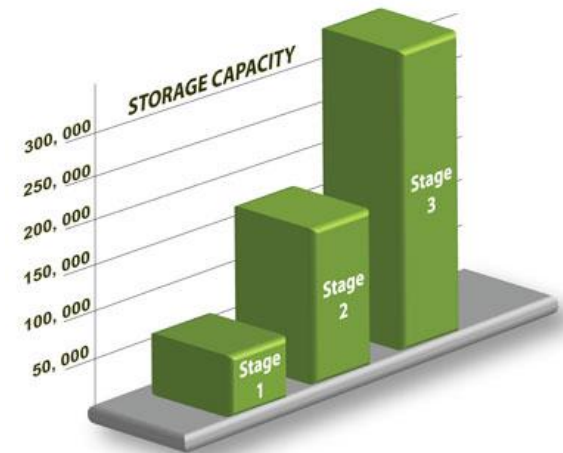# Capacity
Planning and measurement

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PPU426

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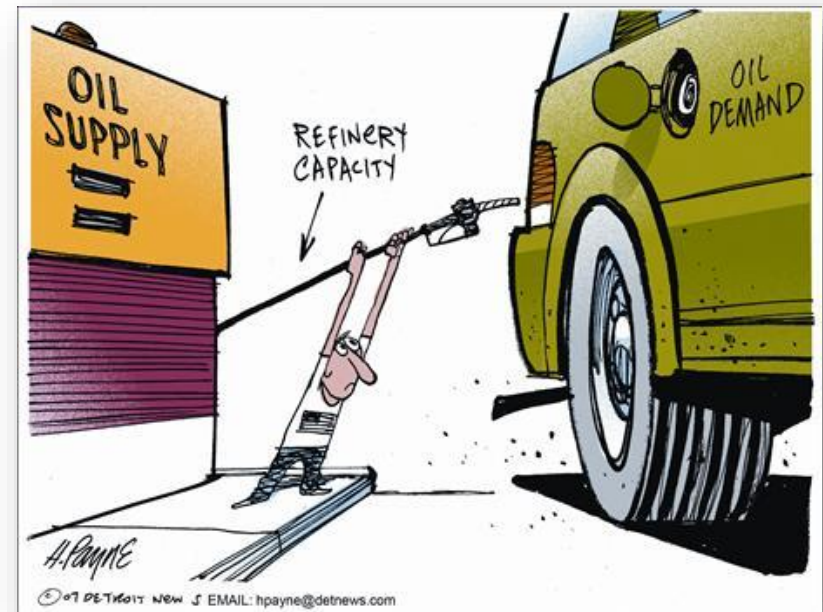| BSc in Nursing	→	MSc in Engineering	→	Research Assistant

Agenda

- Capacity
- Break even analysis
- Coffee Break
- Waiting lines

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What is production capacity?

The maximum **rate** of output for a facility

OR

The **rate** at which output can be produced by an operating unit (machine, process, workstation, facility or an entire company).

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Factors that determine capacity

- **Process design**
- **Product design**
- **Product variety**
- **Product quality**

The following affect the amount of productive time/utilization

1. **Production scheduling**
2. **Materials management**
3. **Maintenance**
4. **Job design and personnel management**

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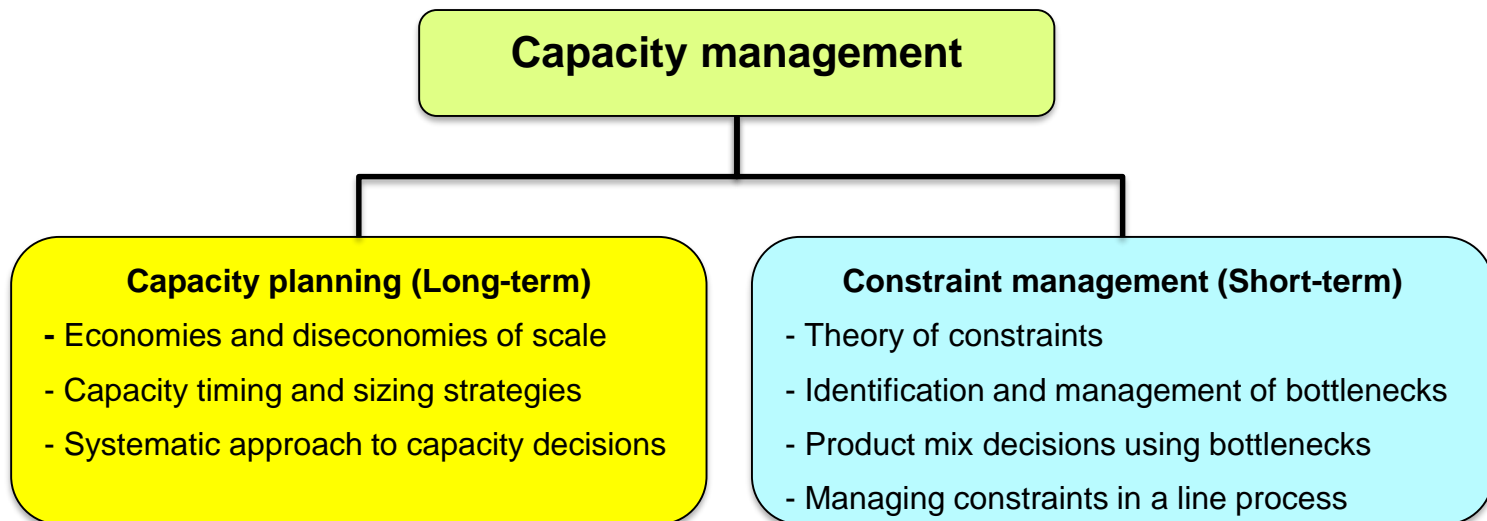
Capacity across the Organization

