of CPI.

Continuous improvement, along with customer satisfaction and people involvement are foundational concepts in **total quality management (TQM) .** According to the *Dictionary,* TQM is

> a management approach to long-term success through customer satisfaction…based on the participation of all members of an organization in improving processes, goods, services, and the culture in which they work.

TQM thought leaders have included many famous names in quality—W. Edwards Deming, Philip Crosby, Kaoru Ishikawa, J. M. Juran, and Genichi Taguchi.

Part of what distinguishes TQM from other approaches is that it is based on the premise that management will support the ongoing improvement of every process involved in the development and distribution of a product. This implies continuous improvement of all processes over time. TQM employs a variety of tools for both qualitative and quantitative analysis to enable these holistic improvements.

Continuous improvement can serve as a driving force in every decision about supply chain design and operations. When designing or redesigning a supply chain, supply chain managers need to research and identify how each process in the supply chain can be optimized. As supply chains are implemented, CI can then be used to further enhance capabilities to meet changing needs.

CI and TQM

Continuous improvement and total quality management efforts go hand in hand across most organizations. Note how **quality ,** as defined by the *Dictionary,* has two major components:

> Quality of conformance: defined by the absence of defects
>
> Quality of design: measured by the degree of customer satisfaction with a product's characteristics and features

This two-pronged definition underscores how critical it is for product design to be factored into both supply chain design and operations so that product traits and features will meet customer expectations.

There are several key premises of TQM that create its foundation and impact the guiding principles of an organization that uses it for continuous improvement:

- Management must be committed participants in the quality initiative in the organization. They will be the role models others look to for direction. Since TQM is an ongoing process, it requires an ongoing commitment to action.

- It is understood by the entire workforce that the goal is not to point fingers but to strive for better processes that have fewer issues in the first place. When everyone embraces it, participates on teams, and sees the results, it creates enthusiasm.
- It focuses on the customers and puts their needs at the front of every discussion about improvement. Customers can be internal or external, such as coworkers, supply chain partners, or consumers. Will this change be better for all customers? How could it impact them negatively? How will we prevent that from happening?
- Many categories of suppliers are considered partners, and the various levels of ongoing relationships should never be adversarial.
- There must be standard performance measures so that incremental improvements can be measured and tracked over time and across partners.

Purposes

Common purposes of continuous process improvement are

- To continuously refine the processes of manufacturing or service, not simply to focus on the quality of the goods or services produced
- To incorporate improvement into the processes themselves, not merely to subject processes to periodic reviews and audits
- To define achievable goals and set quantitative measures to chart progress toward reaching those goals
- To train employees to identify waste (wasted resources, wasted motion, wasted time, etc.) and participate in eliminating the waste
- To empower workers by involving everyone in the assessment and improvement of the processes they oversee, manage, or carry out
- To increase productivity
- To improve worker satisfaction by improving workplace safety, eliminating unnecessarily strenuous or stressful work, making performance assessments more rational, and enhancing the quality of jobs and career options

Reasons for Adopting CI

Reasons for taking a continuous improvement approach to supply chain design follow.

- **Supply chain management is process-oriented.** The basic units of the supply chain are not products or services that emerge from the chain; they are the processes that flow along the supply chain among functions and partners.

- **Supply chains are dynamic.** A supply chain constantly expands, contracts, and incorporates new stakeholders and new products. A constantly changing system requires continuous reengineering and process improvement.

- **Supply chains evolve.** Supply chains have evolved from functional isolation, to cross-functional cooperation, to global networks linked by electronic communications and enterprise software. As supply chains evolve across new frontiers of organization, scope, and technological complexity, they are in constant need of process improvement and redesign.

- Continuous improvement of the supply chain design can reduce the costs of poor quality. The *APICS Dictionary,* 16th edition, defines **cost of poor quality** as follows:

> The costs associated with performing a task incorrectly and/or generating unacceptable output. These costs would include the costs of nonconformities, inefficient processes, and lost opportunities.

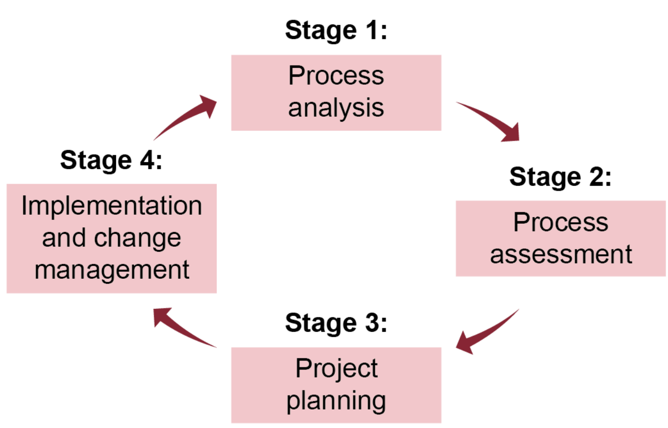
A related term is **appraisal costs ,** defined in the *Dictionary* as follows:

> Those costs associated with the formal evaluation and audit of quality in the firm. Typical costs include inspection, quality audits, testing, calibration, and checking time.

Applying the CI Model

The continuous improvement (CI) model can be used to analyze, assess, plan, and implement changes that will improve the supply chain and its people and processes. The CI model we're using here, shown in Exhibit 4-40, builds upon other supply management concepts, such as benchmarking and change management.

Exhibit 4-40: Continuous Improvement Model



- **Stage 1: Process analysis.** The initial step in continuous improvement requires taking a hard look at internal and external supply chain design to find locations where waste or non-value-added activities could occur.

- **Stage 2: Process assessment.** This stage involves reviewing the various key performance indicators (KPIs) that are being or might be used to measure how the supply chain is performing.

Benchmarks can be used to set a specific performance goal, such as reducing manufacturing time along the supply chain by a set percentage.

- **Stage 3: Project planning.** Next a realistic schedule for the design, development, and review of the proposed supply chain change is developed. Responsibilities and accountability are assigned, needed resources are identified, and a budget and schedule are created and approved. Specific commitments from stakeholders should be gathered so that the design is understood and supported.
- **Stage 4: Implementation and change management.** Once the design is completed, it will need to be implemented. Implementation feedback should be used to improve the process prior to sharing it with other internal stakeholders or supply chain partners. Each supply chain entity needs to know how making this change will contribute to the supply chain's overall success and its ability to meet customer satisfaction. The entities also need to know how to fulfill their roles and responsibilities in the new supply chain design.

Personnel Improvement

Personnel improvement involves working to develop supply chain personnel's knowledge, skills, and abilities over time. **Knowledge** is the information needed to perform a task correctly. **Skills** are behavior changes in how a person performs tasks. **Abilities** are a person's current capacity to perform necessary job tasks and apply relevant knowledge and skills. This improvement normally happens informally as people gain experience doing their jobs, but a formal system can help challenge individuals and allow organizations to measure progress.

Investing in personnel improvement also directly helps improve supply chain effectiveness and efficiency, because it increases worker consistency and reduces learning curves. While poorly trained operators tend to be inconsistent in achieving standard work times, trained personnel tend to be able to meet or exceed standards. Workers who are used to training and re-training will have lower learning curves when learning new skills. Their output reaches desired levels more quickly.

When designing training, it is important to understand that different individuals have different learning styles. Visual learners learn best when pictures or graphics are available and the purpose and method of the training are well laid out. Tactile learners desire "hands-on" training opportunities. Auditory learners have better results when they are told the information rather than just reading it. In addition, adult learners prefer self-directed learning and need to know why the learning is needed and beneficial. Effective adult motivators include presenting learning as a way of solving a problem and giving learners a chance to apply their experience. Finding ways to empower individuals and help them believe that they can succeed are powerful levers for any learner.

Another source of motivation is a formal system of employee goal setting and management review. Each supply chain manager will mutually set training or learning goals for a period of time with his or her superior and also review progress toward prior goals. It is important to involve the learner in goal setting to get buy-in. A career path laid out with the necessary knowledge, skills, and abilities clearly communicated as minimum requirements can be a strong motivator.

Training can be internal or external, formal or informal. Some examples of training delivery methods are discussed next. This area concludes with a discussion of evaluating training effectiveness.

Informal, On-the-Job, and Cross-Training

Informal training involves regular interactions between individuals and other daily experiences. It is an effective and necessary way that people learn and comprises the majority of learning for individuals.

On-the-job training and cross-training are ways to accelerate learning in the job environment.

On-the-job training is an informal but planned activity conducted by a superior or peer, who shows other personnel how to perform a task or process. This is the most common form of planned training, because it can be done without taking personnel away from their other duties. It should involve time for learners to practice what they have learned, and there needs to be a follow-up session to ensure that the new information is being applied on the job.

Cross-training involves training people to do their own job and someone else’s job, which appeals to organizations because that person can cover someone else’s work or assume a new position.

Formal or Informal Coaching or Mentoring

Coaching involves superiors giving training and feedback to subordinates on a regular basis. It is a form of learning by doing. Coaching skills can be taught to managers. Informal coaching should occur organically as personnel need or request feedback, but formal coaching should involve planning what will be taught, accounting for learner styles, and so on.

Mentoring is a process of pairing an individual with a person who is further along the same career path. It can be effective at teaching not only technical skills but also interpersonal skills. It is especially useful for helping less-experienced managers grow into better managers. The mentor also learns how to impart wisdom effectively.

Internal or External Training Courses

Training courses can be conducted in-house using employees or consultants, or personnel can be sent to off-site courses. External training is often the most cost-effective for small or mid-size organizations who don’t have a large number of students needing the same training. Instructor-led training is a very popular mode of delivery. Using vendors and suppliers to provide training has increased in popularity in recent years, especially for software training. Training that results in a certification can be a significant motivator. Training offered at conventions or conferences can provide a number of classes in a short time away from the office. A good way to reinforce learning from training courses or independent study is to have the supply chain manager present a recap to a group of peers.

Online Training

Online training can take the form of on-demand training or virtual classroom training.

On-demand training can be available on the organization's intranet site and accessed at any time by large numbers of persons at a low cost. Many younger workers prefer this method of training. A drawback is that it may not result in high retention rates. Some subjects are better retained than others, so some skills are best taught using other methods. Tests, practice, visuals, and other methods help with reinforcement. Tests and assignments can be used as proof of training.

Virtual classroom training may involve a live instructor or an offline instructor who reviews assignments. The virtual space can be attended by people from all over the world. These can be internally developed classes, classes that use an outside instructor, or online college or university courses with access to lecture materials, chat rooms, and file exchange. These setups keep learners motivated at a lower cost than classroom training, but they are less good for networking and learning interpersonal skills.

Evaluating Training

It is important to continually improve training in any form in which it is provided. Training results should outweigh the costs of providing that training. Costs can be compared against measurements of employee retention of learning, improvements in customer service, numbers of work errors, or learning curve time for performing new processes. Benchmarking various methods can help organizations determine how to reallocate training budgets.

Process Analysis and Improvement

Continuous improvement is directed from the top down and implemented from the bottom up. Selecting processes for improvement is a job for top management. They are accountable for the strategic direction of the company, and so it is they who decide the priority order of process improvement. Projects must be selected in harmony with overall business strategies and with the collaboration of the executive team. Management must become the driving force that gives the continuous improvement its momentum and credibility.

Given this direction, a team should form that includes employees, especially those who operate within the process itself. Implementation of quality initiatives is a companywide process (or a supply-chain-long process) and should involve employees at all levels. The members' detailed knowledge is required to analyze weak points, suggest improvements, and implement solutions.

A first step is to learn about the process in depth and define the "as is" state of the process. There's a saying in quality movement, "Facts are your friend." You need a lot of data to manage supply chains effectively, to select processes for improvement, to map a process accurately, and to measure the progress of your process improvement initiatives toward their goals. Given an understanding of the process as it is, the next step is to analyze the process to find the root causes of inferior performance—the fundamental reasons it isn't contributing to achieving supply chain goals. The result will be a "to be" version of the process that can be submitted for review and approval prior to being planned in detail and implemented.

