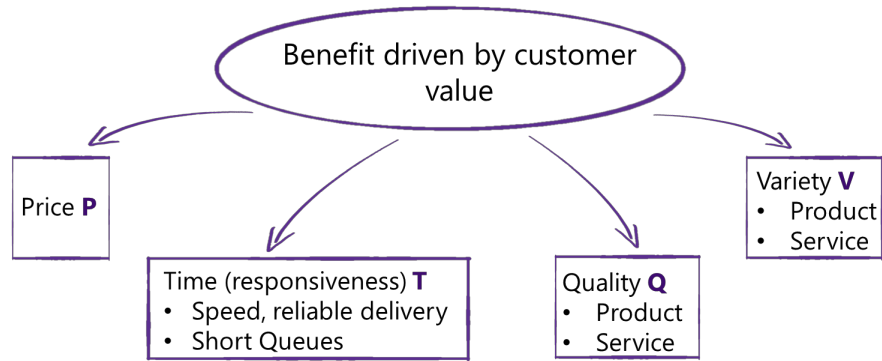


What components of consumer benefit do these products perform well on?



Example: Efficient Frontier

- There are four hotels competing with otherwise very similar products on the dimensions of price (\$ per night) and amenities (measured by the number of *s awarded by customer reviews).
- Which Hotels are on the efficient frontier?

Hotel A: price = \$200 per night; rating: ***

Hotel B: price = \$150 per night; rating: ****

Hotel C: price = \$300 per night; rating *****

Hotel D: price = \$80 per night; rating **

Check Your Understanding

Which of the following is an appropriate flow unit for a roller coaster at an amusement park?

- A. Seats on the roller coaster
- B. Riders
- C. Employees
- D. Miles per hour (as in the speed of the roller coaster)
- E. Operating time (as in the number of hours operated per day)



Example: Flow Unit

For the purpose of process analysis, which of the following measures would be considered an appropriate flow unit for analyzing the main operation of a local accounting firm?

Number of accountants

Number of tax returns completed

Number of customers with past-due invoices

Number of reams of paper received from suppliers



Check Your Understanding: Flow Rate

Over the course of an 8-hour day, a dentist's office treats 24 patients. What is the flow rate of patients in this dentist's office per hour?



Donut Shop



During a typical Friday, the West End Donut Shop serves 2,400 customers during the 10 hours it is open.

A customer spends (on average) 5-minutes in the shop.

On average, how many customers are in the shop simultaneously?

Example: Flow Rate

Ten customers visit Candy Haven Bakery from 8 am to 10 am. The customers spend 10, 15, 20, 11, 8, 12, 5, 18, 29, and 32 minutes in the bakery. What is the average flow rate of customers in this bakery per hour?

- A. 16
- B. 10
- C. 8
- D. 5

Example: 02-05

The table below provides the time stamps for the 8 people who called a reservation desk for a ferry service between 8:00 am and 8:20 am. Based on the data in the table, what is the flow time of callers?

Caller	Time in	Time out
1	8:01	8:05
2	8:02	8:07
3	8:06	8:08
4	8:09	8:12
5	8:10	8:15
6	8:12	8:20
7	8:16	8:19
8	8:17	8:19

Example: 02-08

A campus deli serves 300 customers over its busy lunch period from 11:30 a.m. to 1:30 p.m. A quick count of the number of customers waiting in line and being served by the sandwich makers shows that an average of 10 customers are in process at any point in time. What is the average amount of time that a customer spends in process?

Example: 02-10

One of the chair lifts at a ski resort unloads 1,800 skiers per hour at the top of the slope. The ride from the bottom to the top takes 12 minutes.

How many skiers are riding on the lift at any given time?

Example: 02-14

A large-scale bakery is laying out a new production process for its packaged bread, which it sells to several grocery chains. It takes 12 minutes to bake the bread.

How large of an oven is required so that the company is able to produce 4200 units of bread per hour (measured in the number of units that can be baked simultaneously)?

Example: 02-17

A consulting company must hire 15 new associates per year to replace those who have left the company for other positions or have retired. The company employs 120 associates overall.

How long is the average associate employed at the consulting company?