- Accounting – evaluation

- Finance – financial analysis

- Marketing – demand forecasts

- Management information systems – electronic infrastructure

- Operations – capacity strategies

- Purchasing – external capacity acquisitions

- Human resources – hiring and training

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Capacity planning

Capacity plans are made at two levels:

- **Long term**: deal with investment in new facilities and equipment (> ~2 years)
- **Short term**: focus on work force size, overtime budget, inventories (< ~2 years)

Capacity management

Capacity planning (Long-term)

- Economies and diseconomies of scale
- Capacity timing and sizing strategies
- Systematic approach to capacity decisions

Constraint management (Short-term)

- Theory of constraints
- Identification and management of bottlenecks
- Product mix decisions using bottlenecks
- Managing constraints in a line process

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Capacity Strategy

- What is the capacity of the current system?
→ Need of a systematic approach

- How much of a *cushion* is needed to handle variable, or uncertain, demand?
- Should we *expand* capacity ahead of demand, or wait until demand is more certain?

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Measures of capacity

No single measure is applicable to all types of situations.

In general, capacity can be expressed in:

- **Output measures:** Usual choice for product focused firms (standardized products/services)
- **Input measures:** Usual choice for process focused firms (flexible flow processes)

Examples:

- **Hospitals**: Number of patients that can be treated per day
- **Retailers**: Annual sales dollar generated per m^2
- **Airlines**: Available seats per month
- **Job shop**: Number of machine hours

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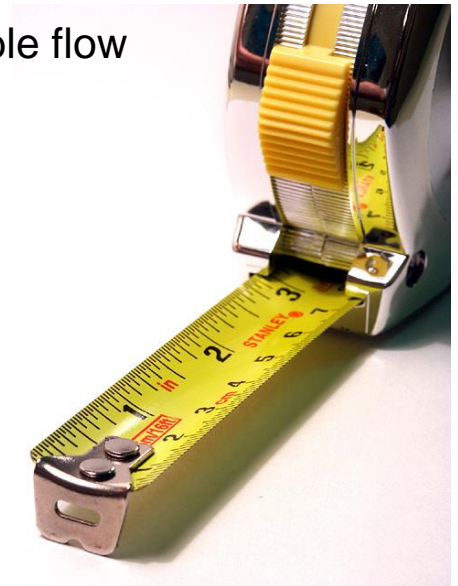
Utilization

Utilization is to which degree equipment, space or labor is currently being used and requires a knowledge about current capacity (expressed in %).
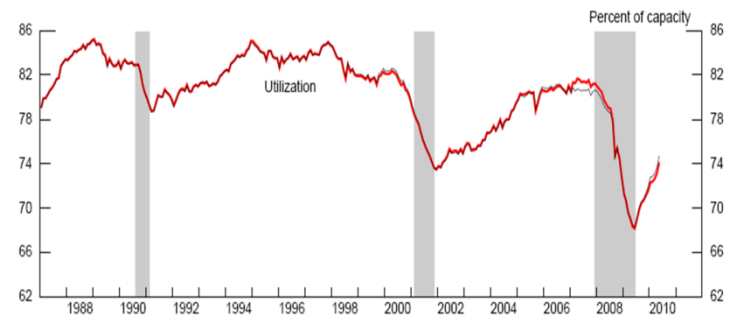
Utilization = (Average output rate/maximum capacity)* 100   [%]

Important! _Average output rate/maximum capacity have to be measured in the same terms (e.g. pc./min, time, SEK, customers etc)_

Two definitions of **maximum capacity:**
- Design capacity/Peak capacity (ideal conditions)
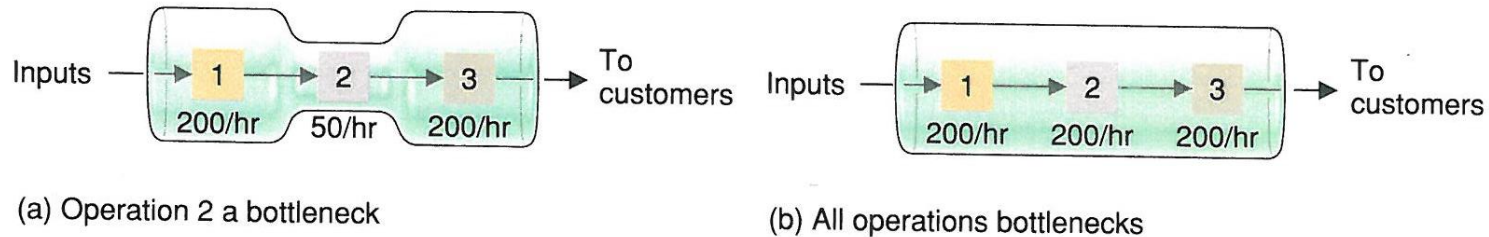- Effective capacity (normal conditions)

(Example)

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Increasing maximum capacity

Most facilities have multiple operations and often their effective capacities are not identical. This can lead to bottlenecks.

Capacity Bottlenecks at a Three-Operation Facility

(a) Operation 2 a bottleneck

(b) All operations bottlenecks

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Theory of Constraints

- Also known as the Drum-Buffer-Rope method.

- Developing schedules that focus on bottlenecks.

Overview:

1. Identify the bottlenecks

2. Exploit the bottlenecks

3. Subordinate all other decisions to step 2

4. Elevate the bottlenecks

5. Do not let inertia set in

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Theory of Constraints

1. Identify the bottlenecks

The bottleneck is the operation that has the lowest real capacity of the system. It might be a high speed machine with low utilization as well as a low speed machine with high utilization.

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Theory of Constraints

2. Exploit the bottlenecks

Increase the capacity of the bottleneck as much as possible within the existing system. This is often achieved through increase of the utilization.

