Dealing with Uncertainty: Concepts and Tools

1.040/1.401J
System and Project Management
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Decision Making Under Risk

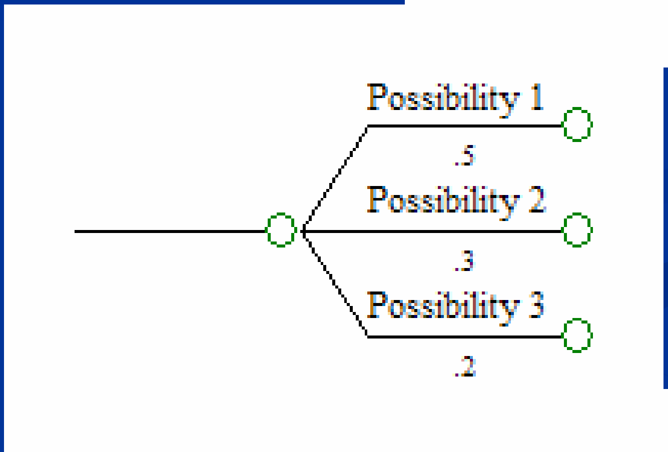
- Decision trees for representing uncertainty
- Examples of simple decision trees
- Risk Preferences, Attitude and Premiums
- Decision trees for analysis
- Flexibility and real options

Introduction to Decision Trees

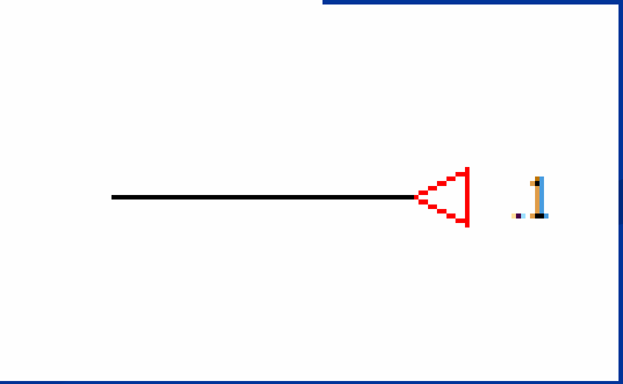
- We will use decision trees both for
  - Diagrammatically illustrating decision making w/uncertainty
  - Quantitative reasoning
- Represent
  - Flow of time
  - Decisions
  - Uncertainties (via events)
  - Consequences (deterministic or stochastic)
- Learn well: *Decision trees will reappear throughout the course*

Decision Tree Nodes

- Decision (choice) Node



- Chance (event) Node



- Terminal (consequence) node

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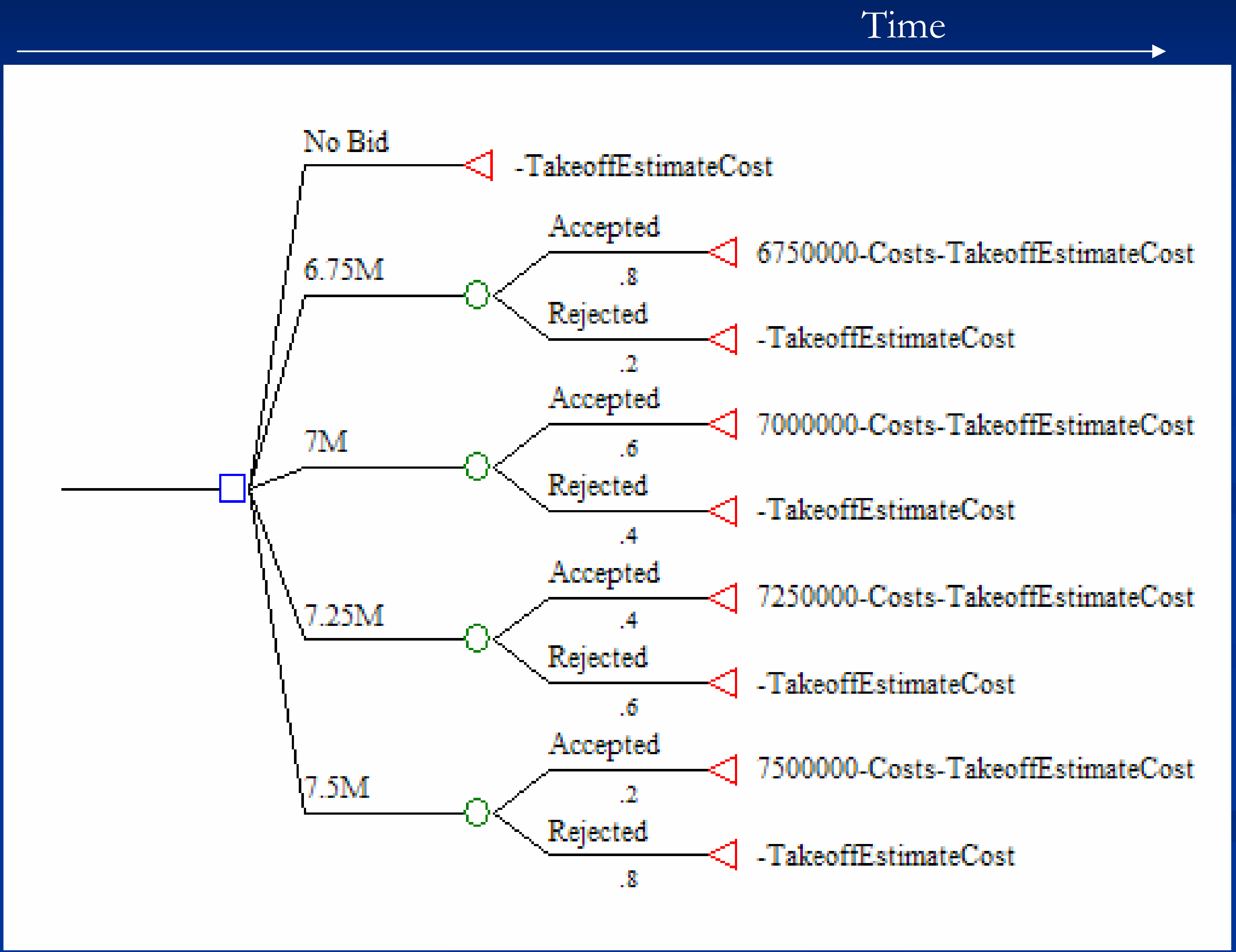
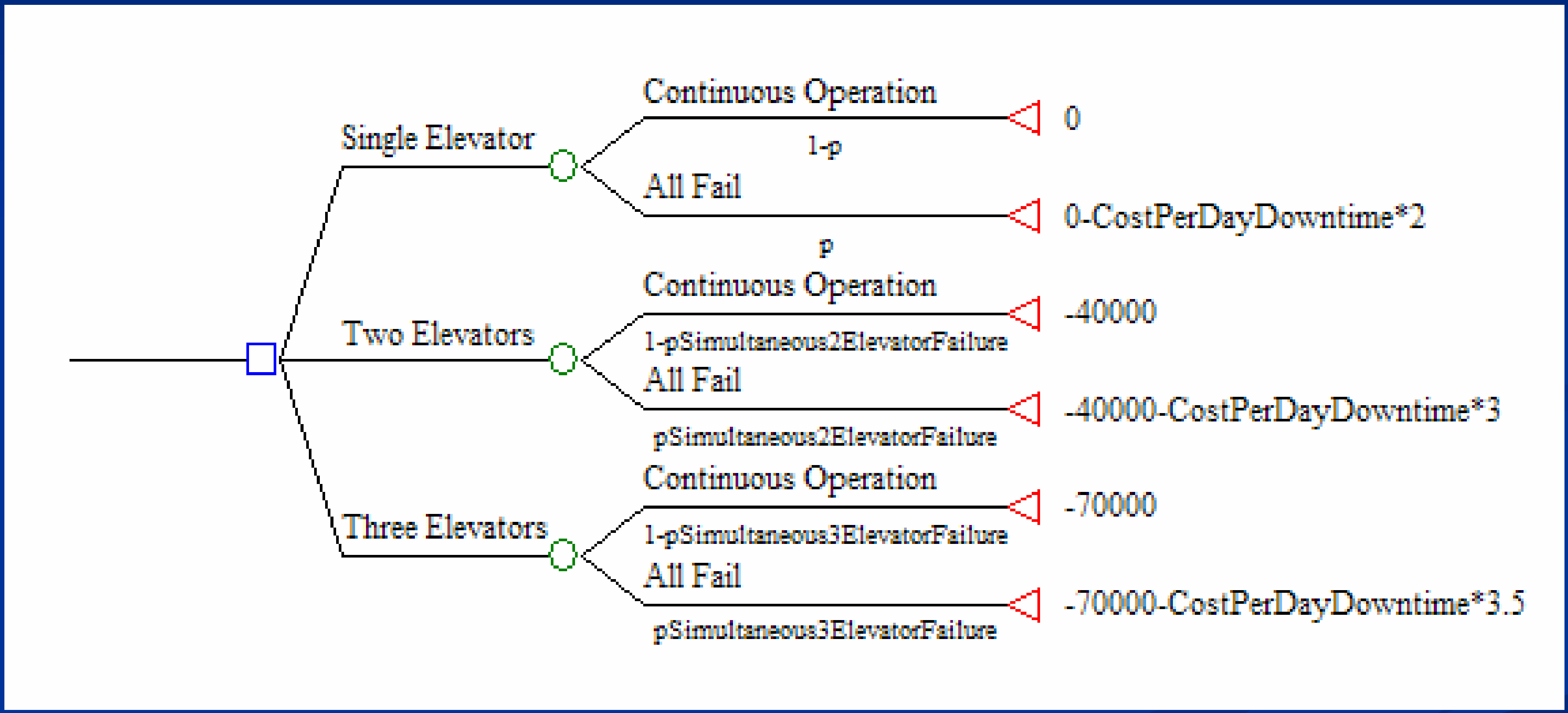
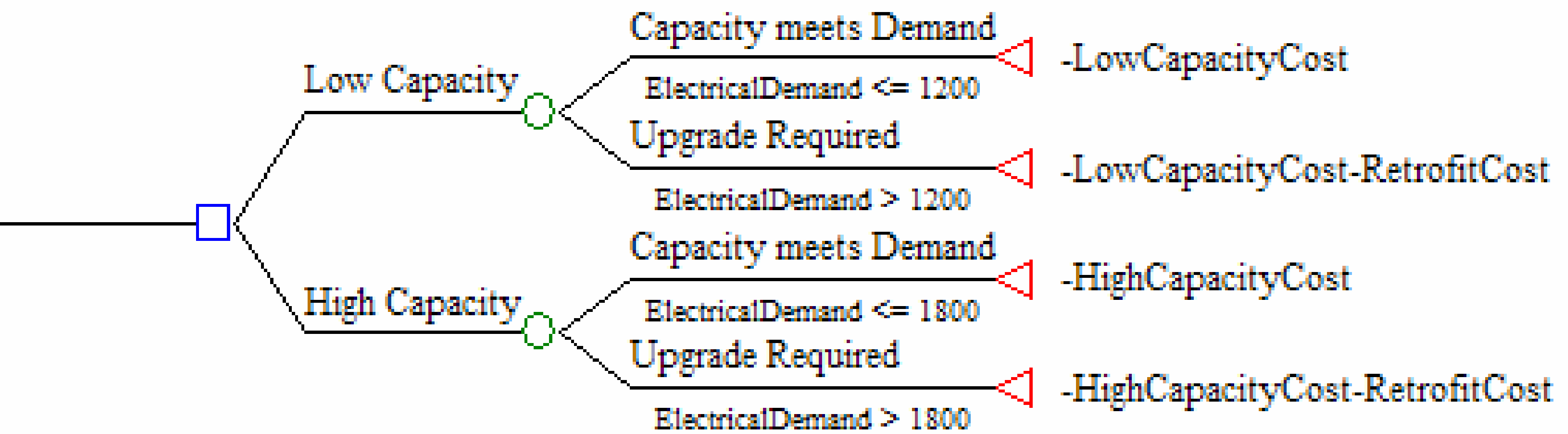
Example Bidding Decision Tree