Teams will be directed by top management toward a prioritized set of initiatives. A continuous improvement team may want to do preliminary research to determine which issues or areas will be relatively fast fixes or "low-hanging fruit." Success in small-scale improvement projects will help build momentum. Team members can analyze other improvement opportunities based on the perspectives of key stakeholders such as customers, suppliers, employees, etc. As teams build expertise and confidence in themselves, they will become more proficient at using continuous improvement philosophies and tools and will be better prepared to take on more extensive and complex supply chain processes.

Here are some common CI initiatives for supply chains:

- Customer responsiveness
- Perfect customer orders
- Performance improvement (by supply chain, function, teams, supplier groups, etc.)
- Increased productivity
- Strategic and financial alignment
- Asset management
- System infrastructure
- Demand planning
- Logistics
- Professional development of employees

Continuous Improvement Tools

Continuous improvement teams use a number of techniques and methods for continuously improving supply chain processes:

- **Pattern identification—**pinpoints a pattern of variability within a process
- **Defect measurement—**identifies the number of defects that represent product or service failures
- **Root cause analysis—**identifies the root cause (versus the symptoms) of a problem with an unacceptable rate of defects
- **Benchmarking—**sets goals at specific levels by reference to an outside performance standard

A description of one of these methods—benchmarking—follows as an example.

Benchmarking

Benchmarking is a way of setting goals at specific levels by reference to an outside performance standard, such as best practices or the performance of another department or enterprise. For example, a benchmark might be best-in-class cycle time for any enterprise in an industry or a competitor with the lowest cycle time on a particular process. The Supply Chain Council conducts benchmarking surveys that are available to its members, allowing them to judge their own performance against that of other organizations using SCOR metrics. Another method is to benchmark against a checklist of world-class processes (rather than specific performance measures).

There are several broad approaches to benchmarking: competitive, best-in-class, and process. Each approach has its merits.

- **Competitive benchmarking.** In competitive benchmarking, an enterprise compares its performance to that of a competitor in its own industry. For example, assume that manufacturing lead time is a key performance indicator for an enterprise. Benchmarking would begin with determining average lead time and variability over a number of production cycles. These numbers could be compared with the performance of a competitor, an enterprise with similar challenges in the same industry. Perhaps that competitor has a 25 percent shorter lead time and less variability but is able to produce at the same level of quality. The process improvement team can use this competitor's lead time as the goal for improvement. It is quantifiable, measurable, and realistic, since the competitor is already achieving it. Therefore, it is an acceptable benchmark.

  There's an obvious payoff to competitive benchmarking as a method of setting a performance goal. Reaching the benchmark, or surpassing it, means the enterprise has improved its competitive position. Ford Motor Company used competitive benchmarking to make a breakthrough in improving their accounts payable process. Their first restructuring of accounts payable, without a benchmarked goal, yielded a 20 percent reduction in personnel. For a second pass at improving the process, Ford benchmarked its performance against Mazda and was able to cut personnel from 500 to 75.

- **Best-in-class benchmarking.** With the best-in-class benchmarking strategy, a company looks to the best anywhere to develop a goal for improvement. Widening the search for a benchmark makes it possible to find even more dramatic and inspiring possibilities. Accounts payable doesn't differ radically from industry to industry; Ford might have been able to find an even more efficient model for the process by looking outside the car industry.

  Even in areas where at first the dissimilarities seem an overwhelming barrier, a best-in-class approach may still help develop the most inspiring goals. A major health-care provider in Minnesota revamped the procedures in its endoscopy clinic by borrowing from Toyota's lean production system. While receiving some criticism for borrowing assembly-line methods to improve delivery of a service, in fact the provider not only enabled doctors to reduce the backlog of patients waiting for exams but it allowed the doctors to have at least as much time with each patient. The improvements also saved substantial money. The decision to process patients with the same efficiency Toyota achieves in its manufacturing plants turned out to be good for the doctors, the patients, and the clinic. The health-care provider benefited from getting outside its own industry—not only for a benchmark but for innovative process improvement techniques.

- **Process benchmarking.** Another approach to improving a process is to benchmark it against a checklist of world-class process descriptions. Rather than focusing on measurable aspects of process performance such as cycle time duration, a process checklist draws attention to the features of the process, to its qualitative aspects. The Oliver Wight group of business excellence consultants provides such a checklist for use in all industries. The process descriptions reflect the consultants' global experience, and they include considerations such as
    - Use of strategy to drive supply chain planning and execution
    - Optimization of capacity, inventory, and other supply chain elements
    - Use of monthly reviews for monitoring capability and flexibility
    - Presence of data-sharing processes, financial integration, and teams including suppliers and customers.

In sum, benchmarking your goals against the best in your industry or the best in class provides an effective way to choose realistic yet inspiring goals. It's only natural to have more faith in your ability to reach a goal if you know someone else has been there before. Not long after British athlete Roger Bannister reset the long-held benchmark for running a mile at slightly less than four minutes in 1954, other runners not only broke four minutes but ran past Bannister's own mark.

It's worth noting that Bannister himself did not use another runner's performance as his benchmark. He reached beyond any other current or historical mile runners for a pioneering goal. Sometimes, even the best-in-class mark may be too limited a goal for a company to follow. Someone—or some enterprise—has to be first. But even a pioneer like Bannister followed a strategy of continuous improvement to reach his goal. He got there through years of training, continuously shaving small amounts of time off his previous performances until he surpassed the speed that some believed was physiologically impossible. He reached his goal, quite literally, one step at a time.

Topic 3: Quality Tools

The seven basic tools of quality and the seven new tools of quality are described here.

Seven Basic Tools of Quality

The seven basic tools of quality are a set of tools that help organizations understand their processes in order to improve them. These tools (also known as B7) include process mapping, control chart analysis, the Pareto chart, the cause-and-effect diagram, the histogram, the check sheet, and the scatter chart.

Process Map

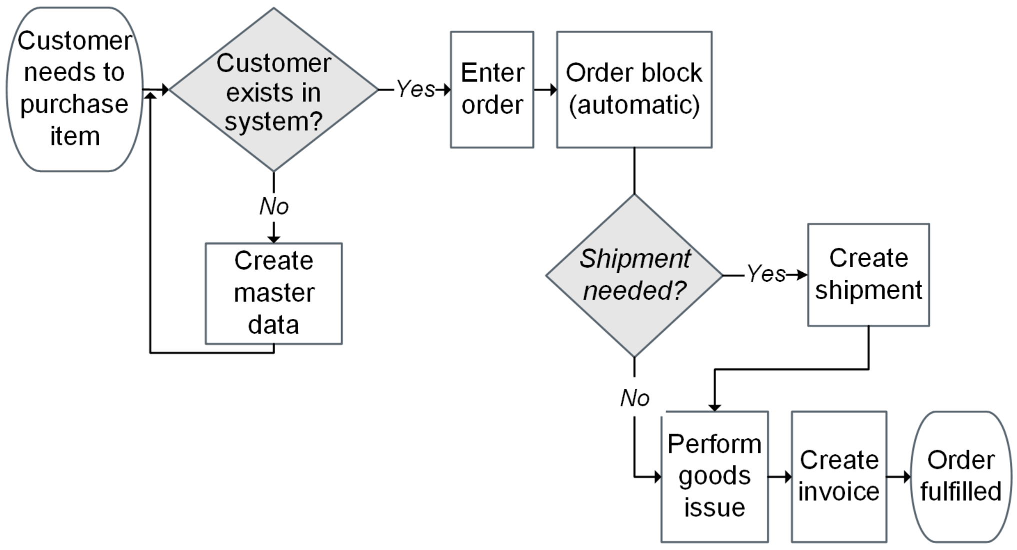
The *APICS Dictionary,* 16th edition, defines a **process map** (or flowchart) as follows:

> A diagram of the flow of a production process or service process through the production system. Standardized symbols are used to designate processing, flow directions, branching decisions, input/output, and other aspects of the process.

Process maps can be used to map all types of processes—manufacturing flow, information flow, the stages of a financial transaction, and so on. Mapping the process helps members of an improvement team identify significant aspects of an inefficient or ineffective process and then locate the problem areas. In addition to illustrating each step in a process, the chart or map can include other useful information such as the duration of each step, required resources, responsible positions, and financial impact. Process maps can be produced with pencil and paper, but they can also be put into various types of software.

Exhibit 4-41 shows a typical process map in the form of a flowchart, depicting the order fulfillment process.

Exhibit 4-41: Process Map of the Order Fulfillment Process



One way to carry out process mapping is to schedule it as a brainstorming session for the improvement team. Using Post-it® Notes, each team member individually lists every task he or she can identify in the process, one per note. After a half hour (or other appropriate time), team members stick the notes with the task listings on the chalkboard, one person at a time, while others continue thinking and writing. When all tasks have been posted, individuals or teams attempt to group the tasks by themes and put the groups in the order of performance. Next the group selects names for the themes, and a volunteer writes a final list of tasks, by theme, on a flip chart. At the end of the session, the entire process should be mapped, with all essential tasks in order and associated with the names of performers and the time each takes.

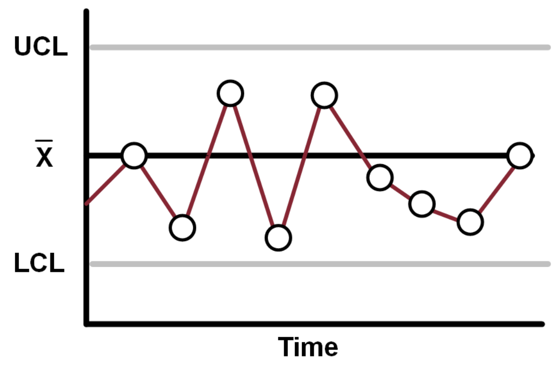
Control Chart

The **control chart ,** according to the *Dictionary,* provides “a graphic comparison of process performance data with predetermined computed control limits.”

Control charts are useful graphical tools to differentiate special cause variation and common cause variation in a given process. This activity is called **statistical process control** (or statistical quality control) and is defined in the *Dictionary* as “the application of statistical techniques to monitor and adjust an operation.”

Exhibit 4-42 illustrates a control chart with a center line representing the mean value and upper and lower control limits (UCL and LCL) representing plus or minus 3 sigmas from the center line respectively. In general, if the data readings taken fall within the control limits, the process variation is considered to be in control. In this chart all the opportunities fall within the acceptable range.

Exhibit 4-42: A Control Chart



In addition to control limits, which are set using statistics, a process used to produce a product or service can also have specification limits, which are set by the customer. Like the control limits, there is an upper and lower specification limit (USL and LSL). If the process commonly has results outside these limits, there will be many rejected units and the process would need to be reviewed to make failures far less common.

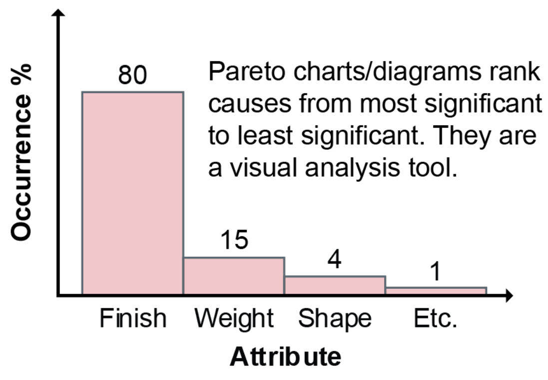
Pareto Chart

Pareto analysis, which shows the frequency of items in a data set, is based on **Pareto’s law ,** defined in the *Dictionary* as “a concept developed by Vilfredo Pareto, an Italian economist, that states that a small percentage of a group accounts for the largest fraction of the impact, value, and so on.” Closely associated with Pareto’s law is the **80-20 rule ,** which “suggests that most effects come from relatively few causes; that is, 80 percent of the effects (or sales or costs) come from 20 percent of the possible causes (or items)” (*Dictionary*).

The *Dictionary* defines a **Pareto chart** (or diagram) as “a bar graph that displays the results of a Pareto analysis...[it] show[s] a distinct variation from the few compared to the many.” By identifying the significant few and separating them from the trivial many, a team will be better prepared to focus its resources efficiently and effectively to achieve the biggest gains.

