Announcements

▶ Please fill out survey!
▶ First Midterm exam scheduled for October 11 (in class)
▶ Last lecture covered is today
▶ We've posted old midterms, will follow approx same format
▶ 5 questions, each w/ several parts (use your time wisely, not all parts have same number of points!)
▶ Will provide you w/formula sheet & scratch paper
▶ Closed book, closed note, closed internet
▶ Bring boring old calculator (for doing simple arithmetic, cannot use smartphone)
▶ Shiro's review session scheduled for Tues
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Roadmap

- Finishing up continuous distributions with the Normal distribution (and Standard Normal)
- Decision analysis → application of random variables and their expected value
- Setting up decision trees to conduct decision analysis
- Walk through an application
Roadmap

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Normal Distribution

- Most widely
- Is a bell-shaped curve (also know as the Gaussian distribution)
- Many random phenomena in the world can be modeled by a Normal distribution (though many cannot)
- Human heights
- Velocity of molecules in gases
- Yearly rainfall in geographic unit
- Politicians' approval ratings as measured by several polls

Preview: Because so many processes follow Normal Distribution, used as basis for statistical inference
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Normal Distribution

PDF fully determined by its mean and standard deviation denoted as $X \sim N(\mu, \sigma^2)$, where $\mu$ is the mean and $\sigma^2$ is the variance.

PDF given by:

$$f(x) = \frac{1}{\sigma \sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$

and the CDF by:

$$F(x) = \frac{1}{\sigma \sqrt{2\pi}} \int_{-\infty}^{x} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$

Normal distribution is symmetric around its mean.
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You may be thinking: Normal PDF, CDF looks hard to use!

Many use rule of thumb:

- 68% of probability mass falls within 1 SD of mean
- 95% of probability mass falls within 2 SD of mean
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Or use STATA or R (or other software)
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\( X \sim \text{Normal}(6, 1) \)

\[ P(\ ? \leq X \leq \ ?) = 0.68 \]
$X \sim \text{Normal}(6, 1)$

$P(5 \leq X \leq 7) = 0.68$
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$P(5 < X < 7) = 0.68$

$P(5 \leq X \leq 7) = 0.68$
$X \sim \text{Normal}(6, 1)$

$P(\, ? \leq X \leq \, ?) = 0.95$
$X \sim \text{Normal}(6, 1)$

$P(4 \leq X \leq 8) = 0.95$
$X \sim \text{Normal}(6, 1)$

$P(4 \leq X \leq 8) = 0.95$
Calculating more unusual probabilities difficult (especially before statistical software)

Thus: Common to use Standard Normal

Special case of a Normal: 

\[ Z \sim \mathcal{N}(0, 1) \]

Can convert any normally distributed random variable \( X \) to a Standard Normal via standardizing transformation:

\[ Z = \frac{X - \mu}{\sigma} \]

PDF given by:

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Table entry for $z$ is the area under the standard Normal curve to the left of $z$.

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Using Standard Normal

1. Assess what quantity you are looking for – Range? Cumulative probability?

2. Calculate the necessary z-scores via standardizing

3. Use Standard Normal probability table to calculate probability based on z-scores

▶ Range (e.g., \([a, b]\)):
\[P(Z \leq b) - P(Z \leq a)\]

▶ Cumulative:
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Use Standard Normal to solve many problems

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Rainfall Example

Suppose you are an NGO advising rural farmers in Burkina Faso about which crops to plant. Farmers considering planting cotton need between 500 and 610mm of rain to grow. Distribution of annual rainfall follows a Normal distribution:

\[ X \sim N(600\text{ mm}, 50^2\text{ mm}) \]

Based upon rainfall info only, what is probability that cotton succeeds?
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   ▶ Range: Probability rainfall is between cotton growing limits

   \[ P(500 \leq X \leq 610) \]

2. Calculate the necessary z-scores:

   \[ Z = \frac{X - 600}{50} \]

   \[ a = \frac{500 - 600}{50} = -2 \]

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3. Use Standard Normal probability table to calculate associated probabilities:

   \[ P(a \leq Z \leq b) = P(Z \leq b) - P(Z \leq a) = 0.5793 - 0.0183 = 0.561 \]
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Decision Analysis

Many decisions involve uncertainty – "what if"?