Check Your Understanding

Airport security consists of the following steps:

1. Verifying ID and boarding pass
2. Searching the passenger for metal objects (security scan)
3. Running the carry-on luggage through X-ray machine

There is a long line of passengers before the first step, but sometimes lines also build up at steps 2 and 3. Step 2 and 3 are parallel; that is customers go through the metal detector while their luggage is in the X-ray machine. Draw a process flow diagram of this process.



Capacity: One-step-process, Examples

It takes a color printer 10 seconds to print a large poster. What is the capacity of the printer expressed in posters per hour?

A call center has one operator who answers incoming calls. It takes the operator 6 minutes to answer one call. What is the capacity of the call center expressed in calls per hour?

Check Your Understanding

A primary care doctor has the capacity to see 16 patients per day. The demand rate is, however, only 12 patients per day.

- a. What is the flow rate?
- b. What is the utilization of the doctor?
- c. What is the cycle time, assuming a 10-hour workday?



The Time to Produce a Certain Quantity: Example

Question: Consider again the example of the three-step airport security. The first step, verifying ID and boarding pass, takes 30 seconds per passenger. The second step, searching the passenger for metal objects using a metal detector, takes 10 seconds per passenger. The third step, running the carry-on luggage through an X-ray machine, takes 60 seconds per passenger.

The process is empty at 7 am in the morning when a group of 30 passengers arrives.

How long will it take to serve all 30 passengers?

Example: 3-01

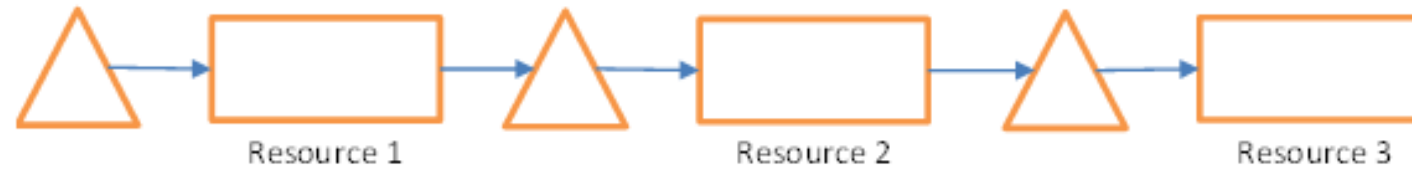
It takes a barber 15 minutes to serve one customer.

- a. What is the capacity of the barber expressed in customers per hour?
- b. Assuming the demand for the barber is 2 customers per hour, what is the flow rate?
- c. Assuming the demand for the barber is 2 customers per hour, what is the utilization?
- d. Assuming the demand for the barber is 2 customers per hour, what is the cycle time?

Example: 3-03

Consider a process consisting of three resources. Assume there exists unlimited demand for the product.

- Resource 1 has a processing time of 6 minutes per unit.
- Resource 2 has a processing time of 3 minutes per unit.
- Resource 3 has a processing time of 5 minutes per unit.



The three resources are staffed by different workers individually. The flow diagram is shown above.

- a. What is the capacity of resource 2?
- b. What is the bottleneck in the process?
- c. What is the utilization of resource 2?
- d. How long does it take the process to produce 200 units starting with an empty system, assuming this is a worker-paced process?

Example: 3-09

Consider a four-step serial process with the number of workers at each step and processing times given in the following table.

Process Step	Number of Workers	Time per Customer (in Minutes)
1	1	5
2	5	15
3	3	10
4	1	3

Assuming that the process starts out empty and is worker-paced, how long will it take (in minutes) to serve 20 customers?

Check Your Understanding

Consider the following example of a three-step process.

- The first step takes 20 minutes/unit.
 - The second step takes 10 minutes/unit.
 - The third step takes 15 minutes/unit.
-
1. Each step is staffed by one worker. What is the labor content of the process?
 2. What is the total idle time of the process, assuming unlimited demand?

Check Your Understanding

Question:

An assembly process requires the completion of six activities. A1 takes 3 minutes/unit, A2 2 minutes/unit, A3, 6 minutes/unit, A4, 1 minute/unit; A5, 2 minutes/unit; A6, 1 minute/unit. Right now, the six tasks are assigned to three workers as follows.