Pareto charts can be applied to any measurable data, including currency units, time, defects, suppliers, etc. Exhibit 4-43 illustrates the basic shape of a Pareto chart. After determining the categories for the bars, the bars are always ranked from highest to lowest. The set of bars that make about 80 percent of the causes would be the vital few causes to study. Here the largest bar is 80 percent on its own and is the major cause of the particular occurrence.

Exhibit 4-43: Pareto Chart

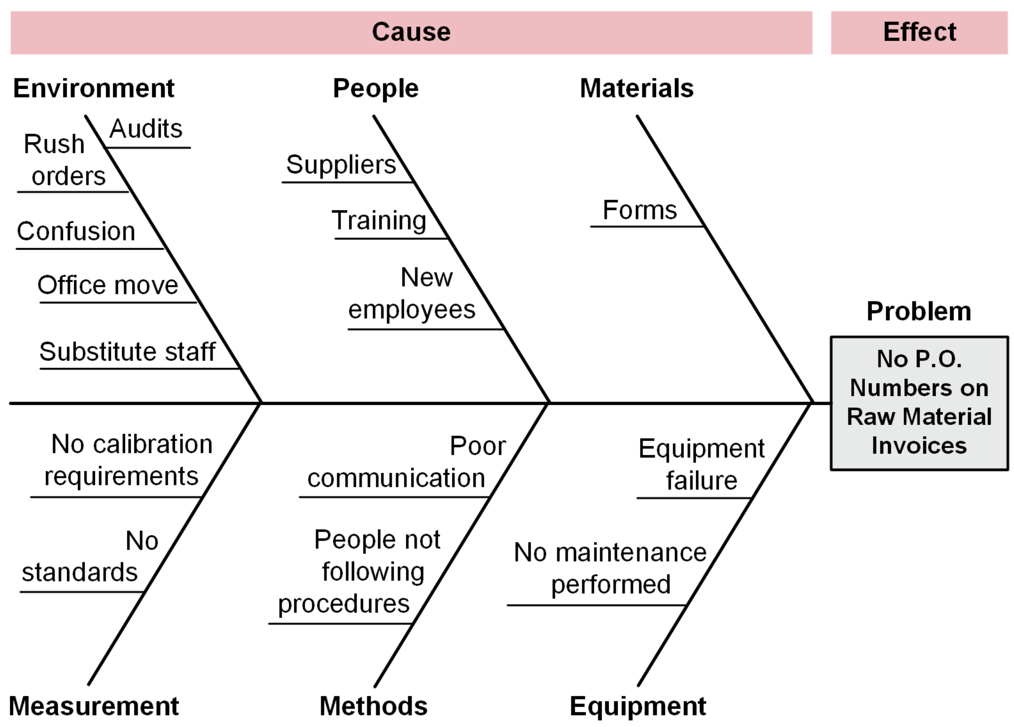


Cause-and-Effect Diagram

A cause-and-effect diagram links an effect with the possible causes of the effect. It is a method of organizing factors (causes) and subcauses that affect a problem or process being investigated (effect). This type of diagram may also be called an Ishikawa diagram, after the person who first developed it, or a fishbone diagram, as the elements of the diagram resemble the skeleton of a fish. The goal of a cause-and-effect diagram is to identify all of the possible causes of an effect and then select the most likely ones for further investigation. The idea is to find the root cause of the effect in order to correct and solve the problem for the long term.

Exhibit 4-44 illustrates a cause-and-effect diagram showing commonly cited categories of causes (environment, people, materials, measurement, methods, and equipment). For every cause, there are usually several potential underlying subcauses (such as equipment failure or no maintenance performed). The development of a cause-and-effect diagram is a repetitive process that requires going back and forth to identify causes and effects.

Exhibit 4-44: Cause-and-Effect Diagram



Eliminating the underlying root cause of a defect can bring a process into conformance, while attacking a secondary symptom or the wrong cause may do little or nothing to eliminate the customer complaints.

For example, sometimes training to improve employee skills will be suggested as a solution for a problem, when in fact employee skill or understanding is not the real source of the difficulty. If a system is broken, no amount of employee training will fix it. Let's say a financial service provider is receiving a high rate of complaints from customers who can't understand their account reports, and the company responds by training sales assistants to give better explanations of the reports when customers call in to complain. The documents are the root cause of the problem, and the training is not the most efficient way to invest to provide what customers need.

The Japanese have a method of approaching root cause analysis called the "Five Whys," because it is based on the theory that answering a question about causation five times will lead you through the false causes or symptoms to the real cause. Whether or not five is the magic number is less important than the underlying concept.

Finding root causes may take considerable digging through layers of superficial symptoms or secondary problems. An automotive company, as an example, conducted customer interviews to determine why they were receiving complaints that the seats in their cars were too low. Since that complaint was factually inaccurate, the researchers probed more deeply and discovered that the problem could be resolved by setting the side window ledges lower in the doors. The answer "low seats" was superficial. The root cause of the complaint was really about the relative placement of the windows.

Histogram

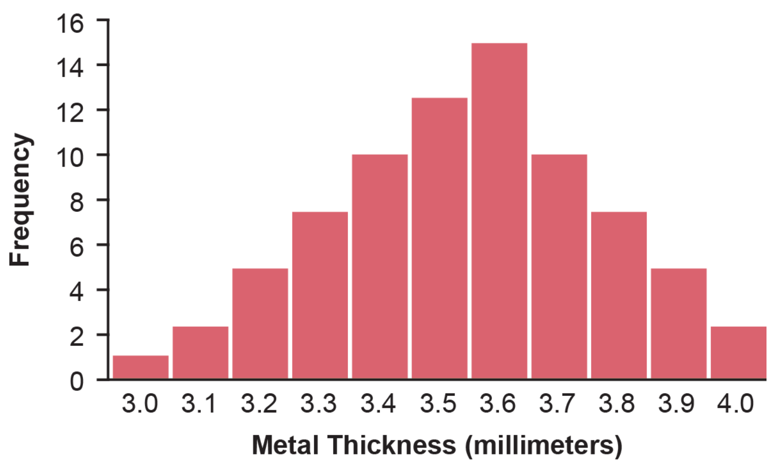
A histogram is a bar graph that displays the frequency distribution of measurement data, such as dimensions, temperature, or weight, for a process. It shows the amount of variation and the range of variation within a process. The frequency is shown on the *y* (vertical) axis. The *x* axis shows the range of variation.

The goal is to identify whether

- There are surprises like unnatural distributions. (A bell-shaped distribution demonstrates that the largest number of measured units is in the center, with about half that number falling on either side. Twin peaks may indicate that data are coming from two or more sources that have variation, like different shifts or production equipment.)
- The variation of the bar graphs falls within or outside of specifications, indicating the amount of variability or number of failures.
- The top portion of the bell curve is in the middle or at either end, indicating that the data are skewed. (For example, if a pizza company studies the amount of toppings added to an average pizza, a person who always adds more than the recommended amounts would have results that skew toward the high end.)

At first glance it may seem that the Pareto tool is a histogram, but it is a different type of bar chart. The Pareto chart illustrates only the categories of an issue, such as type of defects, rather than showing a continuous range of data, as a histogram does. Exhibit 4-45 shows an example of a histogram.

Exhibit 4-45: Histogram Example



Check Sheet

A check sheet is a simple and easy-to-use tool for summarizing a tally count of event occurrences such as the frequency of certain defects in a product in a specified period of time. In Exhibit 4-46, for instance, a manufacturer of fabric hearts uses a hash mark (or slash mark) to record every time an item is either too pink, too red, lacks fragrance, or is the wrong size in the first four days of production runs in February.

This is often the starting point in continuous improvement projects that can then be further explored using other CI tools. It's important that the data gathered are from a single entity, such as the same piece of equipment or a particular production line employee. In addition, it is critical to ensure that the observations recorded are representative and that the team members who create the check sheets have sufficient time to do it accurately.

Exhibit 4-46: Check Sheet

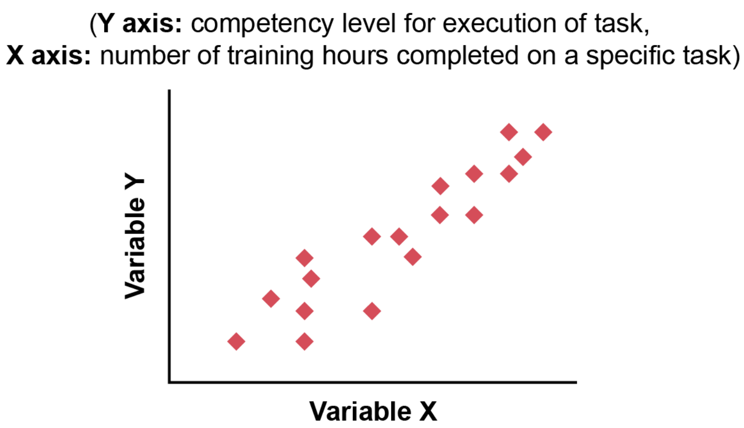
Defect	February				
	1	**2**	**3**	**4**	**Total**
Too pink	卌 I	III	I	卌 II	**17**
Too red	I	I	—	II	**4**
No fragrance	II	—	I	III	**6**
Wrong size	IIII	II	I	卌	**12**
Totals	**13**	**6**	**3**	**17**	**39**

Scatter Chart

A scatter chart—also known as a cross plot, scatter diagram, or scatterplot—is a tool for showing the relationship of two variables in terms of whether they are interdependent and to what extent. The diagram has a horizontal *x* axis and vertical *y* axis that represent the two variables being tested. The *y* axis is typically for the dependent variable, that is, the one that changes in relation to variable *x,* which is called the independent variable. The direction of the scattered points and their closeness to each other and an overall trend line indicate the type and strength of the correlation.

Exhibit 4-47 shows a scatter chart.

Exhibit 4-47: Scatter Diagram Showing Positive Correlation between Training and Job Performance



As seen in the exhibit, if you were to draw a diagonal line from the interior corner of the graph to the points in the upper right portion, it would be easy to see that the points are fairly close together and that they trend upward and to the right. This shows a positive correlation between the two variables, such as training and job performance, which means that an increase in *y* may be dependent upon an increase in *x* and therefore, if *x* can be controlled, there might also be a chance of influencing *y.* In other words, an increase in task competency could be linked to an increase in the number of hours of task training received by an employee in the supply chain. (If the points were more scattered but formed the same shape, there would be less positive correlation.) In another example, a scatter chart can be used for associative forecasting (such as regression analysis), in which case the independent variable is used to predict how the dependent variable should behave in the future.

Seven New Tools

In the mid-1970s, a consortium of Japanese engineers and scientists discussed the need to augment the seven basic tools of quality with an additional set that could enable them to express important production-related information, support innovation, and facilitate the planning of major projects. They wanted to be able to communicate important information that could be put into action.

With those goals in mind, they developed seven management and planning tools:

- Affinity diagram
- Tree diagram
- Matrix diagram
- Process decision program chart
- Relationship diagram
- Matrix data analysis chart
- Activity network diagram

Affinity Diagram

An affinity diagram is a tool for organizing a large number of brainstormed ideas by employees striving to solve a particular issue. Participants in the brainstorming session provide anonymous ideas and suggestions and, based on the number of them that relate to each topic, the group can get a sense as to the seriousness of the issue. It begins with a discussion leader presenting the topic or problem, which the employees then brainstorm about, recording each idea on a slip of paper or an index card. The ideas are then posted in one place, and the group determines how to group them by category or theme.

As seen in Exhibit 4-48, each group of ideas is then given a descriptive title that encompasses the ideas below it. In this case, the challenge was trying to identify causes of product recall for a manufacturer. The group generated causes that fell into these six broad categories: inspection, customer feedback, product materials, frequency, costs, and return processes.