Examples:

- Government decision about how many vaccines to produce for H1N1 virus
- Decision on whether or not to purchase a warranty on your new smartphone
- Whether New Jersey should order evacuations in light of approaching hurricane

Turns out that these hinge on random variables → outcomes over which there is chance.
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- Decision on whether or not to purchase a warranty on your new smartphone
- Whether New Jersey should order evacuations in light of approaching hurricane
Decision Analysis

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- Examples:  
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  - Decision on whether or not to purchase a warranty on your new smartphone  
  - Whether New Jersey should order evacuations in light of approaching hurricane  
- Turns out that these hinge on random variables → outcomes over which there is chance
Decision Analysis

Assists us by breaking down problem into manageable chunks

Quite similar to game theory

Game theory: Usually has multiple decision makers

Decision analysis: Focus is on what's best decision for single policy maker

Formally represents the choices available to the decision maker

(So, doing game theory with a single "player")

Similar also to setting up a probability problem using decision trees, but in this case we are introducing a random component
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Four key elements:
1. Set of choices
2. Set of possible uncertain events (e.g., events that are basically random variables)
3. Probabilities associated with uncertain events (e.g., probability distributions of these random events)
4. Preferences over outcomes ("Utility")

Note: In game theory, uncertain events determined by non-player actor often referred to as "Nature"
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Example: Food Aid in Africa

Suppose you work for USAID. There's a severe drought in Africa, and you want to deliver aid. Two ways to deliver aid:

1) By airlift
   → Costs $1 million, no possibility of delay

2) By truck convoy
   → Costs $400K, truck breaks down 40% of the time
   → Must then send back-up convoy ($1.4 million)

We will use cost to calculate our utility (but note that this is only one way to conceptualize a “good” outcome!)
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Must make decision ex-ante (before the event) → outcome of truck breaking down like a random variable → take on certain values (break down or not) with some probabilities

Expected cost (or expected utility) analogous to expected value of a random variable

Note: Utility can incorporate other values (lives saved, personal preferences, tradeoffs between different costs, etc.)

Also, in real world have to consider tolerance of risk (analogy: variance/standard deviation of random variable)
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Decision Trees

A graphical representation of decision analysis problems
Can be used in a wide range of decision-making situations
Show all the possible outcomes that can occur at each stage
(at a chance node)
Presents all options that may be pursued (at a decision node)
To arrive at the optimal solution to our question, we work backwards
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- Model each decision/possible outcome as a fork in tree
- At chance nodes (.charset), we assess possible outcomes and calculate expected outcome
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Decision Trees

- Airlift
  - Breakdown: -$1 million
  - No Breakdown: Truck Convoy
    - $1 million
    - Airlift
      - Breakdown: -$1.4 million
      - No Breakdown: $0.4 million
    - E[Payoff] = -$0.8 million
    - E[Cost] = $0.8 million
    - 0.4
    - 0.6
  - Build Sequentially
    - -$400,000
Decision Trees

Airlift

Breakdown
- $1 million

No Breakdown
- $1.4 million

Truck Convoy
E [ Payoff ] = -$0.8 million
E[Cost] = $0.8 million

Solve Backwards

0.4

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Example: Food Aid in Africa

Doing the calculations:

$E[Airlift] = -1,000,000$

$E[Truck] = 0.4 \times (-1,400,000) + 0.6 \times (-400,000) = -560,000 + (-240,000) = -800,000$

So truck still a better choice (ex ante), despite uncertainty
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Example: Snow Removal

- Last year Boston paid $35 million for snow removal.
- City considering whether to accept a private company's offer of $14 million for the whole job.
- Suppose 3 possible levels of snow in Boston this winter:
  - Light snow fall (25in) → 40% of time
  - Moderate snow fall (40in) → 30% of time
  - Heavy snow fall (70in) → 30% of time

- What kind of random variable is this? Could you represent this another way?
- Note: In 2015, Boston had 5 blizzards → 108.6 inches (maybe < 1% of the time).
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Two options are available for Boston:

- Hire a private company for fixed fee of $14 million
- Hire its own snowplow operators

Pay per inch of snow removed:

- $250K per inch for first 50 inches
- $500K per inch after that

We'll use value function based only on monetary cost

Given only $ concerns, what is best decision?
Example: Snow Removal

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Outsource

Hire Own Workers
Example: Snow Removal

- Outsource
  - Light: 0.3
  - Moderate: 0.4
  - Heavy: 0.3

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Example: Snow Removal

**Hiring Own Workers:**
- Light: 25*250k = $6.25 million
- Moderate: 40*250k = $10 million
- Heavy: 50*250k + 20*500k = $22.5 million
Example: Snow Removal

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What is expected utility if Boston hires its own workers?