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Theory of Constraints

3. Subordinate all other decisions

The non-bottleneck resources should be scheduled to support the bottleneck and not produce more than it can handle.

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Theory of Constraints

4. Elevate the bottlenecks

If the previous activities have not eliminated the bottleneck, changes of the system should be considered. This might include investments or changed working hours.

Theory of Constraints

5. Avoid inertia

When the original bottleneck is eliminated, there is a high probability that some other part of the process has become a bottleneck. Therefore it is important not to stand still but to start working with the new bottleneck.

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Economies of scale

States that the average unit cost of a service or good can be reduced by increasing its output rate. This is explained by 4 principle reasons:

- **Spreading Fixed Costs**

    Average unit cost drops because fixed costs (e.g. heating) are spread over more units.

- **Reducing Construction Costs**

    Certain activities and expenses (e.g. building equipment) are required to build small and large facilities alike.

- **Cutting Costs of Purchased Materials**

    Higher volumes can reduce the costs of purchased materials and services (e.g. quanity discounts).

- **Finding Process Advantages**

    High-volume production provides many opportunities for cost reduction (e.g. shared process investments).

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Diseconomies of scale

States that a facility can become so large that the average cost per unit increases with the size of the facility. Some examples are:

- **Increased bureaucracy**

  Many layers of employees can impede communication and increase complexity.
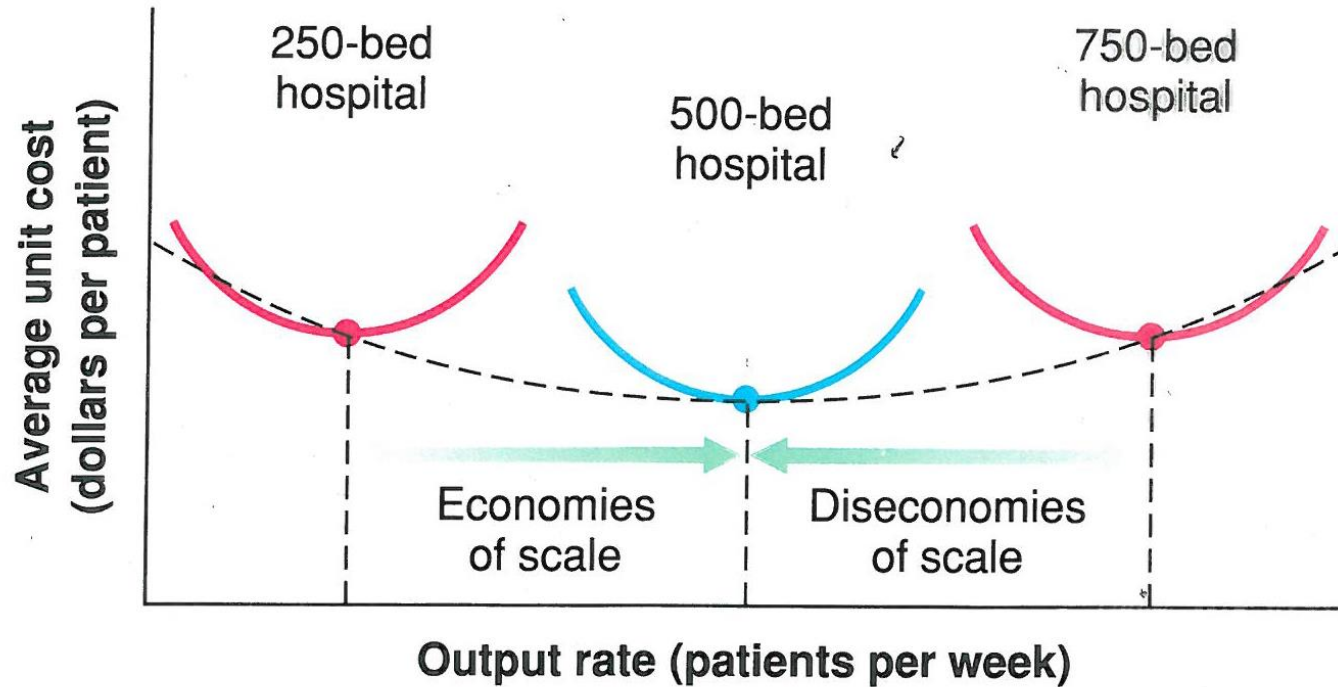
- **Reduced flexibility**

  Less ability to respond to changes in customer demand.

- **Lost focus**

  Focus is turned to administration instead of innovation and development.

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Economies and diseconomies of scale

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Capacity strategies

When choosing a **capacity strategy**, managers must consider questions such as:

