# Lecture outline

- What is a resource?
- Multilayer problems
- Modeling resources
- A battery storage application

# What is a resource?

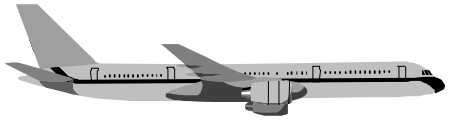
- What is a resource?

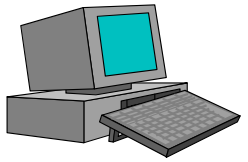
# What is a resource?

- Examples of resources:

**People:**

**Equipment:**

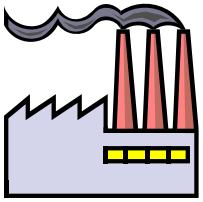




**Consumable goods:**

**Natural resources:** ***Water, minerals***

**Fixed facilities:**



**Financial resources:**

# What is a resource?

- Definition:
  - » A resource:
    - Dictionary:
      - 1) A source of supply, support or aid;
      - 2) the collective wealth of a country;
      - 3) money, or any property that can be converted into money.
    - ORF411:
      - (1) An information class which constrains the system.
      - (2) An *endogenously* controllable information class which constrains the system.
      - (3) An information class that costs money to acquire.
    - There are two important subcategories:
      - Active – These are resources which we can act on directly to change their attributes.
      - Passive – These are resources whose attributes cannot be changed (at least within the time frame of our actions).

# What is a resource?

- What is a resource?

- … an asset?

# What is a resource?

- Definition:
  - » An asset:
    - Dictionary:
      - 1) A useful thing or quality;
      - 2) A single item of ownership having exchange value, especially those convertible to cash.
  - » Q: When is a resource not an asset?

# What is a resource?

# What is a resource?

- In the entrance hall of the American Museum of Natural History

  - *The next generation behaves well if it treats the natural resources as assets which it must turn over to the next generation increased and not impaired in value.*

    - *President Theodore Roosevelt*

# What is a resource?

- What is a resource?
- … an asset?
- … a commodity?

# What is a resource?

- What is a commodity?
  - » Business/economics:
    - Food/agriculture:
      - Pork bellies
      - Grain
    - Natural resources
      - Iron ore
      - Oil
    - A product or service produced using widely available technology
      - TV's
      - Personal computers
      - Plastics

# What is a resource?

- What is a commodity?
  - » Operations research: A type of flow
    - A type of product
      - – Type of aircraft; type of good being moved
    - Flow with a known origin and destination
      - – Passengers, packages, letters, freight
      - – Messages
    - A specific entity
      - – A person, a particular aircraft

$x_{ij}^k$ = Flow of type $k$ from $i$ to $j$

# What is a resource?

- Definition (dynamic resource management)
  - » A "**commodity"** is a set of resources with a common set of static attributes (the commodity type) and a set of dynamic attributes:
    - Fuel
      - Static attribute: octane
      - Dynamic attributes: location
    - Aircraft
      - Static attribute: type of aircraft
      - Dynamic attributes: location, fuel, maintenance
    - Pilot
      - Static attribute: ID (each pilot is a commodity)
      - Dynamic attributes: location, hours, qualification
    - Passengers
      - Static attribute: origin/destination combination

# What is a resource?

- Special types of resources:
  - » Many resource management problems can be described in terms of resources being used to accomplish tasks:

| "Resources" | "Tasks" |
|---|---|
| Taxicab | Customer |
| Hotel room | Guest |
| Student | Term paper |
| Aircraft | Flight |
| Pilot | Aircraft |
| Drilling machine | Piece of metal |
| Programmer | Software bug |

  - » … but the designation of "resource" and "task" can sometimes be arbitrary.