Here, expected utility based only on expected costs (can could look at other quantities policy makers care about – e.g., % union workers, citizen happiness, etc.)

\[ E[U_{Own}] = 0.4 \times (-6.25 \text{ M}) + 0.3 \times (-10 \text{ M}) + 0.3 \times (-22.5 \text{ M}) = -12.25 \text{ M} \]

Again, straightforward analogy to calculating expected value of a random variable

Could do this if snowfall \( \sim \text{N} \) or \( \sim \text{Unif} \)
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\[ E_{\text{Outsource}} = 1.0 \times (-$14\text{M}) = -$14\text{M} \]
Example: Snow Removal

- What is expected utility if Boston outsources?
Example: Snow Removal

What is expected utility if Boston outsources?

\[
E[U_{Outsource}] = 1.0 \times (-14M) = -14M
\]
Example: Snow Removal

- Outsource
  - $14M

- Hire Own Workers
  - Light 0.4
    - $6.25M
  - Moderate 0.3
    - $10M
  - Heavy 0.3
    - $22.5M

E[U] = -$12.25M

Hiring Own Workers:
- 25*250k = $6.25 million
- 40*250k = $10 million
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Example: Snow Removal

Comparing Options:
- -$14 million
- -$12.25 million
- Hiring own workers best option

$E[U] = -$12.25M
Example: Snow Removal and Flooding

Let's make this more complicated (realistic)

Boston must also consider flooding (remember?)

More heavy snow → coastal areas more likely to flood

Make simply and assume that if there is heavy snow, coastal flooding occurs 50% of the time
Example: Snow Removal and Flooding

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Example: Snow Removal and Flooding

If Boston previously chose option of hiring its own workers:

1. Must pay overtime for them to deal with flood waters.
2. Costs city an additional $2 million.

If Boston previously chose option of outsourcing snow removal, then it has two options:
1. (a) Retain private specialized flood company workers at end of season for $4 million.
2. (b) Release all company workers, but take on risk of having to pay emergency clean up costs of $7 million in case of a flood.

Must make decision on whether to go w/option (a) or (b) after learning of a heavy snow (i.e., at end of winter but before flooding).
Example: Snow Removal and Flooding

- If Boston previously chose option of hiring *its own* workers:
  
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Example: Snow Removal and Flooding

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Not Heavy 0.7
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Flood

No Flood
Example: Snow Removal and Flooding

- If outsource and hire flood company:
  - flood → $14m + (−$4m) = −$18m
  - none → $14m + (−$0m) = −$14m

- If outsource and not hire flood company:
  - flood → $14m + (−$7m) = −$21m
  - none → $14m + (−$0m) = −$14m

- If hire own workers:
  - flood → $22.5m + (−$2m) = −$24.5m
  - none → $22.5m + (−$0m) = −$22.5m
Example: Snow Removal and Flooding

▶ If outsource and hire flood company:

- If outsource and hire flood company: $-14m + (-4m) = -18m$
- If hire own workers: $-22.5m + (-2m) = -24.5m$

- If none: $-14m + (-0m) = -14m$
Example: Snow Removal and Flooding

- If outsource and hire flood company:
  
  \[-$14m + (−$4m) = −$18m\]
Example: Snow Removal and Flooding

- If outsource and hire flood company:

  \[-14m + (-4m) = -18m\]

- If outsource and not hire flood company:

  \[-14m + (-7m) = -21m\]

  \[-14m + (0m) = -14m\]

- If hire own workers:

  \[-22.5m + (-2m) = -24.5m\]

  \[-22.5m + (0m) = -22.5m\]
Example: Snow Removal and Flooding

- If outsource and hire flood company:
  
  \[-14m + (4m) = -18m\]

- If outsource and not hire flood company:
  
  \[\text{flood} \rightarrow -14m + (7m) = -21m\]
  \[\text{none} \rightarrow -14m + (0m) = -14m\]
Example: Snow Removal and Flooding

