CPIM
CERTIFIED IN PLANNING AND INVENTORY MANAGEMENT

MODULE 5:
DETAILED SCHEDULES

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Module 5 Overview

Detailed Schedules

- Section A: Planning Detailed Schedules

- Section B: Scheduling and PAC Methods

- Section C: Creating Production and Service Schedules

- Section D: Managing Detailed Schedules and Scheduling Materials

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SECTION A:
PLANNING DETAILED SCHEDULES

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Section A Learning Objectives

- Components of lead time

- Evaluating throughput

- Production activity control (PAC) objectives, roles, and responsibilities

- PAC inputs

- Dispatching rules

- Forward, backward, and central scheduling with finite and infinite loading

- Techniques to improve efficiency and control

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Execution in Manufacturing Planning and Control

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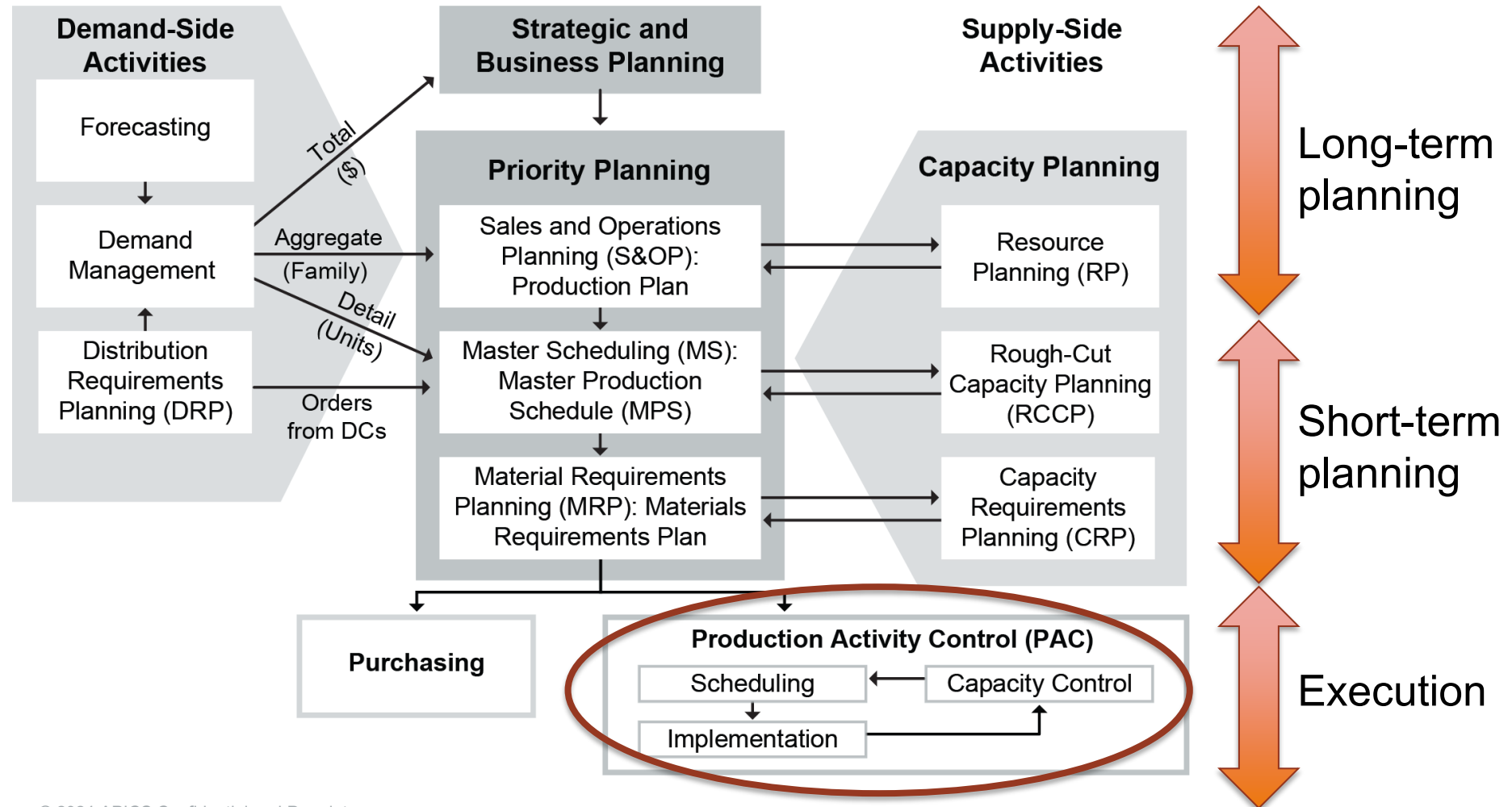
Detailed Scheduling Objectives

Objectives

- Make best use of manufacturing resources to meet delivery dates.

- Ensure that resources are available when needed.

- Schedule feasible start and completion dates for each shop order at each work center.

- Utilize capacity effectively.

- Minimize lead times.

- Meet customer service goals.

Objectives provide guidance on addressing tradeoffs between:

- Labor and equipment

- Lead time

- Inventory levels

- Processing times.

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Detailed Scheduling Inputs and Elements

- What to make
- When to make
- Where to make
- How to make
- How much to make
- Time needed to make
- Material availability
- Due date
- Machine maintenance schedules/failure rates
- Expected rework and scrap percentages
- Other demands on facility

Schedule

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Detailed Scheduling Components

- Operations necessary to complete an item
- Sequence and routing of operations
- Start and finish dates of each operation
- Time estimates for each operation
- Work centers where operations are performed

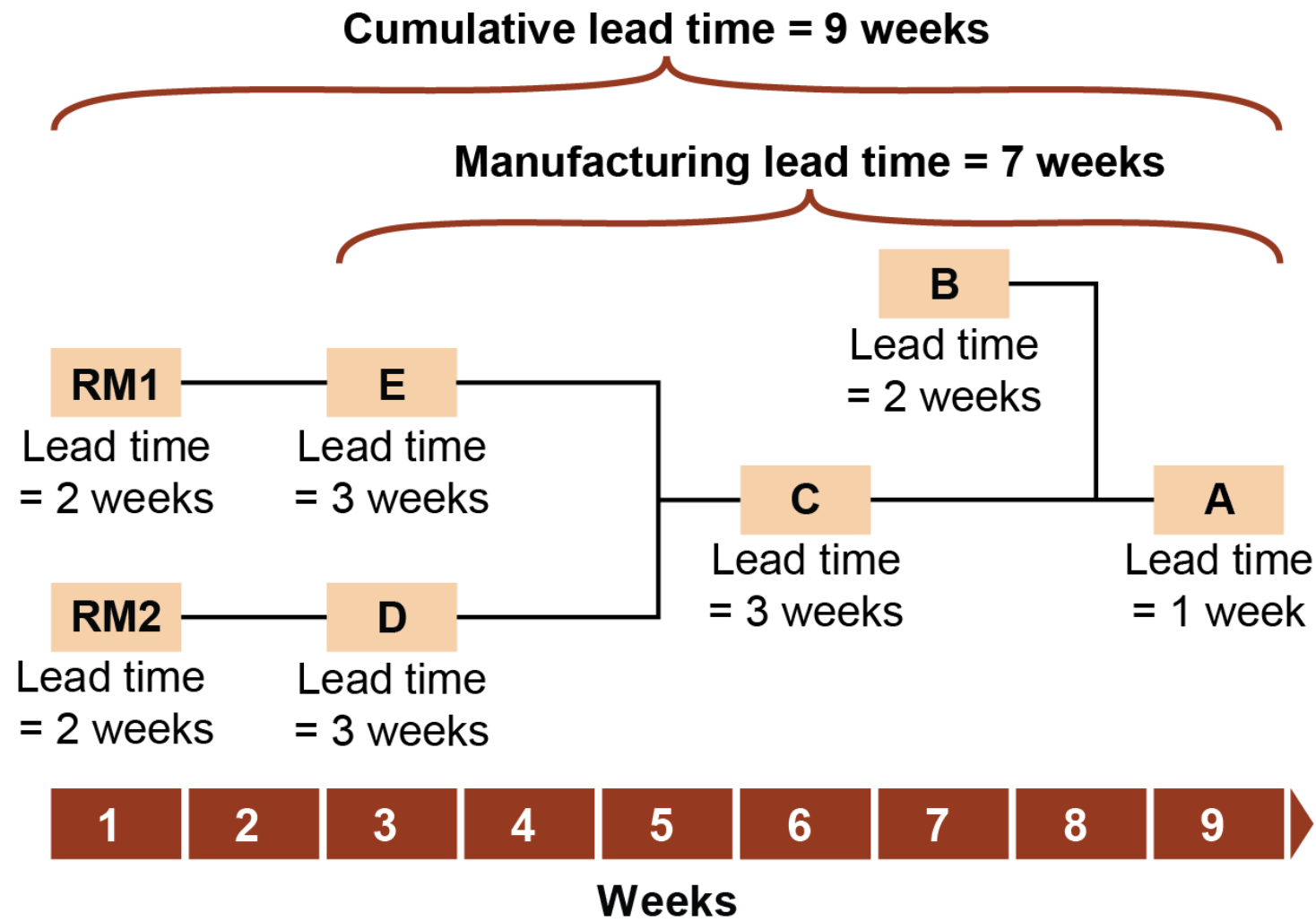## Lead Time for One Operation or Work Center

Lead time is the sum of

- Operation time (load)

  – Setup: from last good item A to first good item B

  – Run time: time doing operation (not including setup)

- Interoperation time (not load)

  – Queue: waiting to begin; often largest component

  – Wait: waiting after operation ends

  – Move: physical move time between operations
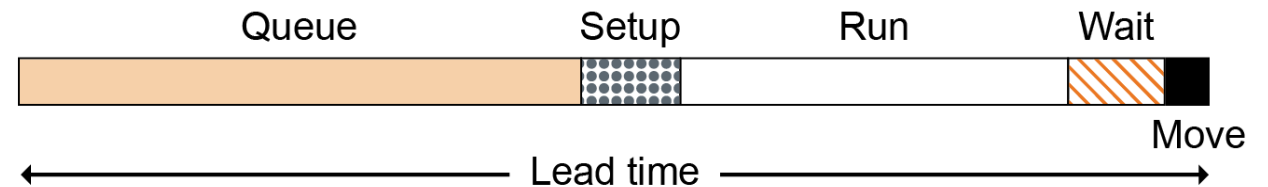
Product Structure

Routing and Lead Time Data

Part D Routing							
Operation	Work Center	Queue Time	Setup Time	Run Time	Move Time*	Total Time	Rounded Time
1	200	2.6	0.4	2.4	0.4	5.8	6.0
2	201	4.0	0.8	2.1	0.4	7.3	7.0
3	202	0.7	0.2	0.5	0.3	1.7	2.0

Total lead time (days) = 15.0 (*includes wait time)

Part E Routing							
Operation	Work Center	Queue Time	Setup Time	Run Time	Move Time*	Total Time	Rounded Time
1	200	2.6	0.6	2.5	0.3	6.0	6.0
2	205	0.5	0.1	0.2	0.3	1.1	1.0
3	206	1.5	0.2	0.3	0.1	2.1	2.0
4	207	1.5	0.6	1.0	0.8	3.9	4.0

Total lead time (days) = 13.0 (*includes wait time)

Operation Setback Chart
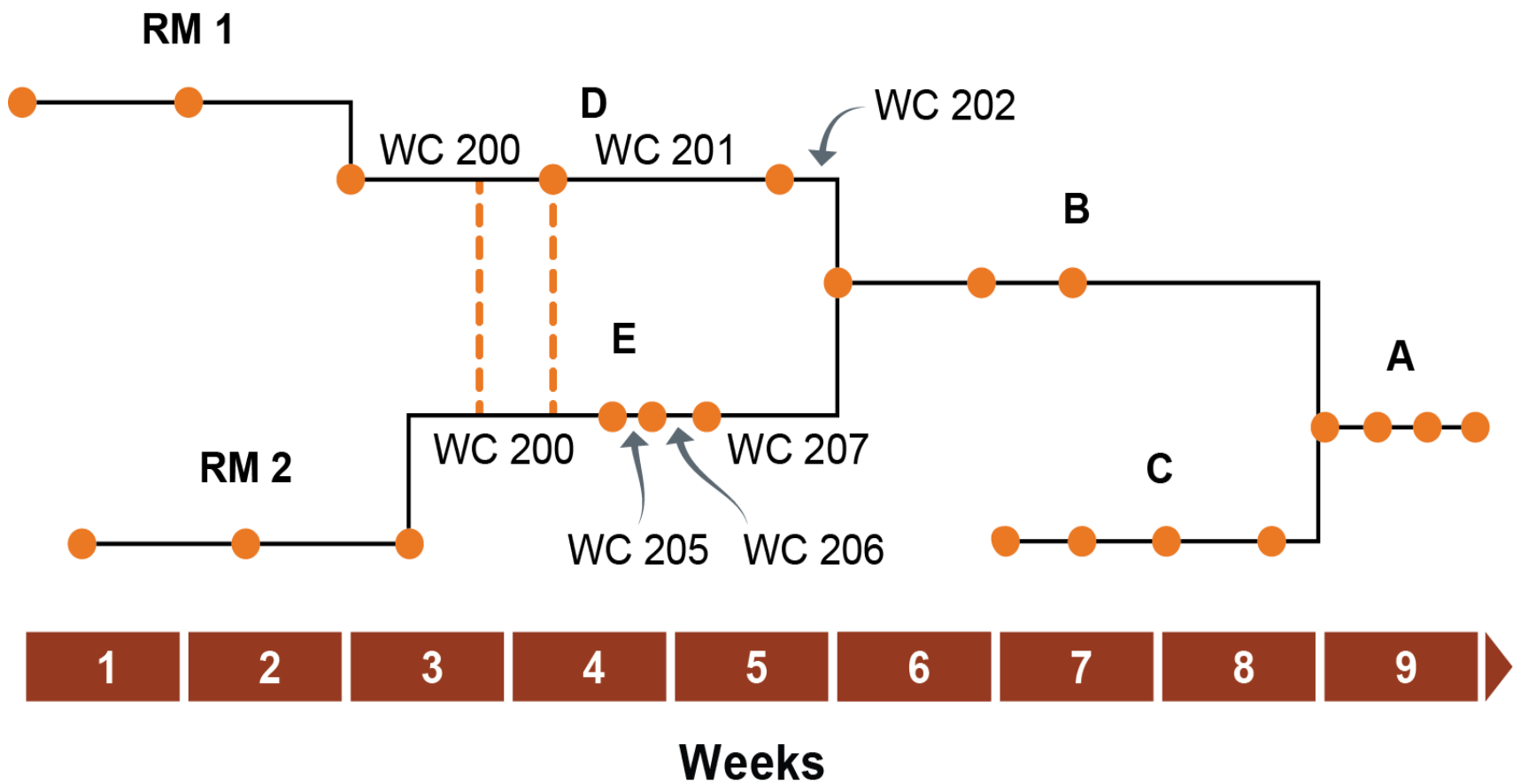
Gantt Charts

Parts D and E with MRP lead times
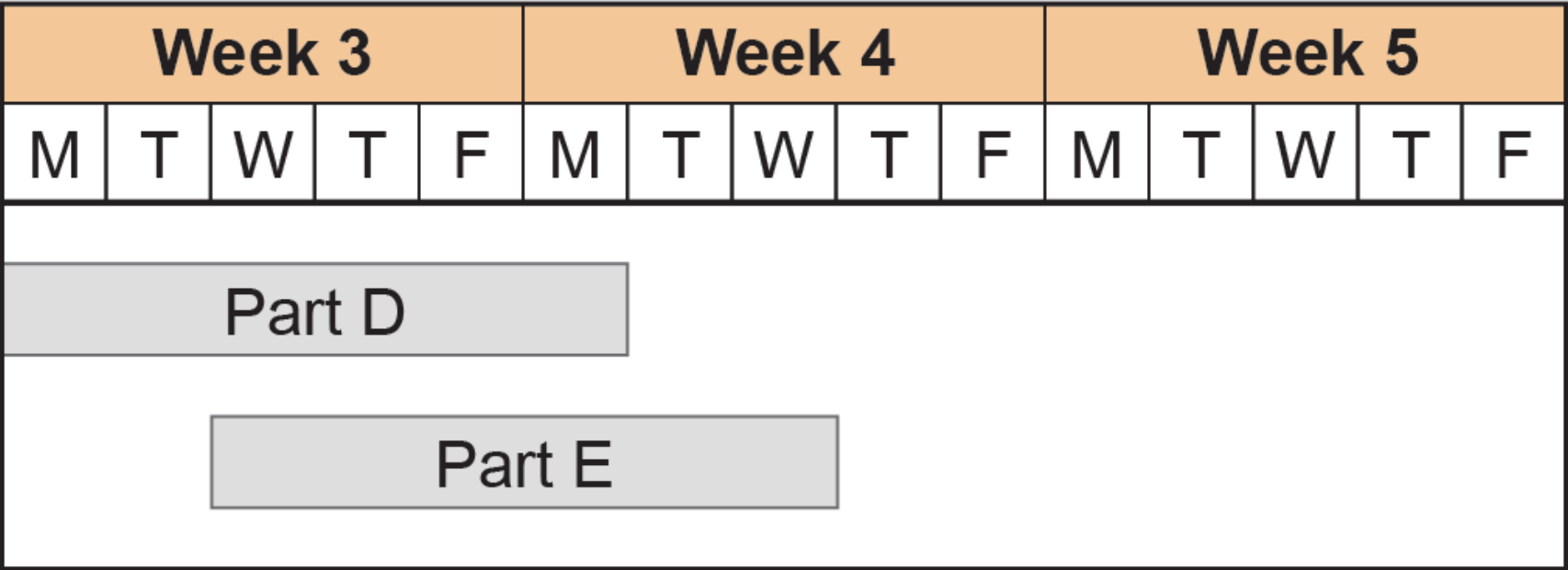
Evaluating Throughput

Throughput metrics

- Efficiency
- Utilization
- Productivity
- Input/output control metrics
- Cycle time or throughput time
- Cycle time versus takt time
- Visual management systems related to throughput
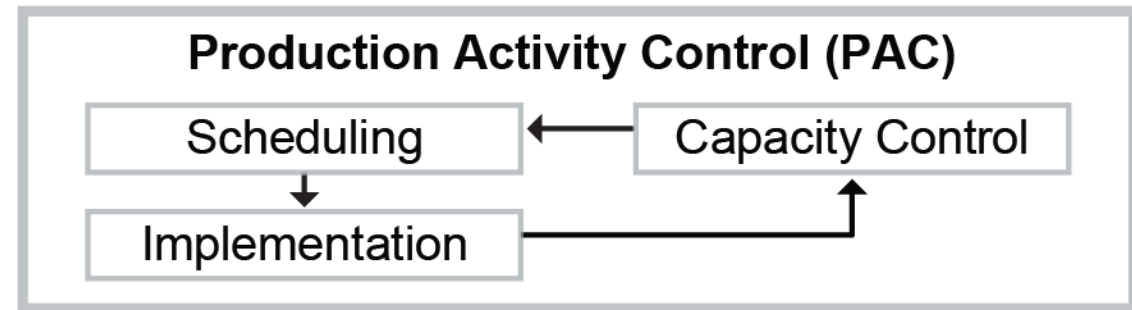
Service industry throughput

- Value-added
  - Service provision ("run" time)
  - Set time range
- Non-value-added
  - Minimize queue, setup, wait, and move
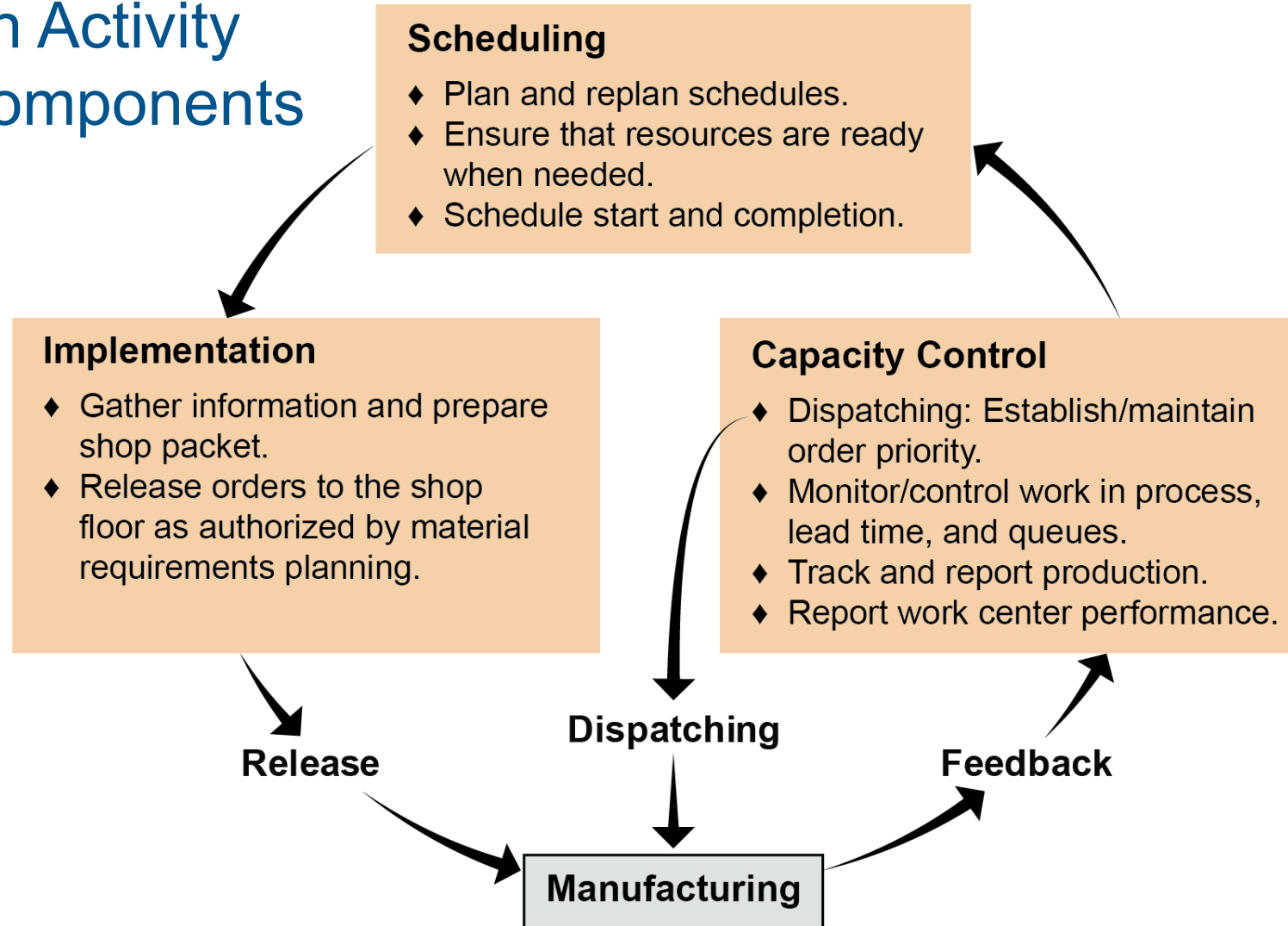
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Production Activity Control (PAC) Road Map

If done correctly, PAC will

- Execute orders authorized in MPS and MRP
- Plan and release individual orders to factory and vendors
- Optimize use of resources
- Provide availability information to production coordinators
- Provide early warning signals and status information to other MPC modules
- Meet customer service targets
- Provide information on WIP inventories
- Shorten both queue and move
- Provide feedback on shop and suppliers' performance against plans.