# What is a resource?

- What is a task?
  - a.k.a.:
    - Customer
    - Job
    - Order
    - Demand
    - Request
    - Requirement
    - Need
  - All of these carry the connotation of an exogenous agent who will reward the process for a service.
  - Sometimes there is more than one class of “exogenous agent”

# What is a resource?

- What is a task?
  - » Define the resources and tasks for:
    - A management consulting firm needs to assign newly hired ORFE majors to work on consulting projects around the world.
    - A semiconductor plant: wafers have to move through a sequence of machines before becoming a semiconductor.
    - A pilot and aircraft are needed to move a set of passengers from Newark to Chicago.
    - A locomotive, operated by a crew, has to pull a set of box cars from one location to the next.

# What is a resource?

- We can divide resources into six classes:
  - Physical
    - People
    - Objects (fixed, movable)
  - Financial
    - Money
    - Convertible assets
  - Informational
    - Phone calls, TV, WWW
    - Newspaper, books, magazines
  - Time
    - Years/months/days/hours/minutes/seconds
  - Energy
    - Calories, watts, horsepower, $E = mc^2$
  - Limits/targets
    - Risk
    - Corporate average fuel economy standards
    - Customer service constraints

# What is a resource?

- We can divide our resource classes into two broad groups:
  - Active
    - Physical
      - People
      - Objects (fixed, movable)
    - Financial
      - Money
      - Convertible assets
    - Informational
      - Phone calls, TV, WWW
      - Newspaper, books, magazines
  - Passive
    - Time
      - Years/months/days/hours/minutes/seconds
    - Energy
      - Calories, kilowatts, horsepower, $E = mc^2$
    - Limits/targets
      - Risk
      - Corporate average fuel economy (CAFÉ) standards for MPG
      - Customer service constraints

# What is a resource?

- Resource dimensions
  - » "Resources" vs. "tasks"
    - Resources: actions on "resources" generate a negative contribution.
    - Tasks: actions on "tasks" generate a positive contribution.
  - » Attributes
    - Static - the type of aircraft
    - Dynamic - its location.
  - » Attribute space
    - No attributes
    - Single dynamic attribute
    - Single static attribute; single dynamic attribute
    - Multiple attributes
  - » Actionability
    - Active - The aircraft.
    - Passive - The fuel.

# What is a resource?

- Resource dimensions:
  - » Persistence
    - Persistent - resources which “hang around”
      - – Perishable - food, passengers
      - – Reusable - aircraft, pilots
    - Transient
  - » Recurrence
    - Recurrent -
      - – Periodically returns to a base state (or set of states)
    - Nonrecurrent
  - » Discreteness
    - Discrete
    - Continuous

# Lecture outline

- What is a resource?
- Multilayer problems
- Modeling resources
- A battery storage application

# Multilayered systems

- Composite resource: Sandwich
  - » Primitive resource layers
    - Bread
    - Lettuce
    - Tomatoes
    - Meat
  - » Bundles:
    - Four slices of tomato
    - Four slices of cheese
    - Two pieces of lettuce
    - Three slides of meat
  - » Coupling of bundles – new behavior:
    - Satisfies demand for lunch

# Multilayered systems

- Resource layering
  - » Often we create more complex resources by combining (bundling and/or coupling) them
    - Pilots in an aircraft
    - Auto components assembled into a car
    - A portfolio of financial assets
    - A medical team with support staff, equipment and medicines.