- **Sizing capacity cushions**

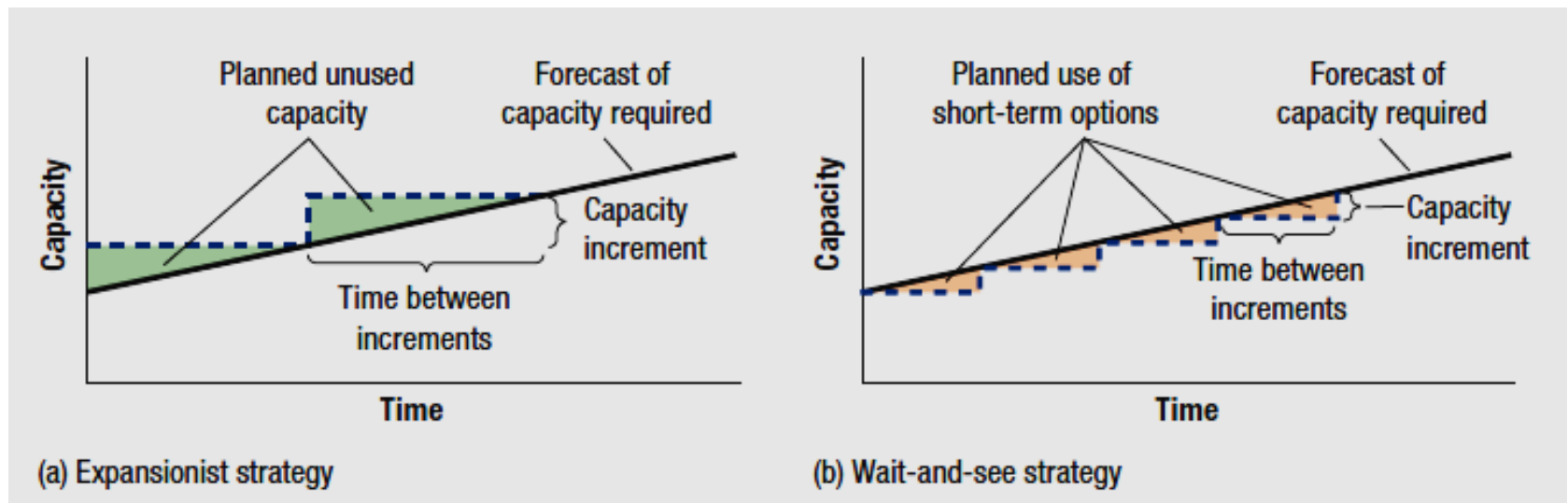 How much "cushion" is needed to handle variable, uncertain demand?

- **Linking capacity and other decisions**

  How should we link capacity decisions to e.g. location, resource flexibility and inventory decisions.

- **Timing and sizing of expansion**

  Should we expand capacity before demand or wait until demand is certain?

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Timing and Sizing Expansion – Two strategies

(a) Expansionist strategy

(b) Wait-and-see strategy

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A systematic approach to long term capacity decisions

Although each situation is somewhat different, a four-step procedure generally can help managers make sound capacity decisions.

- (Step 0: determining the process's existing capacity and assessing whether its current capacity cushion is appropriate)
- **Step 1: Estimate capacity requirements (M)**
- **Step 2: Identify gaps**
- **Step 3: Develop alternative plans for reducing the gaps.**
- **Step 4: Evaluate each alternative, both qualitatively and quantitatively, and make a final choice.**

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A systematic approach to long term capacity decisions

Step 1: Estimate capacity requirements (M)

- What capacity should be for some future time period to meet the demand of the firm's customers (external or internal), given the firm's desired capacity cushion.

- The foundation for the estimate is forecasts of demand, productivity, competition, and technological change

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A systematic approach to long term capacity decisions

Step 2: Identify gaps

    Any difference (positive or negative) between projected capacity requirements (M) and current (available) capacity.

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A systematic approach to long term capacity decisions

Step 3: Develop alternative plans for reducing the gaps.

Compare with the base case (to do nothing).

Expanding capacity at a different location or using short-term options, such as overtime, temporary workers, and subcontracting.

Reducing capacity through the closing of plants or warehouses, laying off employees, or reducing the days or hours of operation.

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A systematic approach to long term capacity decisions

Step 4: Evaluate each alternative, both qualitatively and quantitatively, and make a final choice.

Qualitative concerns: How each alternative fits the overall capacity strategy and other aspects of business not covered by the financial analysis, e.g. uncertainties in demand, technological change etc.

Quantitative concerns: How the change in cash flows for each alternative over the forecast time horizon compares to the base case.

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Capacity: Single products

Capacity requirement =

$$\frac{\text{Processing hours required for year's demand}}{\text{Hours available from a single capacity unit (such as an employee or machine) per year, after deducting desired cushion}}$$

$$M = \frac{Dp}{N[1 - (C/100)]}$$

D = demand forecast for the year (number of customers serviced, or units of products)

p = processing time (in hours per customer served or unit produced)

N = total number of hours per year during which the process operates

C = desired capacity cushion (expressed as percent)

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Capacity: Multiple products

Capacity requirement = $\dfrac{\text{Processing and setup hours required for year's demand, summed over all services or products}}{\text{Hours available from a single capacity unit (such as an employee or machine) per year, after deducting desired cushion}}$

$$M = \frac{[Dp+(D/Q)s]_{\text{product 1}} + [Dp+(D/Q)s]_{\text{product 2}} + \ldots + [Dp+(D/Q)s]_{\text{product n}}}{N[1-(C/100)]}$$

Q = number of units in each lot

s = setup time (in hours) per lot

EXAMPLE **1**

Capacity planning

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D = demand forecast for the year (number of customers serviced, or units of products)

p = processing time (in hours per customer served or unit produced)

N = total number of hours per year during which the process operates

C = desired capacity cushion (expressed as percent)

Q = number of units in each lot

s = setup time (in hours) per lot

A copy center in an office building prepares bound reports for two clients. The center makes multiple copies (the lot size) of each report. The processing time to run, collate, and bind each copy depends on, among other factors, the number of pages. The center operates 250 days per year, with one 8-hour shift. Management believes that a capacity cushion of 15 percent (beyond the allowance built into time standards) is best. It currently has three copy machines. Based on the following table of information, determine how many machines are needed at the copy center.

Item	Client X	Client Y
Annual demand forecast (copies)	2,000	6,000
Standard processing time (hour/copy)	0.5	0.7
Average lot size (copies per report)	20	30
Standard setup time (hours)	0.25	0.40

$$M = \frac{[Dp+(D/Q)s]_{\text{product 1}} + [Dp+(D/Q)s]_{\text{product 2}} + \ldots + [Dp+(D/Q)s]_{\text{product n}}}{N[1 - (C/100)]}$$

$$M = \frac{[Dp + (D/Q)s]_{\text{product 1}} + [Dp + (D/Q)s]_{\text{product 2}} + \cdots + [Dp + (D/Q)s]_{\text{product } n}}{N\,[1-(C/100)]}$$

$$= \frac{[2{,}000(0.5) + (2{,}000/20)(0.25)]_{\text{client X}} + [6{,}000(0.7) + (6{,}000/30)(0.40)]_{\text{client Y}}}{[(250 \text{ day/year})(1 \text{ shift/day})(8 \text{ hours/day})][1.0 - (15/100)]}$$

$$= \frac{5{,}305}{1{,}700} = 3.12$$

Rounding up to the next integer gives a requirement of four machines.

