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 產品組合會影響瓶頸

Lucy

Operational Measures vs. Financial Measures

Inventory: 系統內所有的原料、在製品、成品

Throughput = min { supply, capacity, demand }

Total Cost = Fixed Cost + Variable Cost

$$\text{Utilization} = \frac{\text{Actual output}}{\text{Max. capacity}} \times 100\%$$

Theory of Constraints

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

If demand ≥ the capacity of the process, the bottlenecks should be scheduled to maximize throughput.* 使瓶頸產能最大化

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

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.* 有效利用瓶頸就能降低庫存與人力

Every capital investment must be viewed from the perspective of the global impact on overall throughput, inventory, and operating expense.

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Implementation of The Theory of Constraints

1. Identify the System Bottleneck(s)
2. Exploit the Bottleneck(s): Maximize the throughput of the bottleneck(s). 使瓶頸產能最大化
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
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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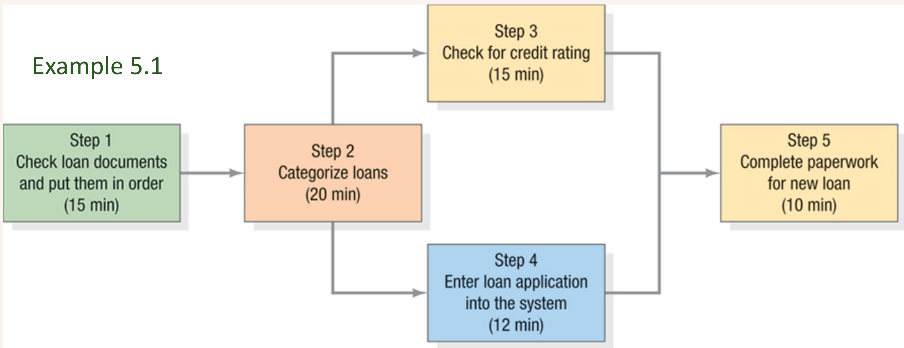
Managing Bottlenecks in Service Processes

- 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



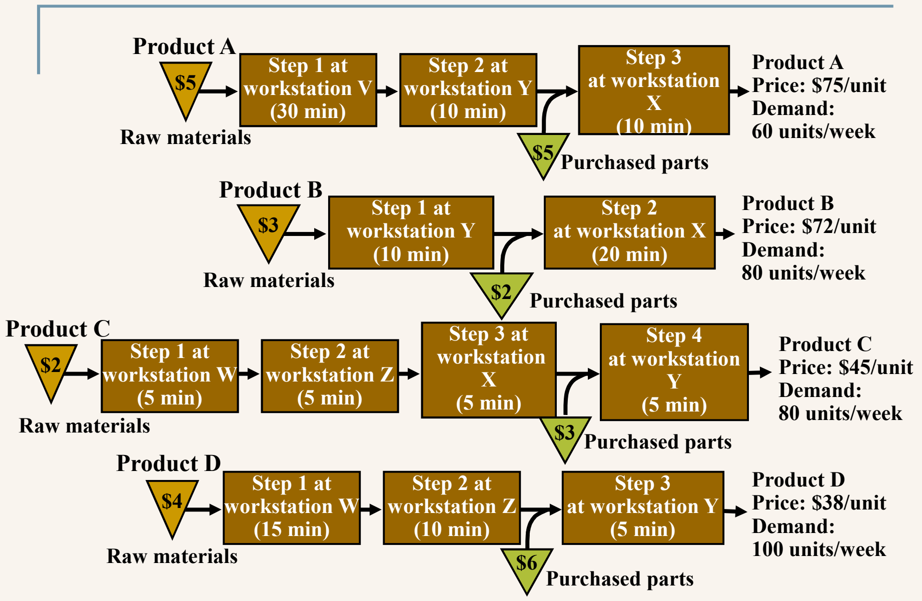
How many approved loans can be processed in a 5-hour work day?

Managing Bottlenecks in Manufacturing

- Manufacturing processes often pose complexities when identifying bottlenecks. If multiple products are involved, extra setup time is usually needed... 生產多種產品時，管理瓶頸更難

Example 5.2: Identifying Bottlenecks 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.



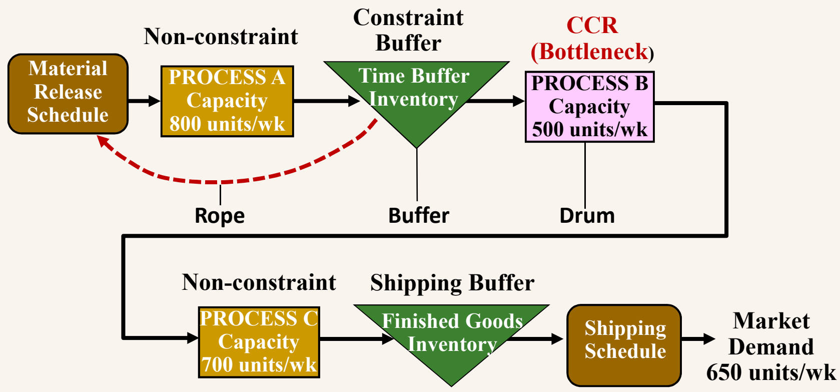
Example 5.2

Each week consists of 2,400 minutes of available production time. 如何做好做滿？

Workstation	Load from Product A	Load from Product B	Load from Product C	Load from Product D	Total Load (min)
V	60×30 = 1800	0	0	0	1,800
W	0	0	80×5 = 400	100×15 = 1,500	1,900
X	60×10 = 600	80×20 =1,600	80×5 = 400	0	2,600
Y	60×10 = 600	80×10 =800	80×5 = 400	100×5 = 500	2,300
Z	0	0	80×5 = 400	100×10 = 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setup時間不能忽略...

