

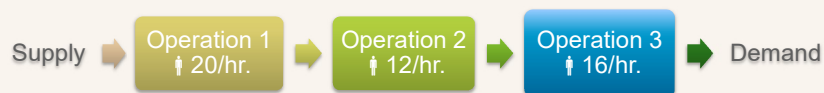
Chapter 5

Managing Process Constraints

- Theory of Constraints
- Managing Bottlenecks
- Assembly Line Balancing

What is a Constraint?

Constraint: Any factor that limits the performance of a system and restricts its output. 包括供應商能力或市場需求



Bottleneck: A capacity constraint resource (CCR) whose available capacity limits the organization's ability to meet the product volume, product mix, or demand fluctuations required by the marketplace 自身產能的瓶頸

Lucy

Operational Measures vs. Financial Measures

Operational Measures	TOC View	Relationship to Financial Measures
Inventory (I)	All the money invested in a system in purchasing things that it intends to sell	A decrease in I leads to an increase in net profit, ROI, and cash flow.
Throughput (T)	Rate at which a system generates money through sales	An increase in T leads to an increase in net profit, ROI, and cash flows.
Operating Expense (OE)	All the money a system spends to turn inventory into throughput	A decrease in OE leads to an increase in net profit, ROI, and cash flows.
Utilization (U)	The degree to which equipment, space, or workforce is currently being used; it is measured as the ratio of average output rate to maximum capacity, expressed as a percentage	An increase in U at the bottleneck leads to an increase in net profit, ROI, and cash flows. $U \uparrow \Rightarrow T \uparrow \Rightarrow \text{profit \& ROI} \uparrow$

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Theory of Constraints

The focus should be on balancing flow, not on balancing capacity.

If demand \geq the capacity of the process, the bottlenecks should be scheduled to maximize throughput.* 使瓶頸的產能最大化

An hour lost at a bottleneck... is an hour lost for the whole system. An hour saved at a non-bottleneck resource is a mirage. 不要管非瓶頸

Inventory is needed only in front of bottlenecks and in front of assembly and shipping points.
以庫存保護瓶頸與市場需求

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Theory of Constraints

Work should be released into the system only as frequently as needed by the bottlenecks. Bottleneck flows should be equal to market demand

瓶頸站與市場需求同步

Inventory and workforce levels can be reduced while still effectively utilizing critical resources.* 有效利用瓶頸並降低庫存與人力

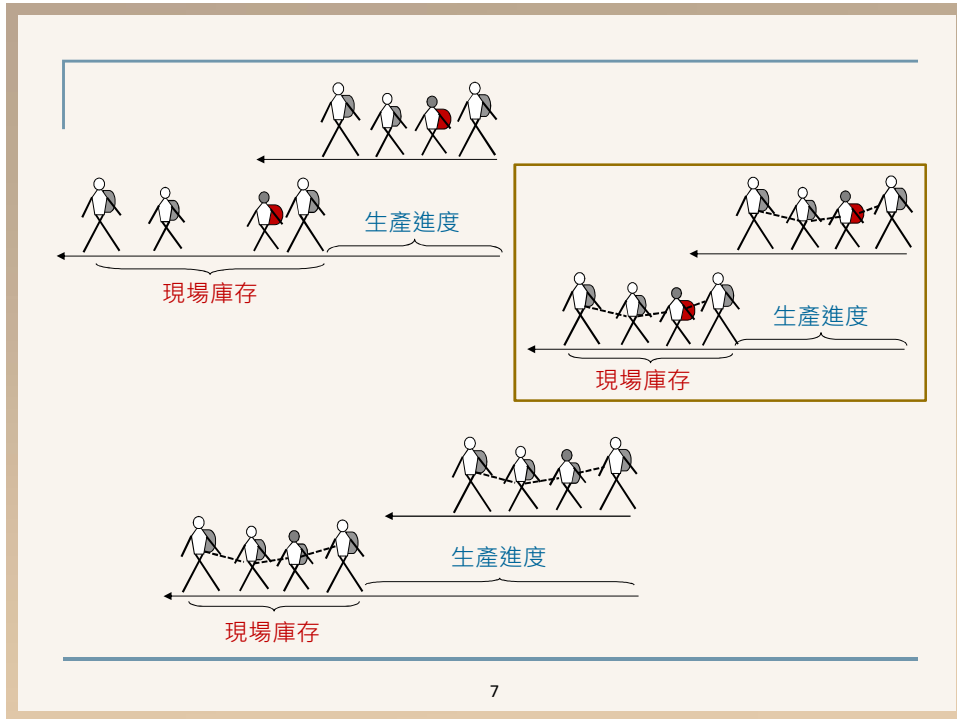
Every capital investment must be viewed from the perspective of the global impact on overall throughput, inventory, and operating expense. 從整體觀點投資產能