Exhibit 4-48: Affinity Diagram

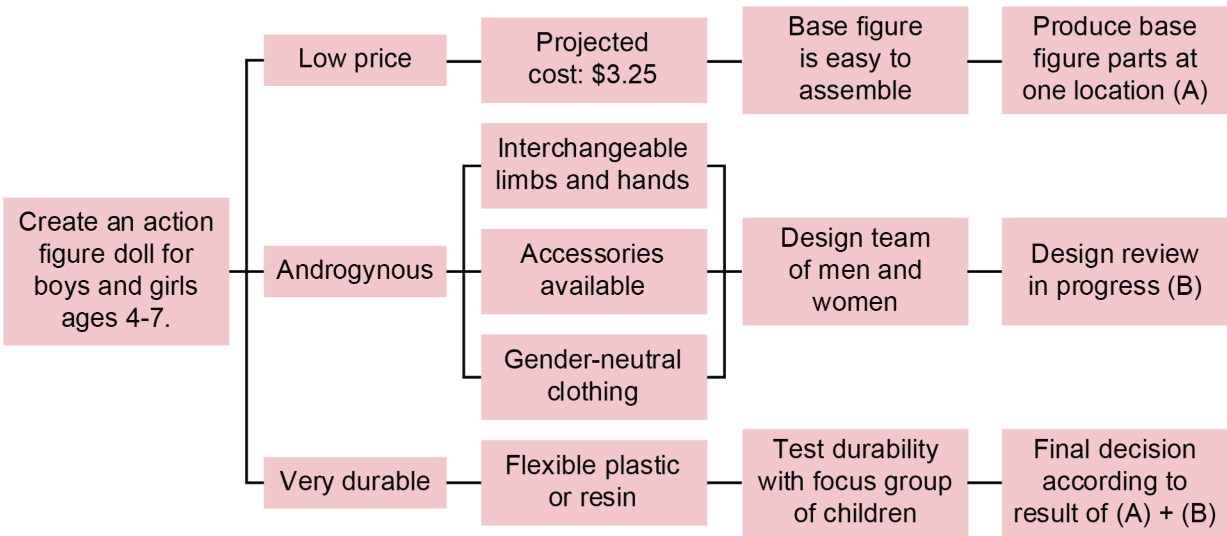
Issue: Product recall causes		
Inspection	Customer feedback	Product materials
Frequency	Costs	Return processes

This tool tends to provide new and more comprehensive insights into an issue that can become an official continuous improvement project. Then other tools can be used to further investigate each category.

Tree Diagram

A tree diagram is a tool that lists tasks and activities in increasingly finer detail in order to meet a specific goal. As seen in Exhibit 4-49, the goal is on the left-hand side and the main branches of the tree “bloom” off of that. Each branch helps to clarify another aspect of the issue. The tree diagram can be used in conjunction with the affinity diagram and the relationship diagram.

Exhibit 4-49: Tree Diagram



Matrix Diagram

The matrix diagram (matrix chart) is a useful tool for showing the relationships between two or more groups of information, the strengths of those relationships, and how those variables interact and respond to each other. Matrix diagrams can be in a variety of shapes: L, T, Y, C, X, and roof-shaped. The most commonly used is the L-shaped matrix, which illustrates how two groups of items relate to each other or one group to itself. As illustrated in Exhibit 4-50, this matrix shows how specifications for a product vary from one customer to the next.

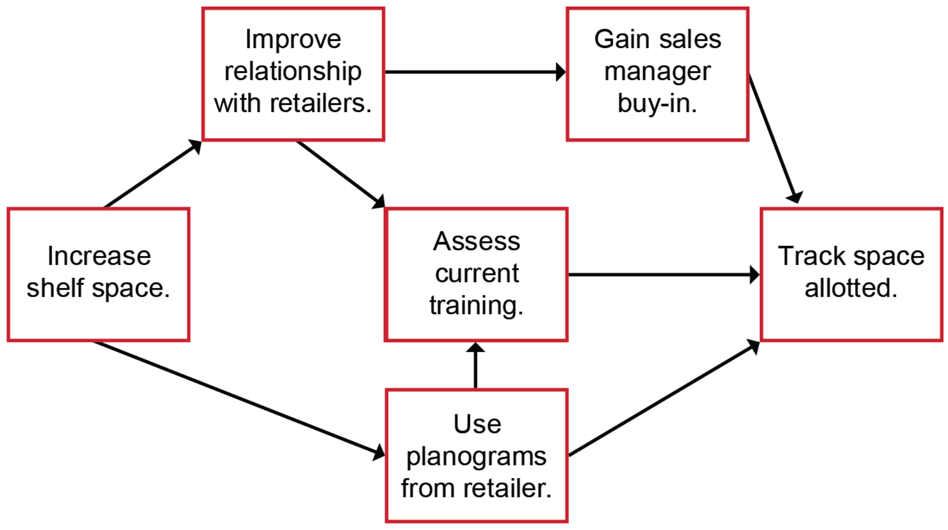
Exhibit 4-50: Matrix Diagram of Customer Specifications for Component #4572

Specification	Customer A	Customer B	Customer C
Width	≤0.789 cm	≤0.790 cm	≤0.785 cm
Length	≤1.11 cm	≤1.20 cm	≤1.01 cm
Thickness	≤0.55 cm	≤0.575 cm	≤0.545 cm
Color (Pantone)	#127	#130	#129

Process Decision Program Chart

The process decision program chart visually captures things that might possibly go wrong in a plan being developed. In Exhibit 4-51, the decision to increase shelf space was mapped out to determine all the related points that could influence a sequence of decisions as to how to reach the goal of achieving a good allotment of space.

Exhibit 4-51: Process Decision Program Chart

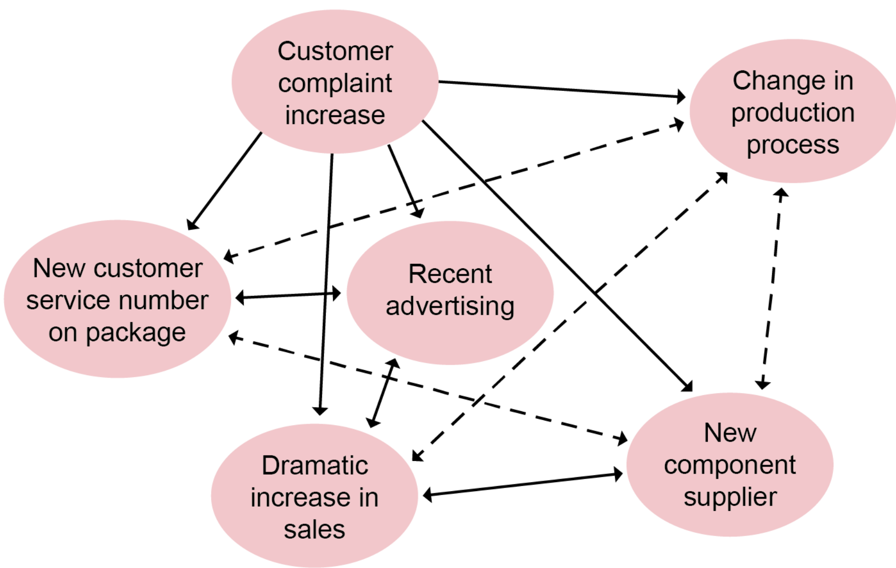


This tool can be used in two different manners: to identify measures that should be taken in order to avoid undesirable, intermediate consequences as progress is made toward the final desired result, and to design a plan to predict future foreseeable problems that can be resolved and ultimately result in achievement of the goal.

Relationship Diagram

The relationship diagram, also called an interrelationship diagram, illustrates cause-and-effect relationships and is particularly useful for evaluating the links between different aspects of a complicated issue. As seen in Exhibit 4-52, the ideas that a team generates are placed in their own respective circles and clustered according to how they may relate to each other. Solid-line arrows are then drawn from each idea that strongly influences another idea. A dashed arrow implies that there is some influence but it is not strong.

Exhibit 4-52: Relationship Diagram



The goal is to identify the following:

- The major cause, that is, the one that has the greatest number of arrows emanating from it

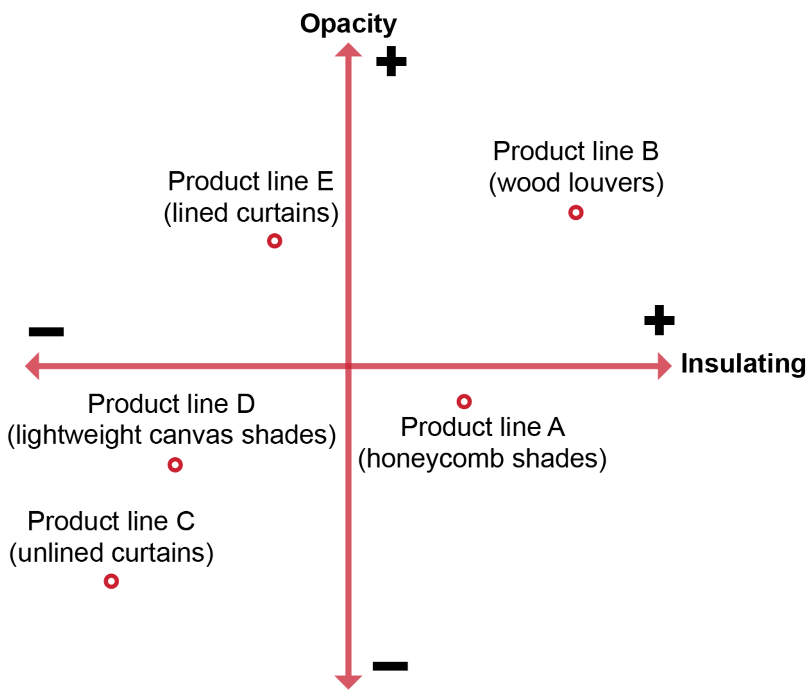
- The most interrelated cause, that is, the one with the most arrows in and out

In this instance, the diagram began with an increase in customer complaints, which had previously been at a minimum level. The team wanted to identify what could be the possible direct and indirect causes of that increase. They concluded that there are four factors that were about equally responsible for the issue. The team decided they would need to do additional analysis of those factors, after which they would be better able to stratify the complaints.

Matrix Data Analysis Chart

The matrix data analysis chart is another tool that can be used to show the relationship between groups of information. As seen in Exhibit 4-53, the two variables (or features) against which the product lines are being measured are opacity and insulating properties. The closer the product line point is to the positive end of each variable, the stronger the feature is for that line, and vice versa. For instance, the wood louvers (product line B) of this manufacturer have significantly higher ratings on opacity and insulating capabilities compared to product lines C and D in the lower left quadrant. This tool can be useful when trying to differentiate marketing messages and compare seemingly similar products.

Exhibit 4-53: Matrix Data Analysis Chart



Activity Network Diagram

The activity network diagram, also sometimes referred to as the arrow diagram or critical path method chart, is particularly helpful when an improvement team wants to identify the required order of tasks within a manufacturing process or project. Its primary benefit is to convey dependencies and simultaneous activities via a simple visual. This chart is critical for project management.

Using the Tools

As you contemplate the 14 quality tools (the seven basic tools and the seven new tools) from which you can select for any continuous improvement project, it will be useful to think about them in the following categories and select the one tool or combination of tools that matches what you are trying to capture:

- Nonquantitative tools: process flow chart or mapping, cause-and-effect diagram, affinity diagram, tree diagram, process decision program chart, relationship diagram, activity network diagram
- Combination tools: matrix diagram (if using points on the diagram that reflect measured data)
- Quantitative tools: scatter diagram, Pareto chart, run chart, histogram, control chart

What's important to remember is that if you have used a tool that did not result in actionable information, you may need to try another for the same task. However, if you think of your tools in these three categories it will be easier to determine which is the most appropriate. It may be appropriate to use a few tools on the same issue to drill down to the details needed.

Topic 4: Continuous Improvement Methods

A number of continuous improvement philosophies such as lean, Just-in-Time (JIT), six sigma, and the theory of constraints are discussed here to show how continuous improvement can be embraced systematically. First there is an introduction to these methods.

Continuous Improvement Methods Road Map

Several well-tested approaches to continuous process improvement evolved during the last half of the 20th century. Many are related to total quality management to one degree or another, emphasizing the reduction of defects or elimination of waste in the use of time and materials. These various approaches are complementary and may have the most impact when combined under a continuous improvement umbrella.