Drum-Buffer-Rope Systems



Applying TOC to Product Mix Decisions

Example 5.3: The management at Diablo Electronics wants to improve profitability by accepting the right set of orders (product mix).

They collected the following financial data:

- Variable overhead costs are $8,500 per week.
- Each worker is paid $18 per hour and is paid for an entire week, regardless of how much the worker is used.
- Labor costs are fixed expenses.
- The plant operates one 8-hour shift per day, or 40 hours each week.

Example 5.3

Traditional Method: accept as much of the highest contribution margin product as possible (up to the limit), followed by the next highest contribution margin product, and so on until no more capacity is available. 只考慮單位利潤

Step 1: Calculate the contribution margin per unit of each product.

	A	B	C	D
Price	$75.00	$72.00	$45.00	$38.00
Raw material and purchased parts	–10.00	–5.00	–5.00	–10.00
= Contribution margin	$65.00	$67.00	$40.00	$28.00

The order of the contribution margin per unit is B, A, C, D.

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=(80×67+60×65+40×40+100×28) – (3600+8500)=$1560

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.

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.

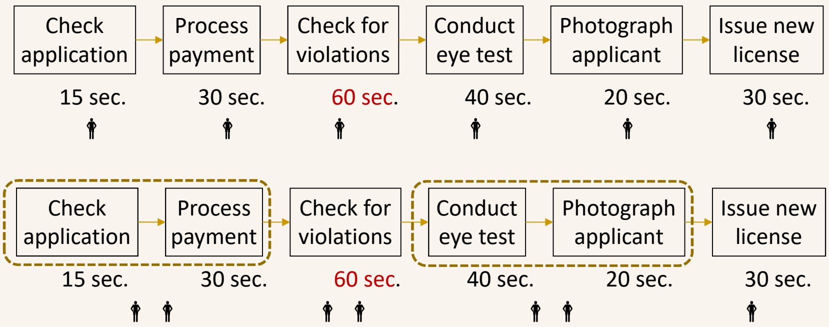
D(100):W15, Z10, Y5 C(80):W5, Z5, X5, Y5 A(60): V30, Y10, X10 B(80):Y10, X20

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=(100×28+80×40+60×65+70×67) – (3600+8500)=$2490

Managing Constraints in a Line Process

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

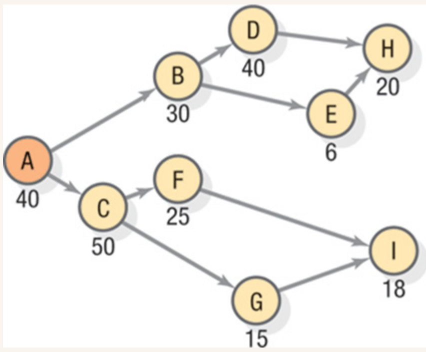


Example 5.4: Green Grass, Inc. is designing an assembly line to produce a new fertilizer spreader.

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)

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

如果市場需求相當於60/hour？

Line Balancing 1/3

- Task: 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.
- Theoretical Minimum (TM): the smallest number of stations possible to achieve the desired output rate r.

$$TM = \frac{\Sigma t}{c}$$ where Σt = total time required to assemble each unit

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.

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

Example 5.5

a. First convert the desired output rate (2,400 units per week) to an hourly rate of 60. Then the cycle time is

$c = 1/r =$ 1/60 (hr/unit) = 1 minute/unit = **60 seconds/unit**

b. Calculate the theoretical minimum for the number of stations by dividing the total time, Σt, by the cycle time, c = 60 sec.

$$\text{TM} = \frac{\Sigma t}{c} = \frac{\text{244 seconds}}{\text{60 seconds}} = 4.067 \text{ or } \textbf{5 stations}$$

The number of stations is at least 5.

Line Balancing 2/3

Any unassigned work elements is a candidate for assignment if:
1. All of their predecessors have been assigned to this station or stations already created. 先行作業均已指派
2. Adding them to the workstation being created will not create a workload that exceeds the cycle time. 不可使總時間超過cycle time

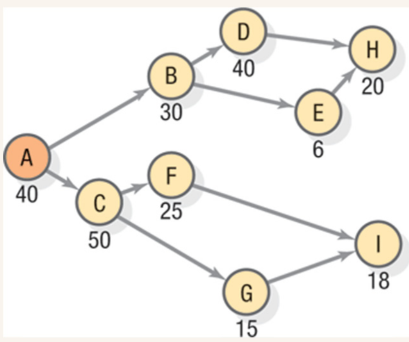
Longest work element: Picking the candidate with the longest time to complete is an effort to fit in the most difficult elements first, leaving the ones with short times to “fill out” the station.

Most followers: When picking the next work element to assign to a station being created, choose the element that has the most followers (due to precedence requirements).

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.



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

- Efficiency: the 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%

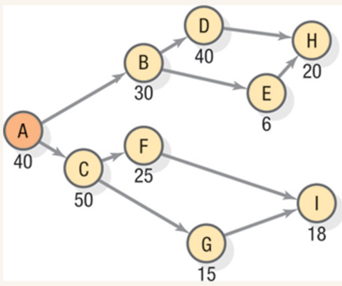
  Balance delay (%) = 100% – Efficiency

Example 5.5

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

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

Balance delay (%)
= 100% – Efficiency = 18.7%



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
  - Behavioral factors such as absenteeism, turnover, and grievances can increase.
  - The number of models produced complicates scheduling and necessitates good communication.
  - Cycle times are dependent on the desired output rate or sometimes on the maximum workstations allowed.