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Implementation of The Theory of Constraints

1. Identify the Bottlenecks (constraints)
2. Exploit the Bottleneck(s): Maximize the throughput of the bottleneck(s). 不浪費瓶頸產能
3. Subordinate All Other Decisions to Step 2: Non-bottleneck resources should be scheduled to support the bottleneck. 非瓶頸站配合瓶頸站運作
4. Elevate the Bottleneck(s): Try to increase the capacity of the bottleneck. **How?**
5. Do Not Let Inertia Set In: Repeat steps 1–4 in order to identify and manage the new set of constraints.

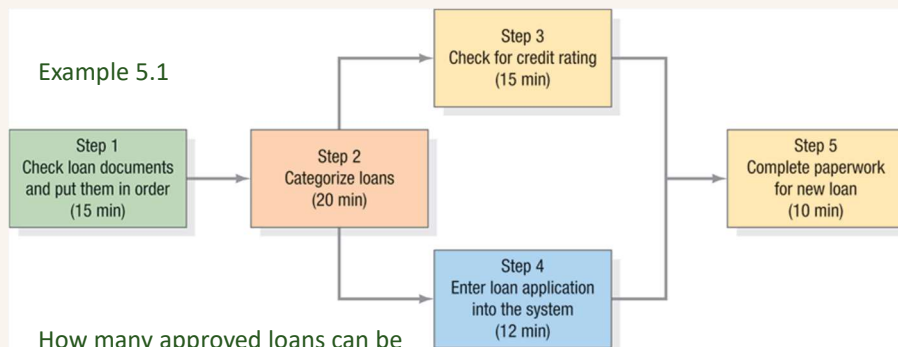
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Managing Bottlenecks in Service Processes

- **Throughput time:** Total elapsed time from the start to the finish of a job or a customer being processed at one or more work centers

Example 5.1



How many approved loans can be processed in a 5-hour work day?