Production Activity Control (PAC)

Scheduling	←	Capacity Control
↓		↑
Implementation	→	

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Production Activity Control Components

Scheduling

- ♦ Plan and replan schedules.
- ♦ Ensure that resources are ready when needed.
- ♦ Schedule start and completion.

Implementation

- ♦ Gather information and prepare shop packet.
- ♦ Release orders to the shop floor as authorized by material requirements planning.

Capacity Control

- ♦ Dispatching: Establish/maintain order priority.
- ♦ Monitor/control work in process, lead time, and queues.
- ♦ Track and report production.
- ♦ Report work center performance.

Release

Dispatching

Feedback

Manufacturing

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Inputs to Production Activity Control

Input	Description	Information Provided
MRP	Authorized production	Shop order quantities, due dates
Item master files	Database of part numbers	Part number and description; quantity on hand, available, on order; manufacturing lead times and lot sizes
BOMs	Options and parts per order	Shop floor pick lists for shop order packet
Routing files	Operations sequence	Work center sequence, manufacturing lead times, capacity required, tools required
Work center files	Work center information	Work center number, shifts, machine and labor hours per shift, capacity, efficiency, utilization, queue time, manufacturing lead time, alternatives
Shop order files	Live document per shop order	Shop order number; quantities; due dates; issued, completed, scrapped, due; planned and actual setup/run; lead times remaining; cost

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Topic 2: Production Activity Control

Some of PAC's major data elements are listed in the table. Identify the sources.

Type of information	Name of system or file source					
	MRP	Item master	Product structure	Routing	Work center	Shop order and detail
Shop order number						X
Quantity on hand		X				
Shop order quantity	X					X
Order due dates	X					X
Operations required				X		
Operations work centers				X		
Manufacturing lead time		X		X	X	
Operation times				X		
Work center capacity					X	
On-order quantity		X				
BOM			X			
Material issue tickets						X
Efficiency/utilization					X	
Tools required				X		
Quantity available		X				
Quantity complete/scrapped						X
Actual versus planned setup/run						X
Lead time remaining						X

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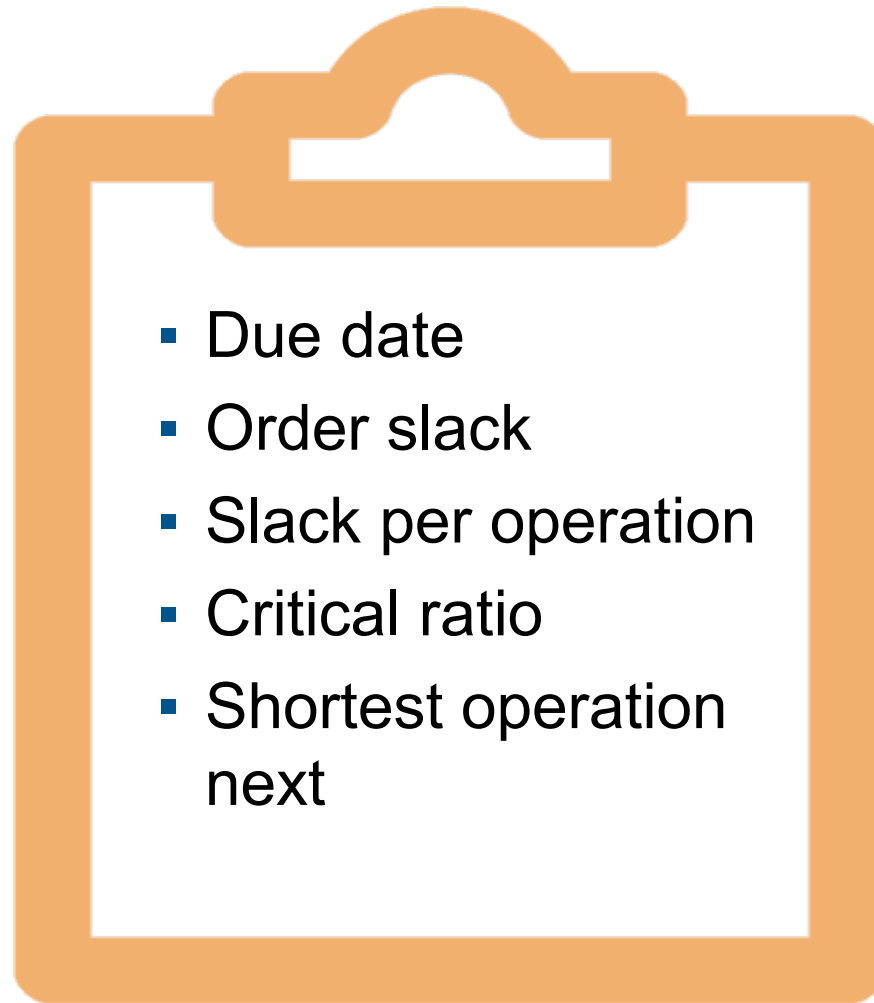## Operations Sequencing and Dispatching

- Priority control: Communicating start and end dates to work centers.

- Operations sequencing: Actual jobs to run based on capacity and priority.

- Dispatching: Executing sequencing at work center level.

- While MPS sets due dates and MRP makes into component due dates, priority control still needed.

Supply and demand in flux:

- Customer changes: due dates, quantities, expediting
- Early or late materials
- Scrap or rejects higher than standard
- Same due date for multiple orders or work center operations

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Sequencing Priority Rules

- Due date
- Order slack
- Slack per operation
- Critical ratio
- Shortest operation next

Dispatching and Dispatch List

- **Select and sequence jobs using dispatch list daily.**
- **Identifies plant, department, and information below.**

Dispatch List — Work Center: 13 — Description: Spot Welding Station — Date: 48

Standard Hours (Available Time): 16 hours per day (8hr shift with 2 Arc Welders)

Order #	Part #	Order Qty.	Setup (hrs.)	Run (hrs.)	Total (hrs.)	Qty. Completed	Remaining Load (hrs.)	Operation Start	Finish Date
988	604	35	0.15	12.3	12.4	28	2.45	47	48
234	569	25	0.25	8.0	8.3	12	4.16	47	48
808	199	80	0.15	20.0	20.2	0	20.15	48	49
Total Available Load in Standard Hours							26.76		
Jobs Coming									
112	199	30	0.15	4.5	4.7	0	4.65	49	49
115	989	50	0.35	17.5	17.9	0	17.85	49	51
Total Future Load in Standard Hours							22.50		

Dispatching Rules

- First come, first served (FCFS)
- Earliest job due date (EDD)
- Earliest operation due date (ODD)
- Shortest process time (SPT)
- Critical ratio (CR)
  – If 0 or negative: expedite, late
  – If < 1: expedite, behind schedule
  – If > 1: ahead of schedule
- Slack time

Order C due day 56, today is day 48, 16 days lead time left

Critical Ratio (CR)

$$= \frac{(\text{Due Date} - \text{Present Date})}{\text{Lead Time Remaining}}$$

$$= \frac{\text{Actual Time Remaining}}{\text{Lead Time Remaining}}$$

$$= \frac{(\text{Day 56} - \text{Day 48})}{16 \text{ Days}} = \frac{8 \text{ Days}}{16 \text{ Days}}$$

= 0.5 (behind schedule)

Comparison of Dispatching Rules

Today's Date: 48   (Units in Days Except CR)

Order	Work Center 13 Process Time	Work Center 13 Operation Due Date	Order Arrival Date	Order Due Date	Lead Time Left	CR
A	2	46	41	47	6	-0.2
B	4	50	40	66	18	1.0
C	3	51	44	56	16	0.5
D	1	49	48	58	7	1.4

Rule	Sequence	Reason
FCFS	B, A, C, D	Order arrival dates: 40, 41, 44, 48
EDD	A, C, D, B	Order due dates: 47, 56, 58, 66
ODD	A, D, B, C	Operation due dates: 46, 49, 50, 51
SPT	D, A, C, B	Process times: 1, 2, 3, 4
CR	A, C, B, D	CR: -0.2, 0.5, 1.0, 1.4

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Slack Time and Critical Ratio Exercise

1. Review the data for work orders W, X, Y, and Z and then calculate slack times and critical ratios.

Order	Due Date	Current Operation Time	Total Operation Time Remaining	Manufacturing Lead Time Remaining	Number of Operations Remaining	Slack Time	Critical Ratio
W	105	1.5	3.0	5.5	4	2.0	.91
X	107	1.0	4.5	9.0	6	2.5	.78
Y	111	2.0	4.0	7.0	5	7.0	1.57
Z	113	3.5	7.0	8.5	3	6.0	1.53

Current date = day 100

Lead time units = days
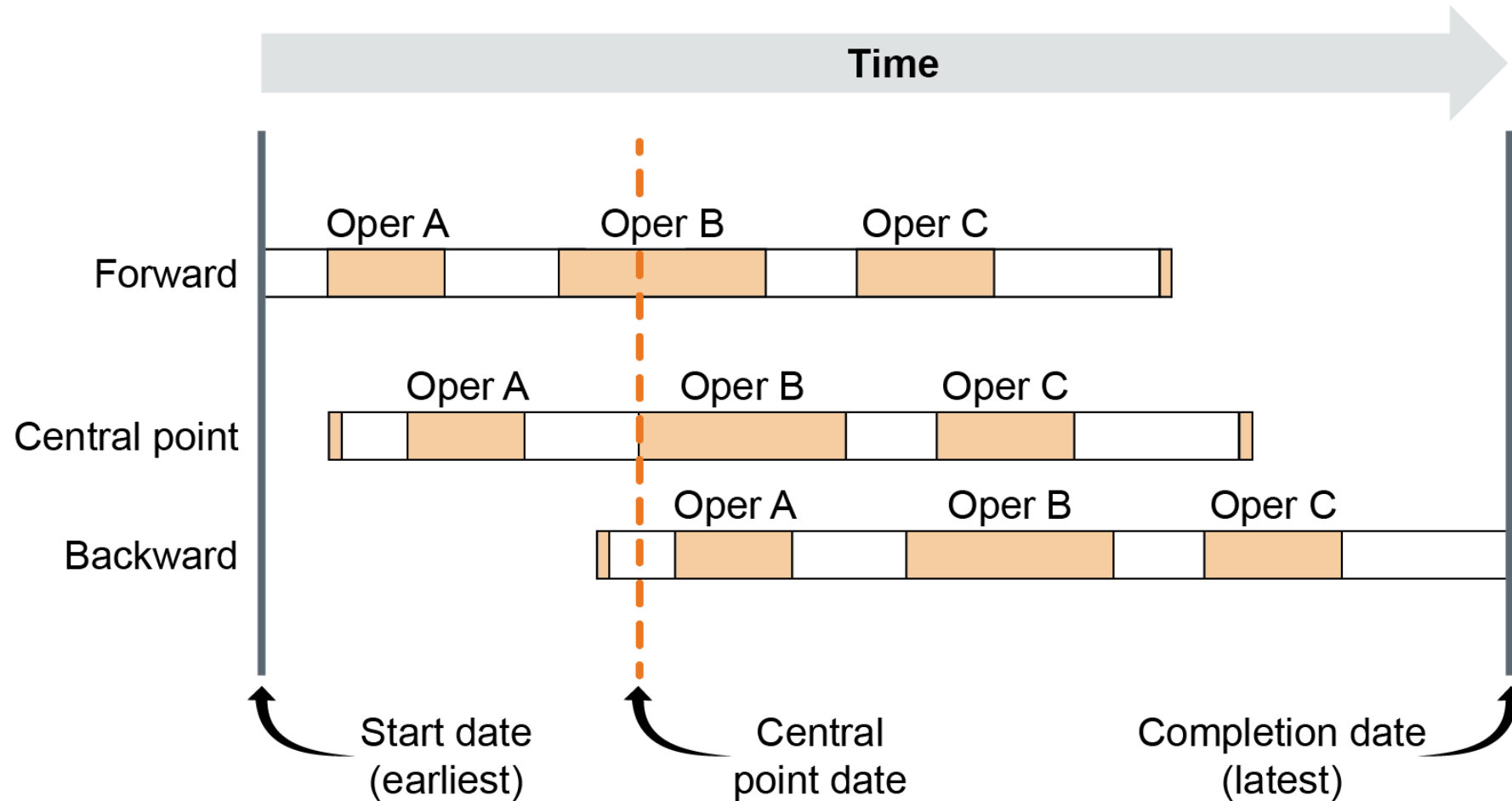
2. Calculate the sequence of orders based on slack times and critical ratios.

Slack time: *W-X-Z-Y*
Critical ratios: *X-W-Z-Y*

Backward, Forward, and Central Point Scheduling

Forward and Backward Scheduling

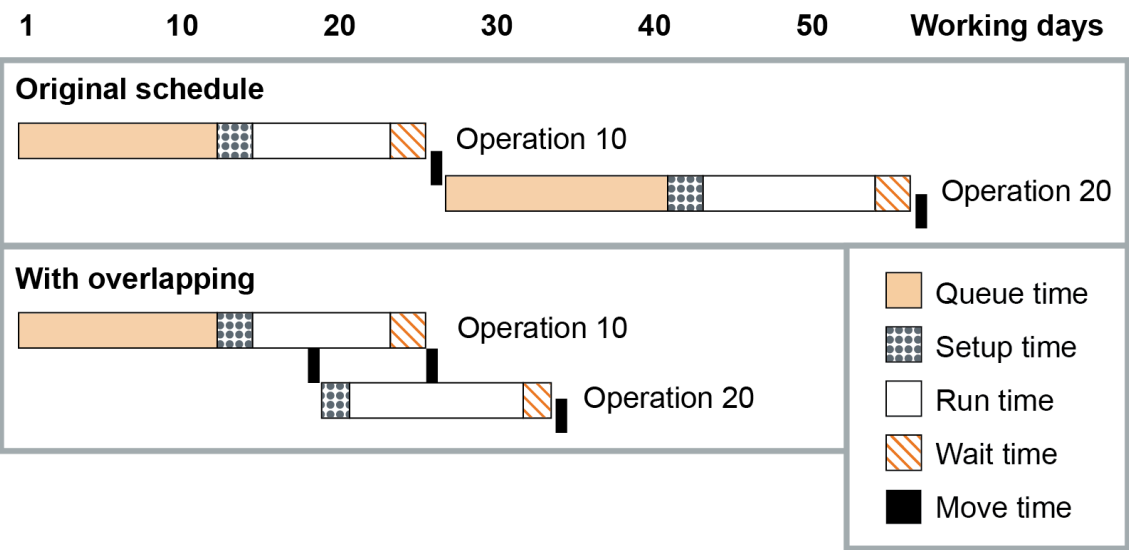| Forward Scheduling	Backward Scheduling
Material procurement and operations scheduling start when order is received.	Uses MRP logic: works back from MRP due date to determine operation start dates.
Operations usually scheduled from first to last.	Last operation scheduled first; previous operations scheduled back from start of last.
More inventory build-up than backward scheduling.	Less inventory build-up than forward scheduling.
If I start now, when can I have it?	When must this be started in order to finish by [date]?
Used when resources are underloaded or capacity-related costs are high and load leveling is desired.	Used when low inventory is a top priority and production is synchronized with order due date.

Infinite and Finite Loading

Managing Lead Time and Other Parameters

Overlapping

Lot splitting
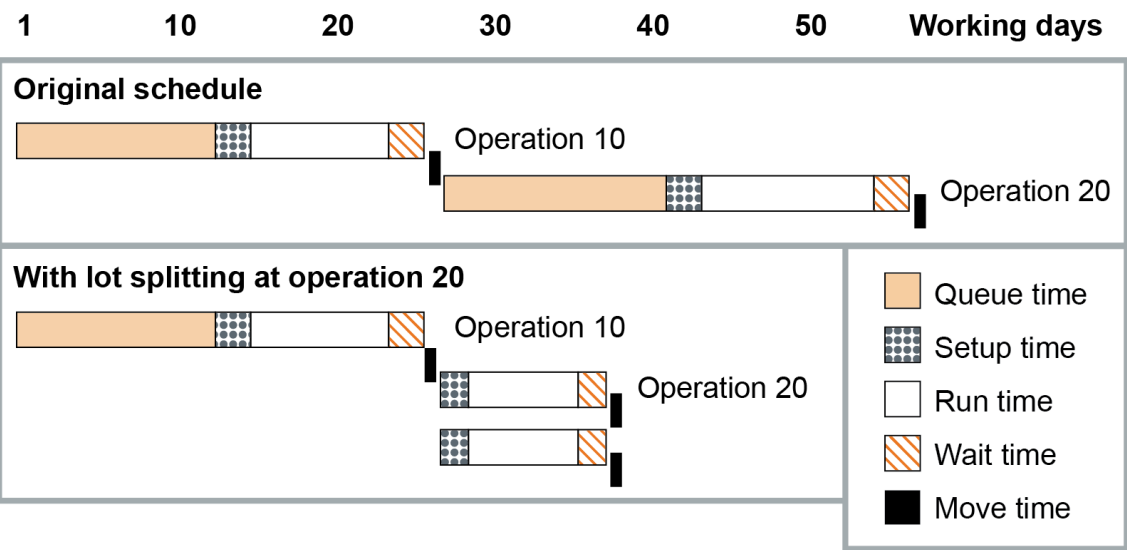
Managing Lead Time and Other Parameters

Lot size reduction

- Lean goal can be used in MRP too

- Smallest lot that keeps good setup-to-run-time ratio

- One less at a time

Automation and queue management

- ERP and APS

- Queue management reduces WIP

Safety capacity (capacity cushion)

- Planned amount by which available capacity exceeds current productive capacity

Productive Capacity +
Safety Capacity +
Excess Capacity
──────────────────
100% of Capacity

Shop Floor Systems: Best Suited*

	MRP-Based (Push)*	Production-Rate Based (Pull)*
Market-Facing Characteristics		
Product design	Custom (MTO)	Standard (MTS)
Product variety	Broad	Narrow
Individual product volume/period	Low	High
Ease of changing total volume	Easy/incremental	Difficult/stepped
Ease of changing product mix	Less difficult	More difficult
Delivery speed	Through schedule change	Through finished goods inventory
Ease of changing delivery schedules	More difficult	Less difficult
Manufacturing-Related Characteristics		
Process choice	Low-volume batch	High-volume batch/line
Changeover cost	High	Low
Work-in-process	High	Low
Cost reduction—overheads	Fewer	More

*There will be exceptions, but as a general rule these are considered to be "best suited" by Jacobs.