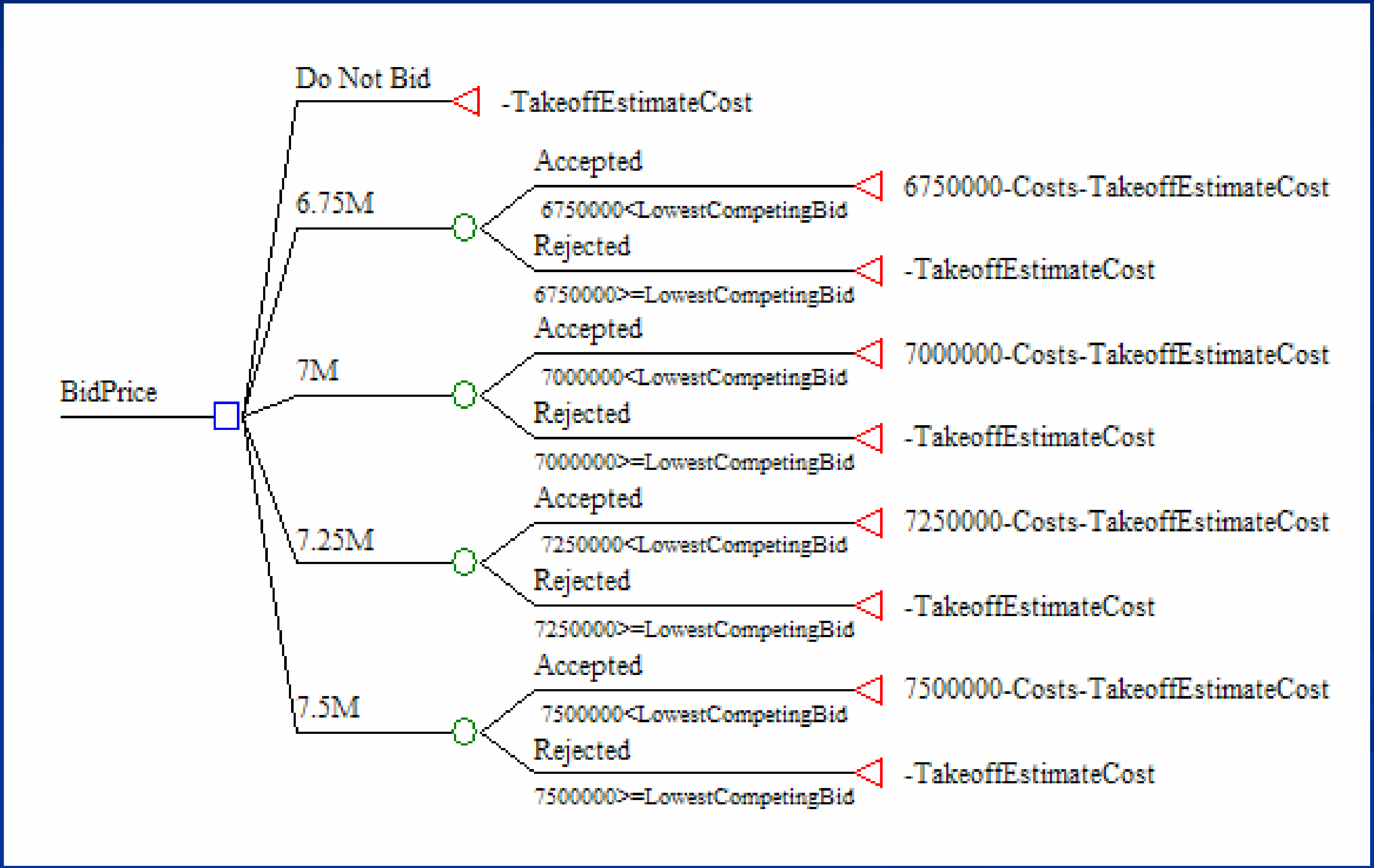
Choosing Elevator Count



Selecting Desired Electrical Capacity



Bidding Decision Tree with Stochastic Costs, Competing Bids



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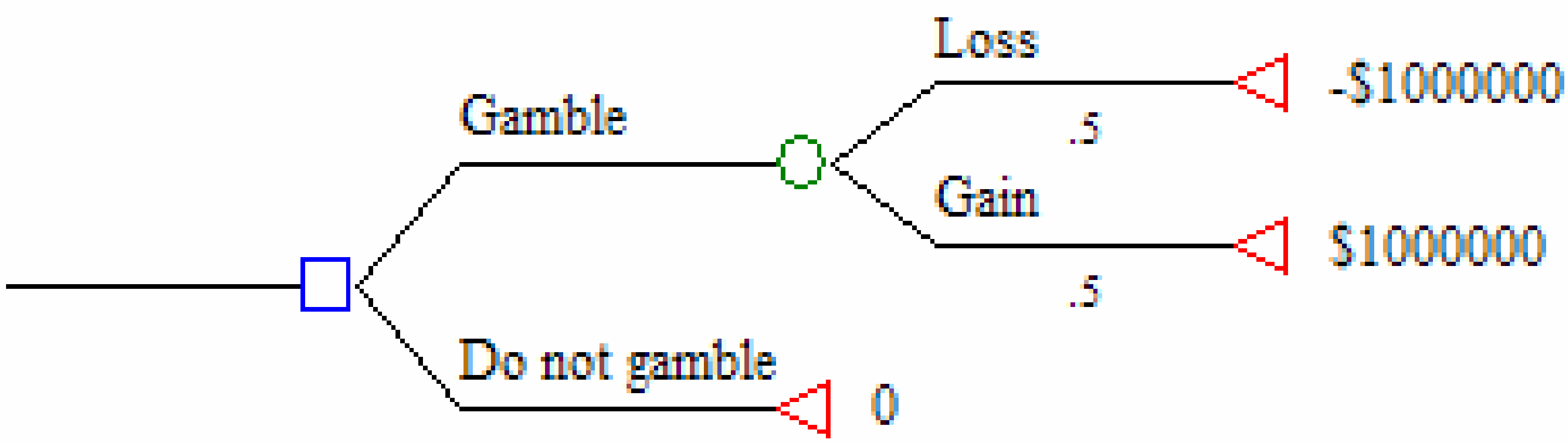
Risk Preference

- People are not indifferent to uncertainty
  - Lack of indifference from uncertainty arises from uneven preferences for different outcomes
  - E.g. someone may dislike losing $x far more than winning $x
- Individuals differ in comfort with uncertainty based on circumstances and preferences
- Risk averse individuals will pay “risk premiums” to avoid uncertainty

Risk Preference



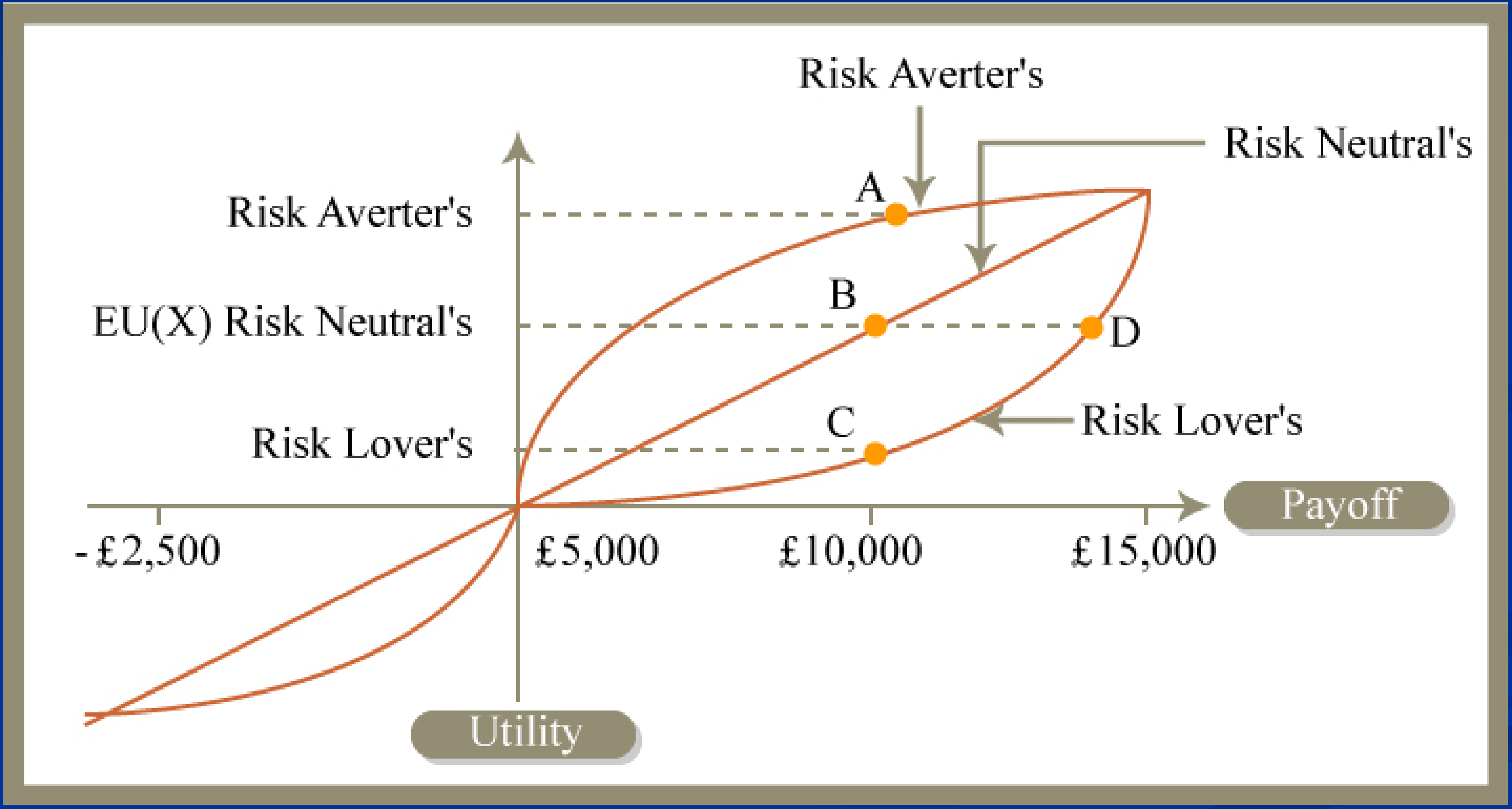
Categories of Risk Attitudes

- Risk attitude is a general way of classifying risk preferences
- Risk averse fear loss and seek sure gains
- Risk neutral are indifferent to uncertainty
- Risk lovers hope to “win big”
- Risk attitudes change over
  - Time
  - Circumstance