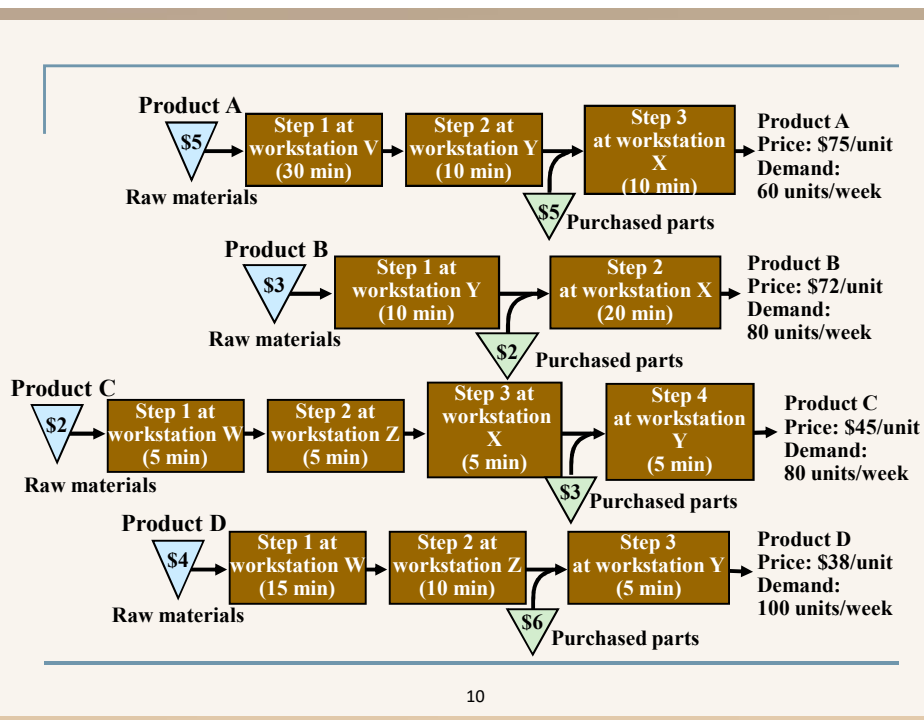
Managing Bottlenecks in Batch Processes

- Manufacturing processes often pose complexities when identifying bottlenecks. 生產多種產品時·管理瓶頸更難
- If multiple products are involved, extra setup time at a workstation increases the overload 如果必須考量setup時間...

Example 5.2 Identifying Bottleneck in a Batch Process

- Four products (A, B, C, D) are fabricated and assembled in five different workstations (V, W, X, Y, Z) using a small batch process. Batch setup times are negligible.
- Diablo can make and sell up to the limit of its demand per week, and no penalties ... for not meeting all the demand.

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Example 5.2

2,400 minutes of production time per week.

Workstation	Load from Product A	Load from Product B	Load from Product C	Load from Product D	Total Load (min)
V	$60 \times 30 = 1800$	0	0	0	1,800
W	0	0	$80 \times 5 = 400$	$100 \times 15 = 1,500$	1,900
X	$60 \times 10 = 600$	$80 \times 20 = 1,600$	$80 \times 5 = 400$	0	2,600
Y	$60 \times 10 = 600$	$80 \times 10 = 800$	$80 \times 5 = 400$	$100 \times 5 = 500$	2,300
Z	0	0	$80 \times 5 = 400$	$100 \times 10 = 1,000$	1,400

Identifying bottlenecks becomes harder when setup times are lengthy and the degree of divergence in the process is greater. 如果必須考量setup時間...

Drum-Buffer-Rope Systems

DBR: A planning and control system that regulates the flow of work-in-process materials at the bottleneck or the capacity constrained resource (CCR) in a productive system

- The bottleneck schedule is the **drum** because it sets the beat or the production rate for the entire plant and is linked to market demand.
- The **buffer** is the time buffer that plans early flows into the bottleneck and thus protects it from disruption. 防止瓶頸閒置
- The **rope** represents the tying of material release to the drum beat, which is the rate at which the bottleneck controls the throughput. 配合瓶頸投料 (synchronizing of the sequence of operations)

Applying TOC to Product Mix Decisions

Example 5.3: Diablo Electronics wants to improve profitability by accepting the right set of orders (product mix: A, B, C, D).

They collected the following financial data:

- Overhead costs are \$8,500 per week.
- Five different work stations, V, W, X, Y, Z.
- Each worker is paid \$18 per hour and is paid for an entire week. Labor costs are fixed expenses.
- The plant operates one 8-hour shift per day, or 40 hours each week.

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Example 5.3

Step 2: Allocate resources V, W, X, Y, and Z to the products in the order decided in Step 1. Satisfy each demand until the bottleneck resource (workstation X) is encountered.

B(80):Y10, X20 A(60): V30, Y10, X10 C(80):W5, Z5, X5, Y5 D(100):W15, Z10, Y5

Work Center	Minutes at the Start	Minutes Left After Making 80 B	Minutes Left After Making 60 A	Can Only Make 40 C	Can Still Make 100 D
V	2,400	2,400	600	600	600
W	2,400	2,400	2,400	2,200	700
X	2,400	800	200	0	0
Y	2,400	1,600	1,000	800	300
Z	2,400	2,400	2,400	2,200	1,200

Step 3: Profit= $(80 \times 67 + 60 \times 65 + 40 \times 40 + 100 \times 28) - (3600 + 8500) = \1560

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Example 5.3 Bottleneck Method (TOC)

Base on the dollar contribution margin per minute of processing time at the bottleneck. 同時考慮瓶頸資源的消耗

Step 1: Calculate the contribution margin/minute of processing time at bottleneck workstation X:

	Product A	Product B	Product C	Product D
Contribution margin	\$65.00	\$67.00	\$40.00	\$28.00
Time at bottleneck	10 min.	20 min.	5 min.	0 min.
Contribution margin per minute	\$6.50	\$3.35	\$8.00	Not defined

Product D is scheduled first because it does not consume any resources at the bottleneck. The manufacturing sequence is **D, C, A, B**.