EXAMPLE 2

Capacity planning

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Problem to solve

A company manufactures touring bikes and mountain bikes in a variety of frame sizes, colors, and component combinations. Identical bicycles are produced in lots of 100. The projected demand, lot size, and time standards are shown in the table below.

Item	Touring	Mountain
Demand forecast	2000 units/year	15000units/year
Lot size	100 units	100 units
Standard processing time	0.5 hour/unit	0.67 hors/unit
Standard setup time	1.0 hour/lot	1.0 hour/lot

The shop currently works 8 hours a day, 5 days a week, 50 weeks a year. The company has 5 workstations, each producing one bicycle in the time shown in the table. The shop maintains a 20 percent capacity cushion. How many workstations will the company require next year to meet the expected demand without using overtime and without decreasing its capacity cushion ?

D = demand forecast for the year (number of customers serviced, or units of products)

p = processing time (in hours per customer served or unit produced)

N = total number of hours per year during which the process operates

C = desired capacity cushion (expressed as percent)

Q = number of units in each lot

s = setup time (in hours) per lot

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$$M = \frac{[Dp+(D/Q)s]_{product\ 1} + [Dp+(D/Q)s]_{product\ 2} + \ldots + [Dp+(D/Q)s]_{product\ n}}{N[1 - (C/100)]}$$

Solution

Summing up the machine hour requirements for both bikes:

R = $[2,000(0.5) + (2,000 / 100)(1.0)] + [15,000(2 / 3) + (15,000 / 100)(1.0)]$

= 11,170 hours

The number of hours (H) provided per work station is :

H = (8 hours/day x 5 days/week x 50 weeks/year)(1.0 – 0.2)

= 1,600 hours

The capacity requirement is:

M = $R/H = 11,170 / 1,600 = 6.98$ or 7 work stations

Trak will require 7 work stations.

Tools for Capacity Planning

Long term planning requires demand forecast for an extended period of time, but forecast inaccuracy increases with a longer time horizon.

- **Break even analysis**

- **Decision trees**

  For evaluating different capacity expansion alternatives when demand is uncertain and sequential decisions are involved.

- **Waiting-line models**

  Use probability distributions to provide estimates of average customer wait time, average length of waiting lines, and utilization of the work center.

  Later today

- **Simulation**

  Identifies the process's bottlenecks and appropriate capacity cushions, even for complex processes with random demand patterns and predictable surges in demand during a typical day.

  Not covered in this course!

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Break even analysis (BEA)

Break-even analysis is used to determine the volume of sales at which a product or service breaks even (total cost = total revenues). It is based on the assumption that all costs related to production of a specific service or product can be divided into two categories: variable costs and fixed costs.

- **Fixed cost, F**

  The portion of the total cost that remains constant regardless of changes in levels of output:, e.g. the annual cost of renting or buying new equipment and facilities.

- **Variable cost, c**

  The portion of the total cost that varies directly with volume of output, e.g. costs per unit for materials, labor, and usually some fraction of overhead.

- **Number of customers served, Q**

  Quantities sold.

- **Revenue per unit sold, p**

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Break even analysis

Total cost = F + c*Q

Total Revenue = p*Q

To calculate the break even quantity Q, set
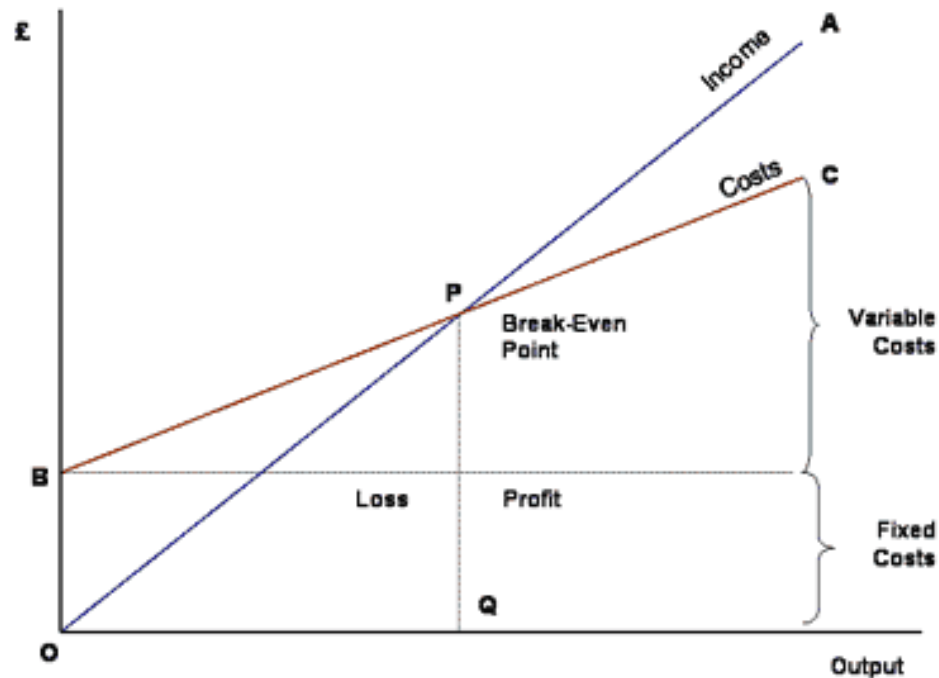total cost = total revenue

F + c*Q = p*Q

(p-c)*Q = F

Q = F/(p-c)

F = Fixed cost
c = Variable cost
Q = Number of customers served
p = Revenue per unit sold

Break even analysis

This linear relationship can also be illustrated graphically

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EXAMPLE **3**

Break even analysis

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A hospital is considering a new procedure to be offered at $200 per patient. Fixed cost per year would be $100,000, with total variable costs of $100 per patient. What is the break-even quantity for this service? Use both algebraic and graphic approaches to get the answer.