In brief, here are some well-accepted continuous improvement approaches:

- **Lean** strives to include quality in the product and processes using empowered teams, and it emphasizes elimination of waste. It grew from the same principles included in **Just-in-Time (JIT),** which focuses on reducing inventories to zero so that products always appear when they are needed, not before. When a lean system is running on "takt" time (releasing supply based on the rate of demand), JIT delivery of supplies is virtually a necessity to honor the commitment to zero accumulation of inventory in production queues.

- **Six sigma** focuses on enhancing the customer experience by reducing the number of defects in a process until they approach statistical insignificance. Six sigma keeps the focus on achieving high-quality processes, not just fast ones. Errors inevitably introduce waste into a process.

- The **theory of constraints (TOC)** provides a systematic method of increasing a system's throughput by identifying the slowest element in the system (the constraint) and focusing initial improvement efforts on that element. As one constraint is eliminated, another appears; hence, TOC is inherently a continuous improvement strategy. Part of that effort involves maintaining buffers at the constraints, which may seem to be incompatible with lean, but as the buffers are added only just before the current constraint and their level is carefully controlled, the other parts of the system could have reduced buffers.

These approaches to continuous improvement can be used successfully together. For example, when TOC has a system running at the speed necessary to satisfy customer demand, lean tactics can be used to reduce waste and optimize delivery timing while six sigma controls smooth out system variability.

Waste is common to both lean and JIT and so is addressed here

Waste

JIT and lean emphasize the elimination of waste (non-value-added activities).

Waste is given a broad definition by the *APICS Dictionary,* 16th edition:

> (1) Any activity that does not add value to the good or service in the eyes of the consumer
>
> (2) A by-product of a process or task with unique characteristics requiring special management control

The definition further explains that

> waste production can usually be planned and somewhat controlled. Scrap is typically not planned and may result from the same production run as waste.

For instance, the first production run of the day may result in start-up waste because the product coloration doesn't meet specifications since the colorants haven't been used since the last run hours ago.

Toyota pioneered JIT and lean and is well known for identifying and tracking wastes in its Toyota Production System.

Exhibit 4-54 shows the types of waste.

Exhibit 4-54: Types of Waste

Type	Description
Process	Taking unneeded steps to produce work; inefficiencies
Movement (transportation)	Moving products unnecessarily
Methods (motion)	Wasted time or efforts by operators

Type	Description
Product defects	Products and services that do not meet specifications
Waiting time	Queuing delays
Overproduction	Making more product than required
Excess inventory	Holding stock not required to fulfill customer orders
Unused people skills	Waste of knowledge or capabilities

Toyota's Taiichi Ohno originally defined the first seven "deadly" wastes in the Toyota Production System. The eighth waste (unused people skills) was defined by James P. Womack and Daniel T. Jones in *Lean Thinking.* Overproduction is considered the most serious of the eight wastes.

While JIT and lean concepts have their most familiar applications in manufacturing, they also have wider application in supply chain management. A smooth-running production process often can be achieved only when it is part of a smooth-running supply chain.

Lean

Lean improvement initiatives focus on reduction or elimination of waste in all areas. The *APICS Dictionary,* 16th edition, identifies "lean" and "lean manufacturing" as synonyms for **lean production ,** which it defines as follows:

> A philosophy of production that emphasizes the minimization of the amount of all the resources (including time) used in the various activities of the enterprise. It involves identifying and eliminating non-value-adding activities in design, production, supply chain management, and dealing with customers. Lean producers employ teams of multiskilled workers at all levels of the organization and use highly flexible, increasingly automated machines to produce volumes of products in potentially enormous variety. It contains a set of principles and practices to reduce cost through the relentless removal of waste and through the simplification of all manufacturing and support processes.

Most lean resources credit Henry Ford as the first person to truly integrate an entire production process when he created what he called "flow production" in 1913. Ford's techniques, however, lacked flexibility; they were intended to produce only black Model T automobiles. During the 1930s, Toyota revised Ford's concepts to provide both continuity in process flow and a wide variety in product offerings. This became known as the Toyota Production System (TPS). We will examine key aspects of the Toyota system throughout this discussion of lean.

Lean thinking has applications all along the supply chain—from eliminating unnecessary steps in product design to aligning suppliers' processes with the delivery schedules required for lean manufacturing. Waste, in the world of lean thinking, is anything that fails to add value in the eyes of the customer. Waste can therefore mean product features or entire products that customers feel are unnecessary. Waste can also refer to unnecessary materials, equipment, processes, plant, personnel, time—any operational element that can be eliminated without reducing the value provided to the customer.

Reducing non-value-added costs and times passed to customers not only makes customers happier; it also tends to lower the organization’s costs or increases profits. For example, checking in and selecting seats online are two examples of ways that airlines have reduced their costs while reducing non-value-added wait time for their customers. This is a definite win-win for the supply chain and for the customer.

Likewise, a supplier of retail goods to a major retailer can “lean” its supply chain by using point-of-sale data from its customers to create replenishment orders to ship the right amount of product directly to each store. This helps minimize the bullwhip effect and keep inventory levels lower than if they were using only forecasting methods to drive their processes.

Lean initiatives are fueled by a specific set of tools and techniques. For example, lean production is also compatible with six sigma.

Exhibit 4-55 outlines the main features of lean production.

Exhibit 4-55: Lean Production

Lean Production — A philosophy of production that emphasizes the minimization of the amount of all the resources used in the various activities of the enterprise

- Identify and eliminate non-value-adding activities in design, production, supply chain management
- Employ teams of multiskilled employees
- Use flexible and automated machines
- Use JIT production and strive toward six-sigma quality
- Consists of a set of principles and practices to reduce costs via removal of waste and simplification of all manufacturing and support processes

Implementation:

1. Map the final assembly process.
2. Clean and organize areas to be changed.
3. Install kanban pull scheduling between order entry and final assembly.
4. Work backward in the production process using kanban to link final assembly to internal and external component suppliers.
5. Reduce setup times and batch sizes.
6. Reduce defects.
7. Do employee training.

Lean Objectives

Lean supply chains strive to achieve the following objectives.

- **Eliminate waste in business value streams.** Lean supply chains eliminate all processes that add cost without adding customer value, including materials handling, inspection (perfect products don’t require inspection), inventory, and rework (get it right the first time). The perfect lean system would also reduce distances that parts and employees have to travel to avoid wasted time and wasted steps.

- **Meet customer demand.** Organizations adopt lean and encourage their suppliers to do so to strengthen the supply chain. Lean systems aim to produce only products and services that customers want and only at the rate that customers want to buy them.
- **Increase velocity.** Velocity refers to the time it takes to provide value to the customer. **Velocity** in supply chain management is defined in the *APICS Dictionary,* 16th edition, as "the relative speed of all transactions, collectively, within a supply chain community." The definition goes on to state that "a maximum velocity is most desirable because it indicates higher asset turnover for stockholders and faster order-to-delivery response for customers." Through the use of JIT and lean techniques, velocity produces products and services only as fast as customers want them.
- **Reduce need for working capital.** Working capital (the cash available for the day-to-day operations of a company) is increased because of reduced inventory and improved productivity.
- **Increase inventory turns.** Inventory turnover, or inventory turns, is the number of times that an inventory cycles, or turns over, during the year. Shortening lead times and assembling to order are ways to increase inventory turns.
- **Gain market share.** Quality, low cost, short lead times, and other lean principles help organizations and supply chains gain competitive advantage.
- **Increase profitability.** Increased profitability results when non-value-added activities are reduced and volume is added without adding resources.
- **Develop the workforce.** Lean reinforces the occupational development of employees though improved job design, training opportunities, more challenging work, more responsibility, participation at all employee levels, and more teamwork. Job titles are typically reduced and worker flexibility is increased.
- **Produce products and services with perfect quality.** When all is functioning according to plan, lean systems allow employees to produce perfect results.

In lean supply chains, organizations find suppliers whose methods will synchronize with lean requirements and develop long-term relationships with them. (Developing relationships with partners rather than seeking low bids for every project is a fundamental lean principle.) Organizations seek or develop suppliers who understand and are willing to play a role in creating value for customers by streamlining processes and developing the organizational capabilities to deliver just in time.

Lean Principles

Lean Thinking by Womack and Jones identifies five principles that epitomize lean. These core lean principles are summarized in Exhibit 4-56. General implications for supply chain management are included.

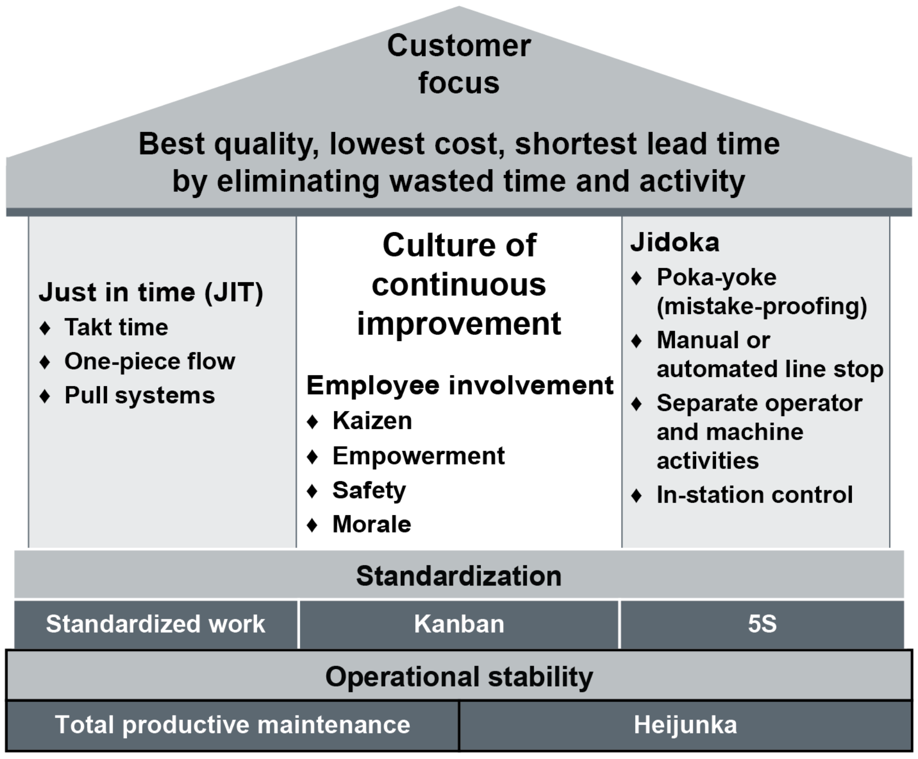
Exhibit 4-56: Lean Principles

Principle	Implications for Supply Chain Management
Create value for the customer.	Only a customer can define what constitutes value in terms of a product or service. When a supply chain creates value for customers, it recognizes what creates value from the customer's perspective and answers the question "What will the customer pay for?"
Identify all steps across a value stream.	As noted in the *APICS Dictionary,* 16th edition, a **value stream** encompasses all "the processes of creating, producing, and delivering a good or service to the market." All of the activities (both value-added and non-value-added and the highly visible and more subtle ones) that are performed to process raw material to finished product, from order to cash and from product concept to product launch, are included. Identifying steps across the entire value stream often exposes waste.
Create value flow.	What are the actions that create value flow? One-piece or continuous, smooth flow is the ultimate objective. When striving for smooth flow, problems that must be dealt with become visible.
Pull products based upon customer demand.	Pull scheduling replaces what is used and drives actions toward a make-to-order environment (versus push production scheduling). In pull, each successive step in an overall process signals the preceding step that it needs more material/product to work on and triggers the predecessor to produce the needed material/product. In a pull environment, no one upstream function or department should produce a product or service until the next customer downstream asks for it.
Strive for perfection by continually removing successive layers of waste.	Relentless continuous improvement removes successive layers of waste. Continuous improvement results are maximized when the first four lean principles are in place.