Preference Function

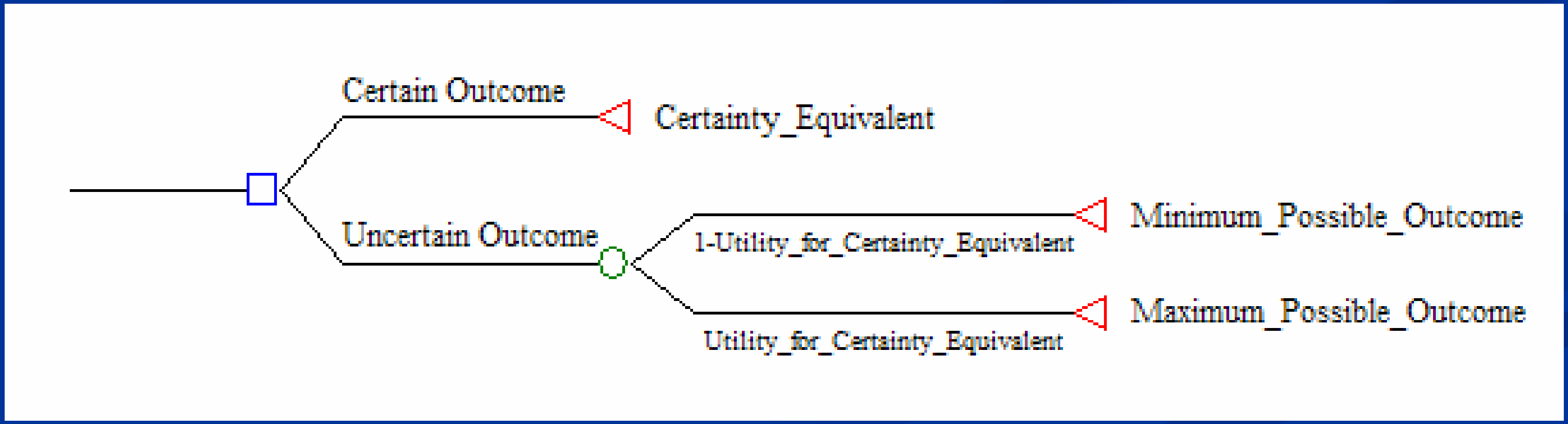
- Formally expresses a particular party's degree of preference for (satisfaction with) different outcomes ($, time, level of conflict, quality…)
- Can be systematically derived
- Used to identify best decision when have uncertainty with respect to consequences
  - Choice with the highest mean preference is the best strategy for *that particular party*

Risk Attitude in Preference Fns



Identifying Preference Functions

- Simple procedure to identify utility value associated with multiple outcomes
- Interpolation between these data points defines the preference function



Notion of a Risk Premium

- A risk premium is the amount paid by an individual to avoid risk
- Risk premiums are very common
  - Insurance premiums
  - Higher fees paid by owner to reputable contractors
  - Higher charges by contractor for risky work
  - Lower returns from less risky investments
  - Money paid to ensure flexibility as guard against risk

Certainty Equivalent Example

- Consider a risk averse individual with preference fn *f* faced with an investment c that provides
  - 50% chance of earning $20000
  - 50% chance of earning $0
- Average *money* from investment = .5*$20,000+.5*$0=$10000
- Average *satisfaction* with the investment: .5*f($20,000)+.5*f($0)=.25
- This individual would be willing to trade for a *sure* investment yielding satisfaction>.25 instead
  - Can get .25 satisfaction for a sure $f^{-1}(.25)$=$5000
    - We call this the *certainty equivalent* to the investment
  - Therefore this person should be willing to trade this investment for a sure amt of money>$5000

Example Cont'd (Risk Premium)

- The risk averse individual would be willing to trade the uncertain investment c for any certain return which is > $5000
- Equivalently, the risk averse individual would be willing to pay another party an amount *r* up to $5000 =$10000-$5000 for other less risk averse party to guarantee $10,000
  - The other party wins because gain *r* on average
  - The risk averse individual wins b/c more satisfied

Certainty Equivalent

- More generally, consider situation in which have
  - Uncertainty with respect to consequence *c*
  - Non-linear preference function *f*
- Note: E[X] is the mean (expected value) operator
- The mean *outcome* of uncertain investment c is E[c]
  - In example, this was .5*$20,000+.5*$0=$10,000
- The mean *satisfaction with* the investment is E[f(c)]
  - In example, this was .5*f($20,000)+.5*f($0)=.25
- We call f^{-1}(E[f(c)]) the *certainty equivalent* of c
  - Size of *sure* return that would give the same satisfaction as *c*
  - In example, was f^{-1}(.25)=f^{-1}(.5*20,000+.5*0)=$5,000
- For risk *averse* individuals, $f^{-1}(E[f(c)])<E[c]$

Motivations for a Risk Premium

- Consider
  - Risk averse individual A for whom $f^{-1}(E[f(c)])<E[c]$
  - Less risk averse party B
- A can lessen the effects of risk by paying a risk premium *r* of up to $E[c]-f^{-1}(E[f(c)])$ to B in return for a *guarantee* of E[c] income
  - The risk premium shifts the risk to B
  - The net investment gain for A is $E[c]-r$, but A is more satisfied because $E[c] - r > f^{-1}(E[f(c)])$
  - B gets average monetary gain of *r*

Multiple Attribute Decisions

- Frequently we care about multiple attributes
  - Cost
  - Time
  - Quality
  - Relationship with owner
- Terminal nodes on decision trees can capture these factors – but still need to make different attributes comparable

Pareto Optimality

- Even if we cannot directly weigh one attribute vs. another, we can rank some consequences
- Can rule out decisions giving consequences that are inferior with respect to *all* attributes
  - We say that these decisions are "dominated by" other decisions
- Key concept here: May not be able to identify *best decisions*, but we can rule out obviously bad
- A decision is "Pareto optimal" if it is not dominated by any other decision

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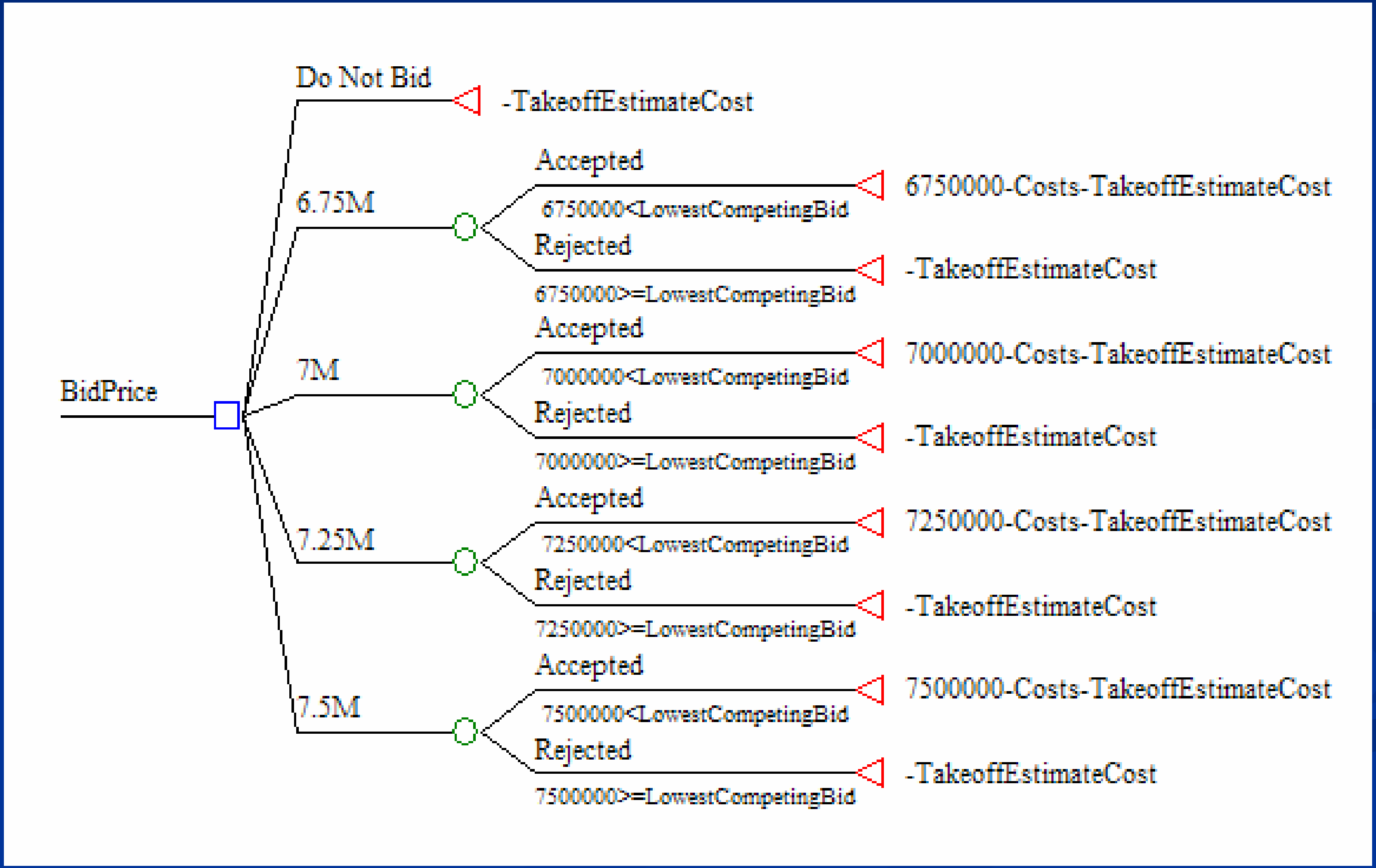
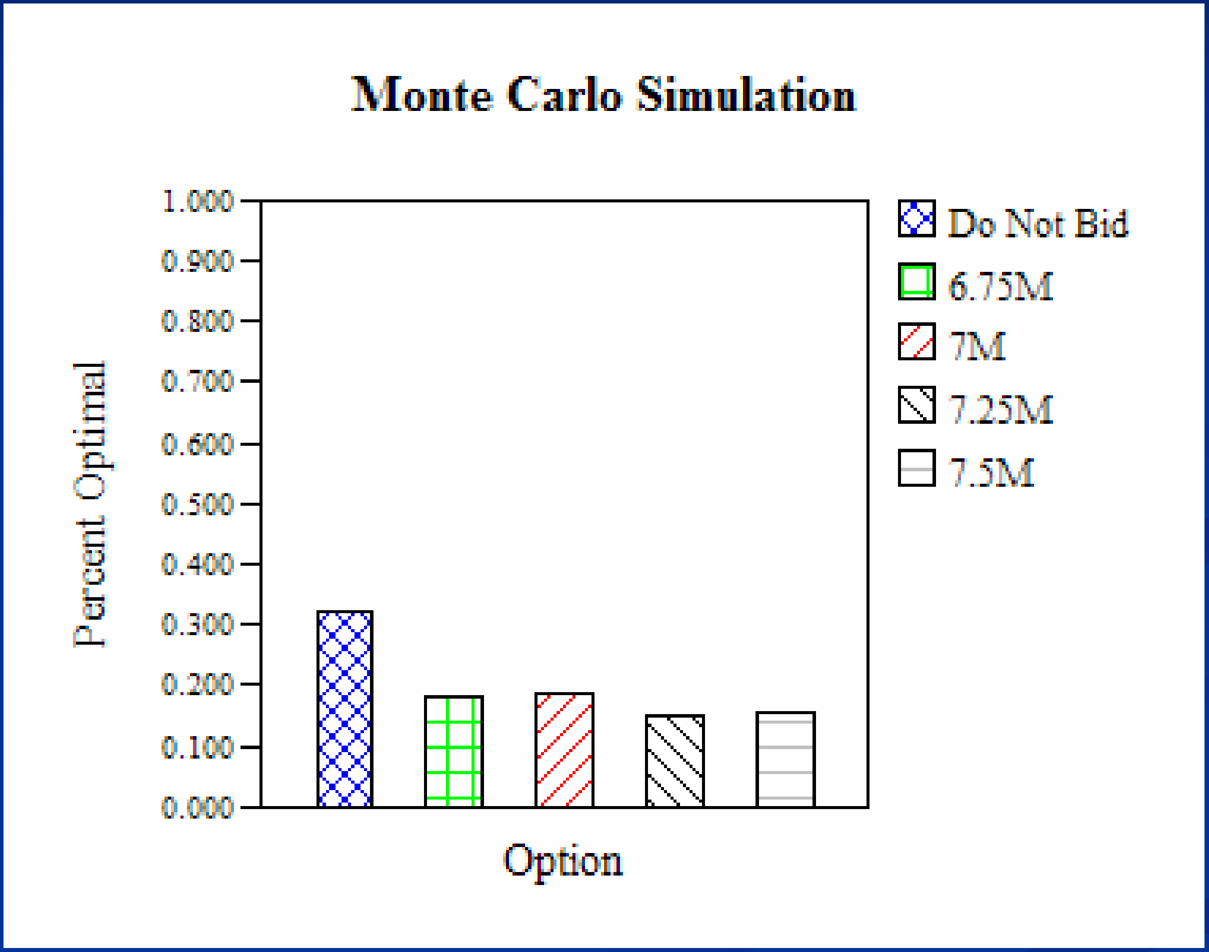
Analysis Using Decision Trees