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Example 5.3

Step 2: Allocate resources V, W, X, Y, and Z to the products in the order decided in step 1. Satisfy each demand until the bottleneck resource (workstation X) is encountered.

D(100):W15, Z10, Y5 **C(80):**W5, Z5, X5, Y5 **A(60):** V30, Y10, X10 **B(80):**Y10, X20

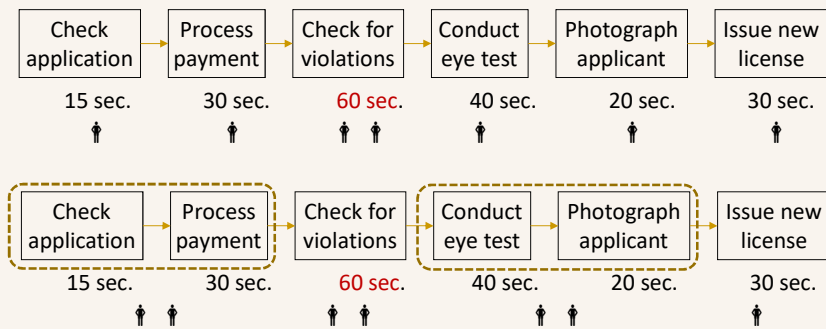
Work Center	Minutes at the Start	Minutes Left After Making 100 D	Minutes Left After Making 80 C	Minutes Left After Making 60 A	Can Only Make 70 B
V	2,400	2,400	2,400	600	600
W	2,400	900	500	500	500
X	2,400	2,400	2,000	1,400	0
Y	2,400	1,900	1,500	900	200
Z	2,400	1,400	1,000	1,000	1,000

Step 3: Profit= $(100 \times 28 + 80 \times 40 + 60 \times 65 + 70 \times 67) - (3600 + 8500) = \2490

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Managing Constraints in a Line Process

Line balancing 生產線平衡 is the assignment of work (elements) to stations in a line process so as to achieve the desired output rate with the smallest number of workstations.



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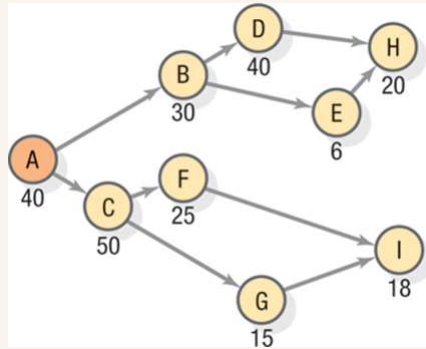
Example 5.4 Green Grass, Inc. is designing an assembly line to produce a new fertilizer spreader.

Work Element	Description	Time (sec)	Immediate Predecessor(s)
A	Bolt leg frame to hopper	40	None
B	Insert impeller shaft	30	A
C	Attach axle	50	A
D	Attach agitator	40	B
E	Attach drive wheel	6	B
F	Attach free wheel	25	C
G	Mount lower post	15	C
H	Attach controls	20	D, E
I	Mount nameplate	18	F, G
		Total 244	

畫出正確作業順序的流程圖 (precedence diagram)

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Precedence Diagram for Example 5.4



One worker for each step (element)
9 workers are needed.
Output rate = one unit every 50
sec. = 72 units/hour

One worker for all steps (elements)
Output rate = one unit every
244 sec. = 14.75 units/hour

市場需求相當於60/hour

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Line Balancing 1/3

- Assignment of work to stations (workers) so as to achieve the desired output rate r with the smallest number of stations.
- **Cycle time:** Maximum time allowed for process a unit at each station to achieve the desired output rate r . $c = \frac{1}{r}$
- Assume one worker for each station. 該站配置兩人則cycle time減半
- **Theoretical Minimum (TM):** the smallest number of stations possible to achieve the desired output rate r .

$$TM = \frac{\sum t}{c} \quad \text{where } \sum t = \text{total time required to assemble each unit}$$

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Example 5.5

Green Grass's plant manager just received marketing's latest forecasts of Big Broadcaster sales for the next year. She wants its production line to be designed to make **2,400 spreaders** per week. The plant will operate **40 hours** per week.