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A hospital is considering a new procedure to be offered at $200 per patient. Fixed cost per year would be $100,000, with total variable costs of $100 per patient. What is the break-even quantity for this service? Use both algebraic and graphic approaches to get the answer.

c

$$Q = F/(p-c)$$

F = Fixed cost
c = Variable cost
Q = Number of customers served
p = Revenue per unit sold

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SOLUTION

The formula for the break-even quantity yields

$$Q = \frac{F}{p - c} = \frac{100,000}{200 - 100} = 1,000 \text{ patients}$$

Graphical solution

1. Plot two lines – one for revenue, one for costs
2. Calculate costs and revenue for two different output levels
   - Set for instance Q=0 and Q=2000

Total cost = F + c*Q = 100 000 + 100 *Q

Total Revenue = p*Q = 200*Q

Quantity (patients) (Q)	Total Annual Cost ($) (100,000 + 100$Q$)	Total Annual Revenue ($) (200$Q$)
0	100,000	0
2,000	300,000	400,000

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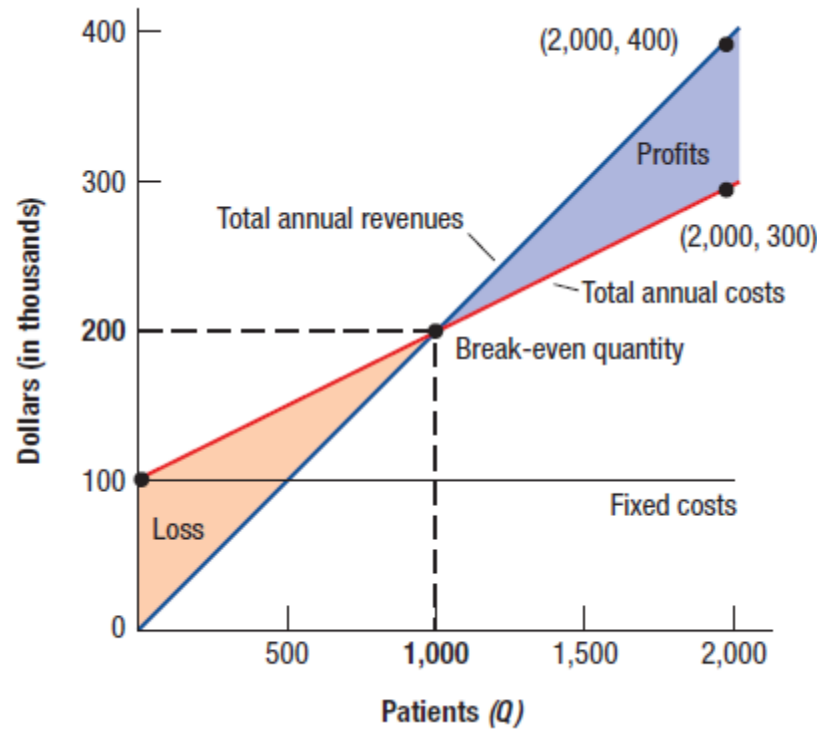
Cost line (red): (0, 100 000) and (2000, 300 000)
Revenue line (blue): (0,0) and (2000, 400 000)
Break even quantity: 1000 patients

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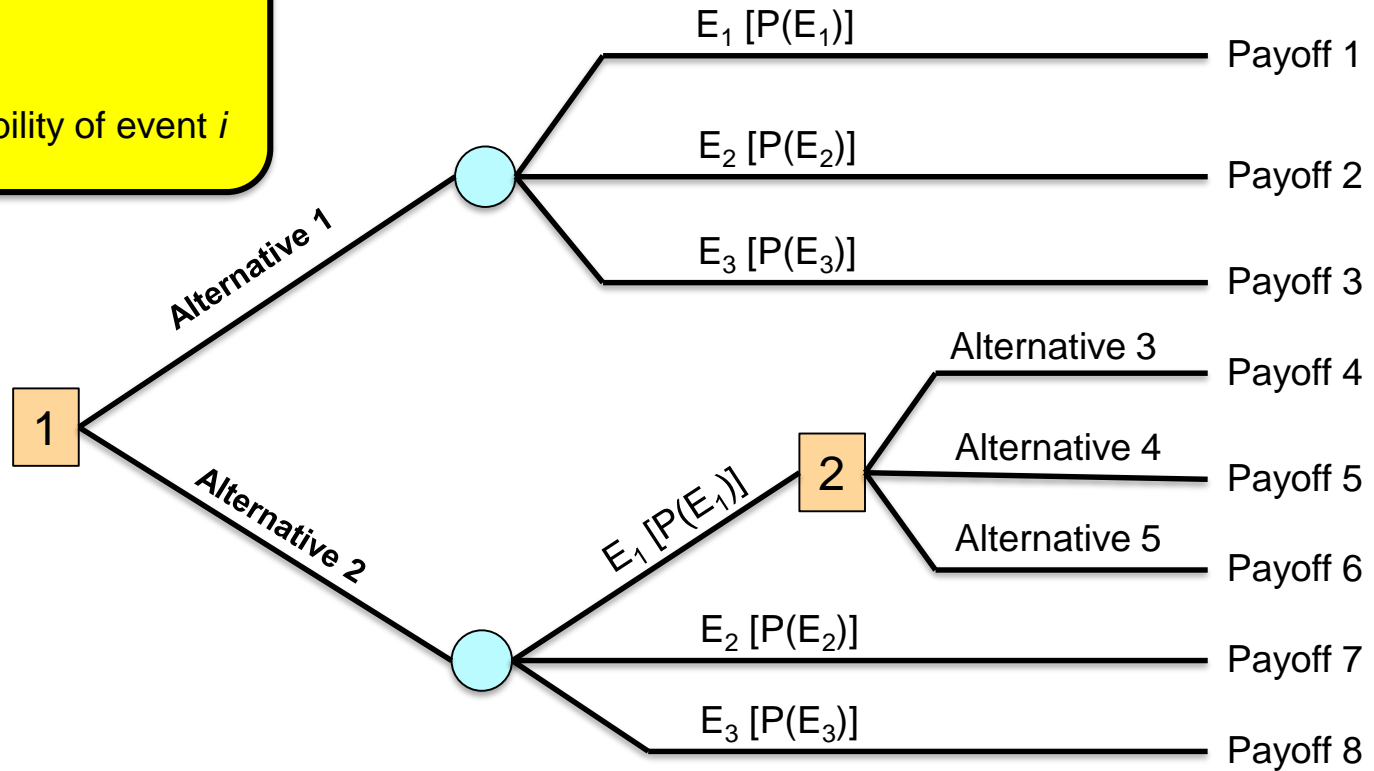
Decision trees