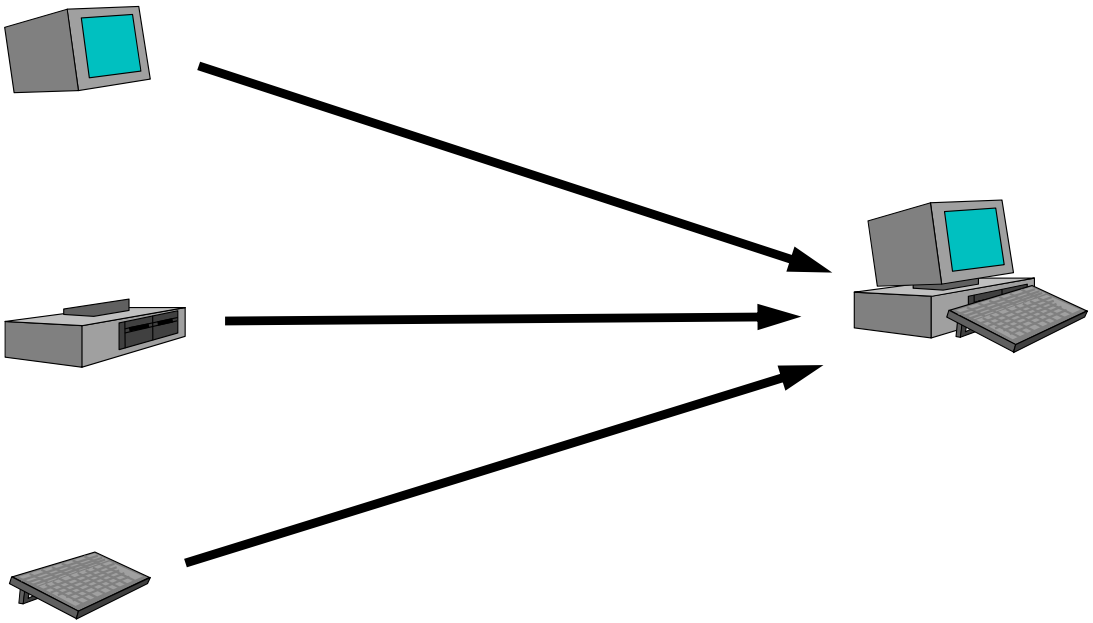
# Multilayered systems

- More composite resources:

**Teams of people with different skill sets.**

# Multilayered systems

- More composite resources:



**Assembling components into products**

# Multilayered systems

- More composite resources:

***Portfolio***

| Asset | Value |
|---|---|
| Microsoft | $34,500 |
| Dell | $23,435 |
| Cinema Theatres | $12,400 |
| General Motors | $65,230 |
| JP Morgan | $17,650 |

# Multilayered systems

- Problem complexity can often be measured by the number of resource layers…
  - One layer
  - Two layer
  - Three layer
  - …
  - Many layers

# Multilayered systems

- **One layer problems:**
  - Financial asset allocation problems
  - Classical inventory planning (but with no demand backlogging).
  - Distribution problems (possibly multiproduct) with stochastic demands (but no demand backlogging).
  - The dynamic travelling repairman problem.
  - Schedule aircraft
  - Rail operations I: distributing box cars to customers with no demand backlogging.
  - Electric power distribution, with storage.

# Multilayered systems

- **Two layer problems:**
  - Multi-skill call centers (technical support agents and customers)
  - Personnel planning (assigning people to jobs).
  - Taxi fleets (taxis and customers
  - Truckload load matching (drivers and loads).
  - The postal service II: Routing shipments and trailers
  - Rail operations II: Scheduling locomotives to move trains.

# Multilayered systems

- **Three layer problems:**
  - Business jets – Pilots, aircraft, customers
  - Truckload trucking (driver, tractor and trailer).
  - Machine scheduling (with setups) with operators (jobs, machines and people).
  - The postal service  III: routing shipments, trailers and drivers.
  - Rail operations III: Scheduling locomotives and crews to move trains.

# The fractional jet ownership industry


Sys
Pilots
Aircraft
Customers
Sys

# Lecture outline

- What is a resource?
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# Modeling resources

- Often, we are managing resource classes:
  - » Money
  - » Agricultural commodities
- If we have only one type of resource, we would use:

$R_t$ = Scalar resource state vector (how much money, oil)

- If we have different types of resources:

$R_{ti}$ = Number of resources of type $i \in I$

$R_t$ = Resource state vector = $\left(R_{ti}\right)_{i \in I}$

- If our resources have complex attributes:

$R_{ta}$ = Number of resources with attribute $a \in A$

$R_t$ = Resource state vector = $\left(R_{ta}\right)_{a \in A}$

# Modeling resources

- Resource classes and attributes

$\mathcal{C}^R$ = Set of resource classes

aircraft, people, oil, medications, money

$\mathcal{A}^c$ = The space of attributes for resources in class $c$.