Section B Learning Objectives

- Batch and flow processes, push or pull, and production rates/flow rates

- Calculating load

- MRP scheduling: push and flow MRP systems, input/output control, authorizing and releasing work orders

- Lean scheduling, including takt time, heijunka, pacemaker, store, production leveling, and one- and two-card kanban

- Product flow (VATI)

- Theory of constraints (TOC) scheduling: drum-buffer-rope scheduling and use in removing bottlenecks

- Process flow scheduling, process trains, and process- versus material-dominated scheduling

Intermittent versus Flow Manufacturing

Critical points and examples

- Intermittent critical points
  - Transfer batch
  - Lot sizing (consider scrap factor)
  - Reorder point
- Flow critical points
  - Bottlenecks
  - Resource constraints
  - Minimizing waste
  - Optimize coupling and connectivity
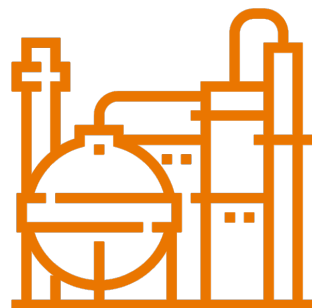
Type	Intermittent	Flow
Batch	MTS shoes in batches	Pharmaceuticals made in constant flow but distinct batches
Line	Different car models in batches, no new setup for accessories	Pickle jarring never stops except for supply/demand issues
Continuous	Different chemicals in batches after cleanout	Glass factory line dedicated to one type of glass

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Intermittent versus Flow Manufacturing

Category	Intermittent Processes		Flow Processes		
Process type	Work center	Batch	Batch flow	Line	Continuous flow
Layout	Functional (process)	Functional (process)	Cellular/product-based	Cellular/product-based	Product
Routing	Product-specific	Product-specific	Product-specific	Fixed	Fixed
Scheduling	Operations	Operations	Operations or rate-based	Production: rate-based	Production: rate-based
Control	MRP/PAC	MRP/PAC	MRP/PAC	MRP/PAC	MRP/process flow scheduling
Transaction requirements	Very high	Very high	Medium	Low	Low
Productivity tools	TOC/six sigma	TOC/six sigma	Lean/TOC/six sigma	Lean/TOC/six sigma	Lean/TOC/six sigma

Push System (MRP-Based Execution System)

Information push

S&OP/resource planning

↓

Master production schedule/ rough-cut capacity planning

↓

Material and capacity planning

↓ ↓

Work order   Purchase order
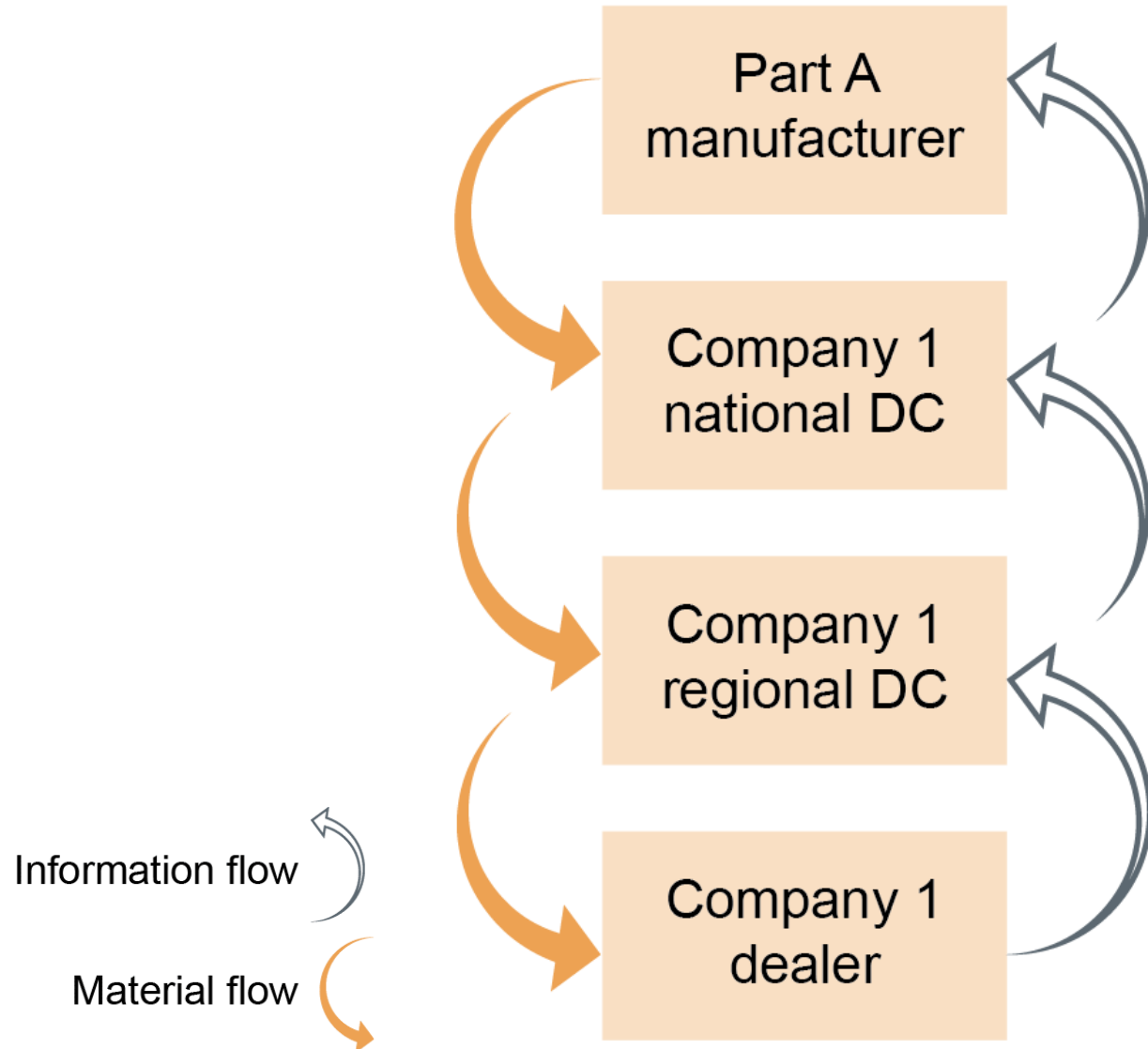
↓ ↓

Work center   Supplier
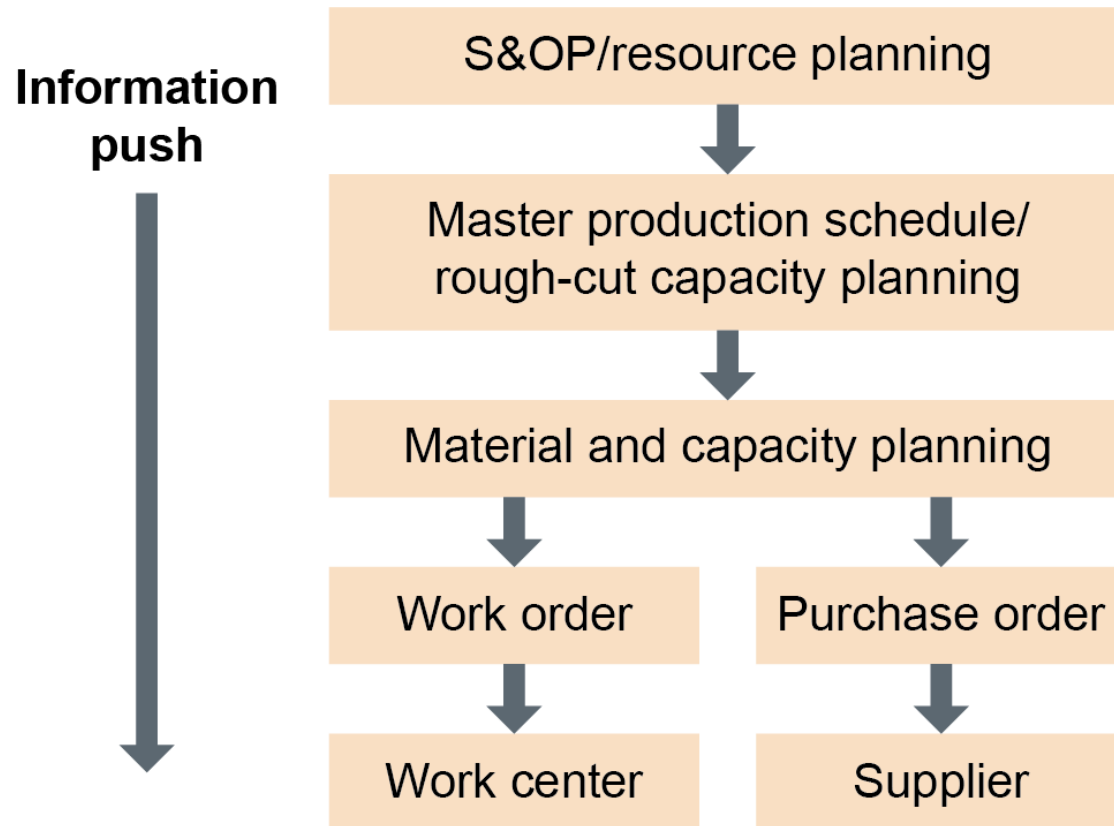
- Sequence of work
- Setup time and changeovers
- Resource constraints
- Alternate routing
- Scheduling method
- Load leveling
- Input/output control

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Pull System Execution

- Mixed-model scheduling
- Synchronization
- Constrained resources
- Rate-based scheduling
- Line balancing

MRP-Based, Lean, and TOC-Based Scheduling

	MRP-Based	Lean	TOC-Based
Primary focus	Minimizing backlog, lead time	Raw material/finished goods velocity, very low WIP, short lead times, de-emphasize utilization	Maximizing throughput
Scheduling method	Forward, backward, or central point	Kanban signals based on demand	Finite forward schedules for bottleneck centers; backward schedules for rest
Scheduling complexity	Very detailed	Very simple: cellular, fast completion times	Exact for gateway and bottleneck; pull for rest
Input priorities	Material + capacity, level loading	Vendor scheduling multiple times a day	Material/capacity simultaneous

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MRP-Based, Lean, and TOC-Based Scheduling

	MRP-Based	**Lean**	**TOC-Based**
Job sequencing	Priority sequencing rules on dispatch list	In order of kanbans received; little sequencing needed	Prioritize on same setup as last batch; priority sequence for rest
Batch/lot sizing	Fixed	Ideally a lot size of one (as small as feasible)	Large batches for bottlenecks; order splitting at others (transfer batches)
Inventory tracking	Manufacturing, purchase orders; shipping/receiving documents	Finished goods receipt used to backflush (little paperwork)	Same as MRP-based
Potential problems	Master schedule not leveled/overcapacity	Vendor relations; supply failures	Varied routings shift bottleneck often

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Scheduling Choice and Decoupling Point

- Point at which a supply chain or organization moves from forecast-based push to demand-based pull

- MRP, TOC, and lean systems impact the decoupling point differently.

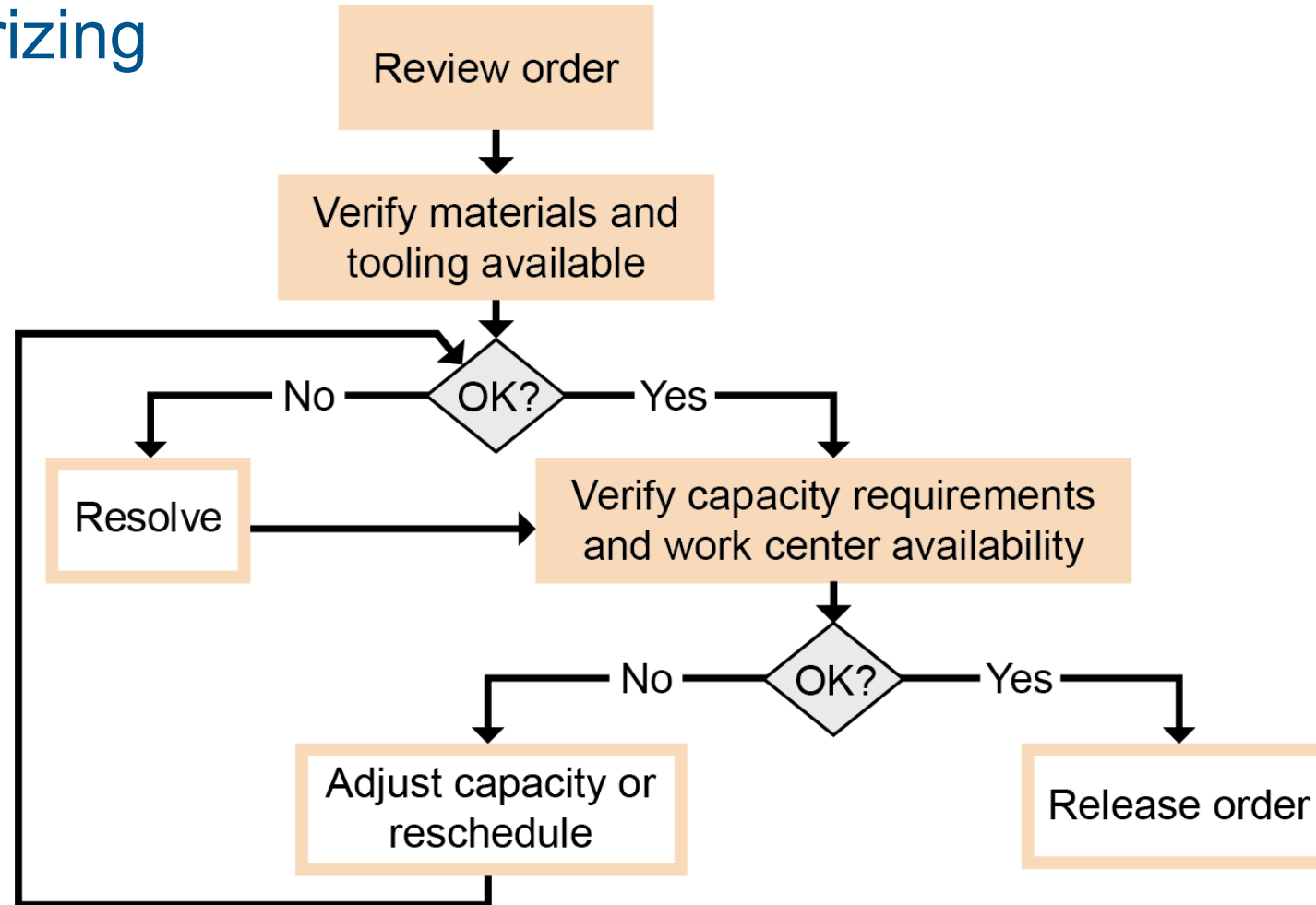| MRP	TOC	Lean
- Redesign processes to meet changes over life cycle.	- Manage bottlenecks by coupling/ decoupling.	- Move decoupling point back up supply chain as far as possible.

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Executing: Authorizing Production

MRP-Based PAC in Batch and Flow

Batch Production	Flow Manufacturing
High-variety, low-volume ATO products.	Standard high-volume MTS products.
Varied routings through general purpose equipment.	Fixed routings: dedicated assembly lines or flow equipment.
Operations time at work centers will vary.	Operations time at work centers about the same: balanced.
High risk that work arrives at work centers late or early.	Flow between work centers is predictable.
Slow throughput.	Fast throughput.
WIP builds up.	Low WIP.
Capacity required varies by item.	Capacity fixed by line.

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Input/Output Control in Intermittent Process Types

Objectives

- Keep WIP and queue times at desired levels.

- Control inputs (schedule, dispatch).

- Control output rate (capacity).

Input Control

Load (Queue, WIP Inventory)

Output Control

Capacity Available (rate)

Capacity Required (rate)

Output per Time Period →

Input/Output Report

Cumulative Variance = Previous Cumulative Variance + Actual Output − Planned Output

Backlog = Previous Backlog + Input − Output

Work Center: 13   Capacity per Day: 16 hours
(All Units in Standard Hours)

−5 + 19 − 16 = −2

−2 + 12 − 14 = −4

8 + 16 − 16 = 8

Mfg. Calendar Day	48	49	50	51	52	SUM
Planned Input	16	16	14	13	20	79
Actual Input	14	16	12	15	16	73
Cumulative Variance	-2	-2	-4	-2	-6	-6
Planned Output	16	16	16	16	16	80
Actual Output	12	18	14	15	19	78
Cumulative Variance	-4	-2	-4	-5	-2	-2
Planned Backlog	8	8	8	6	3	7
Actual Backlog	8	10	8	6	6	3

8 + 14 − 12 = 10

Both input or both output
Both planned or both actual

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Input/Output Report Exercise

Work center: 20
Capacity per period: 40 standard hours

Period	1	2	3	4	5	Total
Planned input	38	32	36	40	44	190
Actual input	34	32	32	42	40	180
Cumulative variance	-4	-4	-8	-6	-10	-10

	1	2	3	4	5	Total
Planned output	40	40	40	40	40	200
Actual output	32	36	44	44	36	192
Cumulative variance	-8	-12	-8	-4	-8	-8

		1	2	3	4	5	
Planned backlog	32	30	22	18	18	22	- -
Actual backlog	32	34	30	18	16	20	- -

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Sequencing Rules

Powder, paint, MRO…

Raw

Masking/removal — A
Powder coating — B
Painting — C
High-temp baking — D
Low-temp baking — E
Buffing and polishing — F

Finished goods

= Work center

= Queue

= Sequencing

Topic 2: MRP-Based Scheduling and PAC

Lead Time Management

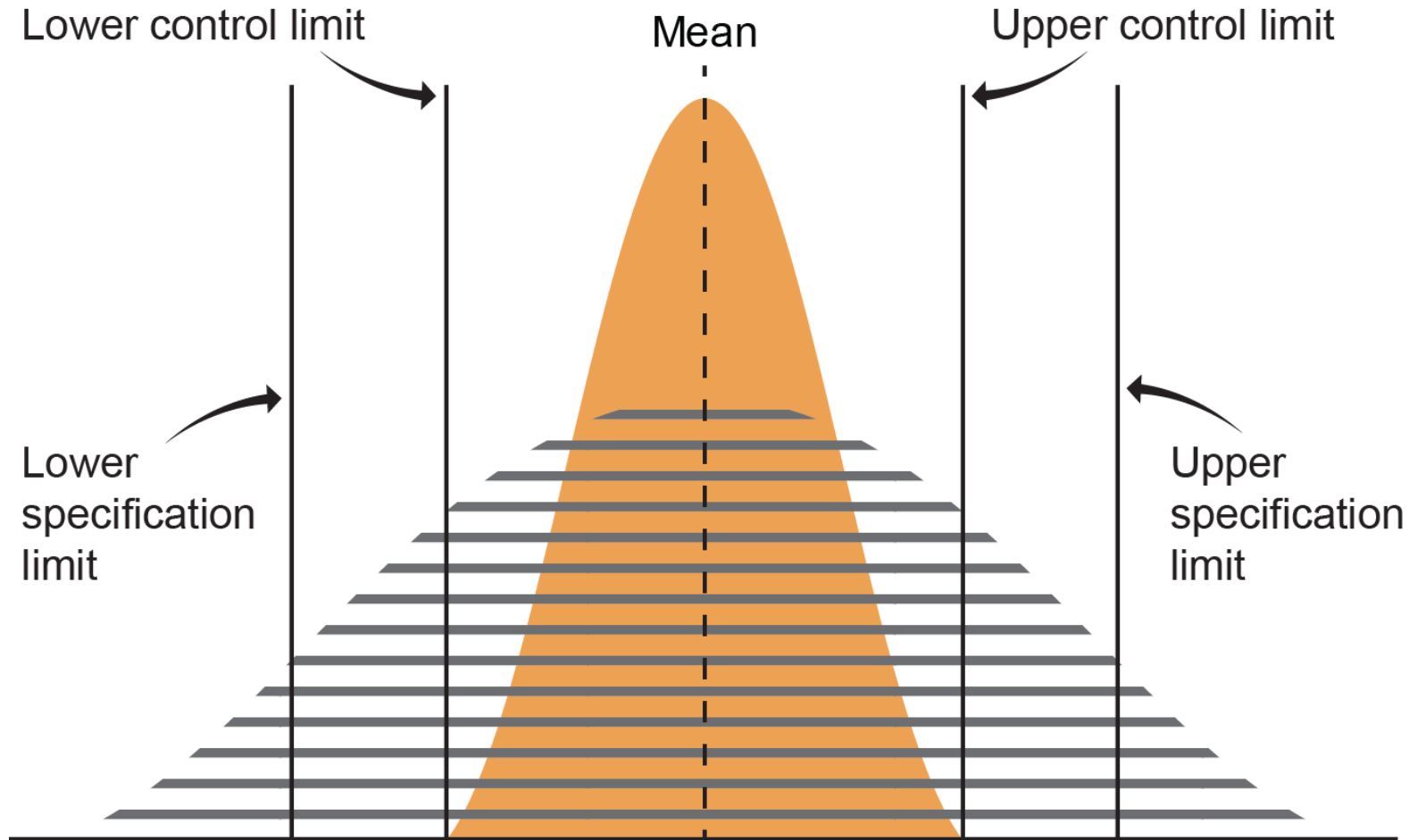| Steps		Actions/Comments
1	Separate lead time into queue and non-queue time.	Non-queue time includes setup, run, wait, and move time.
2	Convert non-queue time to days.	Non-queue time in hours ÷ number of shifts per day (assuming 7 productive hours per shift).
3	Assign queue time based on routing distance to next work center.	Queue time is ▪ 2 days if routing is to a work center in another department ▪ 1 day if routing is to a work center in the same department ▪ 0 days if on the same machine.
4	Calculate lead time as the sum of the queue and non-queue times.	Queue time estimates are often based on padded estimates for a sample of parts. Compensate by continuous queue reduction.

Control Goals

- Integrated performance measurement
- Balanced scorecard
- Performance targets

Tolerance Limits

Operational Capability

Key performance measurement reports

- Day-by-the-hour

- First-time-through

- WIP-to-standard WIP

- Overall equipment effectiveness

Lean Objectives

- Make only those products and services customers actually want.

- Match the production rate to the demand rate.

- Make products and services with perfect quality.

- Make products and services with the shortest possible lead times.

- Include only features actually in demand, excluding all else.

- Keep labor, equipment, materials, and inventory continually in motion, with no waste or unnecessary movement.

- Build worker learning and growth into each operational activity.