- If outsource and hire flood company:
  \[-14m + (-4m) = -18m\]

- If outsource and not hire flood company:
  \[-14m + (-7m) = -21m\]
  \[-14m + (0m) = -14m\]

- If hire own workers:
Example: Snow Removal and Flooding

▶ If outsource and hire flood company:

\[-14m + (-4m) = -18m\]

▶ If outsource and not hire flood company:

\[
flood \rightarrow -14m + (-7m) = -21m \\
none \rightarrow -14m + (0m) = -14m
\]

▶ If hire own workers:

\[
flood \rightarrow -22.5m + (-2m) = -24.5m \\
none \rightarrow -22.5m + (0m) = -22.5m
\]
Example: Snow Removal and Flooding

- Outsource
  - Not Heavy
    - Light: $-6.25M (0.4)
    - Moderate: $-10M (0.3)
    - Heavy: $-22.5M (0.3)
  - Heavy: $-18M (0.3)
- Hire Own Workers
  - Not Heavy
    - $-14M (0.7)
  - Light: $-21M (0.5)
  - Moderate: $-24.5M (0.5)
  - Heavy: $-22.5M (0.5)
Example: Snow Removal and Flooding

Then we can calculate expected values, conditional on heavy snow:

▶ If outsource and not hire flood company (release the workers):

\[ \mathbb{E}[U_{\text{Outsource}}] = 0.5 \times (-21m) + 0.5 \times (-14m) = -17.5m \]

Note: Since this is better than hiring the flood company ($18M), you would choose this option.

▶ If hire own city workers:

\[ \mathbb{E}[U_{\text{Own}}] = 0.5 \times (-24.5m) + 0.5 \times (-22.5m) = -23.5m \]
Example: Snow Removal and Flooding

Then we can calculate expected values, conditional on heavy snow:

- If outsource and not hire flood company (release the workers):
  
  \[
  E[U_{\text{Outsource}}] = 0.5 \times (-\$21) + 0.5 \times (-\$14) = -\$17.5
  \]

- Note: Since this is better than hiring the flood company ($18M), you would choose this option

- If hire own city workers:
  
  \[
  E[U_{\text{Own}}] = 0.5 \times (-\$24.5) + 0.5 \times (-\$22.5) = -\$23.5
  \]
Example: Snow Removal and Flooding

Then we can calculate expected values, conditional on heavy snow:

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\[ E[U_{\text{Own}}] = 0.5 \times (-24.5m) + 0.5 \times (-22.5m) = -23.5m \]
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- If outsource and not hire flood company (release the workers):

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\[ = \text{-}17.5m \]

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Example: Snow Removal and Flooding

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- Note: Since this is better than hiring the flood company ($18M), you would choose this option

- If hire own city workers:

  \[ E[U_{Own}] = 0.5 \times (-$24.5m) + 0.5 \times (-$22.5m) \]
  \[ = -$23.5m \]
Example: Snow Removal and Flooding

Outsource

Hire Own Workers

Light

Moderate

Heavy

0.3 Heavy

0.4

0.3

0.7

-$14M

-$6.25M

-$10M

-$21M

-$24.5M

-$22.5M

-$14M

-$10M

-$21M

-$24.5M

-$22.5M

-$14M

-$6.25M

-$10M

E[U] = -$17.5M

E[U] = -$23.5M
Example: Snow Removal and Flooding

Outsource

-0.3

Hire Own Workers

-0.4

Light

-0.3

Moderate

-0.5

Heavy

-0.5

Not Heavy

-0.7

Hire Flood Co

-0.3

Heavy

-0.5

Flood

-0.5

No Flood

-0.5

E[U] = -$17.5M

E[U] = -$23.5M

-$18M

-$21M

-$14M

-$24.5M

-$22.5M

-$14M

-$6.25M

-$10M

-$24.5M

-$22.5M
Example: Snow Removal and Flooding

Then we can calculate expected values, from beginning:

- If outsource:
  \[ E[U_{\text{Outsource}}] = 0.3 \times (-17.5\text{ m}) + 0.7 \times (-14\text{ m}) = -15.05\text{ m} \]