The first worker takes activities A1 and A2, the second worker takes activities A3 and A4, and the third worker takes activities A5 to A6. How can you improve the process by balancing the line?

Example 04-02

Mr. K's is a very popular hair salon. It offers high-quality hair styling and physical relaxation services at a reasonable price, so it always has unlimited demand. The service process includes five activities that are conducted in the sequence described next (the time required for each activity is shown in parentheses):

- Activity 1. Welcome a guest and offer homemade herb tea (10 minutes).
- Activity 2: wash and condition hair (10 minutes).
- Activity 3: Neck, shoulder, and back stress-release massage (10 minutes)
- Activity 4: Design the hairstyle and do the hair (25 minutes).
- Activity 5: Check out the guest (5 minutes).

Three servers (S1, S2, and S3) offer the services in a worker-paced line. The assignment of tasks to servers is the following: S1 does Activity 1, S2 does activities 2 and 3, and S3 does activities 4 and 5.

- a. What is the labor content?
- b. What is the average labor utilization?
- c. At a wage rate of \$20 per hour, what is the cost of direct labor per customer?
- d. Mr. K considers hiring a new employee to help one (and only one) of the servers without changing the tasks performed by each server. What will be the new direct labor?
- e. Mr. K contemplates redesigning the assignment of tasks to servers. For this, Mr. K is evaluating the reassignment of Activity 5 from S3 to S1. What will be the new direct labor?
- f. Mr. K is thinking to add one additional worker to the process. The worker would be assigned to the same set of tasks as one of the current workers. First, decide which set of tasks would benefit from one additional worker, then calculate the process capacity (customers per hour)?
- g. Suppose 4 minutes of processing time from activity 4 could be moved to activity 3 while keeping the task assignments the same. What would be the capacity of this new process (customers per hour)?
- h. Suppose each worker could be trained to complete all activities and they could all work independently of each other. What would be the capacity of this process (customers per hour)?

Example 04-03

Consider a process consisting of three resources. Assume there exists unlimited demand for the product, and that all activities are always performed in the following sequence.

- Resource 1 has a processing time of 7 minutes per unit.
- Resource 2 has a processing time of 4 minutes per unit.
- Resource 3 has a processing time of 6 minutes per unit.

All three resources are staffed by one worker and each worker gets paid \$10 per hour.

Do not round your intermediate calculations. Round your answer to 2 decimal places.

- a. What is the cost of direct labor?

Do not round your intermediate calculations. Round your answer to nearest whole number

- b. What is the labor content?

Do not round your intermediate calculations. Round your answer to 2 decimal places.

- c. What is the average labor utilization?

Do not round your intermediate calculations. Round your answer to 2 decimal places.

- d. Assume the demand rate is 24 units per hour. What is the takt time?

Do not round your intermediate calculations. Round your answer to 2 decimal places.

- e. Assume the demand rate is 24 units per hour. What is the target manpower?

Do not round your intermediate calculations. Round your answer to 1 decimal place.

- f. If one additional worker could be hired, to which resource should the additional resources be assigned? Calculate the process capacity.

Do not round your intermediate calculations. Round your answer to 1 decimal place.

- g. If they could take 1 minute of task time from one resource and give it to another resource (so the labor content remains the same), What would be the new capacity of the process (units per hour)? Assume that there is still only 1 worker per station.

Do not round your intermediate calculations. Round your answer to 1 decimal place.

- h. What would be the capacity of the process if they integrated the work so that all workers do all three tasks (units per hour)? Assume that there is still only 1 worker per station.

Sudsy Car Wash – Demand Table

Sudsy car wash offers two types of services. Exterior car wash only and Full-service, which includes the Exterior services but adds an interior cleaning. Exterior-only cars go through the automated car wash, then go to a hand drying station where a car-appearance expert hand-dries the car with towels. Full-service cars also go through the automated car wash but then go to the vacuum and fragrance station where an internal automotive aesthetic expert vacuums and cleans the car's interior. After the interior is clean, the full-service cars get hand-dried. Demand for full-service washes is 10 cars per day and demand for exterior washes is 30 cars per day.