Lean versus MRP Scheduling

MRP (Push-Based) System	Lean (Pull-Based) System
Process layout; complex routings	Flow layout; standard routings
Long lead times	Short lead times
High WIP	Low WIP
High work center utilization = goal	Work centers may have surge capacity; utilization flexes by production rate needed to meet customer orders
Detailed scheduling routes work through work centers	Work completed quickly; jobs easily tracked visually

Lean Documentation and Backflushing
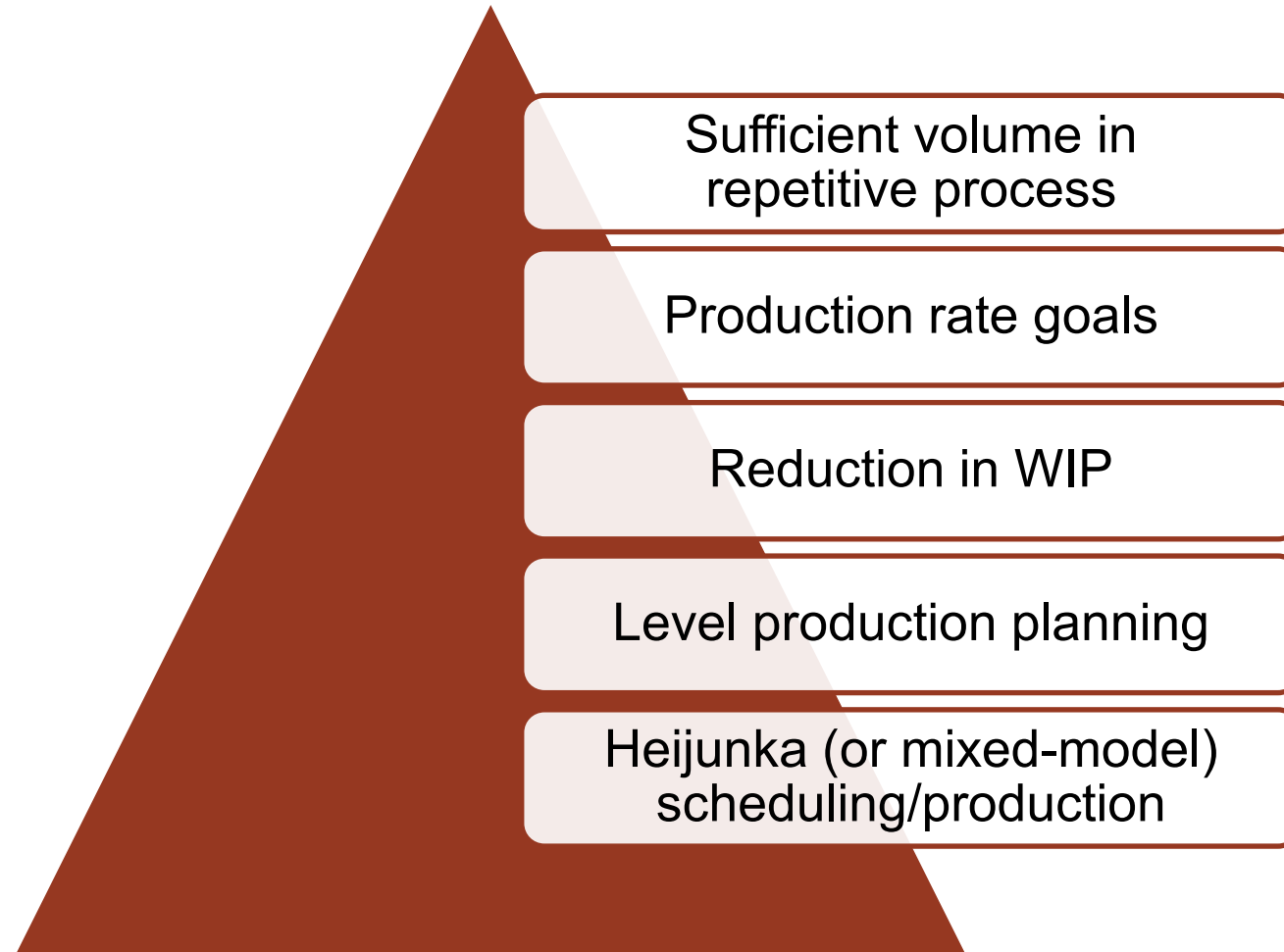
Lean Documentation	Backflushing
▪ Kanban instead of order release, job packet. ▪ Visibility of material/tools. ▪ Continuous flow so no detailed routings or work center start/finish dates. ▪ Less feedback/reporting. ▪ Production reports displayed at cell level.	▪ Used in lean systems to handle recording. ▪ Inventory record is automatically reduced after completion of activity on upper-level parent. ▪ Works best when lead times are short and BOMs are accurate.

Elements of Lean Scheduling

Sufficient volume in repetitive process

Production rate goals

Reduction in WIP

Level production planning

Heijunka (or mixed-model) scheduling/production

Level Production Planning

Takt time = rate of production/customer demand

- Wood + Brass Takt Time = 100,000 Units/250 Days = 400 Units per Day

	Model A	Model B	Model C	Model D
Option configurations:				
Handle	Wood	Wood	Steel	Steel
Head	Brass	Alloy steel	Brass	Alloy steel
Annual forecast (units)	100,000	1,250	12,500	50,000
Possible mixed production schedules:				
Daily batch MPS	400	5	50	200
Hourly batch MPS	50	.625	6.25	25

MPS: master production schedule
Assumes a 250-day work year and an 8-hour day
Total annual forecast 163,750 hammers
Total daily batch quantity is 655

Heijunka

Heijunka

Scheduling

Control of production
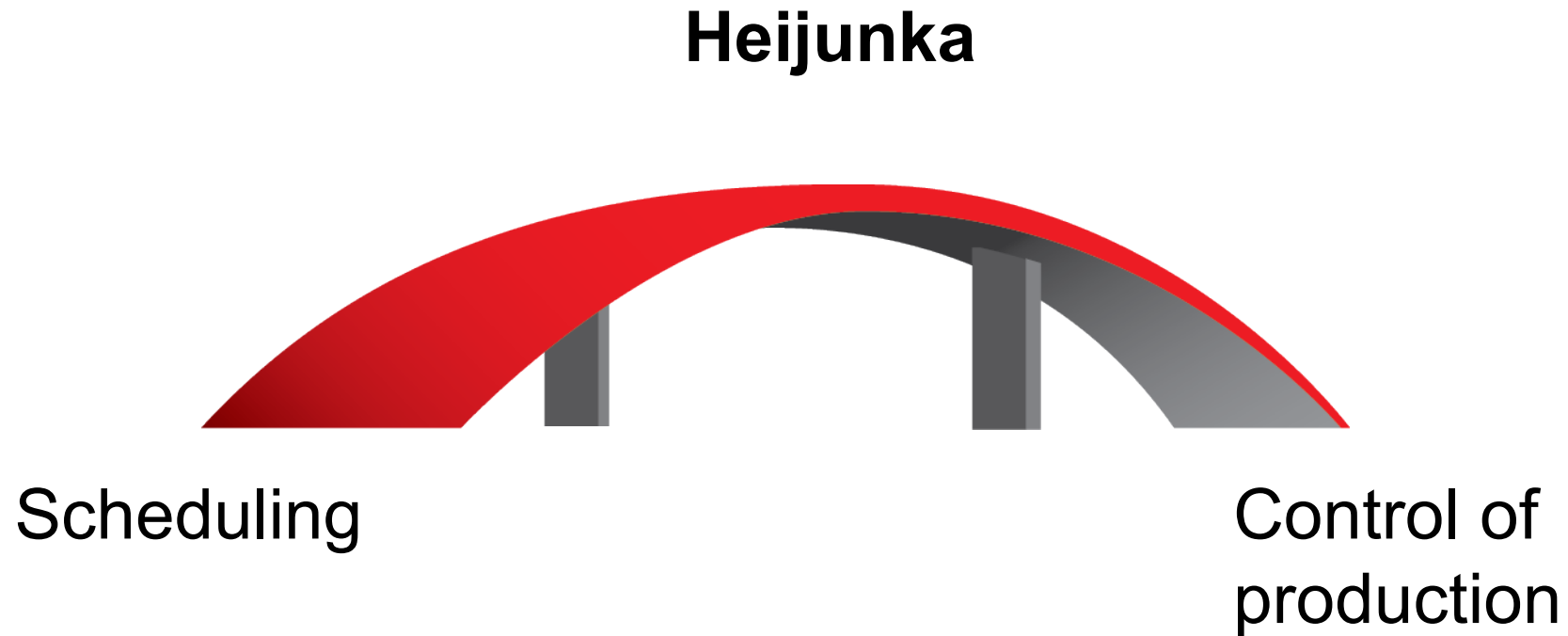
Heijunka Scheduling Techniques to Improve Flow

Using control limits	Not over-reacting to demand changes	Prioritizing regular orders	Using ATP logic	Moving to "milk runs"
If demand stays within plan, plan should not change.	Use takt time to manage and control time.	Don't let large or unusual orders derail regular orders.	Logic in master scheduling software.	Frequent small batches are delivered on one vehicle.

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Takt Time

Store/supermarket

- Controlled inventory of parts or finished goods that schedules an upstream process through a kanban signal.

Pacemaker

- Raw material or other point's cycle time that sets a pace that enables all other processes to achieve the takt time objective.

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

$$\frac{445 \text{ Minutes} \times 2 \text{ Shifts}}{890 \text{ Units per Day}} = 1 \text{ Minute per Unit}$$
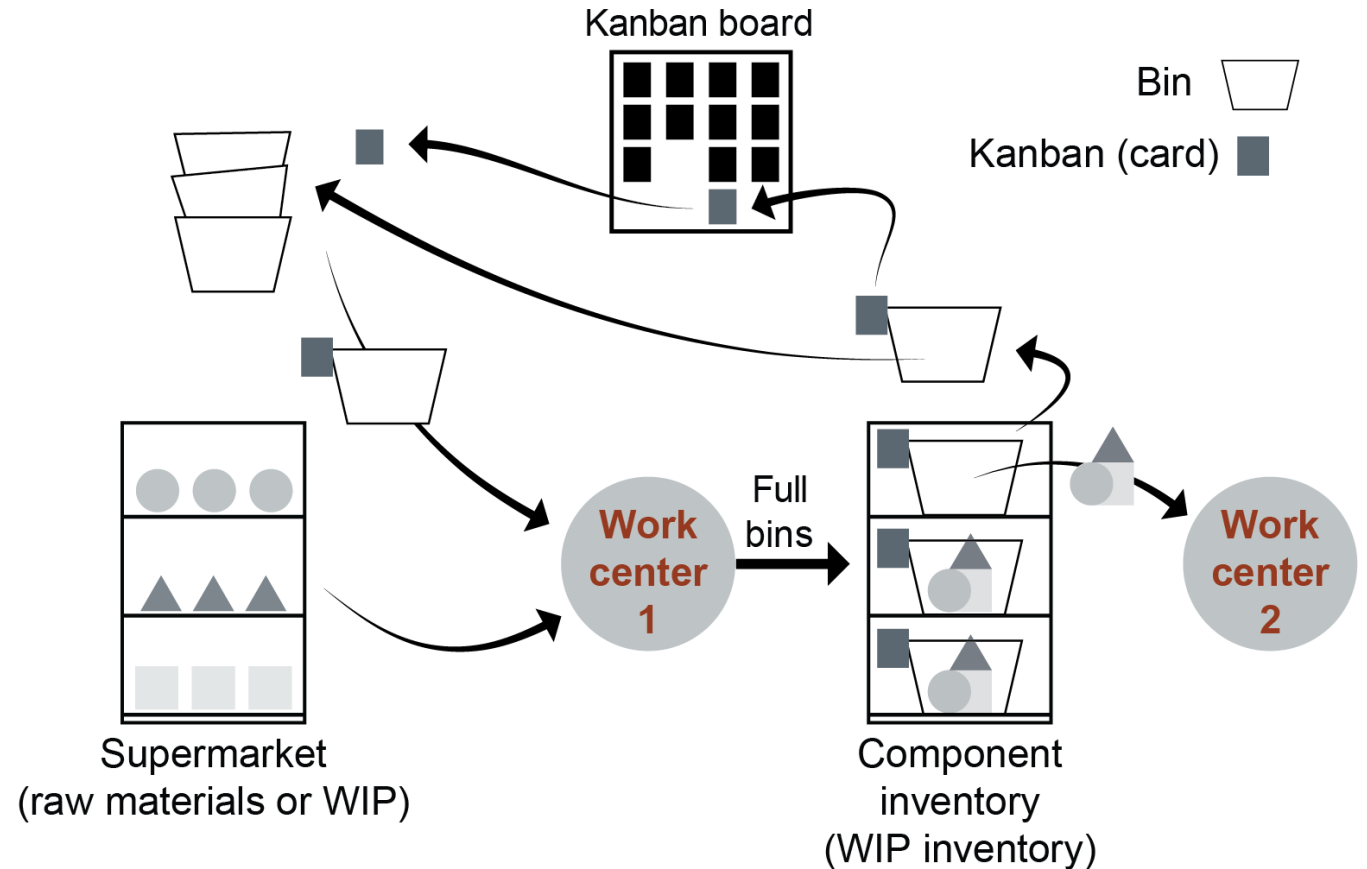
Kanban Systems

Process

- Authorize production at processes upstream from pacemaker.

- Pull parts through upstream processes to pacemaker based on production schedule.

- Establish number of parts containers between processes on shop floor.

- Use visual controls in fast throughput environment.
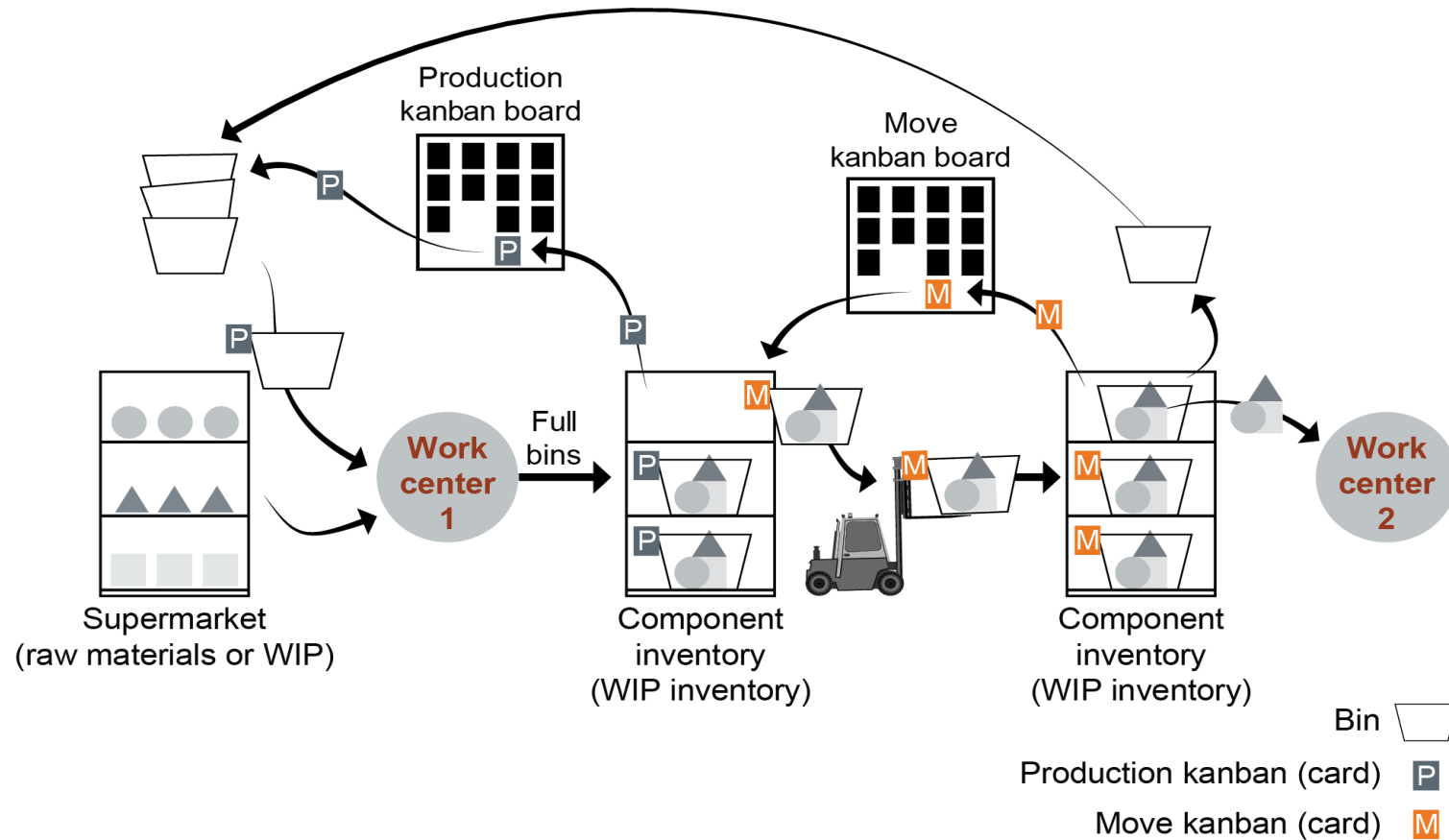
One-card kanban system

Limiting Number of Kanban Cards

- Each container of parts must have a kanban card.

- The number of parts in a container is fixed, and no partial containers will be put into storage.

- Parts are always pulled by the user department.

- No parts are obtained without a kanban card.

- All containers contain standard quantities, and only the standard container for the part can be used.

- No extra production is permitted; production can start upon receipt of a production kanban card.
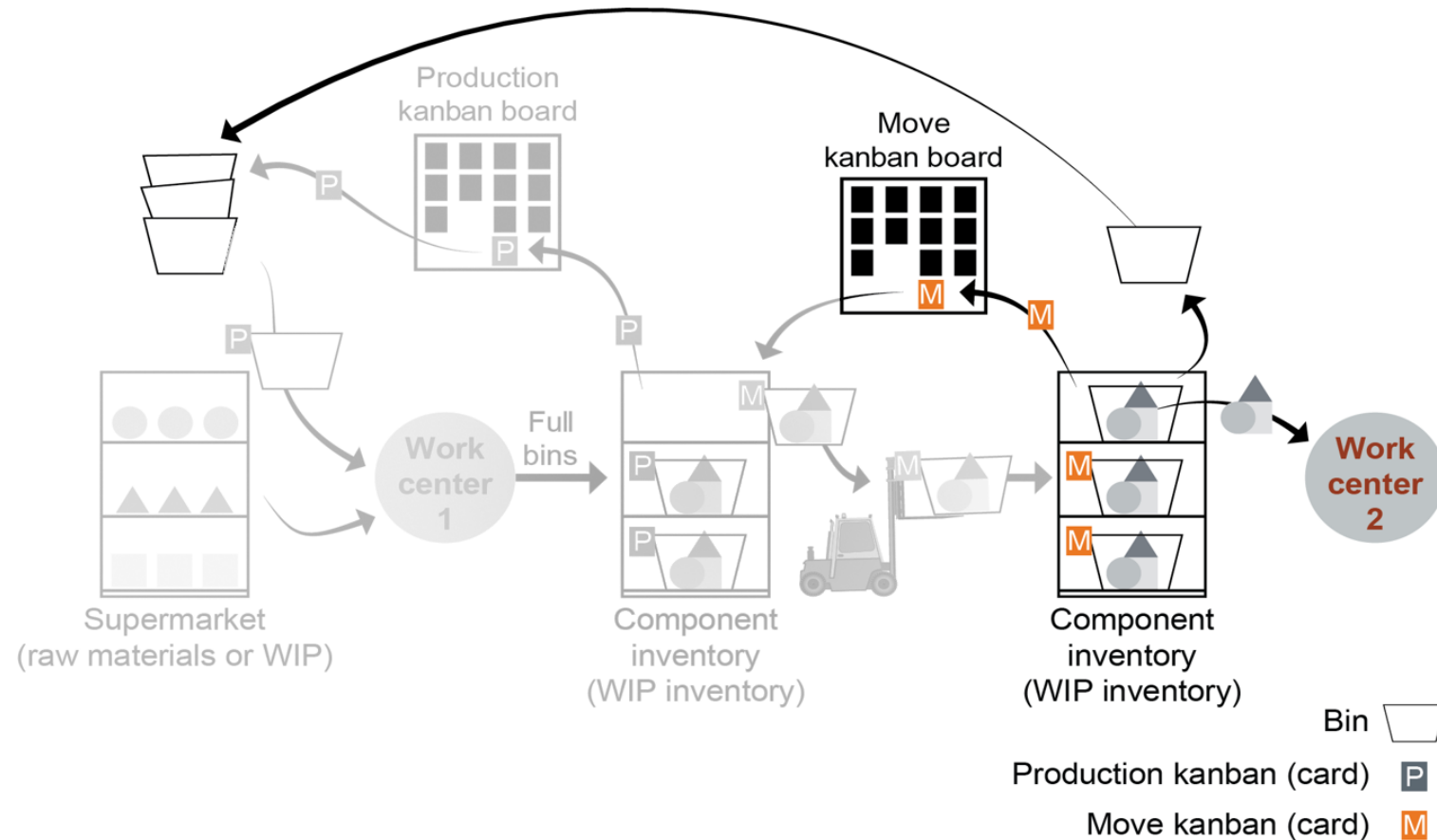
APICS
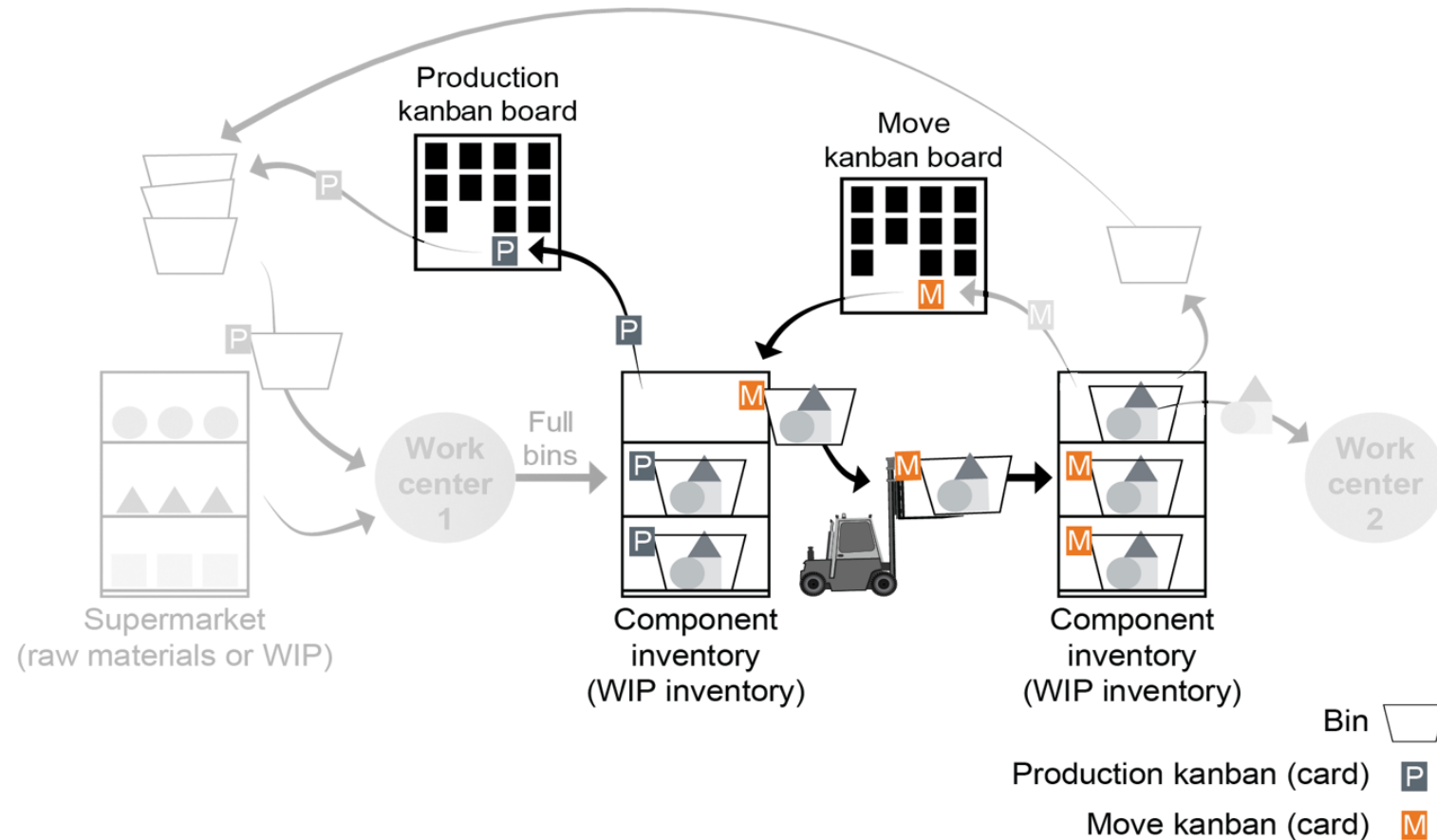
Two-Card Kanban Systems