- Decision trees are a powerful analysis tool
- Addition of symbolic components to decision trees greatly expand power
- Example analytic techniques
  - Strategy selection
  - One-way and multi-way sensitivity analyses
  - Value of information

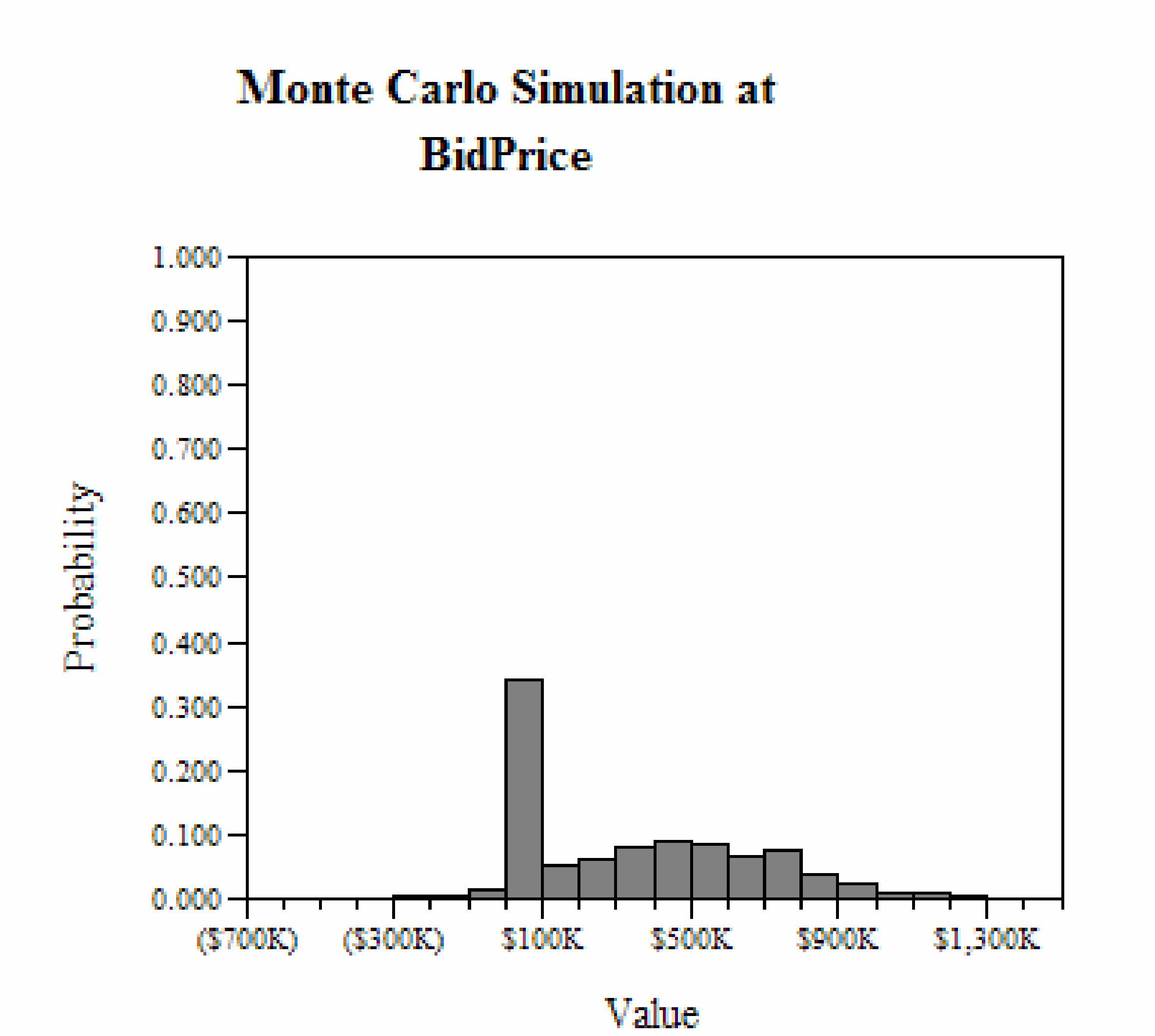
Recall Competing Bid Tree



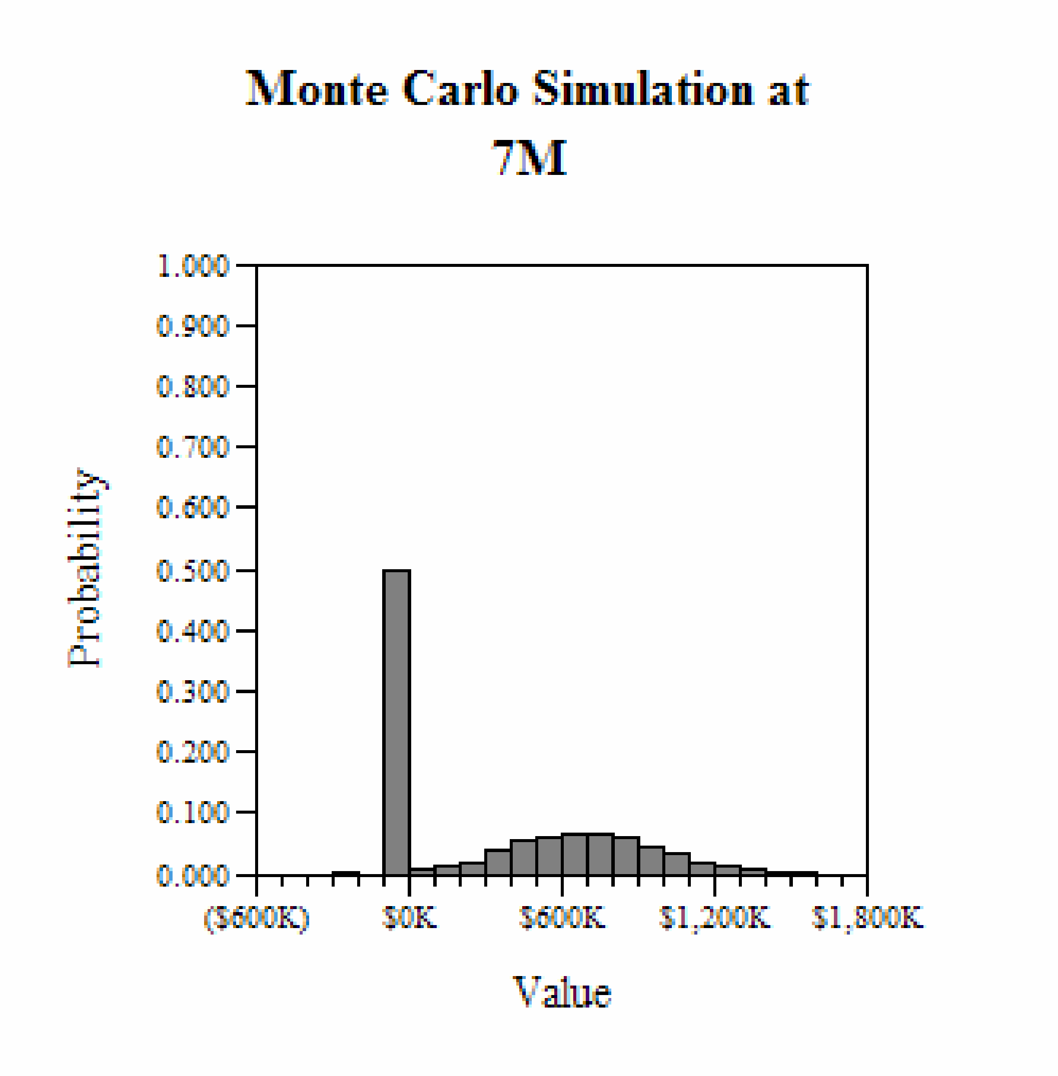