- General approach to a wide range of OM decisions
- Particularly valuable for evaluating different capacity expansion alternatives
- A schematic model of alternatives

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Decision trees

⬤ = Event node

1 = Decision node

E_i = Event i

$P(E_i)$ = Probability of event i

$E_1 [P(E_1)]$ — Payoff 1

$E_2 [P(E_2)]$ — Payoff 2

$E_3 [P(E_3)]$ — Payoff 3

Alternative 1

Alternative 3 — Payoff 4

Alternative 4 — Payoff 5

Alternative 5 — Payoff 6

1

2

Alternative 2

$E_1 [P(E_1)]$
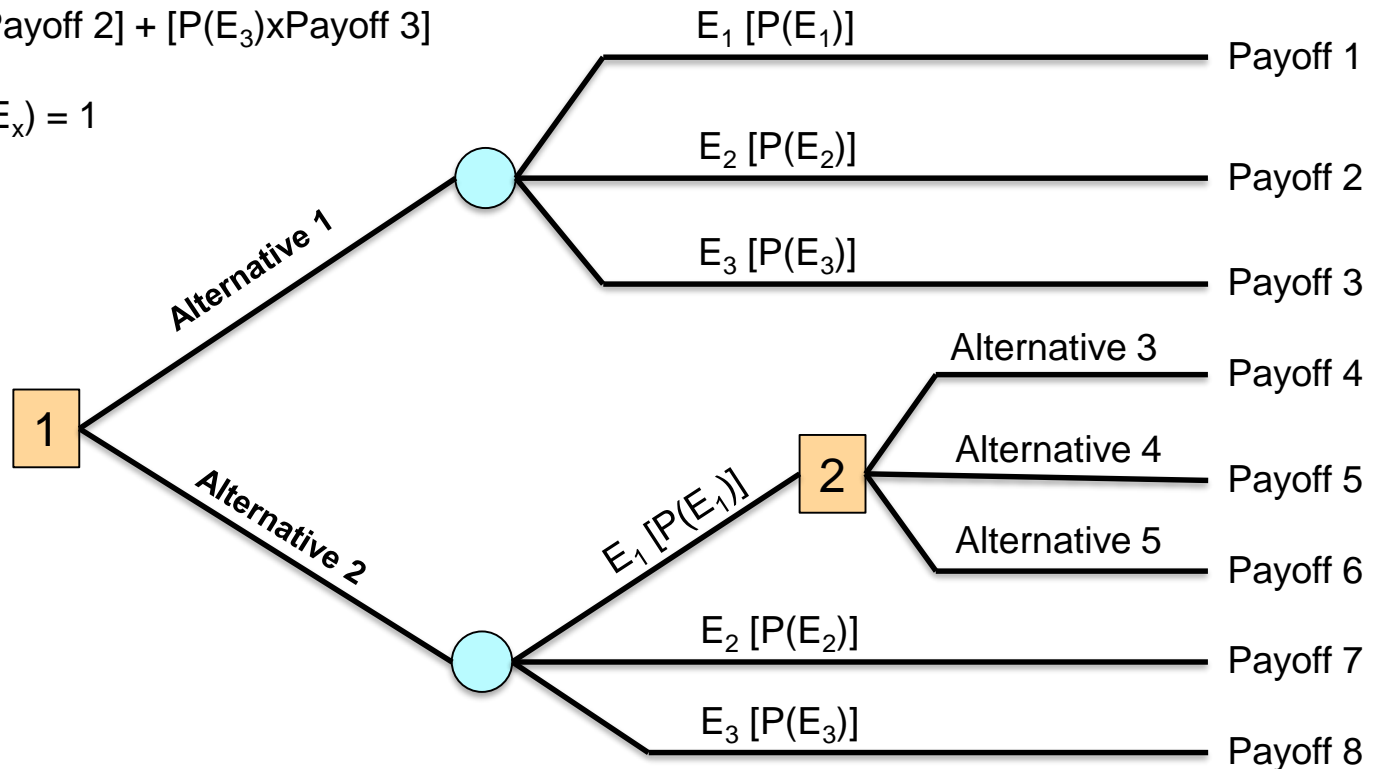
$E_2 [P(E_2)]$ — Payoff 7

$E_3 [P(E_3)]$ — Payoff 8

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The expected payoff of Alternative 1is:
$[P(E_1) \times \text{Payoff 1}] + [P(E_2) \times \text{Payoff 2}] + [P(E_3) \times \text{Payoff 3}]$