Two-Card Kanban Systems

Two-Card Kanban Systems

Two-Card Kanban Systems
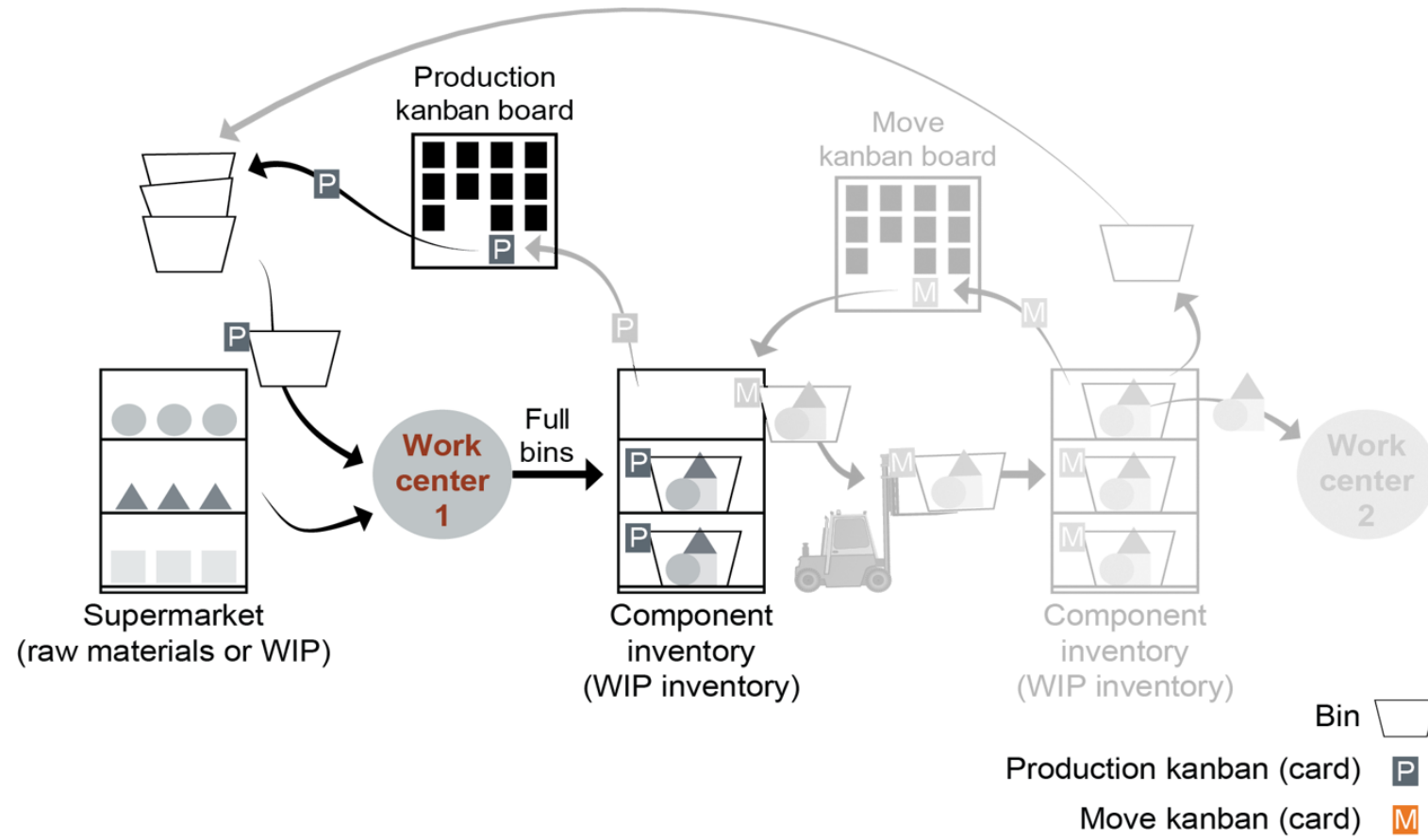
Control Systems Exercise

Complete the "Lean-Based" column in the table.

Element or Factor	MRP-Based	Lean-Based
Control objective	Work center capacity utilization	Overall product flow rate
Control of material flow	Push: schedules, shop orders, batches, job sequencing rules	Pull: flow production in response to customer requirements
Operations sequencing	Important; based on due date priorities at each work center	Not a concern; relatively quick flow-through to finished goods
Order tracking	Important; track production floor transactions by operation	Not necessary; minimal WIP; quick flow-through; no need for tracking
Monitoring and feedback	Critical; input/output control and work center load reports	Less central; focuses on the overall result
Preferred lot size	Large	One or small
WIP and safety stock	Large	Small
Product demand	Low/medium volume, high variety with variable demand and lead times	Best with medium/high volume, low variety, and stable demand

Product Flow (VATI) Analysis

- Look at routings, BOMs, and BOM explosions.
- Study in operation; watch out for spontaneous shifts.

Finished products

Processes

Raw materials
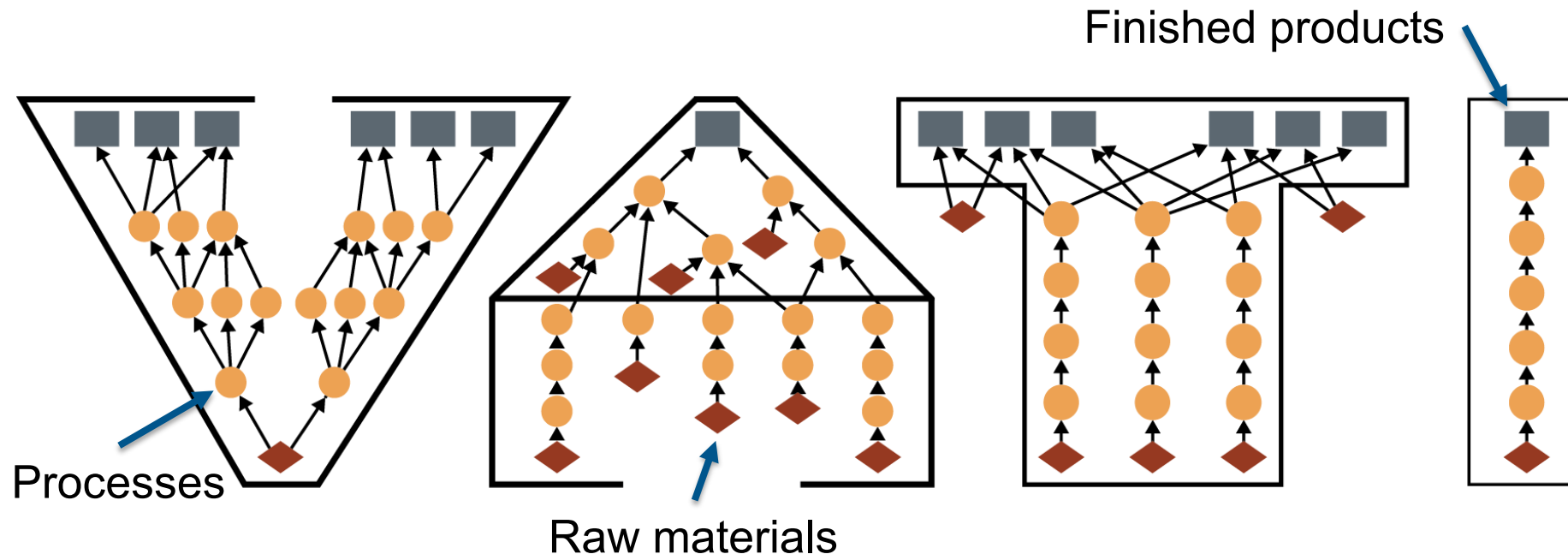
Theory of Constraints (TOC)

- Dr. Goldratt principle: Complex systems have simplicity.

  – Very small number of variables, maybe one, that limit higher attainment of goal.

  – Improvement at only constraint area creates net gain.

  – Strengthening other areas wastes effort, no net gain.

- Constraint often easy to see.

  – Full-capacity work center.

  – WIP accumulating.

  – Downstream work centers waiting.

- Throughput "goal units," e.g., revenue per time period.

Types of Constraints

Physical constraints	Capacity-constrained resources (CCRs)	Behavior-based constraints
▪ Limited resources: – Equipment – Labor – Materials ▪ Market constraint (Sales is the constraint.)	▪ Resource that could become a constraint if not managed carefully	▪ Managerial constraints ▪ Time-consuming administrative policies ▪ Personnel unaware they are working at a bottleneck ▪ Inability to detect need for, fund, or initiate improvements ▪ Complex problem

Constraints

a) If the market demand is 600 per hour, what is the active bottleneck?

b) If the market demand is 80 per hour, what is the constraint?

c) If the market demand is 150 per hour, what is the role of resource D?
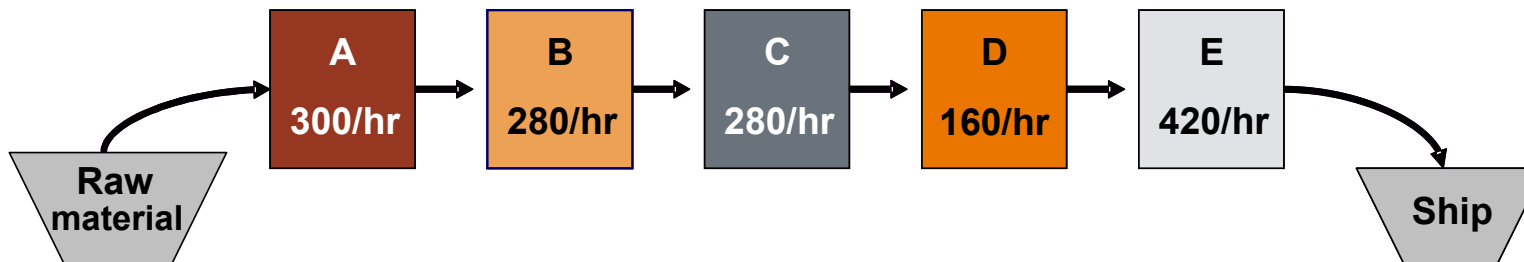
Principles of Bottleneck Management

Bottlenecks

- Rate at which bottleneck processes work is rate at which inputs should be provided.

- Capacity of production process depends on bottleneck capacity, so breakdowns/slowdowns reduce throughput.

- Priority (demand) for different types of units promotes more setups, but each new setup is opportunity cost.

- Output from bottleneck areas should be provided to next work center(s) in smaller lots than full batch size.

- Goal is to maximize total plant throughput. Schedule capacity-constrained resources to avoid bottlenecks.

Non-bottleneck areas

- Non-bottleneck capacity improvements do not improve total capacity.

- Non-bottleneck areas set maximum utilization based on rate determined at bottleneck.

- Using non-bottleneck area 100% of time does not result in 100% utilization, just more WIP.

ΛPICS

Drum-Buffer-Rope

Organizations use TOC scheduling, called drum-buffer-rope (DBR), to

- Identify and schedule constraints carefully

- Buffer constraints with inventory

- Maximize utilization at bottlenecks or constrained resources

- Maximize system throughput.

Drum-Buffer-Rope

- Drum schedule sets pace for entire system.
  - Like takt time but based on constraint rate (or demand).
  - Production initiated by drum to avoid queue and wait.
- Buffer
  - Time buffer: Materials arrive specific time before need.
  - Not general parts but parts allocated to future orders.
- Rope
  - Like demand-pull, but signal is constraint throughput rate.
  - Adjust pull to keep buffer from shrinking or growing.

Drum-Buffer-Rope

Drum

Rope

Protective capacity

| A
150/hr | B
110/hr | C
80/hr | D
140/hr | E
150/hr | Shipping |

Constraint buffer
(5-hour lead time)

Shipping buffer
(3-hour lead time)

Raw materials

| F | G | H |

Assembly buffer
(7-hour lead time)

= Buffer inventories

Market demand = 75 per hour

Raw materials

Drum, Buffer, Rope

Capacity = Units/Day
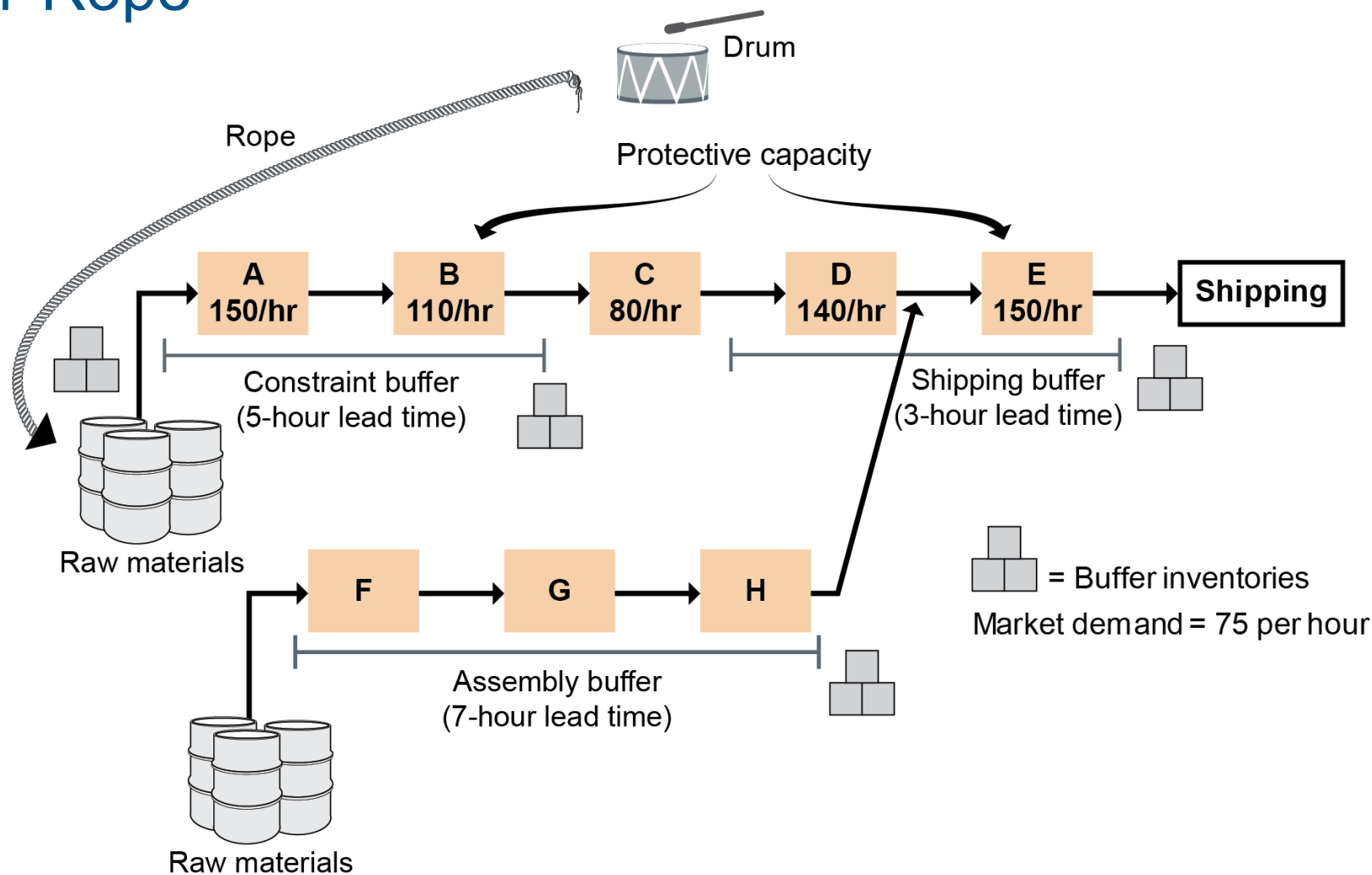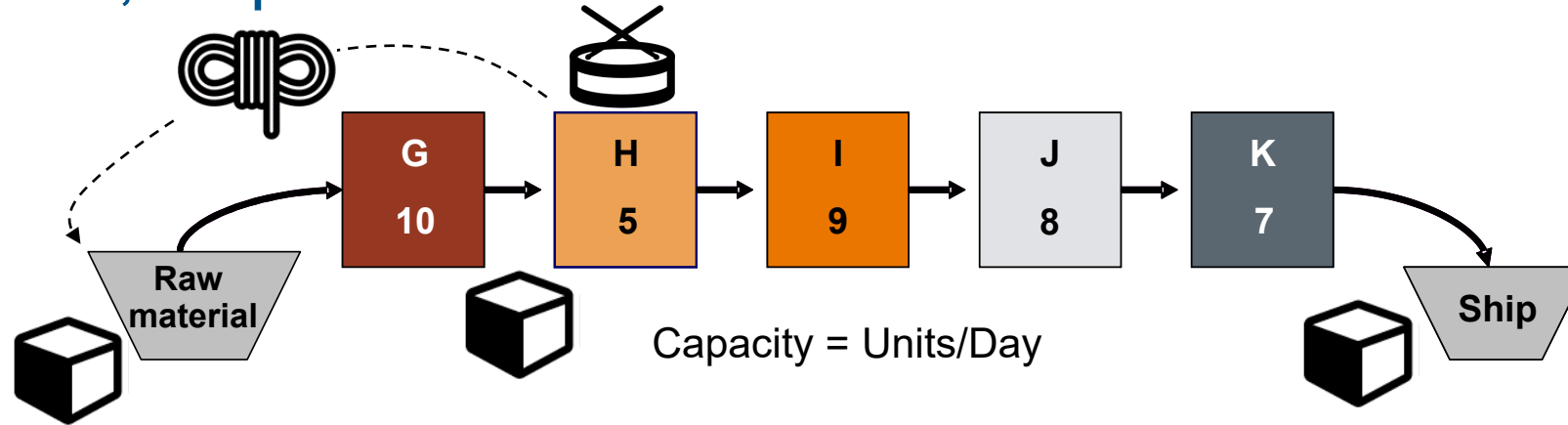
Where is the drum?

Where should stock buffers be located?

Where is the rope?