Build the demand table for Sudsy's



Sudsy Car Wash – Bottleneck



Sudsy car wash offers two types of services. Exterior car wash only and Full-service, which includes the Exterior services but adds an interior cleaning. Exterior-only cars go through the automated car wash, then go to a hand drying station where a car-appearance expert hand-dries the car with towels. Full-service cars also go through the automated car wash but then go to the vacuum and fragrance station where an internal automotive aesthetic expert vacuums and cleans the car's interior. After the interior is clean, the full-service cars get hand-dried. Demand for full-service washes is 10 cars per day and demand for exterior washes is 30 cars per day.

The capacity is 30 cars per day at the automated car wash, 20 cars per day at the interior cleaning station, and 40 cars per day at the hand-drying station.

What is the bottleneck?

Sudsy Car Wash – Flow Rates



Sudsy car wash offers two types of services. Exterior car wash only and Full-service, which includes the Exterior services but adds an interior cleaning. Exterior-only cars go through the automated car wash, then go to a hand drying station where a car-appearance expert hand-dries the car with towels. Full-service cars also go through the automated car wash but then go to the vacuum and fragrance station where an internal automotive aesthetic expert vacuums and cleans the car's interior. After the interior is clean, the full-service cars get hand-dried. Demand for full-service washes is 10 cars per day and demand for exterior washes is 30 cars per day.

The capacity is 30 cars per day at the automated car wash, 20 cars per day at the interior cleaning station, and 40 cars per day at the hand-drying station.

What would be the actual and maximum flow rates (capacities) for the two car wash types, assuming the relative proportion between the two remains constant?

EXHIBIT 5.1 How to Find the Bottleneck and the Flow Rates in a Process with Multiple Flows

- Step 1:** Evaluate the demand table, with rows representing resources and columns representing different flows. The last column is the total demand rate across the row.
- Step 2:** Evaluate the capacity for each resource. Be sure that the capacity is given in the same time unit as the demand rate. For example, if demand is measured in loans per day, then capacities should also be in loans per day.
- Step 3:** Evaluate the implied utilization for each resource:

$$\text{Implied utilization} = \frac{\text{Resource's total demand}}{\text{Resource's capacity}}$$

- The resource with the highest implied utilization is the bottleneck.
- Step 4:** The capacity for each type of flow (assuming capacity is divided proportional to demand) is that flow's demand divided by the highest implied utilization. The actual flow rate for each flow depends on if the process is demand-constrained or supply-constrained:
- If the highest implied utilization is less than or equal to 100 percent, the flow rates equal the demand rates.
 - If the highest implied utilization exceeds 100 percent, divide the demand rate for each flow type by the highest implied utilization.

EXHIBIT 5.2 How to Find the Bottleneck and the Flow Rates in a Process with Flow-Dependent Processing Times

- Step 1:** Compute the workload for each resource and type of demand. The workload of a resource from a type of demand equals the resource's processing time for that demand times the demand rate.
- Step 2:** Sum the workloads for each resource across all demand types.
- Step 3:** Compute each resource's capacity (i.e., available time), which is the number of workers at the resource times 60 minutes per hour.
- Step 4:** Compute the implied utilization for each resource:

$$\text{Implied utilization} = \frac{\text{Demand rate in minutes of work}}{\text{Capacity in minutes of work}}$$

- The resource with the highest implied utilization is the bottleneck.
- Step 5:** The maximum flow rate for each flow equals its demand rate divided by the process's maximum implied utilization. The actual flow rate for each flow is evaluated as follows:
- If the highest implied utilization is less or equal to 100 percent, the actual flow rates equal the demand rates.
 - If the highest implied utilization exceeds 100 percent, the actual flow rate equals the demand rate for each flow divided by the highest implied utilization.

Hiring Interns

WeDoEverything Inc. is hiring interns to work as operations managers in their distribution centers across the US. Candidates submit their applications, then they go through a 3-step vetting process. Resumes are reviewed, then candidates who meet resume requirements take an online assessment. Candidates who successfully complete the online assessment are then interviewed. Offers are then made to candidates who impress the interviewer. 50% of all applicants make it to the online assessment. Then 25% of the candidates who take the online assessment progress to the interviews. Only 10% of the interviewed candidates get internship offers.