Optimal Strategy



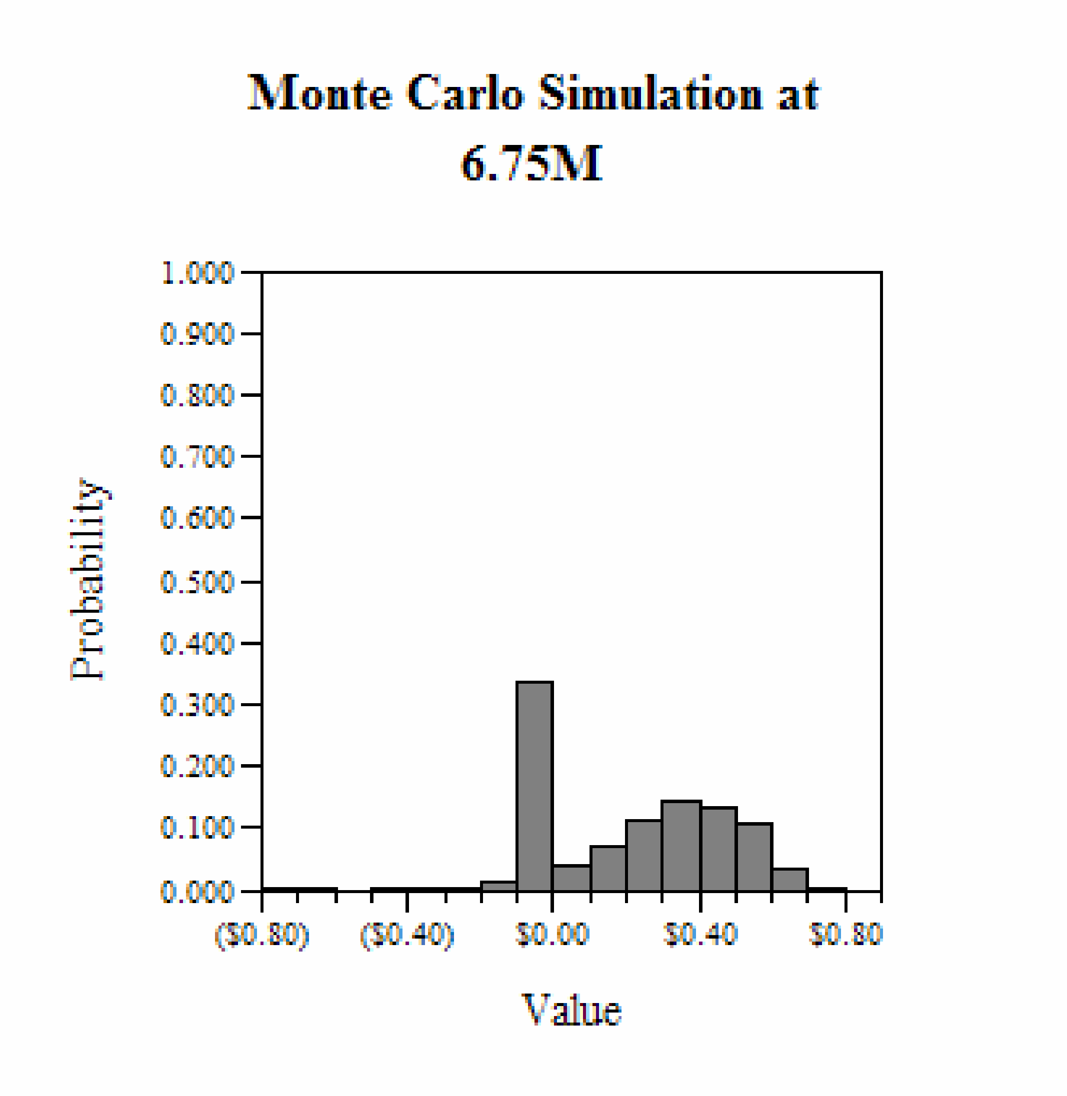
Monetary Value of $6.75M Bid



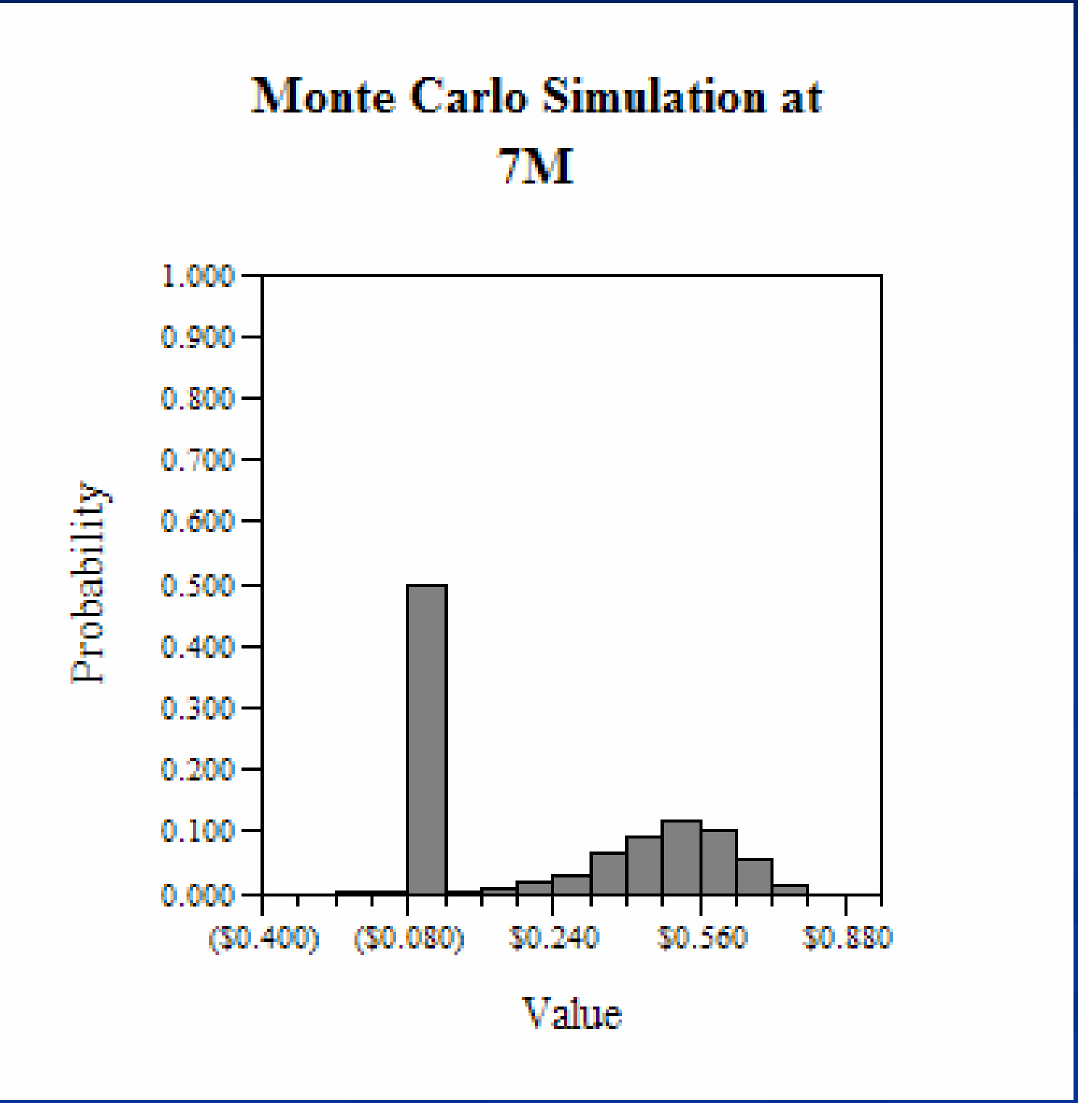
Monetary Value of $7M Bid



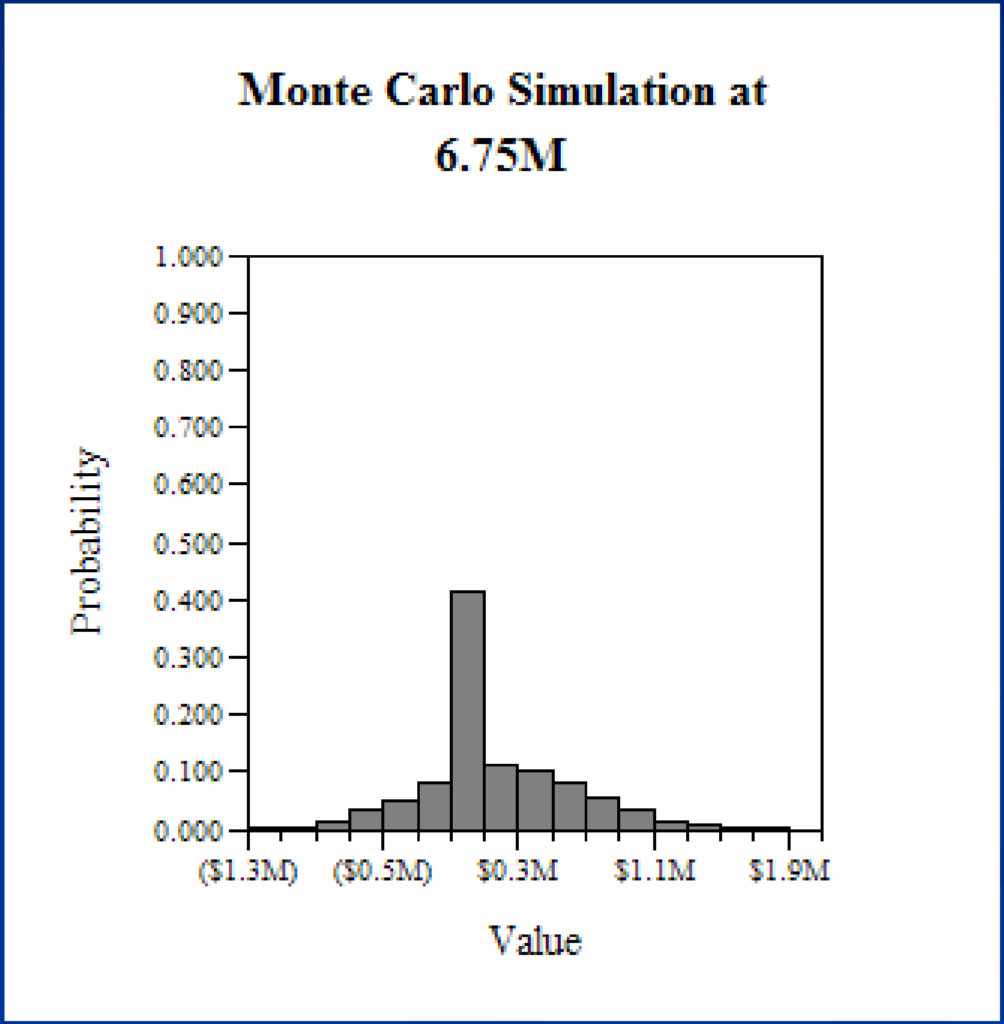
With Risk Preferences: 6.75M



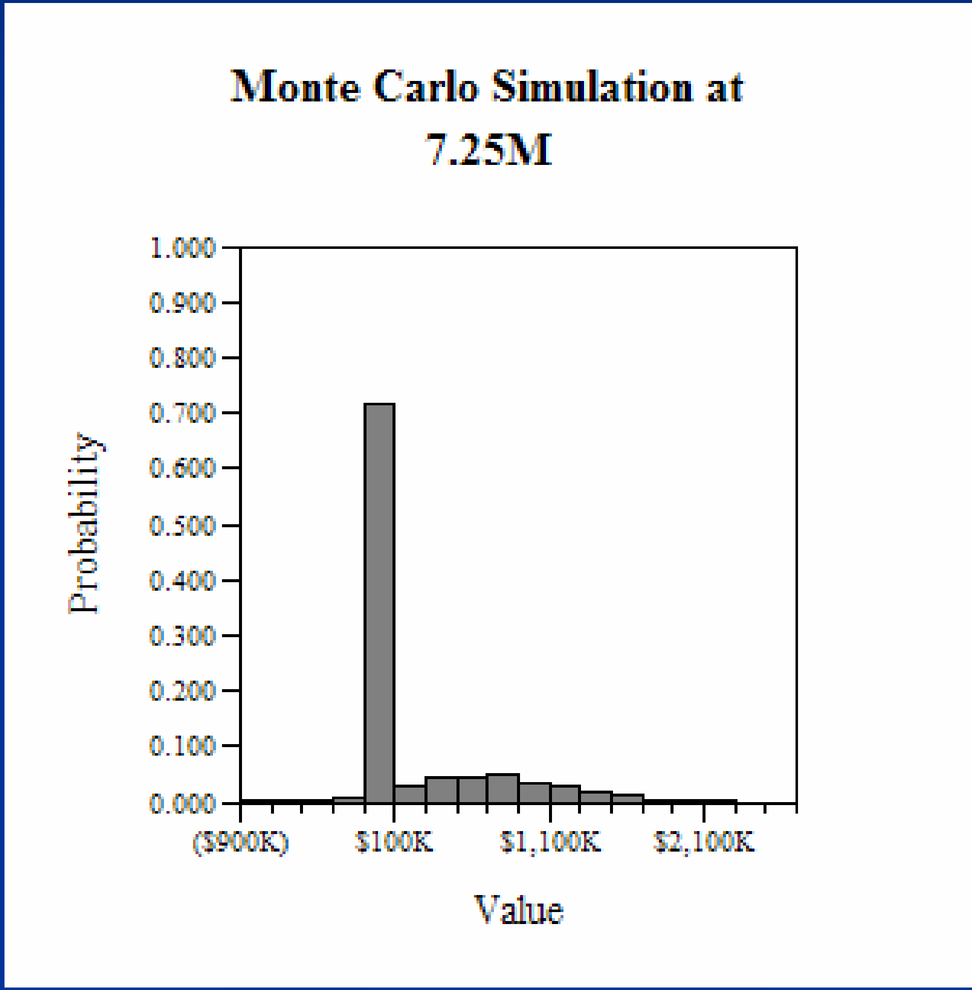
With Risk Preferences: 7M



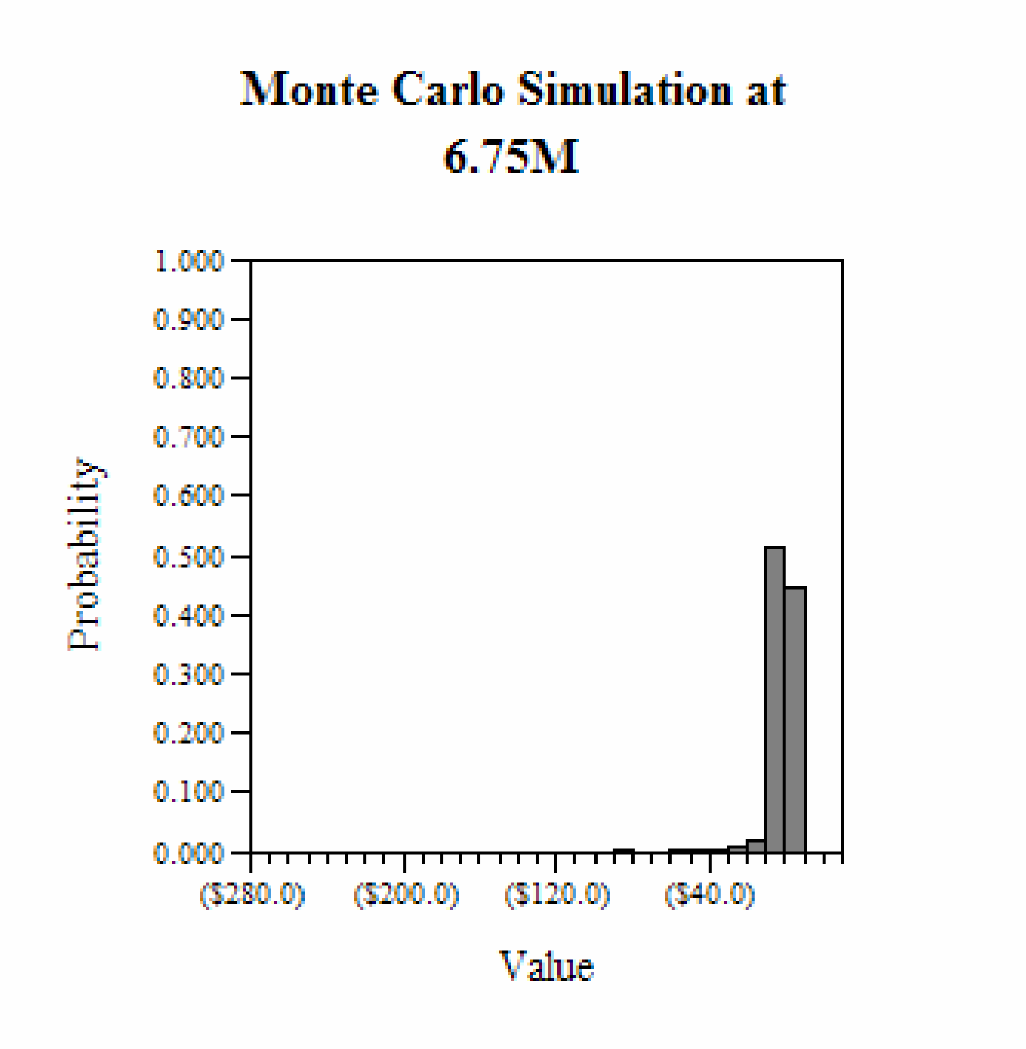