Market Demand as Constraint:
Simplified Drum-Buffer-Rope (S-DBR)

TOC Scheduling Steps
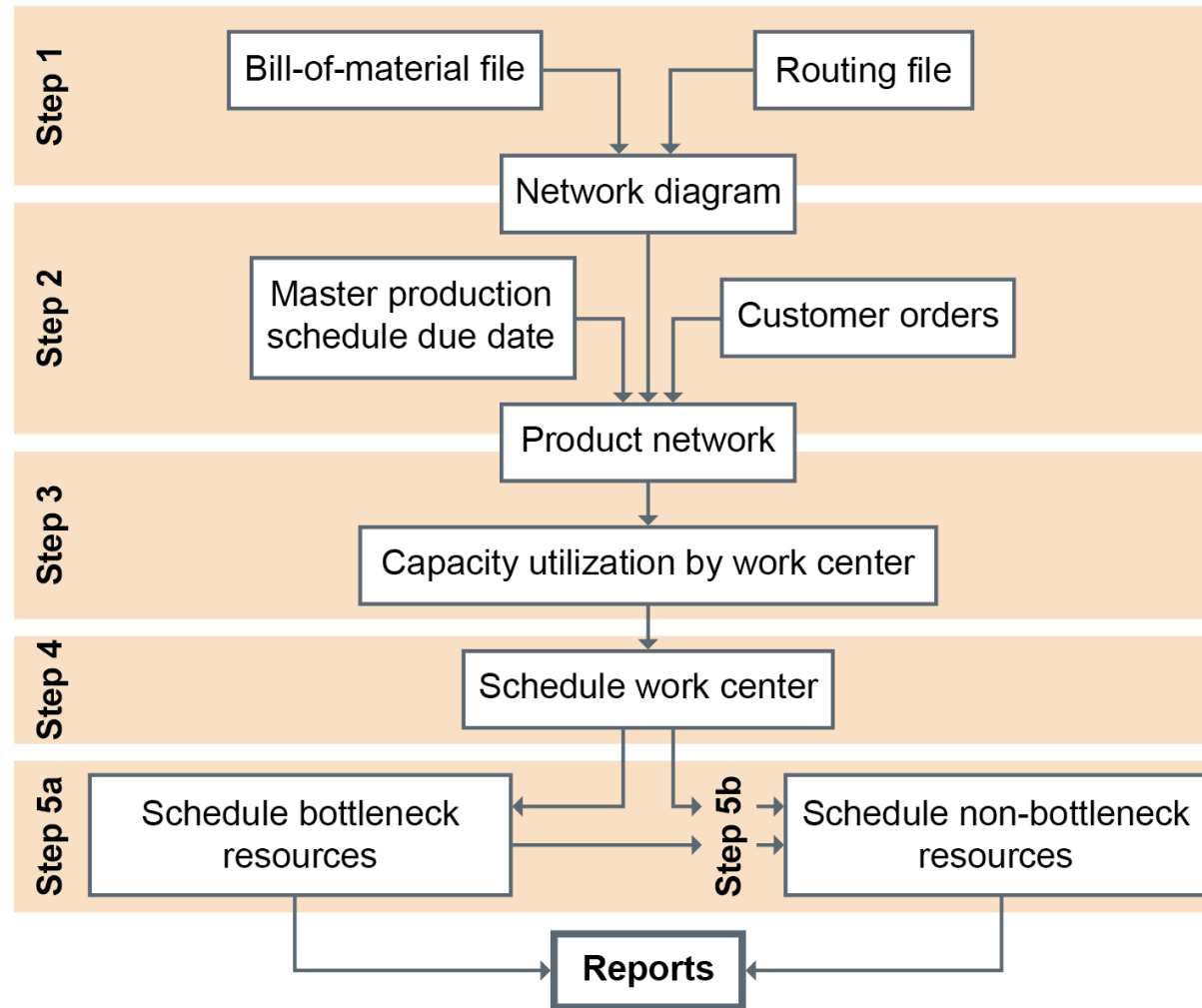
TOC Production Activity Control Scheduling Process

Scheduling the drum

Exploiting the drum

Elevating the drum

TOC Schedule

Releasing material using the rope

Managing buffers proactively
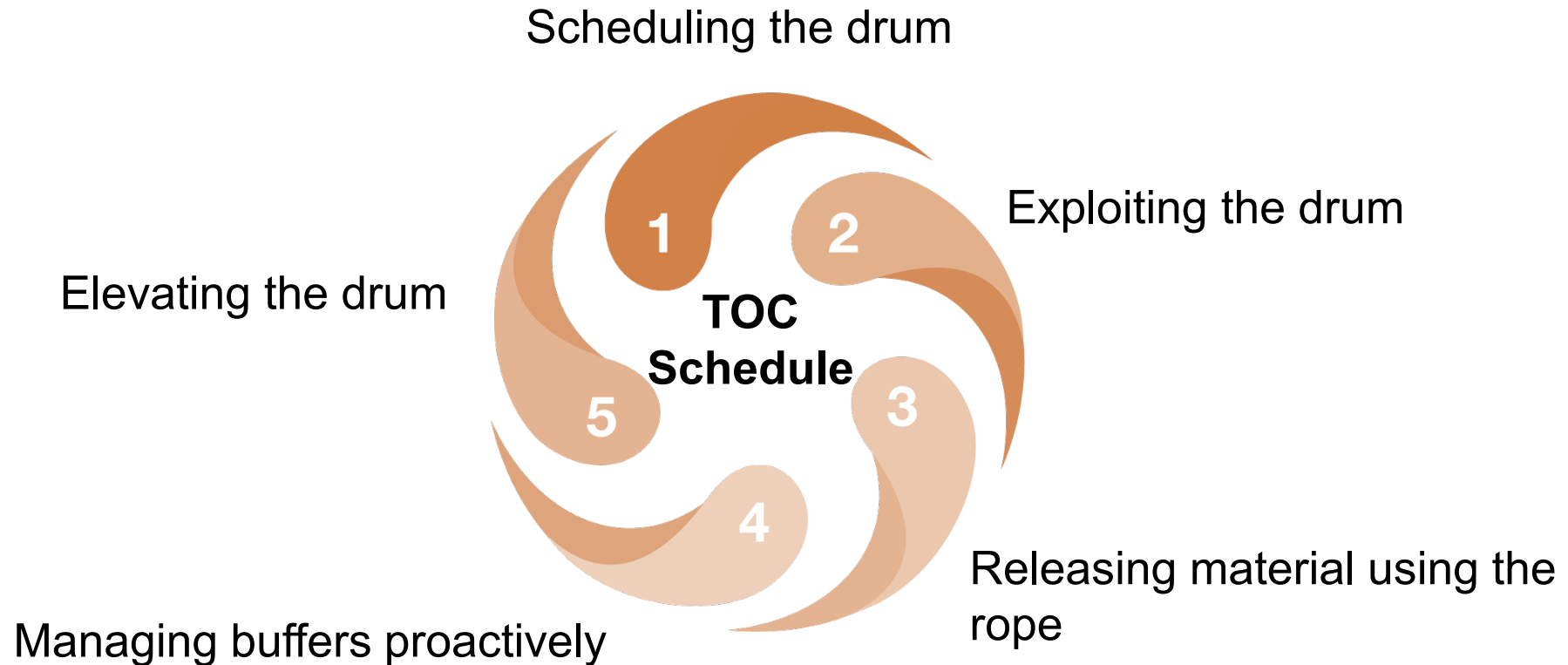
Managing Bottlenecks

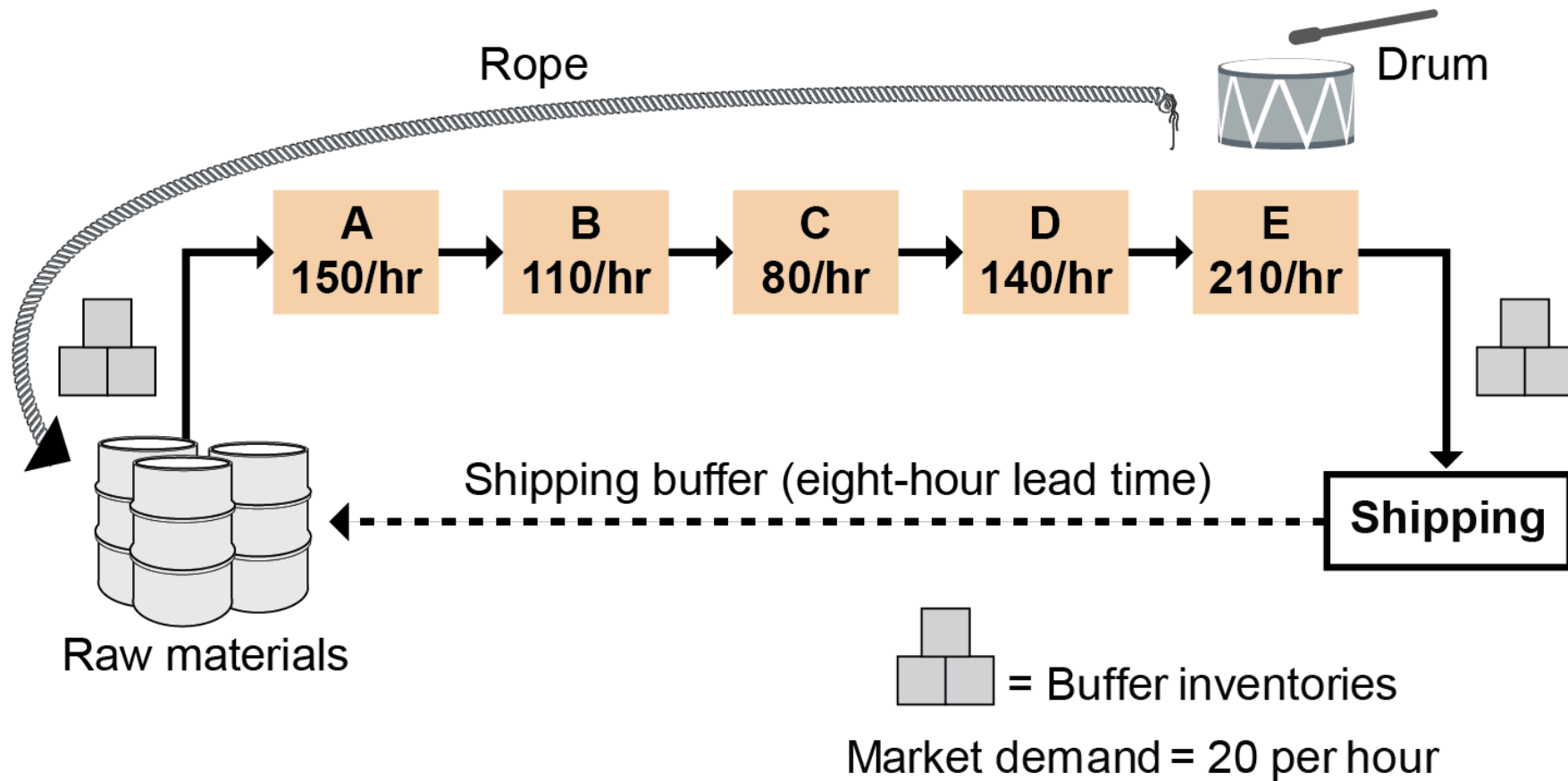| Technique	Explanation
Establish buffer in front of bottleneck.	Create time buffer or queue before bottleneck.
Control rate of material flowing into bottleneck.	Keep bottleneck fed at constant rate that is equal to its capacity so time buffer remains constant.
Focus on maintain or increasing bottleneck capacity.	Look for ways to increase capacity of bottleneck.
Adjust loads.	Reduce load on bottleneck.
Change schedule.	Last resort is to change promised schedule for delivery.

APICS

Elements of Constraint Management

- Identify—Identify the capacity-constrained resource (CCR) before it becomes a bottleneck.

- Exploit—Keep the CCR working.

- Subordinate—Feed into the process only what can be handled at the CCR.

- Elevate—Accelerate and improve the CCR.

- Repeat—After fixing the CCR, return to step 1 to attack the new CCR.

Continuous (Flow) Manufacturing Environments

- Divergent product structure
- Capacity planned first to meet forecast demand
- Continuous flow
- Focus on efficient use of capacity
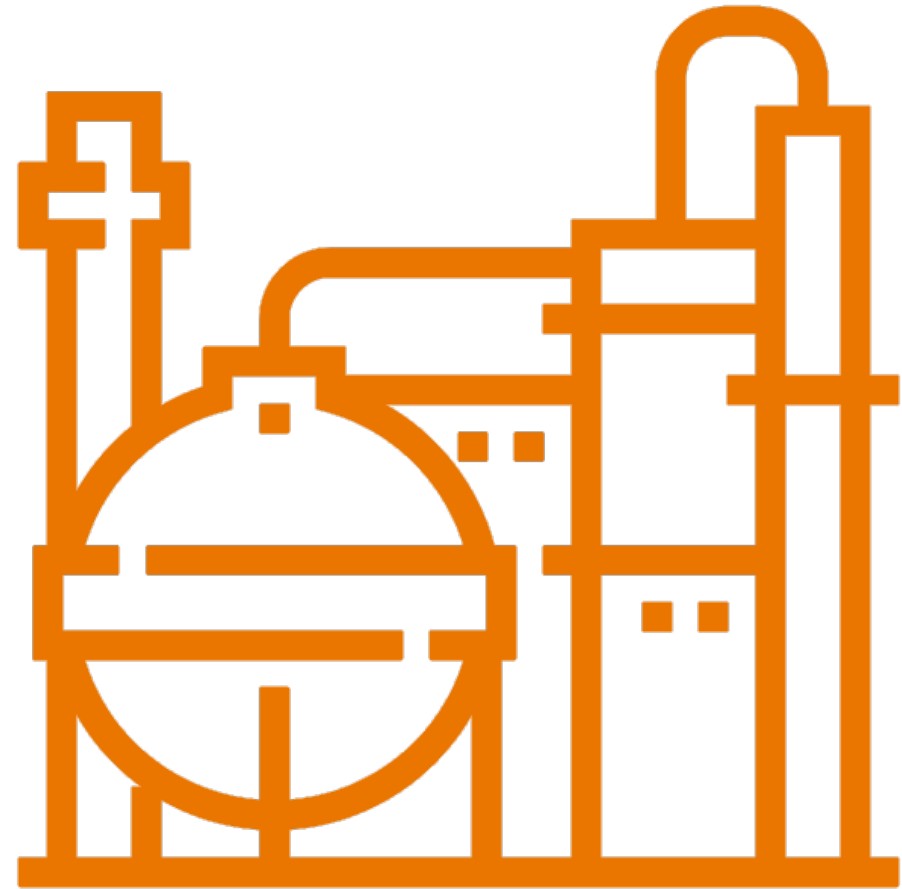
Process Flow Scheduling

Three principles

- Scheduling is based on the process structure.

- Processor- or material-dominated scheduling can be used within a stage.

- Process trains can be scheduled with reverse flow scheduling, forward-flow scheduling, or mixed-flow scheduling.

Process trains

Stages

Units
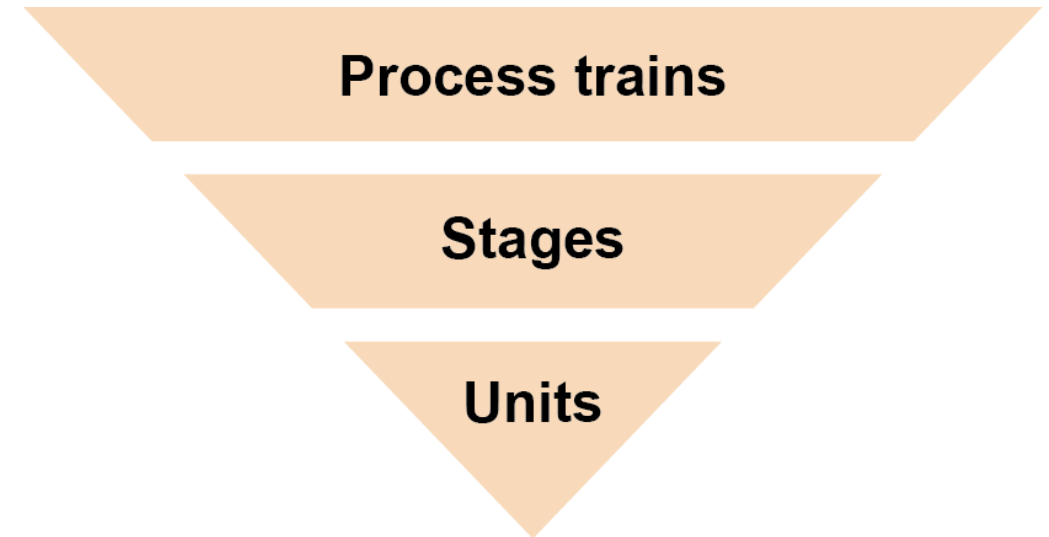
Sugar Refinery Process Train
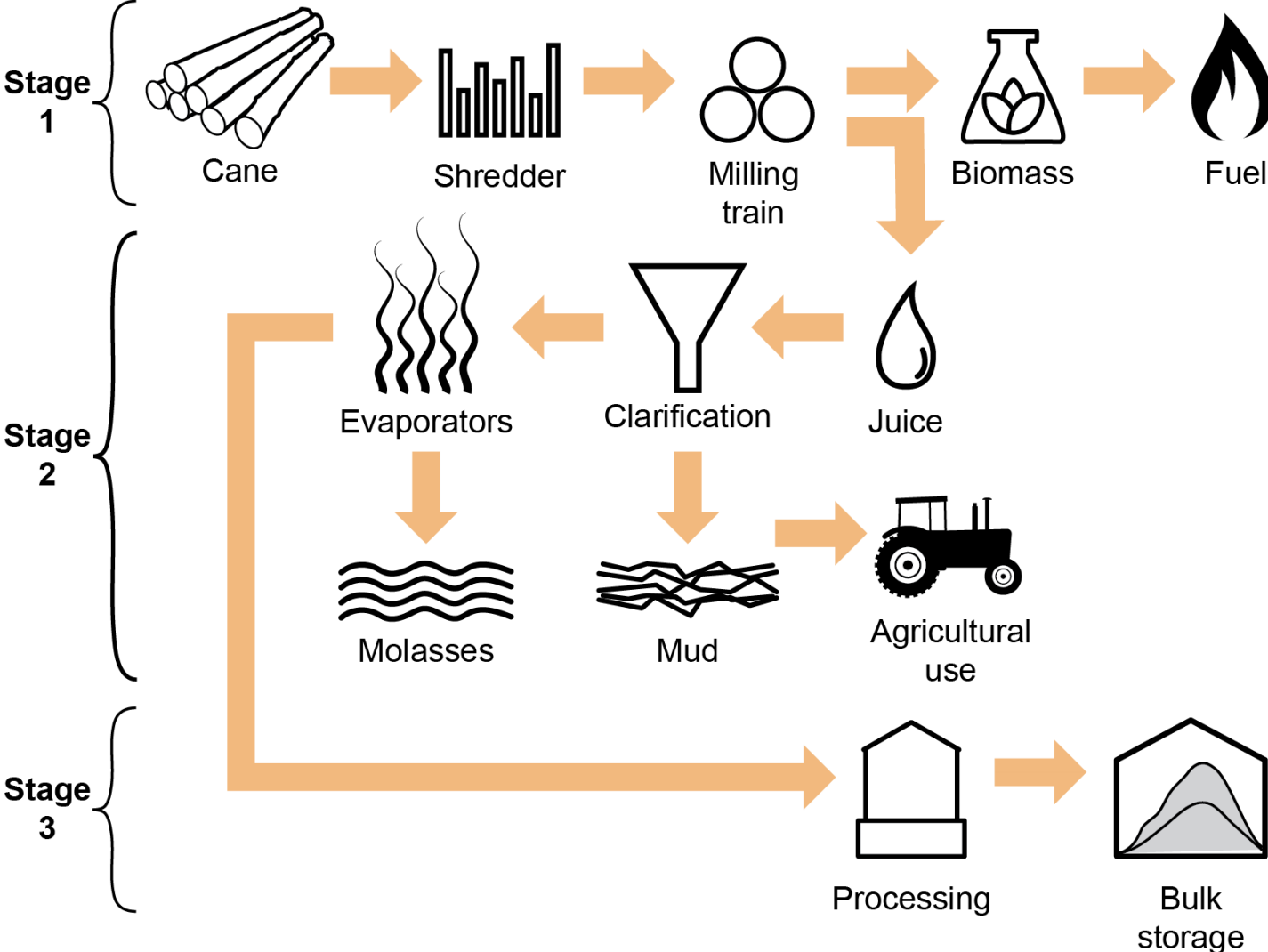
Processor-Dominated Scheduling Approach

1. Prepare finite capacity schedule.

2. Check inventory against min-max levels.

3. Revise production schedule.

4. Schedule raw materials.

Processor schedule for products A, B, and C in a single-stage process train:

Days	1	2	3	4	5	6	7	8	9	10
	A			B		C	B		A	

Max

Min

Inventory graph for product A
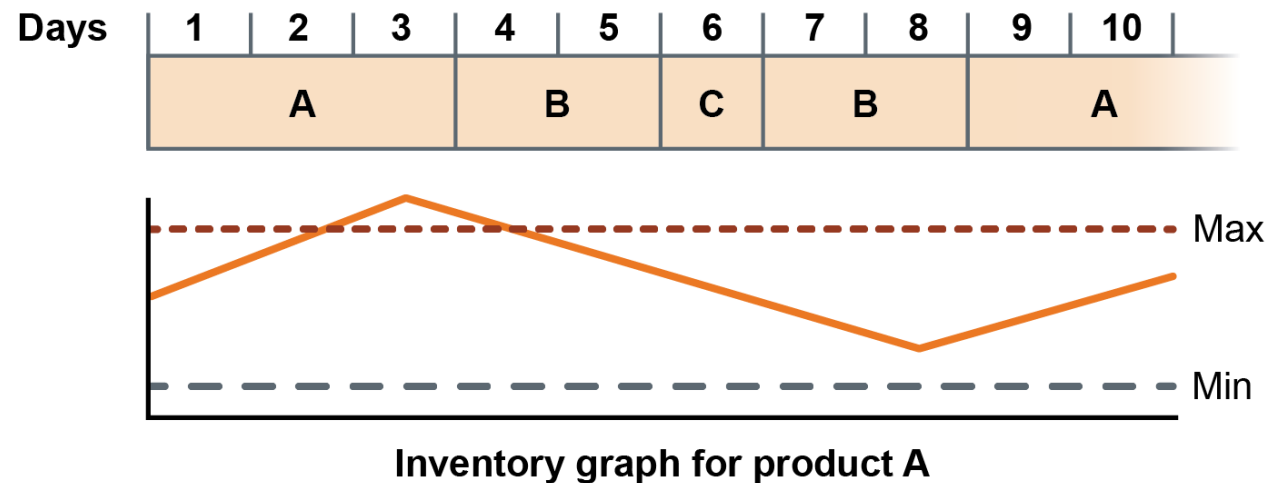
Material-Dominated Scheduling Approach