- If hire own workers:
  \[ E[U_{\text{Own}}] = 0.4 \times (-6.25\text{ m}) + 0.3 \times (-10\text{ m}) + 0.3 \times (-23.5\text{ m}) = -12.55\text{ m} \]
Example: Snow Removal and Flooding

Then we can calculate expected values, from beginning:

\[
\begin{align*}
\text{If outsource:} & \quad E[U_{\text{Outsource}}] = 0.3 \times (-17.5 m) + 0.7 \times (-14 m) = -15.05 m \\
\text{If hire own workers:} & \quad E[U_{\text{Own}}] = 0.4 \times (-6.25 m) + 0.3 \times (-10 m) + 0.3 \times (-23.5 m) = -12.55 m
\end{align*}
\]
Example: Snow Removal and Flooding

Then we can calculate expected values, from beginning:

- If outsource:
  \[
  E[U_{\text{Outsource}}] = 0.3 \times (-17.5) + 0.7 \times (-14) = -15.05 \text{ m}
  \]

- If hire own workers:
  \[
  E[U_{\text{Own}}] = 0.4 \times (-6.25) + 0.3 \times (-10) + 0.3 \times (-23.5) = -12.55 \text{ m}
  \]
Example: Snow Removal and Flooding

Then we can calculate expected values, from beginning:

- If outsource:

\[
E[U_{\text{Outsource}}] = 0.3 \times (-17.5m) + 0.7 \times (-14m) \\
= -15.05m
\]
Example: Snow Removal and Flooding

Then we can calculate expected values, from beginning:

- If outsource:

\[
E[U_{\text{Outsource}}] = 0.3 \times (-17.5m) + 0.7 \times (-14m) \\
= -15.05m
\]

- If hire own workers:
Example: Snow Removal and Flooding

Then we can calculate expected values, from beginning:

- If outsource:

\[ E[U_{Outsource}] = 0.3 \times (-17.5m) + 0.7 \times (-14m) \]
\[ = -15.05m \]

- If hire own workers:

\[ E[U_{Own}] = 0.4 \times (-6.25m) + 0.3 \times (-10m) + 0.3 \times (-23.5m) \]
\[ = -12.55m \]
Example: Snow Removal and Flooding

Outsource

Hire Own Workers

E[U] = -$15.05M

Light

Moderate

Heavy

0.3

0.4

0.3

0.7

-$14M

-$6.25M

-$10M

-$24.5M

E[U] = -$23.5M

-$18M

-$21M

-$14M

-$22.5M

E[U] = -$17.5M

E[U] = -$15.05M

E[U] = -$12.55M

Hire Flood Co

Not Hire Flood Co

Flood

No Flood

0.5

0.5

0.5

-$17.5M

E[U] = -$17.5M

E[U] = -$23.5M

E[U] = -$15.05M

E[U] = -$12.55M
Example: Snow Removal and Flooding

\[ E[U] = \text{-}15.05 \text{M} \]

- Outsource
  - Not Heavy
    - Moderate
      - Heavy
        \[ E[U] = \text{-}18 \text{M} \]
    - Not Heavy
      \[ E[U] = \text{-}14 \text{M} \]
  - Heavy
    \[ E[U] = \text{-}21 \text{M} \]

- Hire Own Workers
  - Moderate
    - Heavy
      \[ E[U] = \text{-}10 \text{M} \]
    - Not Heavy
      \[ E[U] = \text{-}24.5 \text{M} \]
  - Heavy
    \[ E[U] = \text{-}22.5 \text{M} \]

\[ E[U] = \text{-}12.55 \text{M} \]
Example: Snow Removal and Flooding

E[U] = -$15.05M

Outsource

Not Heavy

0.7

-$14M

Hire Own Workers

Heavy

0.3

-$6.25M

Moderate

0.4

-$10M

E[U] = -$12.55M

BEST CHOICE!

Hire Flood Co

-$18M

Flood

0.5

-$21M

No Flood

0.5

-$14M

Not Hire Flood Co

E[U] = -$17.5M

-$15M

Flood

0.5

-$24.5M

No Flood

0.5

-$22.5M
Other factors?

- Safety and efficacy
- Ethical treatment/pay of workers
- Environmental practices
- Citizen satisfaction and political costs
Other factors?

- So far only considered monetary cost of snow removal
Other factors?