What percentage of all applicants get an offer?

EXHIBIT 5.3 How to Find the Bottleneck and the Capacity in a Process with Rework?

- Step 1:** At each resource with rework, evaluate the weighted average processing time. For example, if 70 percent of units take 2 hours and 30 percent of units take 5 hours, then the weighted-average processing time is $0.7 \times 2 + 0.3 \times 5 = 2.9$ hours
- Step 2:** Evaluate the Capacity of each resource, which is $1 / \text{processing time}$.
- Step 3:** Evaluate for each resource the Implied utilization = Demand / Capacity. The resource with the highest utilization is the bottleneck.

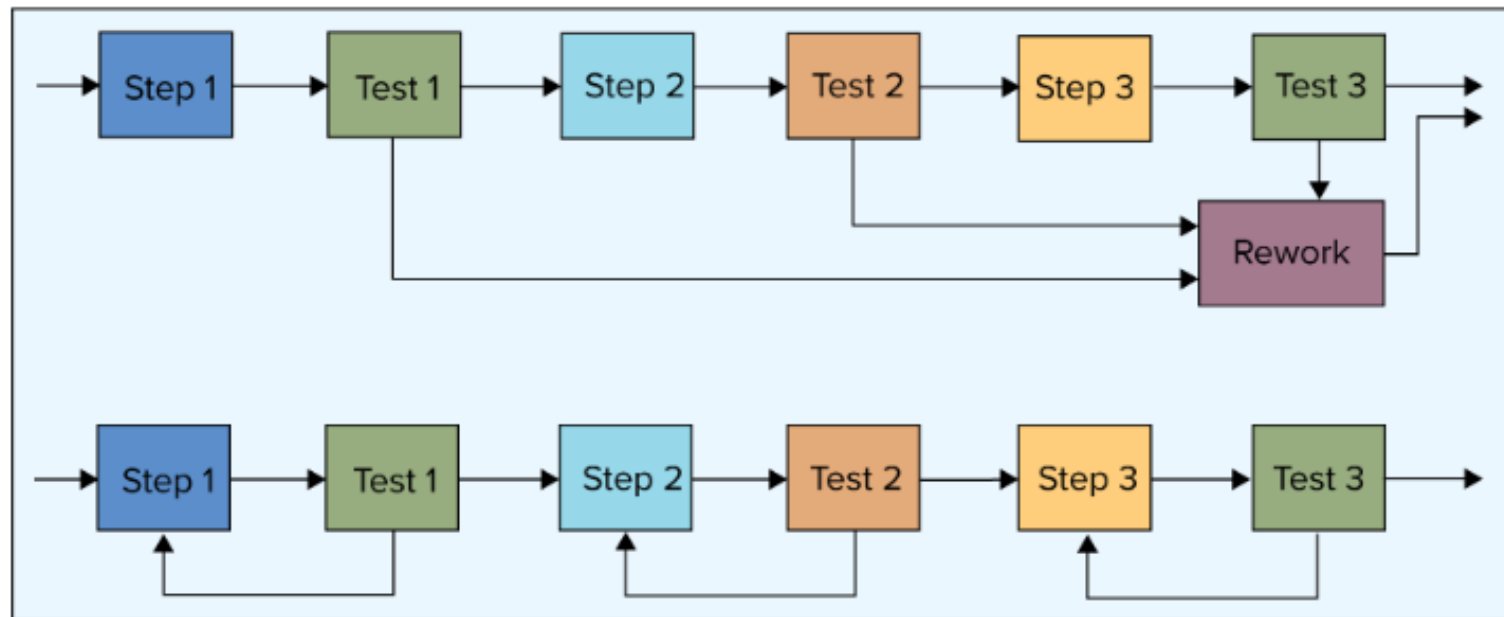


Figure 5.6 Example of two processes with rework

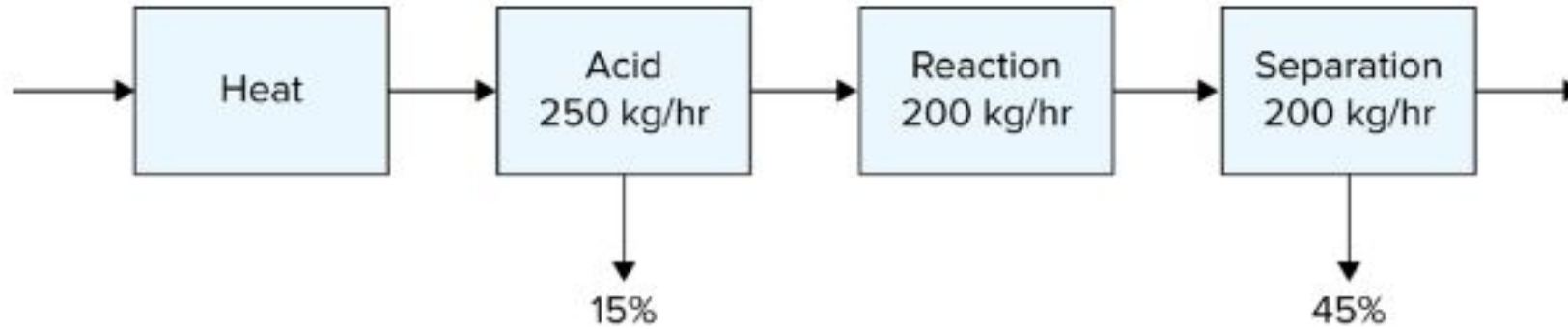
Stepper

A stepper is a piece of equipment in semiconductor manufacturing. Each wafer's initial pass through the stepper requires 15 minutes. For 40 percent of wafers, they make only a single pass through the stepper. But 60 percent of wafers need to make a second pass through the stepper. The processing time on the second pass is 40 minutes.

How many wafers does the stepper complete per hour (wafers/hr) assuming the stepper works at capacity?

Pharmaceutical Production

A pharmaceutical company creates a compound with a four-stage process:



Some of the resources have partial yields: 15 percent of material is discarded after the Acid step and 45 percent of the material is discarded after the separation step. The capacities of the last three steps are indicated in the diagram above.

- (a)** What is the yield of this process?
- (b)** What is the minimum capacity (kg/hr) of the first step, Heat, so that the process can yield 100kg/hr of final product?

Workload Table