Larger Uncertainties in Cost (Monetary Value)



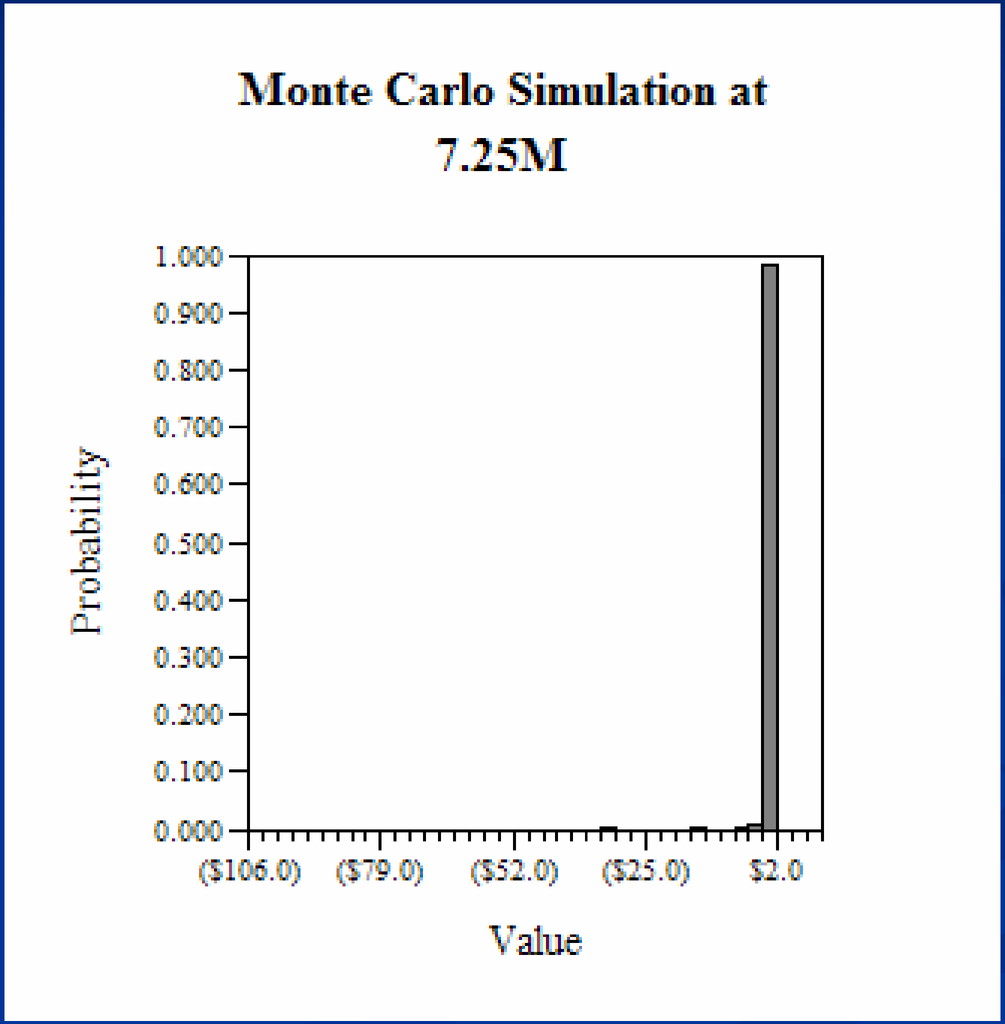
Large Uncertainties II (Monetary Values)



With Risk Preferences for Large Uncertainties at lower bid



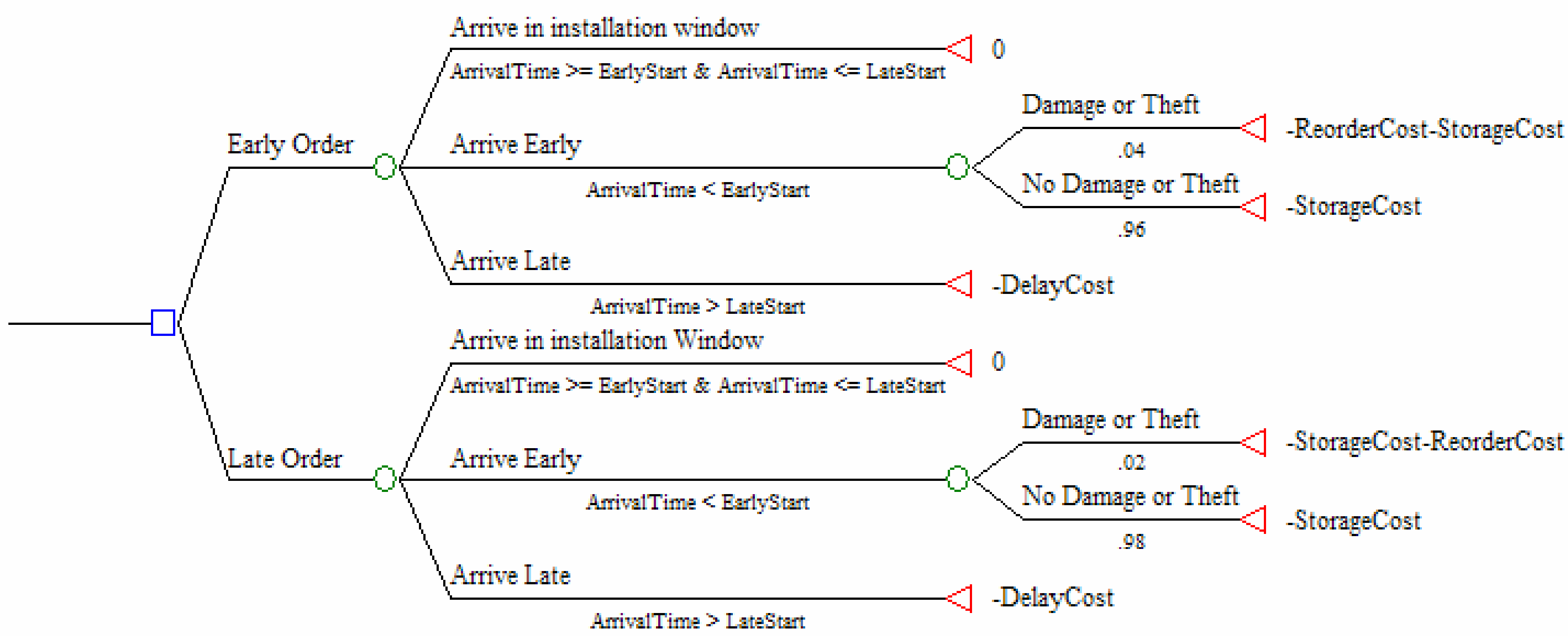
With Risk Preferences for Higher Bid



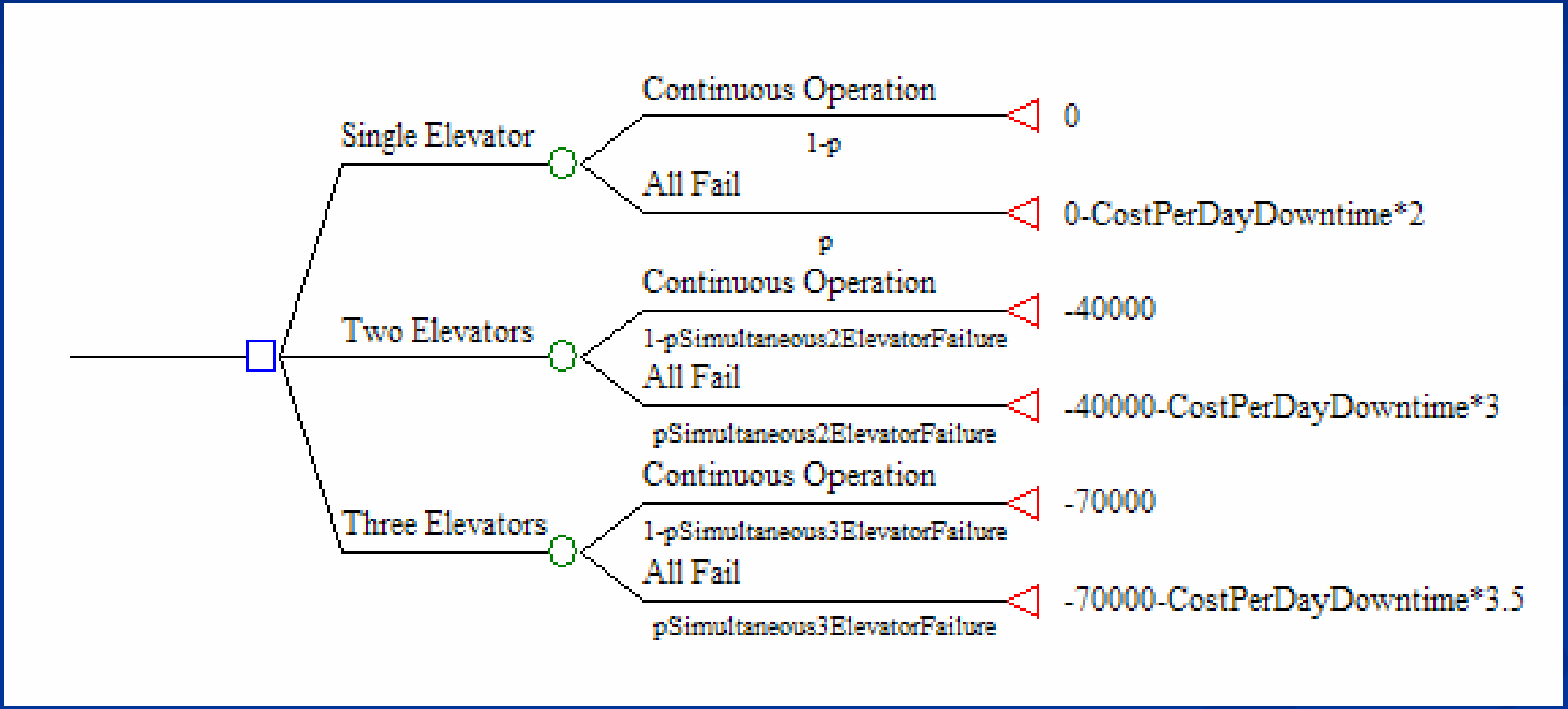
Interactive Decision Tree Example: Procurement Timing