- So far only considered monetary cost of snow removal
- Other possible factors a mayor might consider?
Other factors?

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- Other possible factors a mayor might consider?
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- Other possible factors a mayor might consider?
  - Safety and efficacy
  - Ethical treatment/pay of workers
  - Environmental practices
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Other factors?

Seattle mayor fighting to hold onto his job

A revolutionary in green politics, Seattle Mayor Greg Nickels may lose re-election in November because of the city's inability to clear snow.

Thu, Aug 20 2009 at 8:17 PM EST

By Gene Johnson, Associated Press

Read more: CLIMATE CHANGE, EMISSIONS, POLITICS

INCUMBENT: As of the Tuesday primary, Nickels was narrowly trailing two challengers. (Photo: Ted S. Warren/Associated Press News)

Seattle Mayor Greg Nickels has been hailed as a visionary and a leader on environmental issues, helping persuade nearly 1,000 mayors around the country to abide by the standards of the Kyoto Protocol on global warming.

But an environmental issue of a more basic sort — the city's inability to clear streets during paralyzing snowstorms last winter — might have set the stage for his political undoing.
Other factors?

Two ways it might affect decision analysis:

1. More "nodes," either uncertainty or choice
   - For example, which neighborhoods to include first?

2. Payoffs will change (not just monetary values)
   - For example, political costs of unremoved snow or increased spending
Other factors?

Two ways it might affect decision analysis:
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Example: \textit{Snow Removal and Politics}

Here's an example:

- If Boston spends over $20\text{ million}$ on snow removal, other programs will have to be cut.
- For a mayor, cutting programs is politically costly.
- Incorporate that into the payoff function.
- One way to model political cost: $1$ dollar spent over $20\text{ million}$ is equivalent to spending $2$.
- E.g., if cost = $-21\text{ million}$, then Utility = $-22\text{ million}$.
Example: Snow Removal and Politics

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- E.g., if cost = -$21 million, then Utility = -$22 million
Example: Snow Removal and Politics

- Outsource
  - Light: $0.4M
  - Moderate: $0.3M
  - Heavy: $-$14M

- Hire Own Workers
  - Light: $-$6.25M
  - Moderate: $-$10M
  - Heavy: $-$22.5M
Example: Snow Removal and Politics

Outsource

Hire Own Workers

- Light 0.4
- Moderate 0.3
- Heavy 0.3

-$14M

-$22.5M

-$10M

-$6.25M

$U = -$25M
Example: Snow Removal and Politics

Outsource

Hire Own Workers

Light 0.4

Moderate 0.3

Heavy 0.3

-$14M

-$6.25M

-$10M

-$22.5M

U = -$25M

Now $E[U] = -$13M

$E[U] = -$13M$
Example: Snow Removal and Politics

Outsource

Hire Own Workers

Light
Moderate
-0.3
-0.4
-0.3
-Heavy

-$22.5M
-$10M
-$6.25M
-$14M

U = -$25M

Now E[U] = -$13M
STILL BEST CHOICE!

U = -$25M
Example: Snow Removal and Politics

Outsource

- Not Heavy: 0.7
  - $14M

- Heavy: 0.3
  - $18M
  - Flood: 0.5
    - $21M
  - No Flood: 0.5
    - $14M

Hire Own Workers

- Not Heavy: 0.7
  - $14M

- Moderate: 0.3
  - $6.25M

- Heavy: 0.3
  - $10M
  - Flood: 0.5
    - $24.5M
  - No Flood: 0.5
    - $22.5M
Example: Snow Removal and Politics

- Outsource
  - Not Heavy
    - Heavy: 0.3
      - Hire Flood Co: -$18M
      - Not Hire Flood Co: 0.5
        - Flood: 0.5
          - No Flood: 0.5
            - -$21M
            - -$14M
          - -$24.5M
        - No Flood: 0.5
          - -$22.5M
    - Not Heavy: 0.7
      - -$14M
- Hire Own Workers
  - Moderate: 0.4
    - -$6.25M
  - Heavy: 0.3
    - -$10M
  - No Flood: 0.5
    - -$24.5M
  - Flood: 0.5
    - -$22.5M

\[ U = -$22M \]

\[ \bullet \ 1m \times 2 = 2m \]
Example: Snow Removal and Politics

<table>
<thead>
<tr>
<th>Outsource</th>
<th>Hire Own Workers</th>
<th>Light</th>
<th>Moderate</th>
<th>Heavy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0.3</td>
<td>0.4</td>
<td>0.3</td>
</tr>
<tr>
<td>0.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>-$14M</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hire Flood Co</th>
<th>Flood</th>
<th>No Flood</th>
</tr>
</thead>
<tbody>
<tr>
<td>-$18M</td>
<td>-$21M</td>
<td>-$14M</td>
</tr>
<tr>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
</tbody>
</table>