House of Toyota

The House of Toyota, also called a house of lean, is a framework commonly used to explain the entire scope of lean. The House of Toyota graphic was created by Taiichi Ohno and Eiji Toyoda of Toyota to help explain the Toyota Production System to employees and suppliers. Exhibit 4-57 we see a typical representation of the House of Toyota.

Exhibit 4-57: House of Toyota



Source: APICS Lean Enterprise Workshop Series.

Although Toyota has had its issues such as recalls, the company is still a good example of lean production. These quality issues reaffirm the critical importance of a company aligning its long-term quality strategy and value proposition with its shorter-term growth strategy, thereby ensuring that value will continue to exist.

Foundation

The metaphor of a house was used to convey stability. Operational stability (the house foundation) implies stable demand and processes through leveling, standardized work, and processes improved through kaizen. Let’s look more closely at these three terms.

- The *APICS Dictionary,* 16th edition, tells us that **load leveling** (also referred to as capacity smoothing or level loading) is defined as follows.

  > Spreading orders out in time or rescheduling operations so that the amount of work to be done in sequential time periods tends to be distributed evenly and is achievable. Although both material and labor are ideally level loaded, specific businesses and industries may load to one or the other exclusively (e.g., service industries).

  In the Toyota Production System, **heijunka** is the Japanese term akin to leveling. The *Dictionary* defines it as part of the Just-in-Time philosophy and as “an approach to level production throughout the supply chain to match the planned rate of end product sales.”

- **Standardized work** (or standard work) has been compared to the steps in a dance; it defines tasks (such as content, sequence, and timing) to achieve an optimum process in the time available.

- The *Dictionary* defines **kaizen** as follows:

Continuing improvement involving everyone—managers and workers. In manufacturing, kaizen relates to finding and eliminating waste in machinery, labor, or production methods.

Roof

The House of Toyota roof contains the primary goals of the Toyota Production System achieved by eliminating waste. The primary goal is to have a customer focus, which is addressed in detail elsewhere since this is basically customer relationship management. Other goals include the following:

- **Best quality.** One-piece or continuous flow improves quality because the next (downstream) process uses the piece shortly after it has been produced at the previous (upstream) process. Unless there is batch processing, there will be very few pieces produced with a defect because a defective item should be found soon after it is made. (If there is batch processing, a quality problem could potentially be replicated in the entire batch before it is found in a downstream process.)

- **Lowest cost.** A premise of lean is that the least amount of waste will result in the lowest costs. It should be noted, however, that if standard cost accounting is used for lean projects, the results will actually make it appear as though many lean efforts are having a seemingly negative financial effect on the organization. Here is why: When management accounting methods came into being in the early 1900s, they were designed to support manufacturers that produced large batches of products with long lead times. These manufacturers were also intent on having significant inventory for their customers. Thus, traditional management accounting measurements focused on planned versus actual direct costs and overhead (e.g., machine utilization, cost variance, budget adherence). Lean accounting instead focuses on delivery to the customer (e.g., through cycle time and inventory turns).

  Lean accounting also necessitates different types of financial, behavioral, and core process performance metrics. A **lean metric** is one “that permits a balanced evaluation and response—quality without sacrificing quantity objectives” (*Dictionary*).

  Thus management accounting does not capture or reflect significant productivity gains due to lean practices. It also tends to make profits appear lower than they actually are, even though cash flow has improved due to lean processes.

- **Shortest (delivery) lead time.** With lean’s emphasis on activities such as one-piece flow and pull systems, queue times (wait times for a product awaiting the next step in a process) often shrink significantly. The result is typically a short lead time to the customer.

Two Pillars

Jidoka and Just-in-Time are two important lean concepts. They are shown as the outer pillars in the House of Toyota. The house will not stand without both pillars.

- **Jidoka .** Jidoka is a Japanese term that can be loosely translated as "automation with a human touch." In the House of Toyota, jidoka is facilitated by line stoppage, the separation of operator and machine activities, mistake-proofing, and in-station (visual) control.

  Jidoka is sometimes referred to as "intelligent automation" or "autonomation." It is the ability to stop production lines, by human or machine, in the event of problems such as equipment malfunction, quality issues, or late work. Specially equipped machines can stop a process immediately when a problem occurs and signal for help. Operators stop work and correct the problem. Sometimes managers or supervisors are involved, depending upon the magnitude of the problem. Whether the stoppage is manual or automated, jidoka prevents defective products from being produced. It helps identify and correct problem areas using localization and isolation.

  Poka-yoke is a tool used to support jidoka. Often referred to as mistake-proofing or error-proofing, the term comes from "poka," which means "error," and "yokeru," which means "to avoid." Poka-yoke is a failure mode control—a method or device to detect abnormal conditions and stop the process. An example of poka-yoke is a component with a flange that allows it to be installed in one way only rather than being able to be installed backward by accident.

  In-station control (also referred to as visual control or problem visualization) describes the sequence when a problem arises. Since the equipment stops when an abnormality is detected, a single operator can visually monitor and efficiently control many machines. A problem display board (usually electronic) called "andon" allows an operator to identify problems in the production line at a glance. The problem is corrected, and improvements are incorporated into the standard workflow.

- **Just-in-Time.** JIT allows delivery of the right items at the right time to the right place in the right amounts. Takt time, one-piece flow, and pull systems facilitate JIT. One-piece flow and pull systems are described elsewhere; takt time needs further explanation.

  When a lean system is ticking along at the perfect rate, its production of finished goods is exactly synchronized with the rate of customer demand. This reduces inventories to a minimum, eliminating all but work-in-process and in-transit inventories. The heartbeat of such a synchronized system is called takt time. Derived from the German word for musical meter, takt time uses this ratio:

  $$\text{Takt Time} = \frac{\text{Available Production Time}}{\text{Customer Demand}}$$

  For example, say that customer demand for walking chronometers is running at 1,000 units per day and available capacity is rated at 700 minutes per day; takt time would be 0.7 minutes per unit (700 minutes divided by 1,000 watches). The production system would then have to be designed to produce a unit every 42 seconds (0.7 x 60 seconds), or capacity would have to be increased.

  The end result of JIT is that each process produces only what is needed by the next process in continuous flow.

A Just-in-Time system functions properly when all of the parts that are made and supplied meet predetermined quality standards. Jidoka supports this through the detection of errors or defects during production.

Center of House

The center of the House of Toyota promotes the following core lean principles.

- **Culture of continuous improvement.** In order for lean to be successful, organizational leadership must relinquish hierarchical authority and create a culture of learning and experimentation to support continuous improvement. The continuous improvement mindset starts at the top, and everyone in the organization is involved. Employee involvement plays an important role in lean manufacturing in terms of both continuous improvement and quality control efforts. Employees are rewarded for successful initiatives.

- **Respect for people.** "People" means customers as well as people in the local communities and employees. How is respect for people achieved? Safety is ensured, the wider community is served, and employee morale is boosted. Organizations give back and protect the wider community through green practices and other environmental initiatives. Employees are empowered and take ownership for their work. Teams facilitate creativity, effectiveness, and efficiencies.

Additional Lean Considerations

Let's consider some additional concepts commonly applied in lean initiatives.

Value Stream Mapping

Value stream mapping is a paper-and-pencil tool that helps you to see and understand the flow of material and information as a product or service makes its way through the value stream. While it is similar to process mapping in six sigma, it tends to display a broader range of supply chain processes, stretching all the way from receiving raw material to delivering finished goods. Not only does a value stream map sketch all the steps in a production or service delivery process; it also includes the management and information systems that accompany the process.

The basic procedure of value stream mapping is to begin by drawing the process. Then overlay a map of the information flows that support the process. This provides a picture of the current state of the supply chain, complete with value-adding and non-value-adding activities. (The bottom of the chart clearly differentiates value-added time from non-value-added time, such as waiting for production, and sums them separately.) After completing the value stream map of the current state with input and approval from all stakeholders, the next step is to draw a future state map that eliminates as many wasteful activities as possible. Organizations that successfully convert a shop floor into a lean production area through value stream mapping will sometimes apply the same technique to mapping and improving other areas, such as incoming supply, outgoing distribution, the design process, or administrative procedures.

Value stream mapping is a powerful yet simple tool that does not require advanced technology. Nevertheless, it provides a way to link metrics/reporting requirements and stakeholders from multiple functions (including managers and staff) to sustain a lean initiative across the entire supply chain. It gives managers and employees the same tool and language to use to communicate.

Kaizen Event/Kaizen Blitz

Kaizen is the Japanese word for continuous improvement, and it signifies a carefully designed, evolutionary process. A **kaizen event** is defined in the 16th edition of the *APICS Dictionary* as follows:

> A time-boxed set of activities carried out by the cell team during the week of cell implementation. The kaizen event is an implementation arm of a lean manufacturing program.

A kaizen event is a regularly scheduled event that is designed to be started and completed in a limited time frame, such as a week. Therefore, it is used for continuous improvements that can be identified and enacted without significant disruption to processes or staff. Note that this needs to be a regular process because one or two successes from kaizen events may lead to complacency rather than commitment to long-term reform. Therefore the change leaders in the organization (often assisted by consultants) should embed the kaizen event in a carefully developed long-term plan that is communicated clearly to all stakeholders.

A related term for a more intense version of the process that could make many improvements but keeps the focus area narrow is a **kaizen blitz .** It is defined by the *Dictionary* as follows:

> A rapid improvement of a limited process area, for example, a production cell. Part of the improvement team consists of workers in that area. The objectives are to use innovative thinking to eliminate non-value-added work and to immediately implement the changes within a week or less. Ownership of the improvement by the area work team and the development of the team's problem-solving skills are additional benefits.

In general the kaizen blitz includes basic training, analysis (usually a flowchart of the process to be redesigned), and the design itself. The blitz is something of an anomaly, therefore, and is not without its dangers. For one thing, the quick turnaround time allows for only superficial training in analysis and design methods without attention to the subtleties or tradeoffs. A kaizen blitz can be most useful at the beginning of a lean or TQM initiative to provide a quick demonstration of the possibilities of reform and thus convince skeptics that change can be beneficial.

Lean techniques, such as the kaizen event, may have seen their first applications in Toyota and other Japanese companies, but they can be just as usefully applied in service settings as on shop floors. For example, a Minnesota health-care organization adapted Toyota's Rapid Process Improvement Workshop (RPIW)—essentially a kaizen blitz—to their endoscopy service to reduce the annoyingly long wait for appointments. With the improvements that resulted, they doubled the number of patient visits per day without reducing the time spent with a physician. After that initial success, the medical center conducted dozens more RPIWs, which resulted in a savings of US$7.5 million in the first year. In this instance, the initial blitz was the first step in what became an organization-wide, lean revamping of the service supply chain. It is important to emphasize that TQM, lean, six sigma, and JIT all take years to achieve their objectives and many small improvements (and some large reengineering efforts) are needed in many places to increase the maturity of the system as a whole.

Five Ss

The five Ss refers to a workplace organization method expressed in Japanese: seiri, seiton, seiso, seiketsu, and shitsuke. Collectively they describe how to organize a work space to optimize efficiency and effectiveness. Since order and organization are important concepts in lean, these five Ss (often referred to as 5S) have been adopted and translated into English as "sort, simplify, scrub, standardize, and sustain." The purpose of the five Ss is to make everything about the workplace orderly and clean and keep it so.

describes the five Ss.

Exhibit 4-58: The Five Ss

Term	Description
Sort	Sort means to separate needed items from unneeded ones and remove the latter. Sorting and organizing the work area, leaving only the essential paperwork, tools, and other materials necessary to perform daily activities, improves communication between workers and increases product quality and productivity.
Simplify (set in order)	Simplify means to neatly arrange items for use. The orderly arrangement of needed items makes them easy to use and accessible for anyone to find or put away and eliminates waste in activities.
Scrub (shine)	Scrub means clean up the work area. Sweeping, systematic cleaning, and shining keeps everything in top condition so that when someone needs to use something, it is ready to be used; mess prevention also helps to maintain a safer work area.
Standardize	Standardize means to develop standard work processes. Creating a consistent approach for carrying out tasks and procedures helps clarify what is the "normal" condition and how to correct "abnormal" conditions.
Sustain	Sustain means to always follow the first four Ss. Maintaining and reviewing materials sustains the discipline and commitment of all other stages.