$a \in \mathcal{A}^c$ = The attributes of a resource in resource class $c$.

» Examples:
- Money
- Energy (oil/gas/coal)
- Blood (blood type)
- A car
- A person

$$a^{Aircraft} = \begin{bmatrix} \text{Aircraft type} \\ \text{Location} \\ \text{Fuel level} \end{bmatrix}$$

# Modeling resources

- If we are modeling discrete entities, we might use:

  $\mathcal{R}^c =$ Set of resources in class $c \in \mathcal{C}^R$

  (a list of professors, list of aircraft, list of doctors)

  $r \in \mathcal{R}^c$ would be a particular resource (e.g. an aircraft or doctor)

  $a_r =$ Attribute of resource $r \in \mathcal{R}^c$

- Different types of resources within a class
  - » Employees with different ages, skills
  - » Money in different investments (stocks, bonds)
  - » Baseball players (outfielders, shortstop, catcher,…)
- Resources in different classes
  - » Doctors, waiting rooms, MRI machines
  - » Pilot, aircraft, customer

# Modeling resources

- Major problem classes:
  - » Basic inventory problems:

$$a = [\ \ ]$$

  - » Multiproduct problems:

$$a = [\text{Class}]$$

  - » Single commodity flow problems:

$$a = [\text{State}]$$

  - » Multicommodity flow problems:

$$a = \begin{bmatrix} \text{Resource class} \\ \text{State} \end{bmatrix}$$

# Modeling resources

- Major problem classes:
  - » The heterogeneous resource allocation problem:

$$a^{Pilot} = \begin{bmatrix} \text{Home} \\ \text{A/C certification} \\ \text{Seniority} \\ \text{Current location} \\ \text{Duty hours} \end{bmatrix} \begin{matrix} \left.\vphantom{\begin{matrix}1\\2\\3\end{matrix}}\right\} \text{Static attributes = class} \\ \left.\vphantom{\begin{matrix}1\\2\end{matrix}}\right\} \text{Dynamic attributes = state} \end{matrix}$$

  - » The multilayered resource scheduling problem:

$$a = \begin{bmatrix} a^{Pilot} \\ a^{Aircraft} \\ a^{Customer} \end{bmatrix}$$

# Modeling resources

- A basic inventory problem
  - » Example:
    - How many copies of a particular book should Amazon.com hold in stock?
  - » Resource variable:

    $R_t$ = Amount of product in inventory at time $t$
  - » Decision variable:

    $x_t$ = Amount of product to order in time $t$.

# Modeling resources

- A stochastic shortest path problem
  - » Example:
    - We are trying to traverse a network. The cost $c_{ij}$ from $i$ to $j$ is random. At node $i$, we get to see the actual cost to traverse from $i$ to $j$, but not the costs out of $j$.
  - » Resource variable:

    $R_{ti} = 1$ if we are at node $i$.
  - » Decision variable:

    $x_{tij} = 1$ if we choose to traverse from i to j.

# Modeling resources

- A single commodity flow problem
  - » Example:
    - Distributing heating oil from refineries to storage facilities to customer tanks.
    - Managing inventories of vaccines
    - Controlling the flow of water between reservoirs
  - » Resource variable:

    $R_{ti}$ = Amount of product at location $i$ at time $t$.

    We call "$i$" the *resource state.*
  - » Decision variable:

    $x_{tij}$ = Amount of resources in state $i$ to move to state $j$ at time $t$.

# Modeling resources

- A multicommodity flow problem
  - » Example:
    - Moving different types of computers from the manufacturing plant to distribution centers and retail outlets.
    - Assigning different types of aircraft to serve flights.
  - » Resource variable:

$R_{ti}^k$ = Amount of product $k$ at location $i$ at time $t$.