1. Create a time-phased record of material balances.

2. Add a lot when inventory falls below target.

3. Compile a load profile for the unit.

4. Analyze and reconcile incompatibilities.

Product A
Minimum = 100, Maximum = 800
Production rate = 200/day
Lot size = 600

Material schedule

Day	1	2	3	4	5	6	7	8	9	10
Requirements	100	100	100	100	100	100	100	100	100	100
Production	200	200	200						200	200
Inventory	500	600	700	800	700	600	500	400	300	400	500

Processor schedule (material schedule needs adjustment)
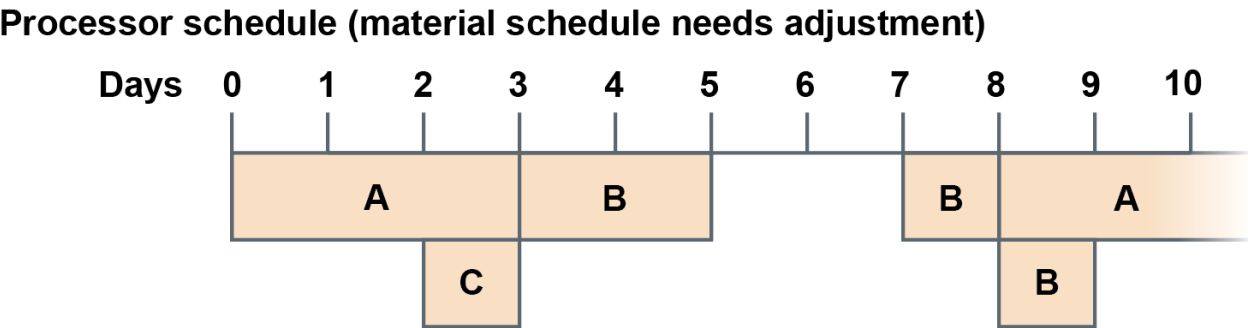
When to Use PDS or MDS

← PDS

MDS →

PDS	MDS
▪ Capacity is relatively expensive. ▪ The process unit is a bottleneck. ▪ Setups are expensive.	▪ Materials are relatively expensive. ▪ There is excess capacity. ▪ Setup costs are low. ▪ Stage operates as job shop.
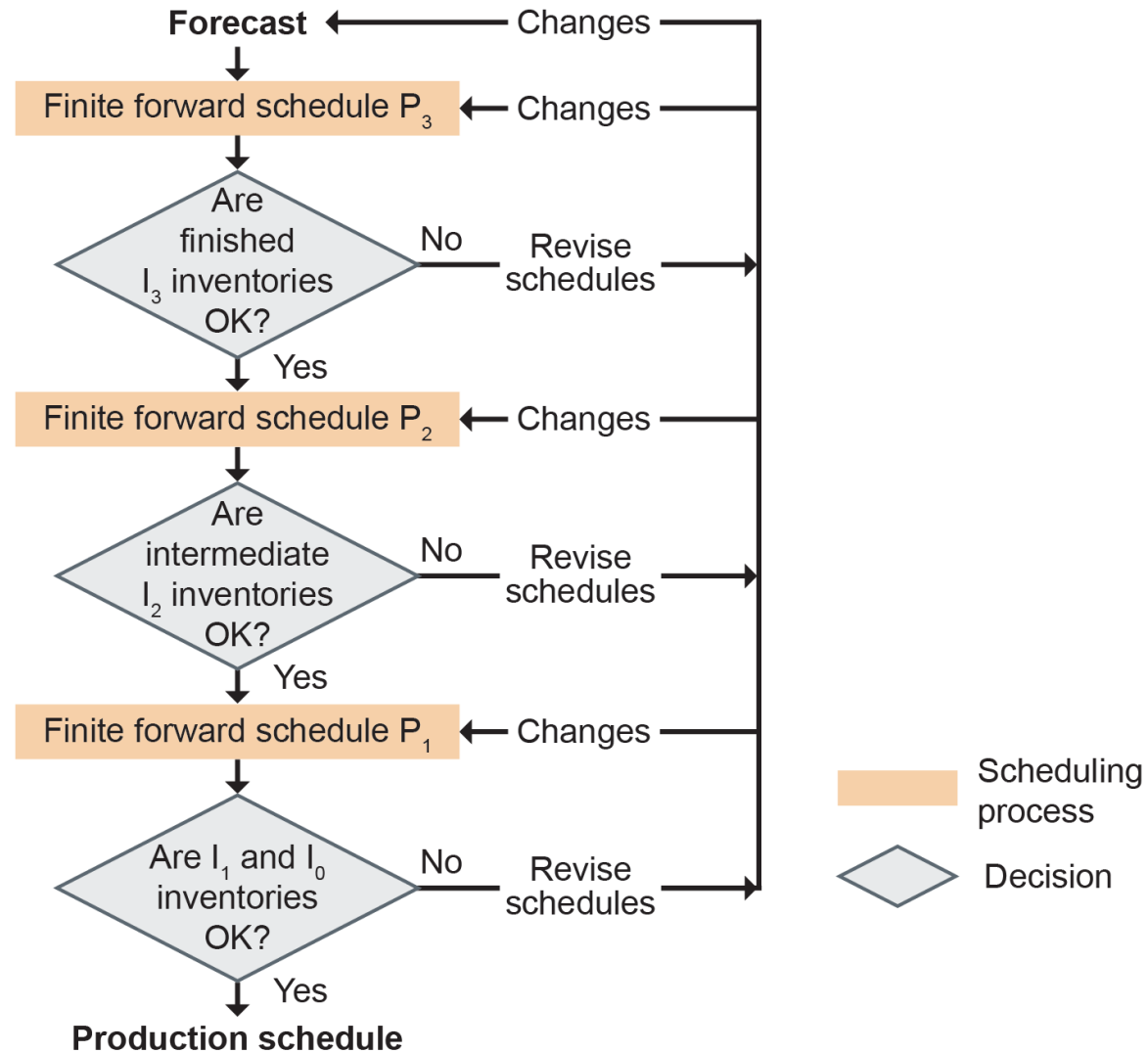
APICS

Reverse-Flow Scheduling

Forecast ← Changes

Finite forward schedule P_3 ← Changes

Are finished I_3 inventories OK?

No → Revise schedules

Yes

Finite forward schedule P_2 ← Changes

Are intermediate I_2 inventories OK?

No → Revise schedules

Yes

Finite forward schedule P_1 ← Changes

Are I_1 and I_0 inventories OK?

No → Revise schedules

Yes

Production schedule

Scheduling process

Decision

APICS

SECTION C:
CREATING PRODUCTION AND
SERVICE SCHEDULES

Section C Learning Objectives

- Capacity terms and goals of capacity management

- Capacity planning in service industries

- CRP steps and inputs

- Calculating rated capacity, demonstrated capacity, efficiency, and utilization

- Safety capacity

- How load is calculated

- Capacity simulation and tactics for resolving imbalances

Detailed Capacity Planning in MPC Process
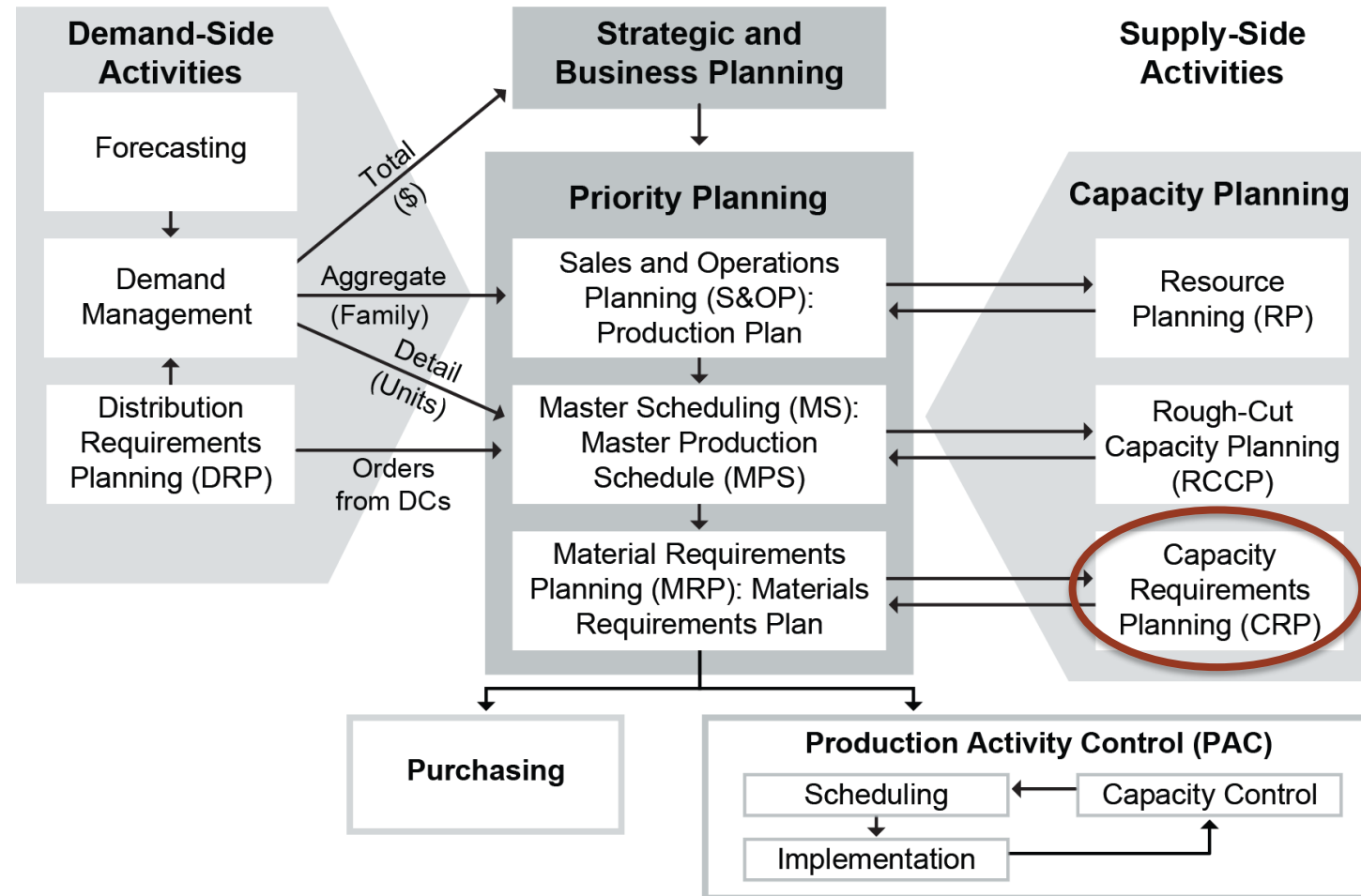
Key Capacity Terms

Capacity
Theoretical capacity, required capacity, budgeted capacity
Capacity planning, capacity management, capacity control

APICS

Capacity Planning Goals and Challenges

Goal: Meet operational performance objectives by

- Increasing productive capacity
- Reducing idle capacity.
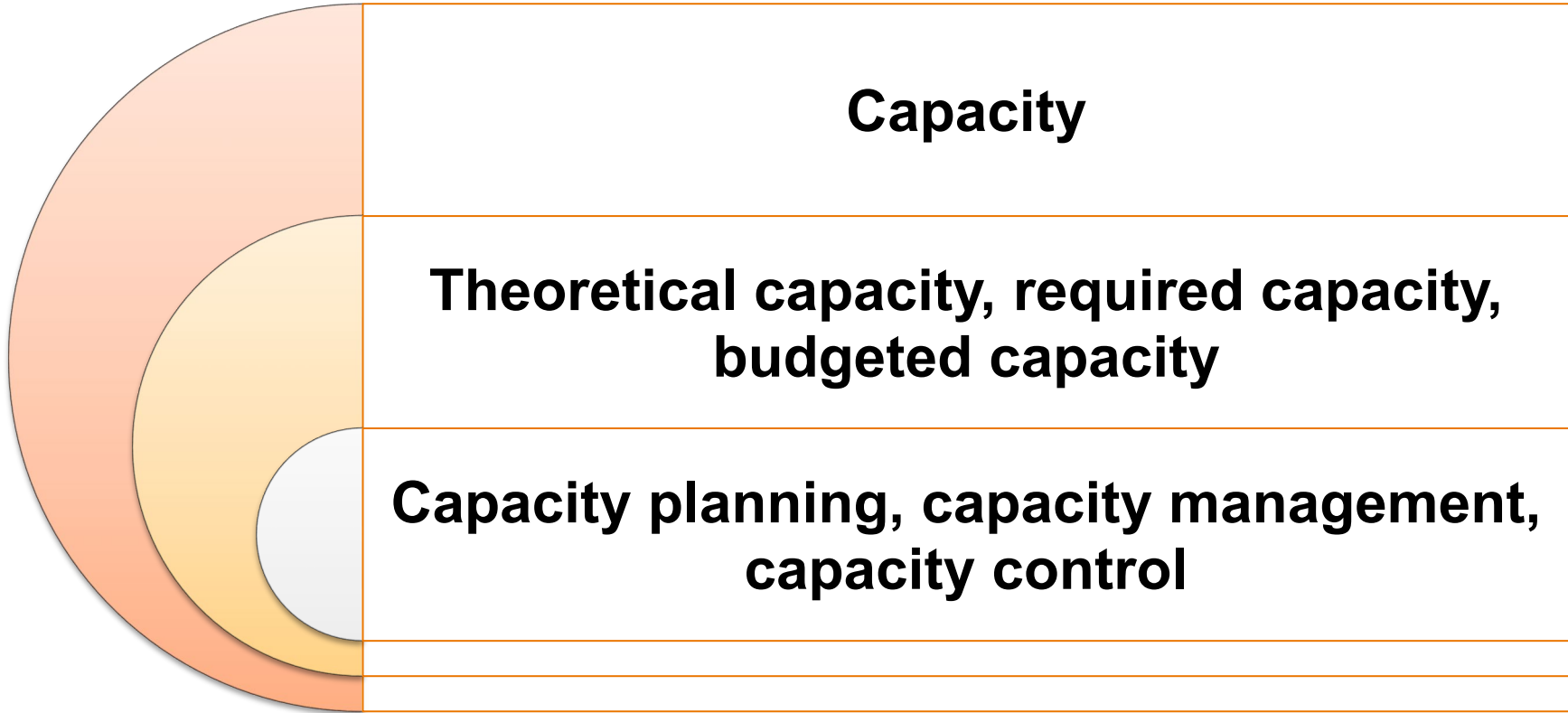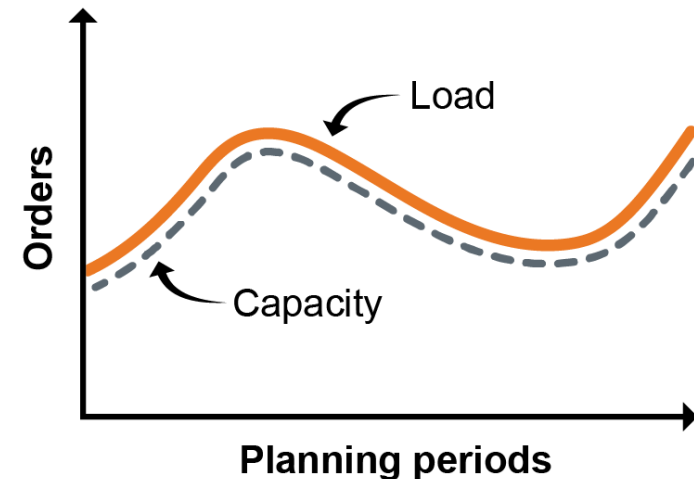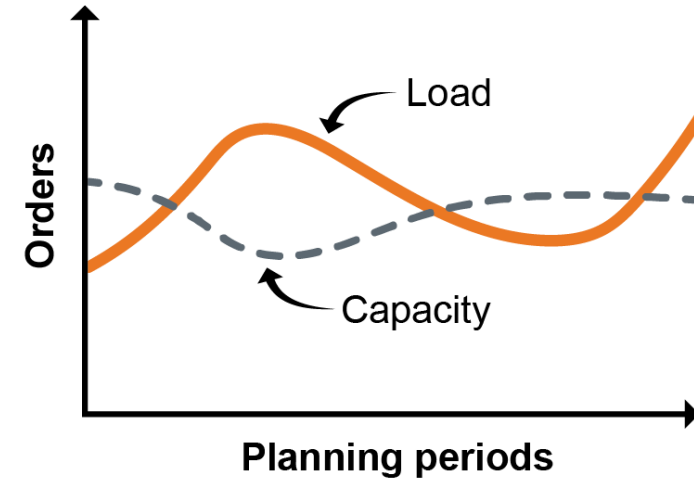
Service Capacity

Capacity in service industries is subject to scarcity and expensive to obtain; it is a risk once obtained (increases break-even point).

Services are inherently perishable (e.g., hotel room shelf life: one day).

Tactics to adjust capacity

- Change workforce level.
- Cross-train.
- Increase customer participation.
- Use automation.
- Extend hours of operation.

Steps in Iterative Capacity Planning Process

1. Calculate capacity available.

2. Calculate load per time bucket (capacity required), and determine differences between capacity available and capacity required.

3. Create work center load reports.

4. Resolve differences. Adjust available capacity first, and, if necessary, change priority plan to match capacity available.

5. Prepare plan for execution.

Capacity Measurement Systems

- MRP priority plan in units of output.

- Capacity rarely in units of output.

  – Different work centers have different output units.

  – Some industries use aggregate measures (e.g., barrels of oil).

- Standard time (standard hours) is common unit.

  – Includes setup and run time.

  – Average worker, prescribed methods, time for rest, unavoidable delays (*ASCM Supply Chain Dictionary*).

- Extensive observation.

- Learning curve issue.

Capacity Available Versus Required

Load

Capacity Available (rate)

Capacity Required (rate)

Output per Time Period
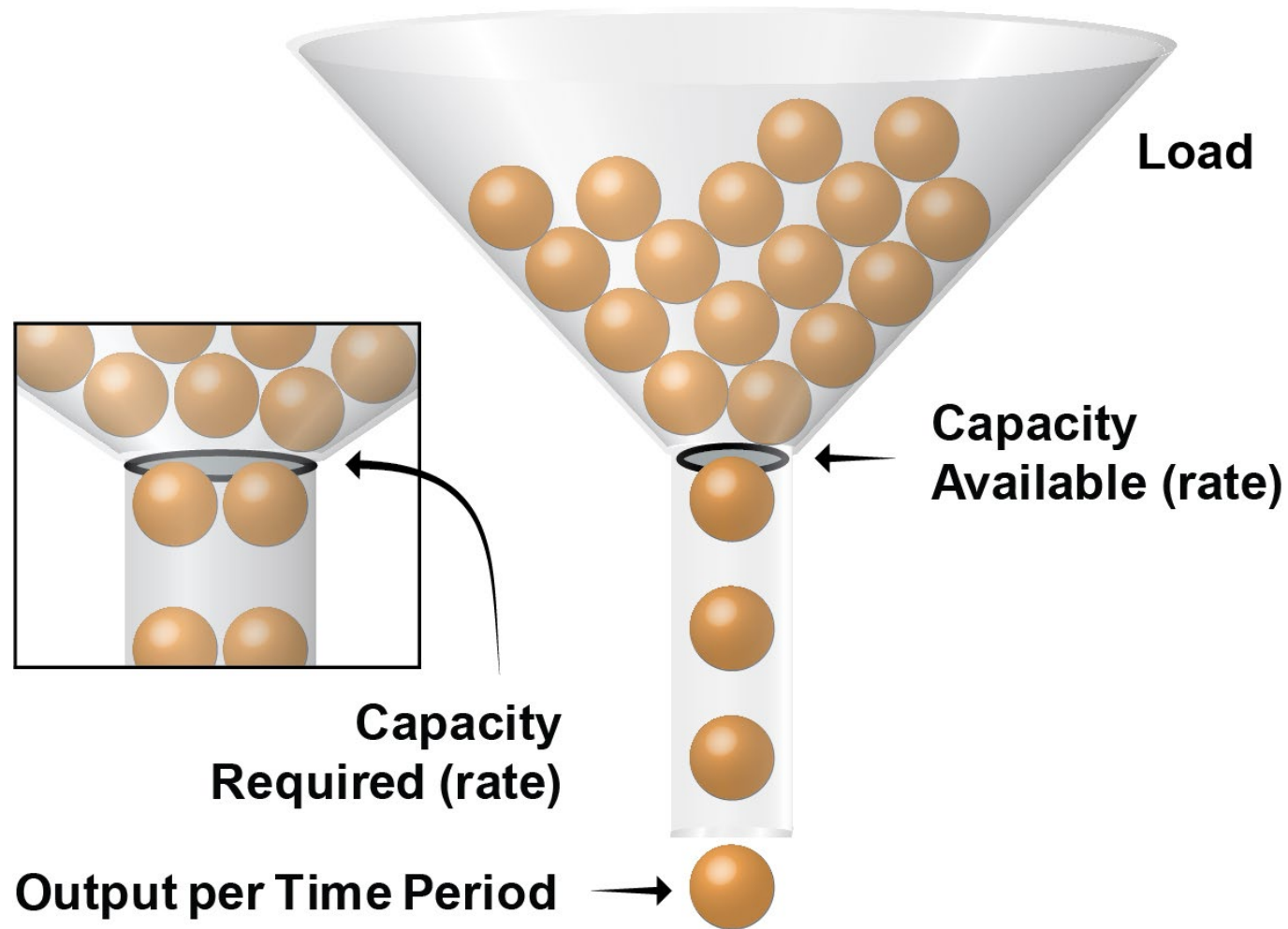
Inputs to CRP

Sources of load and work center data

- Load sources
  - Open orders (already validated) in shop order file
  - Planned order releases from MRP
  - Rework, scrap, process yield, past-due orders, prototypes, tests, etc.
- Work center data
  - Description, workdays, shifts, machines, operators, utilization, efficiency, and standard times