- What should be the line's **cycle time**?
- What is the **smallest number of stations** that she could hope for in designing the line for this cycle time?
- Suppose that she finds a solution that requires only five stations. What would be the **line's efficiency**?

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Line Balancing 2/3

Create one station at a time. For the station now being created, identify the unassigned work elements that qualify for assignment: They are candidates if

- All of their predecessors have been assigned to this station or stations already created.**
- Adding them to the workstation being created will not create a workload that exceeds the cycle time.**

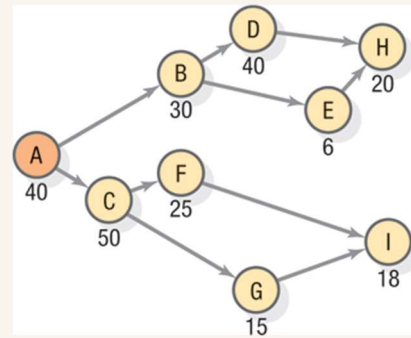
Decision Rule	Logic
<u>Longest work element</u>	Picking the candidate with the longest time to complete is an effort to fit in the most difficult elements first, leaving the ones with short times to "fill out" the station.
<u>Shortest work element</u>	This rule is the opposite of the longest work element rule because it gives preference in workstation assignments to those work elements that are quicker. It can be tried because no single rule guarantees the best solution. It might provide another solution for the planner to consider.
<u>Most followers</u>	When picking the next work element to assign to a station being created, choose the element that has the most <i>followers</i> (due to precedence requirements). In Figure 5.5, item C has three followers (F, G, and I) whereas item D has only one follower (H). This rule seeks to maintain flexibility so that good choices remain for creating the last few workstations at the end of the line.
<u>Fewest followers</u>	Picking the candidate with the fewest followers is the opposite of the most followers rule.

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Example 5.5

The precedence and cycle-time (60) requirements can not be violated.

1. Start with A. → **Station 1**
2. Use longest work element rule to select C. → **Station 2**
3. Use most followers rule to select B. → **Station 3**
 - 3.1 E, F, or G? Add F to Station 3.
4. Use longest work element rule to select D. → **Station 4**
 - 4.1 E or G? Add G to Station 4.
5. Use most followers rule to select E. → **Station 5**
 - 5.1 Add H and I to Station 5.



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Line Balancing 3/3

- Idle time = $nc - \Sigma t$

where n = number of stations, c = cycle time,
 Σt = total time required to assemble each unit

- **Line Efficiency:** ratio of productive time to total time

$$\text{Efficiency (\%)} = \frac{\Sigma t}{nc} \times (100)$$

- **Balance Delay:** the amount by which efficiency falls short of 100%

$$\text{Balance delay (\%)} = 100\% - \text{Efficiency}$$

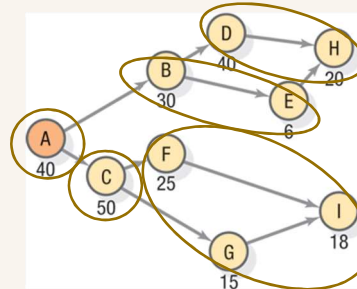
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Example 5.5

- c. The theoretical minimum number of workstations is 5. So this represents an optimal solution to the problem.

$$\text{Line Efficiency} = \frac{\sum t}{nc} \times (100) = \frac{244}{5(60)} \times (100) = \mathbf{81.3\%}$$

$$\begin{aligned} \text{Balance delay (\%)} \\ = 100\% - \text{Efficiency} = 18.7\% \end{aligned}$$



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Rebalancing the Assembly Line

Managerial Considerations

- **Pacing** is the movement of product from one station to the next as soon as the cycle time has elapsed. 控制節奏
- **Behavioral factors** such as absenteeism, turnover, and grievances can increase. 員工管理
- **Mixed model line** achieves high volume production and variety but complicates scheduling. 產品組合的影響
- **Cycle times** are dependent on the desired output rate or sometimes on the maximum workstations allowed. 市場需求

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