Source: Adapted from Five Pillars of the Visual Workplace by Hiroyuki Hirano.

The five Ss create a workplace suitable for lean production. They convey the message that quality starts with the people in the organization. The five Ss provide a framework for a workplace that is clean, uncluttered, safe, and organized, where people become empowered and engaged.

Setup Time Reduction

Setup time reduction has a major impact on production costs and product variety. This practice aims to reduce waste (time and material) in the setup process. It encompasses improved processes as well as having employees being responsible for their own setups. The *Dictionary* defines **setup time** as

> the time required for a specific machine, resource, work center, process, or line to convert from the production of the last good piece of item A to the first good piece of item B.

Reducing setup time increases an operation's velocity and throughput. There are five steps to reduce setup time.

1. Classify internal and external changeover tasks. Internal tasks must be performed while a machine is stopped (idle time); external or preparation tasks can be performed while the machine is still running.
2. Convert internal setup tasks to external tasks. For example, organize tools and materials for setup while the machine is still running a batch.
3. Streamline internal setup. For example, find ways to reduce the time it takes to fasten equipment in place.
4. Eliminate adjustments. Documenting the proper adjustments for different materials helps eliminate wasteful trial and error, as adjustments are repeated until the machine produces an "in spec" product.
5. Minimize external (preparation) time, since small batch processes may not provide enough time to prepare for the changeover.

Remember that reducing changeover time is a part of an overall strategy, and it impacts and is impacted by other areas such as lot size and lead time. Make sure that your setup time reduction accomplishes your strategic goals. Do you aim to reduce time, cost, human resources, maintenance, or a combination? Does quality need to be improved? Although all of the above are often desired, generally not all are possible.

Total Productive Maintenance

Total productive maintenance (TPM) seeks to engage all levels and functions in an organization to maximize the overall effectiveness of production equipment.

The *APICS Dictionary,* 16th edition, defines TPM as follows.

> Preventive maintenance plus continuing efforts to adapt, modify, and refine equipment to increase flexibility, reduce material handling, and promote continuous flows. It is operator-oriented maintenance with the involvement of all qualified employees in all maintenance activities.

TPM aims to reduce mistakes and accidents. Where maintenance departments are traditionally responsible for preventive maintenance programs, TPM seeks to involve workers in all departments and levels, from the plant floor to senior executives, to ensure effective equipment operation.

Three Major Areas of Waste

As lean strives to eliminate waste, there are three broad types of waste it focuses on: muda, mura, and muri, according to Taiichi Ohno.

Muda is synonymous with waste—any activity that consumes resources but creates no value. Recall that value is what the customer is willing to pay for. Mura is a general Japanese term for unevenness or inconsistency. Mura occurs in the demand for production and in processes. In lean, mura creates muri. Muri is an overburdened situation—the overburdening of employees or processes.

For many organizations, mura and muri are the root causes of muda. It is management's responsibility to examine the muda in the processes and eliminate the deeper root causes of the waste by considering the connections to mura and muri.

A typical example of the interplay of muda, mura, and muri is an organization playing catch-up and trying to make forecasted numbers as the end of a fiscal reporting period approaches. Demand is raised, increasing mura. This causes production to try to squeeze extra capacity from the process. Routines and standards are modified or stretched, leading to muri. Ultimately, this results in downtime, mistakes, backflows, and waiting. Muda is the waiting and corrections that result.

Lean takes a problem-solving approach rather than a tools-based approach to eliminating waste. In lean, tools serve specific purposes and support focused improvement efforts.

lists tools that are used to combat muda, mura, and muri.

Exhibit 4-59: Tools to Combat Major Areas of Lean Waste

Muda	5Ss, TPM, setup reduction, flow, pull, kaizen, six sigma
Mura	Takt time, heijunka, flow, pull, six sigma
Muri	Takt time, standard work, flow, pull

As lean strives to identify waste from the customer's perspective and determine how to eliminate that waste, these tools help to make processes more standardized, effective, and efficient. For example, a pull system minimizes inventory waste by pulling inventory through the supply chain based on actual demand signals rather than pushing inventory out based on forecasts that could be inaccurate.

In complex supply chains, especially global ones, implementing lean and responding to demand events from downstream operations poses challenges. But when system wastes are eliminated, lean's benefits will include reduced inventories, lower labor and material costs, energy efficiencies, increased customer value, improved customer satisfaction, coordinated continuous improvement efforts across the supply chain, and competitive advantage and leadership in the global marketplace.

Just-in-Time (JIT)

Just-in-Time is a major component in lean's House of Toyota. However, some organizations may practice JIT without embracing the entire lean philosophy, so it is important to understand JIT as a stand-alone philosophy as well. The *APICS Dictionary,* 16th edition, defines **Just-in-Time** as follows:

> A philosophy of manufacturing based on planned elimination of all waste and on continuous improvement of productivity. It encompasses the successful execution of all manufacturing activities required to produce a final product, from design engineering to delivery, and includes all stages of conversion from raw material onward. The primary elements of Just-in-Time are to have only the required inventory when needed; to improve quality to zero defects; to reduce lead times by reducing setup times, queue lengths, and lot sizes; to incrementally revise the operations themselves; and to accomplish these activities at minimum cost. In the broad sense, it applies to all forms of manufacturing—job shop, process, and repetitive—and to many service industries as well.

JIT places a primary emphasis on eliminating time in queues at work centers by having the right materials arrive at the right places at the right times. This implies more than mere speed or timing; it implies quality as well, so JIT uses total quality management principles. Any lack of quality can prevent the rapid flow of goods to their appointed stations and create queues of stalled inventory. Any worker in a JIT facility has the power, the responsibility, and the means to halt production to pull a defective product.

Exhibit 4-60 illustrates the principal features of JIT.

Exhibit 4-60: Features of Just-in-Time Production

Just-in-Time (JIT) Elements

1. Have inventory only when needed.
2. Quality at zero defects level.
3. Reduce lead times by:
   - Reducing setup times.
   - Reducing queue lengths.
   - Reducing lot sizes.
4. Review and revise operations.
5. Strong supplier relationships.
6. Multiskilled labor force.
7. Move toward cellular manufacturing environment.

JIT Philosophy

- Eliminate all waste.
- Strive for continuous productivity improvements.

Applies to the following forms of manufacturing environments: job shops, process, repetitive.

JIT Benefits

- Manufacturing cycle time reduction
- Inventory reduction
- Labor cost reduction
- Quality cost reduction
- Material cost reduction
- Improved vendor relationships

Three JIT Basics

Three JIT focuses include waste reduction, variability reduction, and pulling materials into a work center rather than pushing them in from the preceding center.

Waste Reduction

Storage, inspections, queues at work centers, and defects all fail to add value while costing money and slowing down production. Through continuous improvement, JIT targets each of these conditions for step-by-step elimination.

Variability Reduction

Continuous improvement includes elimination of variability discovered in the system no matter what the source, internal or external. The source might be inaccurate engineering drawings, equipment that fails to perform up to standards, or going into production without understanding customer requirements.

Pulling Materials into Production

In traditional systems, materials and parts move from place to place by being “pushed” from behind. Raw materials are extracted and sent to manufacturing. Materials and components move away from workstations when the operation there has been completed. Manufacturing ships goods out when they are in finished form. All of this activity takes place in accordance with schedules determined in advance on the basis of forecasts.

JIT takes the opposite approach and “pulls” items through the system when they are demanded, not according to preset schedules. In a pull system, materials don’t move from supplier to plant until requested. Similarly, work-in-process (WIP) doesn’t move from one work center to another until a signal indicates that the time is right. Lots sizes are kept small, and orders are entered more frequently. This reduces or eliminates any inventory waiting to be processed. This brings quality problems to light more quickly. Defects in materials can be hidden when there are inventory buffers; a defective component can be discarded and another taken from the safety stock. But in JIT there is no buffer, so there are no quick substitutions possible when a defective component comes on line. Therefore, a defect causes a slowdown and signals the need for process improvement.

Elements of JIT for Continuous Improvement

Here are some of the elements of the supply chain that are subject to continuous improvement according to JIT principles.

Suppliers

Some supply chains have always included a JIT component. Fine restaurant supply chains are an example. Perishable items for consumption must be delivered on time with minimal variability and waste if they are to be served fresh to high-paying customers. JIT extends that model into manufacturing supply chains by building long-term relationships with a limited number of suppliers who are willing to incorporate JIT principles into their own businesses. A JIT supplier delivers on time, ships only quality goods that require no inspection, and reduces inventory in warehouses and in transit. Sometimes suppliers actually move their warehouses into the plant to ensure that supplies are always available with almost no transport time or other delays.

Not all suppliers are willing to be JIT partners. They may not want to be tied up in a long-term contract or to move at the pace of JIT, which can necessitate frequent, rapid engineering changes. The demand for zero defects and small, frequent shipments may also run counter to supplier preferences.

JIT Layout

Another way to reduce waste is to lay out the production facility in such a way as to minimize distances and maximize flexibility. Employees may be arranged in “work cells” that focus on one family of products manufactured with similar processes. This minimizes the distance the products travel through production and, ideally, allows production of one unit at a time in response to an order. Equipment is designed to be movable, with nothing bolted to the floor, so cells can be easily re-formed to accommodate new product families. Workers, too, are made more flexible by cross-training.

Inventory Reduction

“Inventory is evil,” in the words of Japanese JIT guru Shigeo Shingo. Shingo’s strong statement captures the spirit of JIT, though it might be more proper to say that inventory not in motion is the real problem. Operations managers may begin instituting JIT by reducing inventory to the bare minimum necessary for efficient operation. With no “safety stock,” everything in the system has to work almost perfectly to avoid breakdowns. Continuous improvement finds ways to eliminate variability and defects so the system will work without inventory buffers. Lot sizes must be kept small to avoid accumulation of inventory, and that brings down costs of holding and handling items in storage or in queues. However, as holding costs go down, ordering and setup costs tend to rise. Small, frequent lots mean more orders placed for materials and more setups. Reducing order cost and setup time are JIT improvement projects. Order expense is often eliminated using backflushing, which replaces replenishment purchase orders with an automated order based on actual use in production and the bill of materials (which must be accurate). Various ways to reduce setup time are discussed next.

Changeovers, Lead Time, and Lot Sizes

Quick changeovers can provide immediate benefit in the form of lead time reduction. Reducing lead time using JIT or even by improving lead time in conventional systems can provide a number of benefits. The first benefit is a direct and immediate reduction in product cost, because setup time is a direct cost. It can also eventually reduce lot sizes—and thus order quantities—because setup time will not be as large a component in the tradeoff analysis between the cost of setups and other costs. Reducing lot sizes will also eventually improve quality because defects will have less chance to be replicated across as many units. Another benefit of reducing lot sizes is that WIP inventory and queues (orders awaiting production at a work center) will be reduced because the total amount of inventory in process or waiting to be run at individual work centers is partly a factor of the order size. A side benefit of smaller orders, less WIP inventory, and smaller queues is that when less inventory is held between work centers, it will be easier to establish cellular layouts because the work centers can be physically nearer to each other.

Scheduling

Good communication is essential for efficient scheduling. In JIT, schedules are widely communicated within organizations and along the supply chain, improving suppliers' ability to be responsive to orders.

A finalized production schedule based on actual demand for components and materials is essential to putting JIT into action. However, schedules for JIT differ from traditional make-to-stock schedules. These schedules determine material requirements by focusing on the finished goods being demanded. Two particular types of schedules are favored in JIT: level and kanban.

- A level schedule involves small batches of constantly changing items, so that production for each day exactly meets demand for the day. (Production and demand are level.) This can produce as many units as a large-batch system, but it requires reduction of setup time to do so.

- The kanban system originated in Japan, where display cards are generally used to signal that a work site is ready for a new batch of materials. (In Japanese, "kanban," loosely translated, means card, billboard, or sign.) Kanban works (like JIT in general) in fast-paced mass production environments where one station is close enough to the next that a visual signal will suffice to trigger a delivery. Cards, a light, an empty parts bin, colored golf balls, or even an empty space on the floor can signal readiness for materials.