Routings (lead times here or in work center file)

		Setup Time	Run Time/ Unit	
Operation No.	Work Center	(std. hrs.)	(std. hrs.)	Operation
10	13	0.15	0.07	Spot weld top, center, bottom to side 1
20	16	0.25	0.11	Install glass, molding, caulk, side 2
30	14	0.15	0.06	Spot weld side 2
50	11	0.05	0.05	Grind
60	Stores			Inventory

Part Number: 202   Description: Door, Family A
Drawing Number: D202X

APICS

Inputs to CRP: Manufacturing Calendar
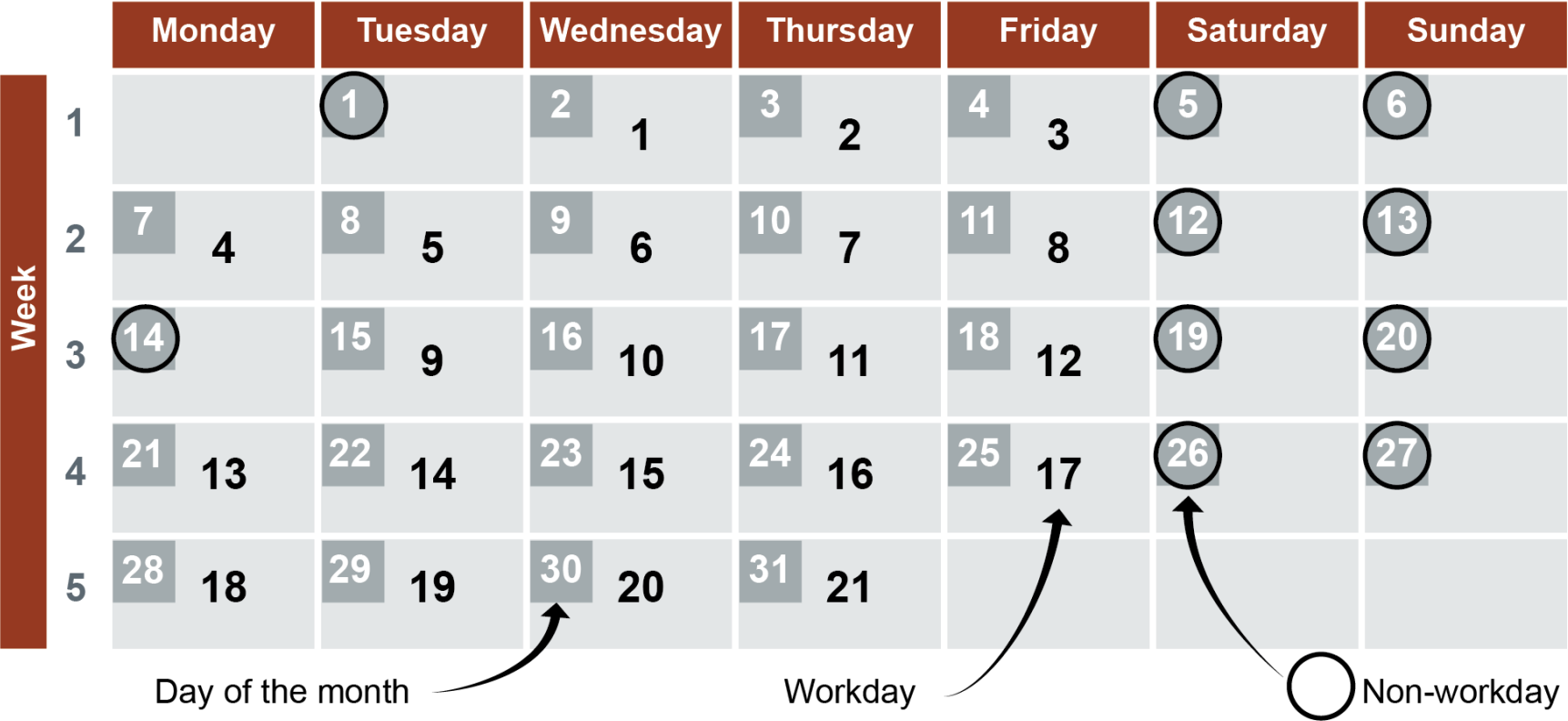
Determining Capacity Available

May depend on

- Product specifications
- Product mix
- Number and output rate of equipment
- Workforce rate of output.

May be determined by

Rated capacity

Demonstrated capacity

Efficiency Calculation Exercise

1. Engineering studies indicate that the standard time to produce one unit is 20 minutes. A work center is expected to produce 24 units of item A on a particular day (eight-hour shift). At the end of the day, 30 units were produced. What is the efficiency?

$$(30 \text{ Parts} \times 20 \text{ Minutes})/60 \text{ Minutes per Hour} = 10 \text{ Standard Hours}$$

$$\text{Efficiency} = \frac{\text{Standard Hours Produced}}{\text{Actual Hours Worked}} = \frac{10}{8} = 1.25$$

2. The standard cost to produce one unit is $20. From a cost accounting standpoint, was production of item A above or below standard cost?

3. If the work center maintains about the same efficiency rate, what should be done to the predetermined standard hours currently in effect?

4. What are some of the possible causes for the deviation from standard hours in this case and in general?

Calculating Rated Capacity

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

Equipment or Workers $\times$ Hours in Bucket =

4 Stations $\times$ (5 Days $\times$ 8-Hour Shifts) = 160 Hours

$$\frac{\text{Actual Hours Worked}}{\text{Available Time in Hours}} = \frac{130 \text{ Hours}}{160 \text{ Hours}} = 0.8125 = 81.25\%$$

$$\frac{\text{Standard Hours Produced}}{\text{Hours Actually Worked}} = \frac{110 \text{ Hours}}{100 \text{ Hours}} = 1.1 = 110\%$$

Rated Capacity = 160 Hours $\times$ 0.8125 $\times$ 1.1 = 143 Hours

Rated Capacity Calculation Exercise

Based on the following information, calculate the rated capacity of a work center:

- Available time = 240 hours per week
- Actual hours worked = 228
- Efficiency = 103 percent

$$\text{Utilization} = \frac{\textit{Actual Hours Worked}}{\textit{Available Time (Hours)}} = \frac{228}{240} = .95$$

$$\text{Rated Capacity} = 240\ Hours \times .95 \times 1.03 = 234.84\ Standard\ Hours$$

Capacity Calculations Exercise

- Available hours = 12,000

- Actual hours worked = 10,440

- Standard hours produced = 11,480

- Utilization $= \dfrac{10,440}{12,000} \times 100\% = 87\%$

- Efficiency $= \dfrac{11,480}{10,440} \times 100\% = 110\%$

- Weekly available time $= 3 \times 16 \times 5 = 240$

- Rated weekly capacity $= 240 \times .87 \times 1.10 = 229.7$ standard hours

APICS

Demonstrated Capacity

- Proven capacity: average items made times standard hours per item.

- Production records (average, not maximum).

- Already factors in utilization and efficiency.

- Scenario: Work center actually produced 100, 110, 90, and 120 standard hours over four five-day weeks.

$$\text{Demonstrated Capacity} = \frac{\text{Sum of Standard Hours per Time Bucket}}{\text{Number of Time Buckets}}$$

$$= \frac{(100 + 110 + 90 + 120)}{4}$$

$$= 105 \text{ Standard Hours}$$

Calculating Load (Capacity Required) and Differences

1.

Calculate operation time per work order (open or planned orders). Convert orders to standard time.

2.

Simulate order scheduling (e.g., backward scheduling) to find start and finish dates per operation per work center.

3.

Establish load profiles. Sum operation times for work center's part of work orders done in time bucket.

Step 1: Calculate Operation Time per Work Order

Part Number: 202   Description: Door, Family A
Drawing Number: D202X

Operation No.	Work Center	Setup Time (std. hrs.)	Run Time/Unit (std. hrs.)	Operati
10	13	0.15	0.07	Spot weld top, center,
20	16	0.25	0.11	Install glass, molding,
30	14	0.15	0.06	Spot weld side 2
50	11	0.05	0.05	Grind
60	Stores			Inventory

Order Number: 808

Operation No.	Work Center	Setup (std. hrs.)		Qty.		Run Time/Unit (std. hrs.)			Total (std. hrs.)	8-Hr. Days (round up)
10	13	0.15	+ (	200	×	0.07	)	=	14.2	2
20	16	0.25	+ (	200	×	0.11	)	=	22.3	3
30	14	0.15	+ (	200	×	0.06	)	=	12.2	2
50	11	0.15	+ (	200	×	0.05	)	=	10.2	2
60	Stores									

Setup and run for each (planned or open) work order

Operation Time per Work Order = Setup Time + Run Time =
Setup Time + (Quantity × Standard Time per Unit)

Topic 2: Capacity Requirements Planning (CRP)

Step 2: Simulate Order Scheduling (Backscheduling)

- Actual scheduling done by PAC.

- Backscheduling starts with end or due date; works backward to determine start date and finish dates for each order in each work center.

- Inputs for backscheduling:

  – Quantity, due date, operation time per work order

  – Operations sequence from routing

  – Queue, wait, and move times and rated or demonstrated capacity from work center file

- Round up to nearest day for setup plus run and for queue, wait, and move.

Step 2: Simulate Order Scheduling (Backscheduling)

Work center file data

Work Center	Queue (days)	Wait (days)	Move (days)
13	2	1	1
16	1	1	1
14	1	1	1
11	1	1	1

Order Number: 808

End here

Operation No.	Work Center	Start Date (a.m.)	Queue (days)	Operation (days)	Finish Date (p.m.)	Wait (days)	Move (days)
10	13	32	2	2	36	1	1
20	16	38	1	3	42	1	1
30	14	44	1	2	47	1	1
50	11	49	1	2	52	1	1
60	Stores	54					

Start here

$$54 - 1 - 1 = 52$$

APICS

Step 3: Establish Load Profiles

Work Center: 13	Load Profile				
Week	**1**	**2**	**3**	**4**	**5**
Released Load (std. hrs.)	114	145	85	45	20
Planned Load (std. hrs.)	0	0	25	120	130
Total Load	114	145	110	165	150
Rated Capacity	114	143	114	143	143
(Over)/Under Capacity	0	(2)	4	(22)	(7)

- Future capacity for work center based on released or planned orders for period
- 4-day weeks: 1 and 3
- 5-day weeks: 2, 4, 5

Load Profile as Stacked Bar Chart

Schedule Worksheet

Order quantity = 100 units
From route sheet

Operation	Work center	Setup time (standard hours)	Run time (standard hours)	Total time (standard hours)	Days
10	8	1.5	0.2	21.5	3
20	9	0.5	0.3	30.5	4

From work center files

Work center	Queue (days)	Wait (days)	Move (days)
8	2	1	1
9	4	1	1

Schedule

Operation	Work center	Arrival date	Queue (days)	Operation (days)	Finish date	Wait and move
10	8	103	2	3	108	2
20	9	110	4	4	118	2
Store	Stores	120				

APICS

Order Scheduling Exercise

Use the information shown in the schedule below.

Backschedule the shop order from the due date, or arrival date, at stores on day 150 to the finish dates and arrival dates of prior operations. All times are in days.

Operation	Work center	Arrival date	Queue time	Operation time	Finish date	Wait and move
10	D2	127	3	2	132	2
20	B1	134	5	4	143	2
30	C4	145	2	1	148	2
Store	Stores	150				

APICS

Resolving Differences

| Change capacity first. |
|---|
| ■ Add/remove shift. |
| ■ Overtime/undertime, weekends. |
| ■ Hire/lay off over longer horizon. |
| ■ Cross-train workers. |
| ■ Alternate routing. |
| ■ Improve process. |
| ■ Know worker actual capabilities. |

Alter load and resimulate.
■ Subcontract/outsource (reduces load) or insource.
■ Late/early order release.
■ Alter lot sizes or workload.
■ Revise MPS (last resort).
■ Resimulate schedule: New capacity issues?

APICS

Redistributing Load

- Use alternate work centers.

- Use alternate routings.

- Modify operation priorities.

- Revise MPS or lot sizes.

- Run overlapping operations.

- Use lot splitting.
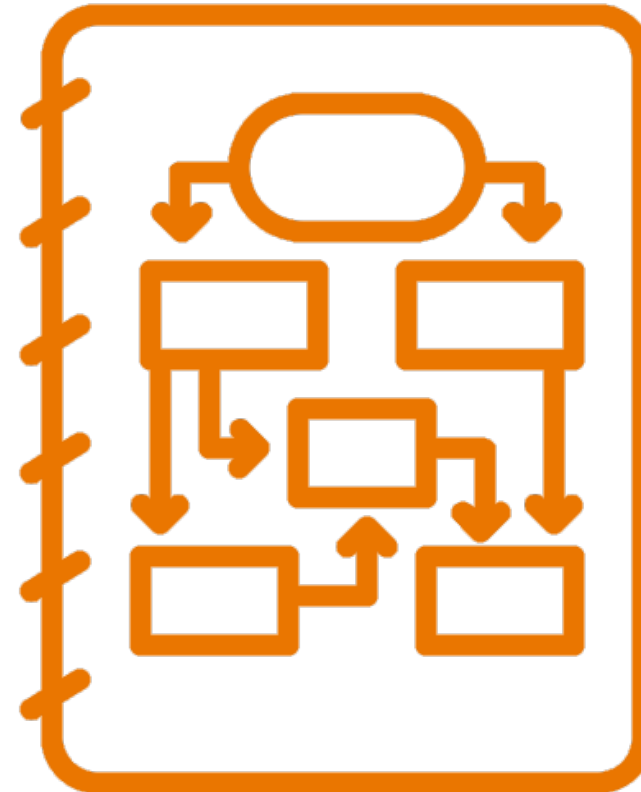
CPIM

CERTIFIED IN PLANNING
AND INVENTORY MANAGEMENT

SECTION D:
MANAGING DETAILED SCHEDULES AND
SCHEDULING MATERIALS

APICS

ASCM

Section D Overview

Section D Learning Objectives

- Labor schedules and managing human resources

- Shop packets

- Manufacturing orders versus work orders

- Alternate routings

- Managing queue size

- Scheduling incoming materials

- Managing exceptions

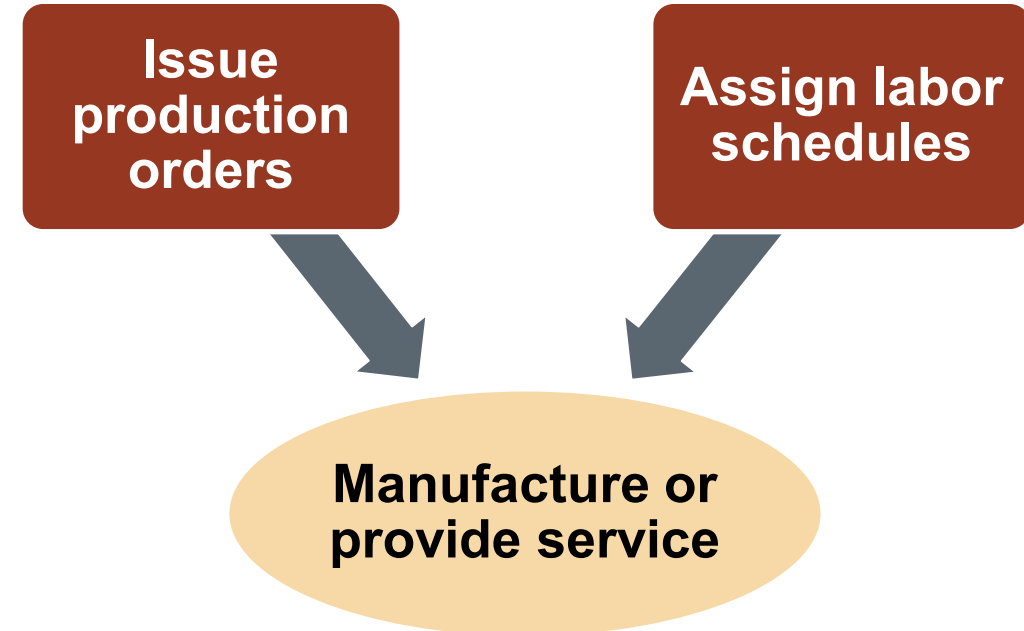- Measuring capacity planning performance

Setting Labor Schedules

- Scheduling software
  - Customizable scheduling rules
  - Templates
  - Integrating shop calendars for availability
- Labor skills matrix
  - Relative employee skill/knowledge level
  - Need for supervision
- Fixed, floating, or flexible schedules

Topic 1: Labor/Production Scheduling and Managing HR

Issuing Production Orders and Assigning Labor

- Within constraints of supply and demand
- Needed elements
  – Start/complete dates
  – Authorization
  – Last check
  – Shop packet

Issue production orders

Assign labor schedules

Manufacture or provide service

Managing Human Resources: Implement and Help Improve

- Skilled managers are fair, communicate clearly, and see issues as problems to be solved.
- Implement effective policies and procedures to stay consistent with the organization's values and expectations.
  - Explain in terms workers easily understand (e.g., in native language).
- Use effective work processes to manage tasks and workplace situations.
  - Evaluate level of detail (neither abstractions nor too detailed).
- Use performance management systems that incorporate feedback and rewards/recognition.
- Job enlargement, job enrichment, and job rotation

Routings and Queue Sizes
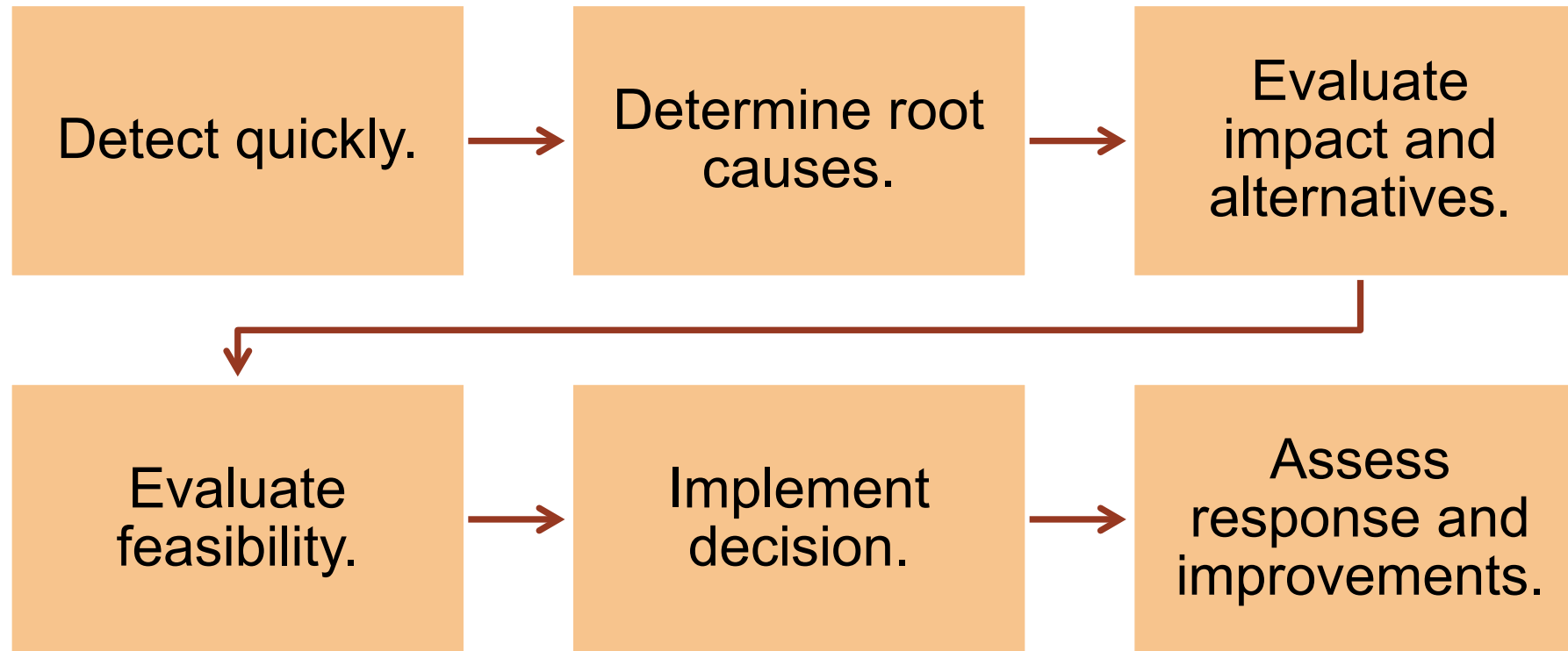
Managing workflows and routings

- Adjust process and transfer batch sizes as needed:

  – Lot splitting

  – Alternate routings

- Consider tradeoffs (e.g., losing workstation efficiency but gaining net efficiency).

Managing queue size

- Consider impact of queue size on queue time.

- Use I/O control, information on load from schedule, status of open orders.

- Increase capacity at affected workstations (e.g., reallocate staff, add overtime).

Exception Management Process

Detect quickly. →	Determine root causes. →	Evaluate impact and alternatives.
Evaluate feasibility. →	Implement decision. →	Assess response and improvements.

APICS

Communications and Vendor-Managed Inventory

Communications

- Robust and timely communication can
  - Reduce lead times and overhead costs
  - Preserve good relations with suppliers.
- Changes can be limited by supplier capacity and contracts.

VMI

- Given uncertain demand, vendor-managed inventory (VMI) can reduce
  - Risk
  - Inventory level
  - Cost.

Topic 2: Execution and Capacity Performance

Capacity Planning Performance Indicators

- Performance to schedule

- Customer service ratings

- Unbudgeted increases in costs

- Orders declined due to lack of capacity

- Quality problems

- Stockouts

- Inventory metrics

- Excessive utilization levels