For each event node: $\Sigma\, P(E_x) = 1$

$E_1\ [P(E_1)]$ — Payoff 1

$E_2\ [P(E_2)]$ — Payoff 2

$E_3\ [P(E_3)]$ — Payoff 3

Alternative 1

1

Alternative 2

$E_1\ [P(E_1)]$

2

Alternative 3 — Payoff 4

Alternative 4 — Payoff 5

Alternative 5 — Payoff 6

$E_2\ [P(E_2)]$ — Payoff 7

$E_3\ [P(E_3)]$ — Payoff 8

EXAMPLE 4

Break even analysis
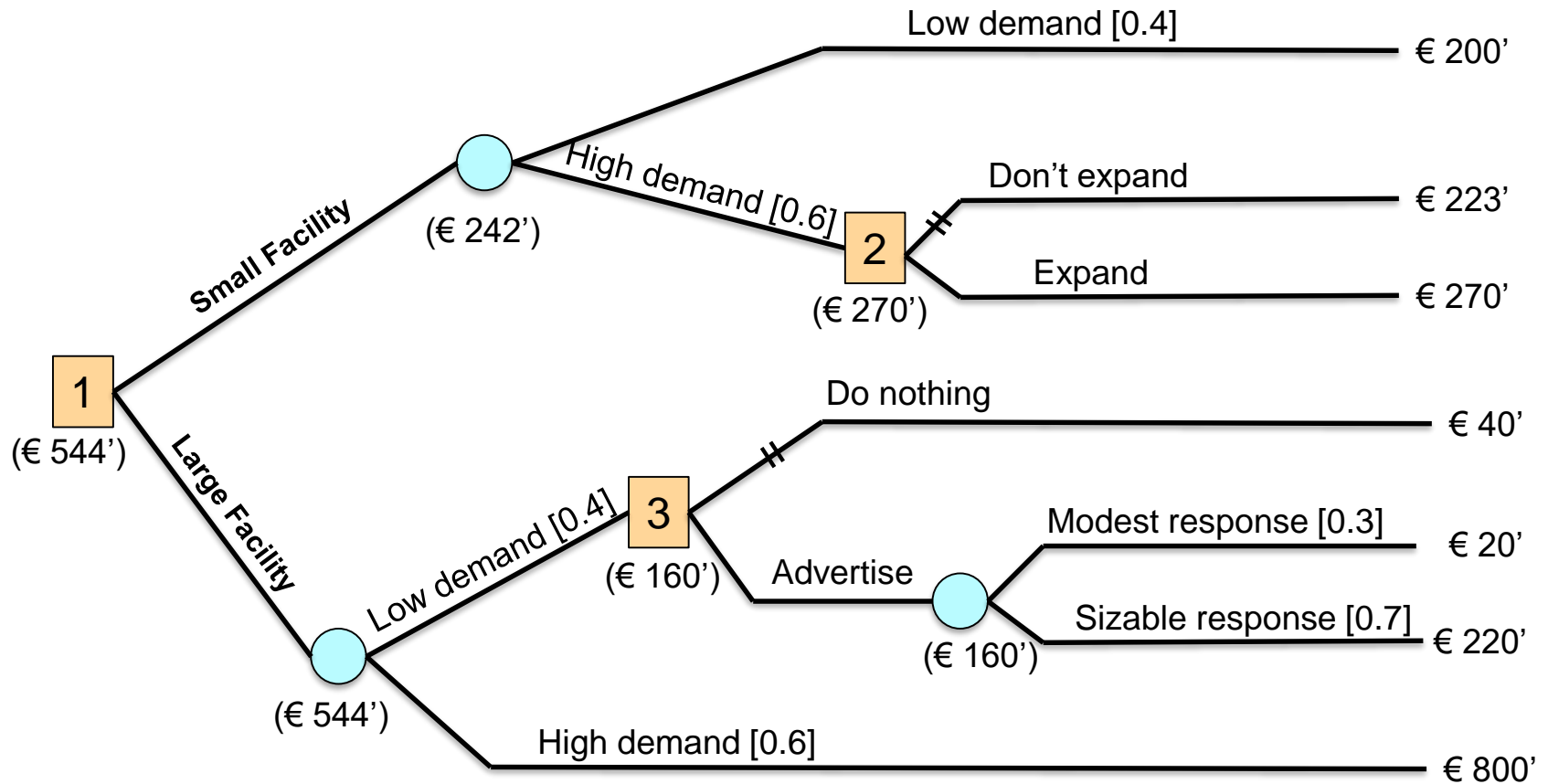
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Decision trees

A retailer must decide whether to build a small or a large facility at a new location. Demand at the location can be either small or large, with probabilities estimated to be 0.4 and 0.6 respectively. If a small facility is built and demand proves to be high, the manager may choose not to expand (payoff = € 223,000) or to expand (payoff = € 270,000). If a small facility is built and demand is low, there is no reason to expand and the payoff is € 200,000. If a large facility is built and the demand proves to be low, the choice is to do nothing (€ 40,000) or to stimulate demand through local advertising. The response to advertising may be either modest or sizable. With their probabilities estimated to be 0.3 and 0.7, respectively. If it is modest, the payoff is estimated to be only € 20,000; where as the payoff will be € 220,000 if the response is sizable. Finally, if a large facility is built and demand turns out to be high, the payoff is € 800,000.

Draw a decision tree. Then analyze it to determine the expected payoff for each decision and event node. Which alternative – building a small facility or building a large facility – has the higher expected payoff?

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Decision trees

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Relevant book chapters

- Chapter: "Planning capacity"

- Supplement A: "Break even analysis"

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Thank you!

Questions?

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Next part of the lecture:

Waiting lines

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