Continuous Job Improvement

JIT includes continuous employee and job improvement as well as continuous process improvement. In JIT organizations, responsibility for process improvement rests upon the workers closest to the process, so those employees take on supervisory responsibilities. The emphasis is on training and cross-training to boost employees' skills and knowledge to keep up with their growing responsibilities. Jobs, too, are expanded and enriched to increase the challenge to employees and to enhance their commitment to continuous improvement of every aspect of the workplace.

Six Sigma

The *APICS Dictionary,* 16th edition, defines **six sigma** as follows:

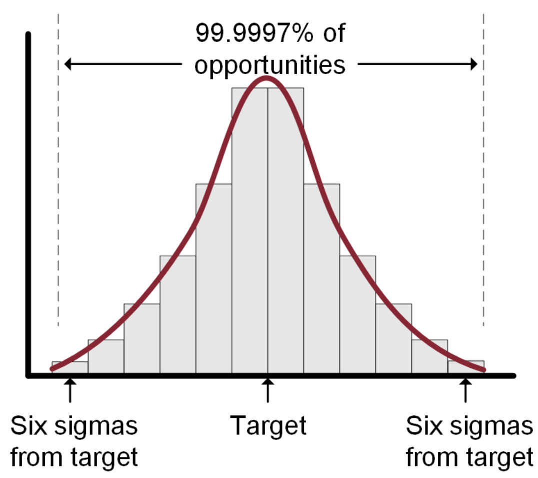
> A methodology that furnishes tools for the improvement of business processes. The intent is to decrease process variation and improve product quality.

Six sigma aims to achieve near-perfect products and services. The specific objective in a six-sigma organization is to get as close as possible to “zero defects,” with an outer limit of 3.4 defects per million “opportunities.” In six-sigma language, a defect is anything that does not conform to customer expectations, and an opportunity is any chance for nonconformance. If a company produces a million light bulbs, no more than 3.4 should fail to meet customer expectations. If a bank sets up ATMs, their customers should experience disappointment during no more than 3.4 times in a million opportunities—which may not be the same thing as one million visits to an ATM. Customers may have more than one expectation; for example, they may expect the machine to be online, the instructions to be easy to understand, the wait for their turn to be short, and, of course, the operation to succeed in delivering or depositing the correct amount. That would be four opportunities for a defect per visit.

One potential challenge to using the six-sigma approach arises from the difficulty of determining what constitutes a defect. Another challenge comes from setting a meaningful limit on variability. For instance, there is probably a range of wait times at the ATM that most customers will generally find acceptable. Is it 30 seconds, a minute, or two minutes? The project team leader, or the executive sponsoring the project, may be tempted to set the limits of variability as wide as possible to achieve a six-sigma level of defects. Also, not all opportunities are as significant as others. While some wait time is likely to be acceptable to customers, failure to record a deposit correctly or deliver the requested amount of cash may be completely unacceptable. (Defect, disappointment, and customer expectations are open to definition by focus group or other research methods.)

Exhibit 4-61 illustrates the aim of six sigma to reduce defects to near zero. Assume that one million opportunities for a defect will result in the familiar bell curve with the target value in the center. If the process is in control from a six sigma perspective, about 99.9997 percent of those opportunities will fall within six sigmas (or standard deviations) from the target value. That will leave only 3.4 opportunities (just over 0.0003 percent) that result in defects.

Exhibit 4-61: Six-Sigma Control



By contrast, traditional quality goals often set the level at three sigmas to either side of the mean. (The mean is the target in the exhibit.) Three sigmas corresponds to 99.74 percent of products with no defects. At that rate, there would be 66,807 defects per million opportunities. When Motorola developed the six sigma concept, they chose six sigmas as an appropriate goal for the types of products they were producing. Some industries might need to set their goals at a different number of sigmas based on what customers find acceptable and what is feasible. Even so, setting ambitious goals and following six sigma improvement processes can result in significant improvements for any organization.

Elements of Six Sigma

Six sigma offers a set of tools for developing repeatable high quality under the guidance of a six-sigma-certified employee or consultant.

Attaining six-sigma quality requires attention to three elements: the customer, the process, and the employee.

- **Customer.** The definition of quality—that is, the acceptable rate of defects—is in the mind of the customer. Customer expectations might include outstanding performance, reliability, competitive price, on-time delivery, excellent service, and so on. All these areas provide opportunities for defects that may drive a customer to a competitor.
- **Process.** Process mapping or flowcharting are techniques used to identify the unique steps in a process. When assessing a process, the company has to adopt the customer's mindset—an "outside-in" view of the company's performance. The goal is not only a low number of errors but also consistent performance. That is, the performance should remain very close to that number of errors and not show a great deal of variability in either direction. For instance, an air-freight carrier with on-time performance that stays right around an acceptable level may create more customer satisfaction than a carrier that has the same average on-time rate but is erratic and unpredictable, with late arrivals counterbalanced by early arrivals. This may produce enough disgruntled customers to erode market share.
- **Employee.** Full employee participation has been a principle of quality systems since the early work of W. Edwards Deming. When it comes to customer satisfaction, there are no irrelevant employees (or processes). Bank tellers, receptionists, and file clerks (or data entry specialists) may occupy low rungs on the corporate ladder, but their "defects" tend to be highly annoying and visible to the customer. A company fully committed to the six-sigma approach will offer training at all levels. Six-sigma initiatives typically are directed from the top but implemented "from below," by employee teams.

  Training in six-sigma tools and techniques takes place at different levels, with the possibility of certification at the level of green belt, black belt, and master black belt. People with any of the three "belts" have sufficient knowledge of quality standards, design and development procedures, and statistical analysis that they can lead process design or process improvement projects. Black belts and master black belts operate as full-time employees; master black belts primarily engage in teaching. Green belts may be consultants or employees with other responsibilities.

Six Sigma Process and Tools

The six-sigma process for conducting a continuous improvement initiative takes place in five phases, known by the initials of the phases as **DMAIC: Define, Measure, Analyze, Improve, Control** (as described in the *APICS Dictionary,* 16th edition).

- **Phase 1: [Define]** Determine the nature of the problem.
- **Phase 2: Measure** existing performance and commence recording data and facts that provide information about the underlying causes of the problem.
- **Phase 3: [Analyze]** Study the information to determine the root causes of the problem.
- **Phase 4: Improve** the process by effecting solutions to the problem.
- **Phase 5: [Control]** Monitor the process until the solutions become ingrained.

Six sigma has developed a similar model to guide the creation of new processes (as opposed to conducting an improvement initiative): Define, Measure, Analyze, Design, Verify (DMADV).

Because of its statistical basis, six-sigma analysis depends heavily upon thorough, reliable, measurable data. Without that level of visibility, there can be no determination of the rate of defects. Six-sigma techniques for defining, measuring, and analyzing a process include quality control tools such as process mapping, control charts, and Pareto diagrams.

Six Sigma Case Study: Single-Source Contracting by U.S. Government

In 2005, the U.S. Navy initiated a process improvement project with a kaizen event that demonstrates the compatibility of the techniques described in this section. The process that needed improving was the “J&A,” Navy-speak for “Justification and Approval to Limit Competition.” The J&A is used to justify sole-source contracting. It affects every contract specialist in the Navy’s air force (NAVAIR), yet studies found that the policy was confusing to new personnel even after training and was subject to divergent interpretation. The result was variability and poor quality in sourcing. The prescription for change was lean six sigma with a focus on reduction of variability and waste.

With the assistance of a black belt lean six-sigma consultant, NAVAIR conducted a kaizen event. Participants sketched out a value stream map of the current J&A process, including a detailed list of “touch times” (six-sigma opportunities for error), waiting times, reviews, and “re-do loops” to document total cycle time. It turned out that the J&A process had 26 steps and 17 rework loops, for a cycle time that varied from 27.75 to 129 days. The next step was to create a future value stream map eliminating wasteful steps and reducing errors, if possible to zero. The result of their efforts was a template to eliminate the “re-do loops” and to make the process so easy to understand that no prior training would be necessary for perfect completion of a J&A. One link in the template, for instance, provided complete guidance on conducting a market survey—a requirement of the process for which there was previously no instruction or explanation. The new template reduced the number of steps from 26 to 13 and the number of rework loops from 17 to zero. Total cycle time dropped 50 percent, to a maximum of 40.5 days and a minimum of 16. The benchmark for the new J&A process was set to no stops and no "re-dos."

Theory of Constraints (TOC)

The theory of constraints (TOC), developed by Eliyahu M. Goldratt, applies to any human organization, not only to businesses. Its central premise is that any system, such as a supply chain or a production process, contains at least one element that limits its maximum output. The *APICS Dictionary,* 16th edition, follows the theory in defining a **constraint** as "any element or factor that prevents a system from achieving a higher level of performance with respect to its goal." An element can be any part of a system, including people, a piece of equipment, a process, a facility, or even a way of thinking, among other possibilities.

Because the constraint determines the maximum output of a system, TOC maintains that it should be the focus of improvement efforts. Why? For the system as a whole to produce maximum throughput, the constraint must be operating at its maximum speed.

Furthermore, there is no benefit to be gained from speeding up the processes before or after the constraint. Imagine an assembly line with the constraint being one workstation that can complete its operation no more than 60 times per hour. Speeding up the process prior to the constraint to deliver 65 units will result in a steady build-up of inventory ahead of the constraint. It will not speed up the final output of the line. Maximum throughput at the constraint will remain at 60 units per hour. Increasing the capacity of the workstation immediately after the constraint to handle more than 60 units per hour will only result in downtime as the station completes its work and waits for the constraint to catch up.

Five-Step TOC Process

Applying TOC as a method of continuous improvement requires five repeatable steps:

1. **Identify the constraint.** A typical indicator of a constraint is an excessive amount of work in a queue. The queue might contain any type of product, from airplanes waiting for a part to be installed to documents accumulating at a copier station. The delay might be the result of various causes, such as inadequately trained employees, a poorly conceived process, or an unreliable piece of equipment.
2. **Exploit the constraint.** Before investing heavily in process improvement, "exploit" the constraint by ensuring that the process is achieving the maximum output possible without major changes. Since the constraint determines the system's overall output, it should never operate below its peak capacity.
3. **Subordinate other processes to the constraint.** Once the constraining element is operating at maximum efficiency, subordinate processes may have to be adjusted to operate at the new speed. This generally applies to processes preceding the constraint. Because the constraint determines the system's maximum output, it must never be idle. Therefore, the processes that feed work to the

constraint must be adjusted to ensure that they deliver work as needed. TOC recommends maintaining buffers ahead of the constraint so that it can keep functioning even if production slows down or halts ahead of it.

4. **Elevate the constraint.** If exploiting the constraint and adjusting subordinate processes result in satisfactory output, then improvement efforts can proceed to Step 5. If output is still inadequate to meet customer demand, then the organization will have to invest in more significant improvements, such as purchasing new equipment, retraining or hiring new staff, or revamping the process itself.
5. **Repeat the cycle.** After completing the first four steps, an organization may start the process over by identifying the new constraint. There is always at least one constraint in a system.

Drum/Buffer/Rope

Explanations of TOC sometimes refer to pace set for the constraint as a drum, because it determines the system's speed as a drummer's beat regulates the pace of a marching band. It is based on the maximum rate of that constraint (but not to exceed takt time [the rate of customer demand]).

The *Dictionary* defines a **buffer** as

> 1) A quantity of materials awaiting further processing. It can refer to raw materials, semifinished stores or hold points, or a work backlog that is purposely maintained behind a work center. 2) In the theory of constraints, buffers can be time or material and support throughput and/or due date performance. Buffers can be maintained at the constraint, convergent points (with a constraint part), divergent points, and shipping points.

The "rope" is the scheduler that pulls orders through the system and schedules the portions of the process that occur before the constraint to ensure that the overall flow conforms to the drum beat of the constraint. One cannot push a rope, only pull it. Like other quality initiatives, TOC emphasizes the importance of pulling orders through the system to meet customer demand rather than pushing inventory through the system without due regard to demand.

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