$k$ is called the *commodity*.

  - » Decision variable:

$x_{tij}^k$ = Amount of resources of type $k$ in state $i$ to move to state $j$ at time $t$.

# Modeling resources

- A multiattribute problem
  - » Example:
    - Assigning staff (people) in a company (e.g. IBM or HP) to different projects over time.
    - Managing fleets of locomotives, capturing the attributes of maintenance, fuel, and orientation (which way is it pointed?)
  - » Resource variable:

    $a =$ Attributes of a person (or type of person)

    $R_{ta}$ = Amount of resources with attribute $a$ at time $t$.
  - » Decision variable:

    $x_{tad}$ = Amount of resources with attribute $a$ that we act on with decision $d$ at time $t$.

# Modeling resources

- What can we do to a resource?
  - Buying/selling
  - What to do
    - What path to take through a network
    - Where to invest money?
    - What job to take?
    - Who do you assign to a task?
  - How much?
    - How much money to invest?
    - How many people should a company hire?
    - How large should the stock of vaccines be?

# Modeling resources

- Types of decisions

  $d$ = A type of decision (buy, sell, move, repair, consume)

  $\mathcal{D}$ = The set of decision types

- The decision vector (a single type of resource)

  $x_{td}$ = The number of times (or amount of resources) we execute decision $d$ at time $t$ (how much to buy, sell, move)

  $x_t = \left(x_{td}\right)_{d \in D}$

- The decision vector (multiattribute resources)

  $x_{tad}$ = The number of times we act on a resource with attribute $a$ with a decision of type $d$.

  $x_t = \left(x_{tad}\right)_{a \in A, d \in D}$

# Modeling resources

- How does the system evolve?
  - » An inventory problem

$$R_{t+1} = \max\{0, R_t + x_t - D_t\}$$

  - » Shortest path problem

$$R_{t+1,j} = R_{ti}x_{tij} = \begin{cases} 1 & \text{if } R_{ti} = 1 \text{ and } x_{tij} = 1 \\ 0 & \text{Otherwise} \end{cases}$$

  - » Multiattribute problem (for complicated problems)

$$\delta_{a'}(a,d) = \begin{cases} 1 & \text{If decision } d \text{ acting on a resource w/ attrib } a \\ & \text{produces a resource with attribute } a' \\ 0 & \text{Otherwise} \end{cases}$$

$$R_{t+1,a'} = \sum_{d \in \mathcal{D}} \delta_{a'}(a,d) x_{tad}$$

# Modeling resources

- Objectives
  - » Maximize profit/minimize cost
  - » Maximize utility
  - » Minimize (or control) risk
  - » Meet goals
    - Multiple performance measures
  - » Discuss multiple objectives that arise when managing:
    - Complex equipment (aircraft, locomotives)
    - People (e.g. employees at IBM)

# Modeling resources

- Modeling a deterministic inventory problem

Variables:

$R_t$ = Amount of inventory (money, energy, blood) available to be used at time $t$.

$x_t$ = Amount ordered at time $t$ (assume it arrives right away)

$D_t$ = Demand during time interval $t$ (between $t$ and $t+1$)

Basic transition function

$$R_{t+1} = R_t + x_t - D_t$$

Notes:

$x_t$ = Represents resources that arrive immediately

$D_t$ = Is demands to be served between $t$ and $t+1$, but known at time $t$

# Modeling resources

- How much do we order?

  What if costs are linear?

$$\min_{x_0,x_1,\ldots,x_T} \sum_{t=0}^{T} cx_t$$

  Optimal solution is to order $x_t = D_t$

  What if the cost function looks like:

$$C(x) = \begin{cases} 0 & x = 0 \\ K + cx & x > 0 \end{cases}$$

  What if the costs depend on time:

$$\min_{x_0,x_1,\ldots,x_T} \sum_{t=0}^{T} c_t x_t$$