$1m \times 2 = $2m

$2.25m \times 2 = $4.5m

$4.5m \times 2 = $9m

U = -$22M

U = -$29M

U = -$25M
Example: Snow Removal and Politics

Outsource

Not Heavy
  0.7  -$14M

Hire Own Workers
  0.4  -$6.25M
    Moderate
      0.3  -$10M
    Heavy
      0.3

Hire Flood Co
  0.3  Heavy

Not Hire Flood Co
  0.5  Flood
    0.5  -$21M
    No Flood
      0.5  -$14M

E[U] = -$18M
U = -$22M

E[U] = -$27M
U = -$29M

E[U] = -$25M
U = -$25M
Example: Snow Removal and Politics

Outsource

Hire Own Workers

$E[U] = -$18M$

$E[U] = -$27M$

$U = -$22M$

$U = -$29M$

$U = -$25M$
Example: Snow Removal and Politics

- Outsource
  - Not Heavy: 0.7 with cost $14M (E[U] = -$15.2M)
  - Heavy: 0.3
    - Flood: 0.5 with cost $21M (U = -$22M)
    - No Flood: 0.5 with cost $14M
- Hire Own Workers
  - Moderate: 0.3 with cost $6.25M (E[U] = -$13.6M)
  - Heavy: 0.3
    - Flood: 0.5 with cost $24.5M (U = -$29M)
    - No Flood: 0.5 with cost $22.5M
- Not Hire Flood Co
  - Moderate: 0.3 with cost $10M (E[U] = -$27M)
  - Heavy: 0.3
    - Flood: 0.5
    - No Flood: 0.5

- The expected utility (E[U]) is calculated based on the probabilities and costs associated with each decision path.
Example: Snow Removal and Politics

Outsource
- $18M

Hire Own Workers

- Heavy
  - $14M
  - $18M

- Moderate
  - $6.25M

- Light
  - $10M

Not Heavy
- $14M

Hire Flood Co
- Flood
  - $21M
  - $22M

- No Flood
  - $14M

BEST CHOICE based upon specified utility function

E[U] = -$15.2M
E[U] = -$18M
E[U] = -$27M
E[U] = -$13.6M

U = -$22M
U = -$29M
U = -$25M

TOTAL
- $24.5M
- $22.5M

$18M
Decision Analysis Summary

Decision analysis is an application of expected values of random variables.

A decision must be made ex-ante, or before uncertainty has been resolved.

We want the outcome with the highest expected utility (corresponds to expected value of an RV).

Utility can represent costs, personal preferences, tradeoff between different types of costs (political versus monetary).
Decision Analysis Summary

- Decision analysis is an application of expected values of random variables.
- A decision must be made ex-ante, or before uncertainty has been resolved.
- The goal is to find the outcome with the highest expected utility, which corresponds to the expected value of a random variable.
- Utility can represent costs, personal preferences, and tradeoffs between different types of costs (e.g., political versus monetary).
Decision Analysis Summary

- Decision analysis an application of expected values of random variables
- Decision must be made *ex-ante*, or before uncertainty has been resolved

Utility can represent costs, personal preferences, tradeoff between different types of costs (political versus monetary).
Decision Analysis Summary

- Decision analysis an application of expected values of random variables
- Decision must be made *ex-ante*, or before uncertainty has been resolved
- Want outcome w/ highest expected utility (corresponds to expected value of an RV)
Decision Analysis Summary

- Decision analysis an application of expected values of random variables
- Decision must be made *ex-ante*, or before uncertainty has been resolved
- Want outcome w/ highest expected utility (corresponds to expected value of an RV)
- Utility can represent costs, personal preferences, tradeoff between different types of costs (political versus monetary)
Next Time

- Start statistical inference by looking at sampling