- Decisions
  - Choice of order time (Order early, Order late)
- Events
  - Arrival time (On time, early, late)
  - Theft or damage (only if arrive early)
- Consequences: Cost
  - Components: Delay cost, storage cost, cost of reorder (including delay)

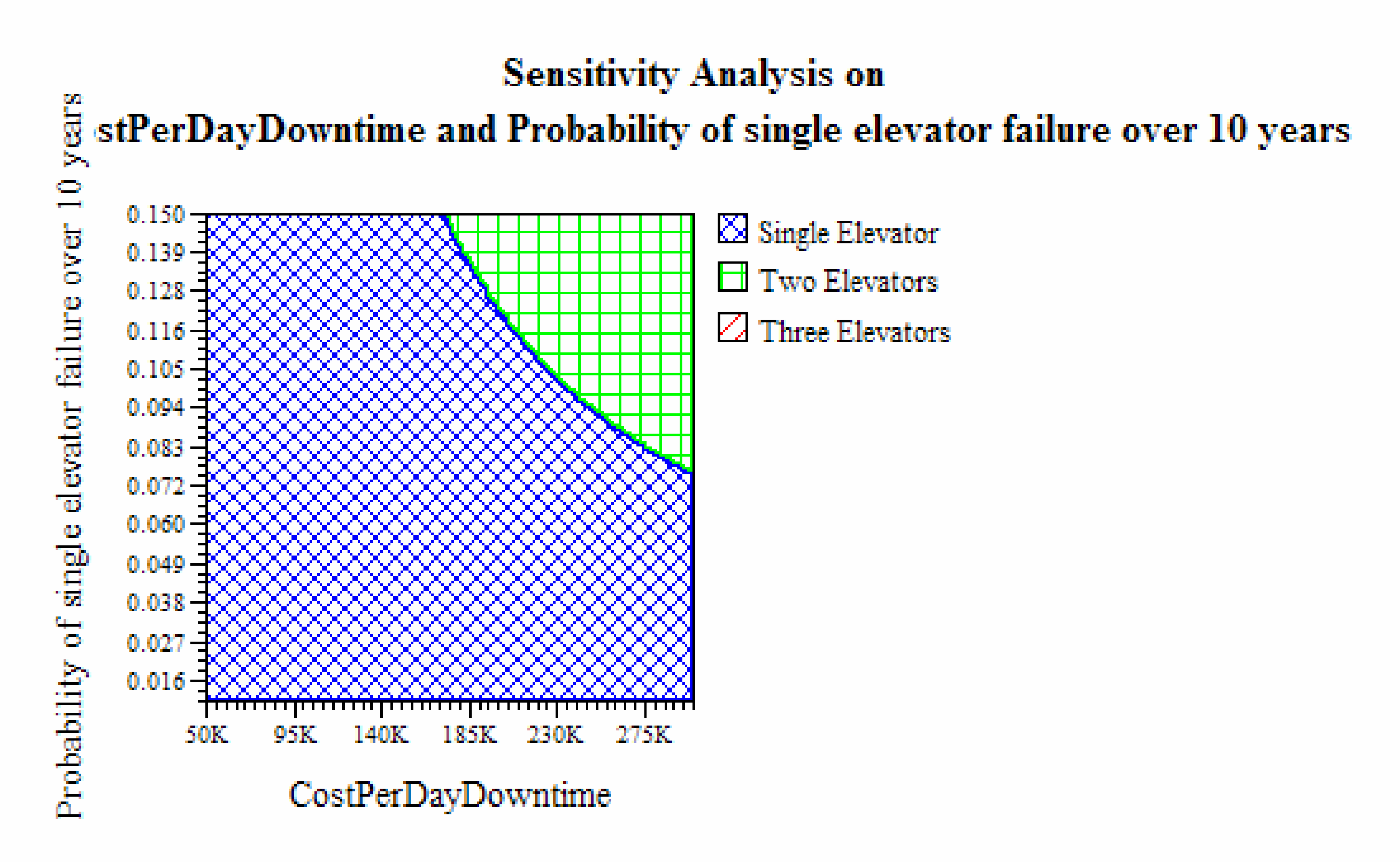
More Sophisticated Procurement



Sensitivity Analysis I



Sensitivity Analysis II



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Flexibility and Real Options

- Flexibility is *providing additional choices*
- Flexibility typically has
  - Value by acting as a way to lessen the negative impacts of uncertainty
  - Cost
    - Delaying decision
    - Extra time
    - Cost to pay for extra “fat” to allow for flexibility

Ways to Ensure of Flexibility in Construction

- Alternative Delivery
- Clear spanning (to allow movable walls)
- Extra utility conduits (electricity, phone,…)
- Larger footings & columns
- Broader foundation
- Alternative heating/electrical
- Contingent plans for
  - Value engineering
  - Geotechnical conditions
  - Procurement strategy
- Additional elevator
- Larger electrical panels
- Property for expansion
- Sequential *construction*
- Wiring to rooms

Illustration of Flexibility

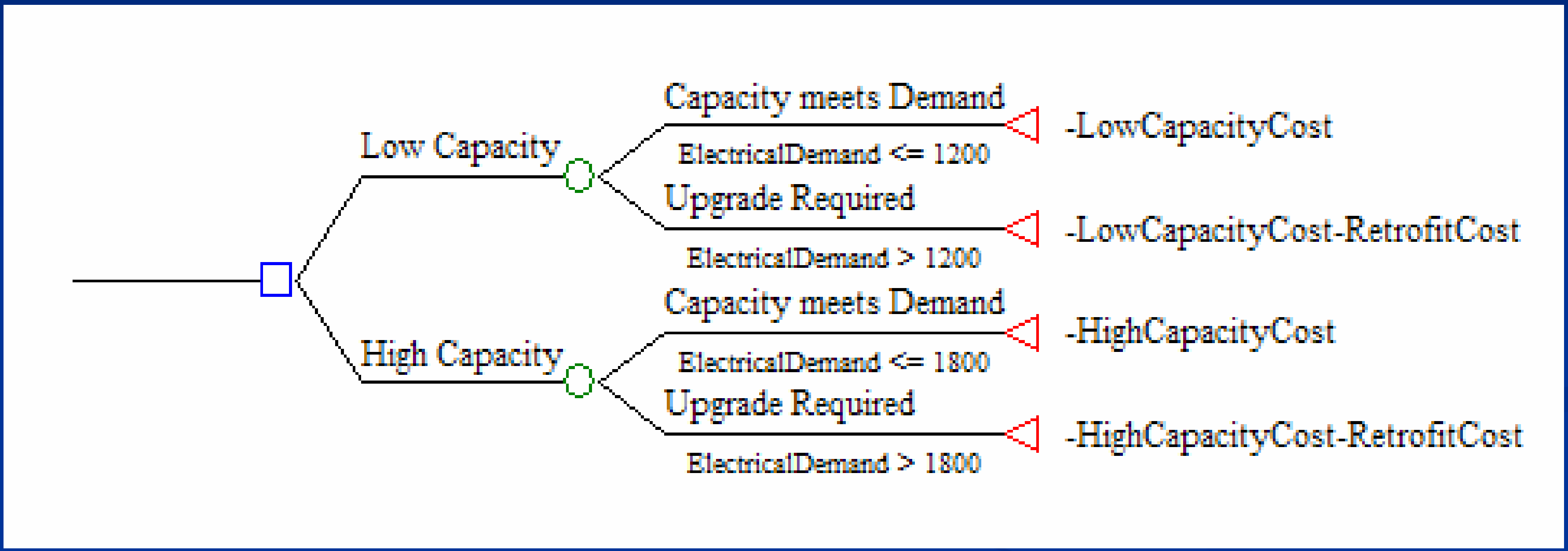
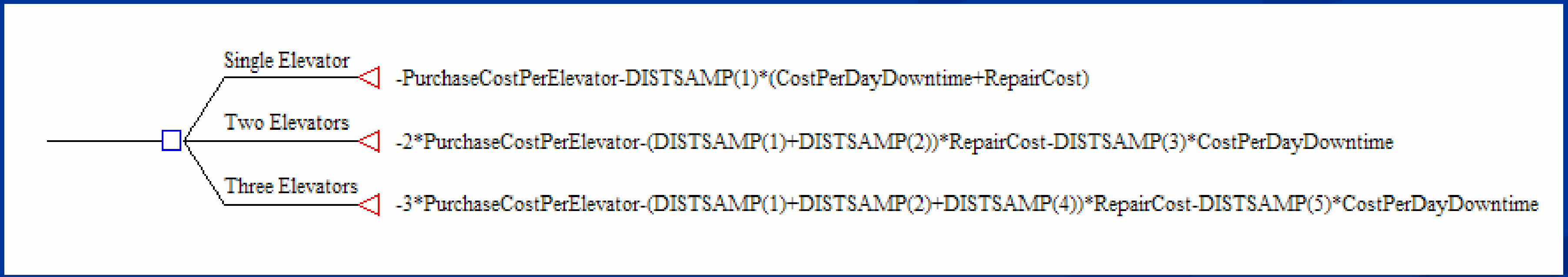
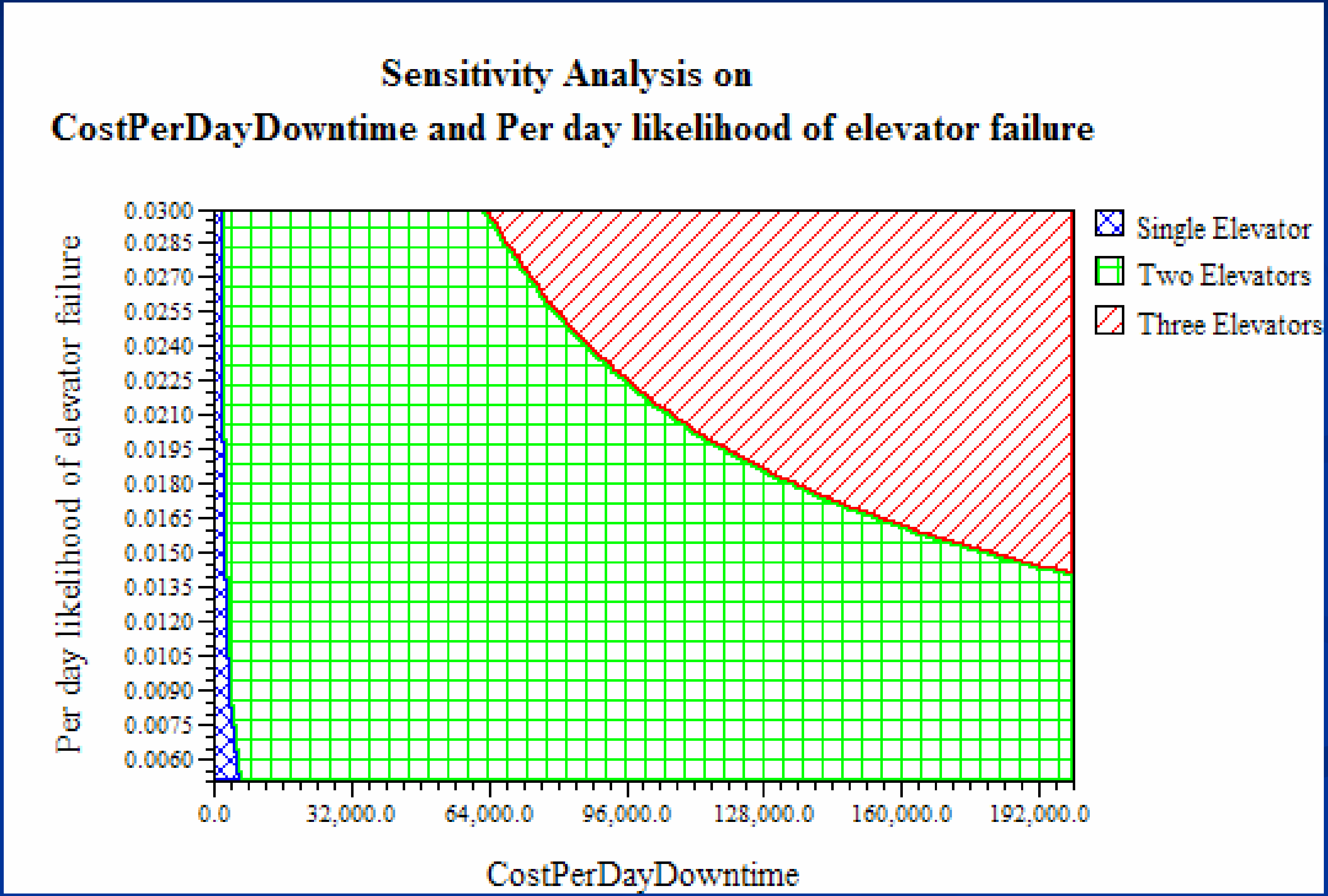