Two types of customers are served by a two-step process. Each resource is staffed by one employee. Customer A spends two minutes at resource X and five minutes at resource Y. Customer B spends five minutes at resource X and two minutes at resource Y. The demand rate per hour is 10 customer As and 15 customer Bs. Which of the following is the workload table for this situation?



	All customers
Resource X	95
Resource Y	80



	Customer A	Customer B
Resource X	2	5
Resource Y	5	2



	Customer A	Customer B
Resource X	20	75
Resource Y	50	30



	Customer A	Customer B
All resources	70	105

HW 4 Problem 3

GV is a small accounting firm supporting wealthy individuals in their preparation of annual income tax statements. Every December, GV sends out a short survey to its customers, asking for the information required for preparing the tax statements. Based on 50 years of experience, GV categorizes its cases into the following two groups:

- Group 1 (new customers): 20 percent of cases
- Group 2 (repeat customers): 80 percent of cases

This year, there are 50 income tax statements arriving each week. In order to prepare the income tax statement, GV has three resources. The activities are carried out by the following three persons who each work 40 hours per week:

- An administrative support person who processes every tax statement.
- A senior accountant (who is also the owner) who processes only tax statements for new customers.
- A junior accountant who only processes tax statements for repeat customers.

Group	Administrator [min/unit]	Handling by Senior Accountant [min/unit]	Handling by Junior Accountant [min/unit]
1	20	40	n/a
2	20	n/a	15

- a. What is the total demand rate for each of the three resources?
- b. Which of the three persons is the bottleneck?
- c. For a mix of 20:80 between new and old cases, what is the flow rate for new and repeat customers
- d. For a mix of 20:80 between new and old cases, what is the capacity for new and repeat customers