Illustration of Flexibility: Selection of Elevator Count

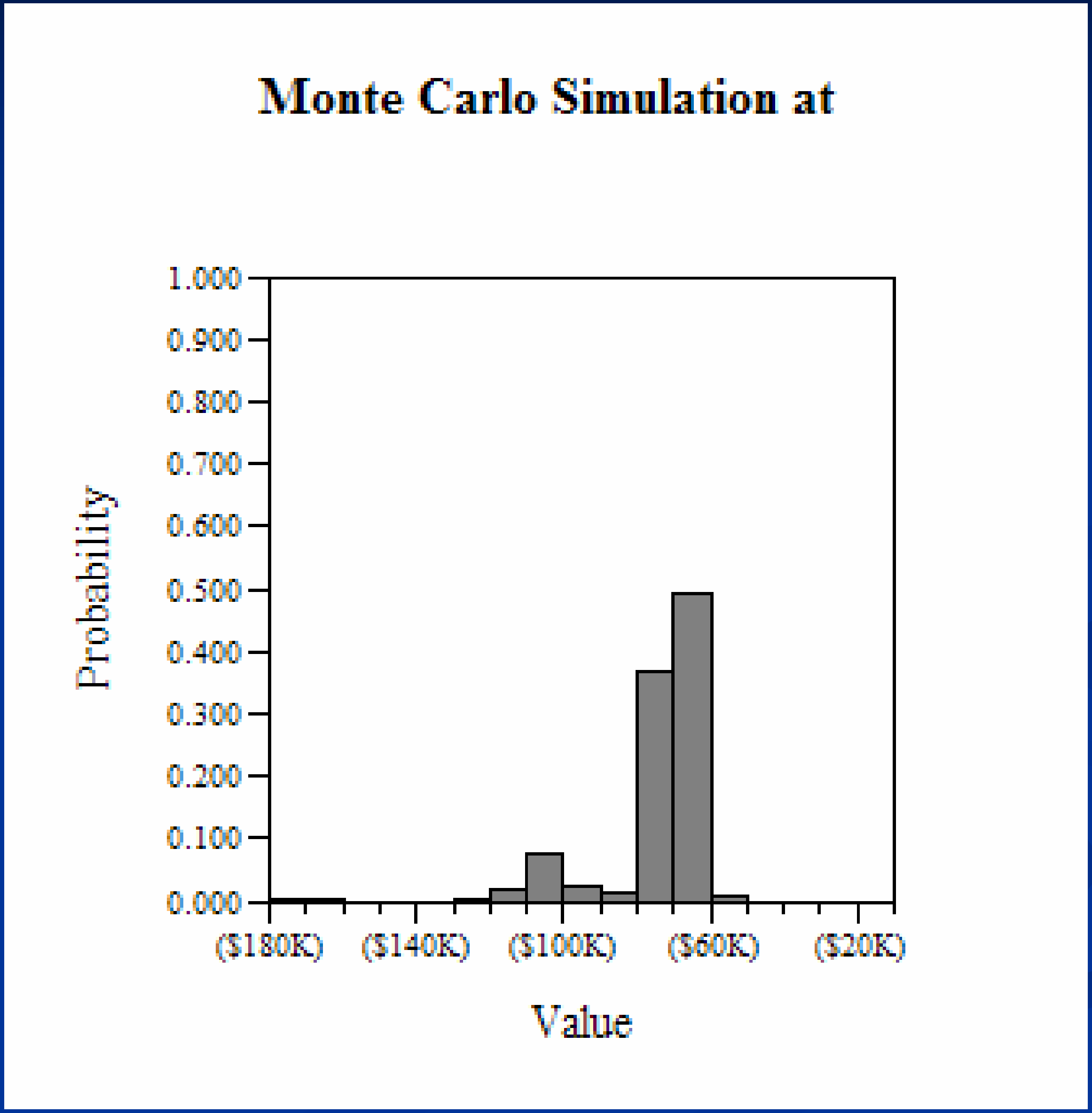
- More sophisticated model taking into account
  - Initial costs
  - Repair costs
  - Loss due to lost conveyance



Sensitivity Analysis

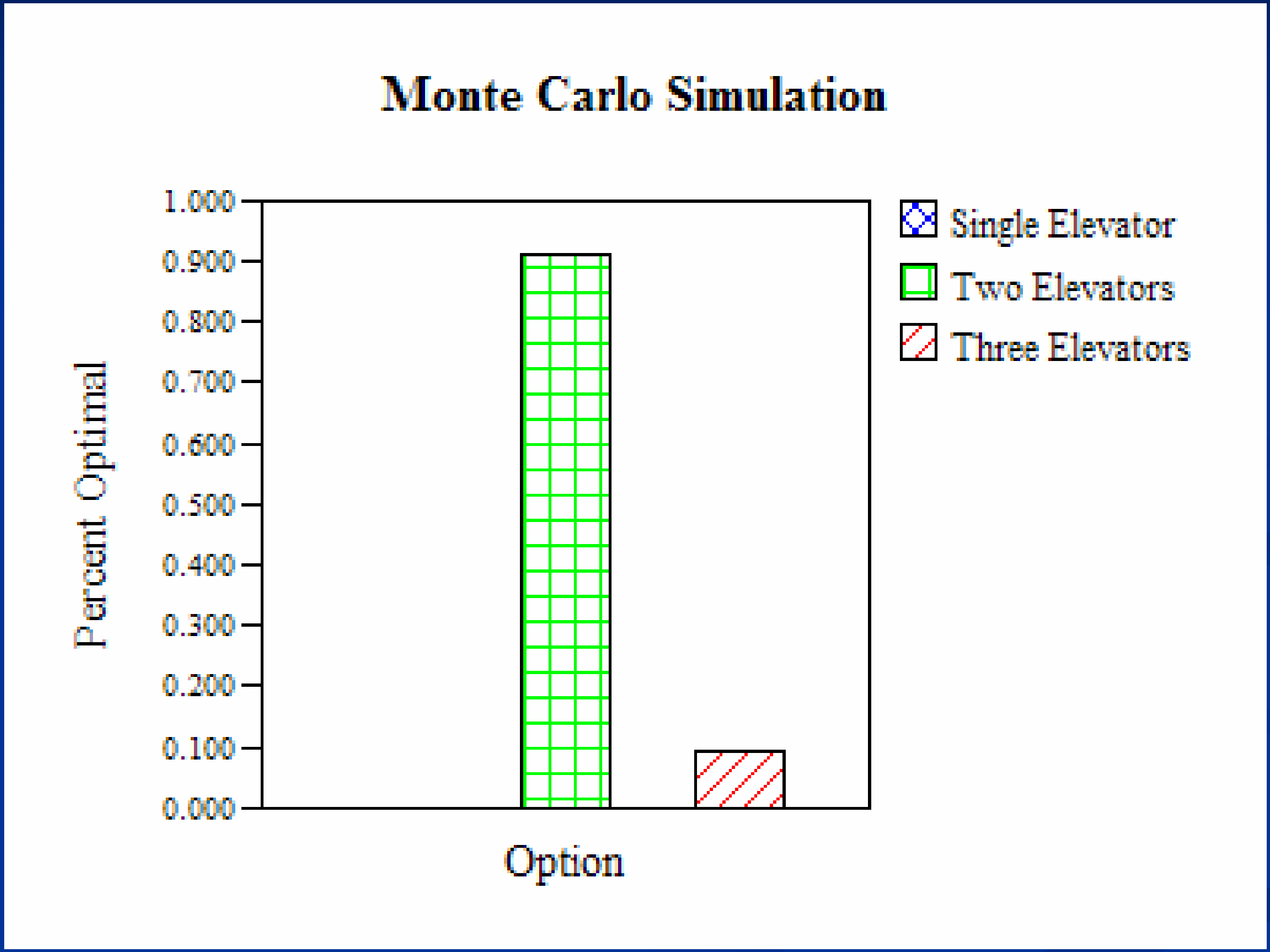


Outcome



Monte Carlo Simulation at
Probability
1.000
0.900
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
($180K)
($140K)
($100K)
($60K)
($20K)
Value

Strategy Selection



Adaptive Strategies

- An adaptive strategy is one that changes the course of action based on what is observed – i.e. one that has flexibility
  - Rather than planning statically up front, explicitly plan to adapt as events unfold
  - Typically we delay a decision into the future

Real Options

- Real Options theory provides a means of estimating financial *value* of flexibility
  - E.g. option to abandon a plant, expand bldg
- Key insight: NPV does not work well with uncertain costs/revenues
  - E.g. difficult to model option of abandoning invest.
- Model events using stochastic diff. equations
  - Numerical or analytic solutions
  - Can derive from decision-tree based framework

Example: Structural Form Flexibility

Considerations

- Tradeoffs
  - Short-term speed and flexibility
    - Overlapping design & construction and different construction activities limits changes
  - Short-term cost and flexibility
    - E.g. value engineering away flexibility
    - Selection of low bidder
    - Late decisions can mean greater costs
  - NB: both budget & schedule may ultimately be better off w/greater flexibility!
- Frequently retrofitting \$ > up-front \$

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