# ECE 307 – Techniques for Engineering Decisions

## Course Overview

**George Gross**

**Department of Electrical and Computer Engineering**

**University of Illinois at Urbana-Champaign**

# SCOPE OF COURSE

- **The course covers *techniques* that are useful when combined with the appropriate technical knowledge, for making *engineering/economic decisions***
- **Such decisions are typical of those made by business firms, government-owned enterprises and agencies and individuals**
- **We focus on the *systematic* evaluation of alternatives before a decision is made regarding a particular problem**

# EXAMPLES OF DECISION MAKING PROBLEMS

- Introduction of a new product
- Expansion of production facilities/warehousing
- Adoption of new technology
- Implementation of a new production schedule
- Changes in the production mix
- Risk management in purchase/sale activities
- Optimal scheduling of processes/projects

# BASIC THRUSTS

- Development of the analytical framework for decision making on a sound and systematic basis with the goal to enable the decision maker to undertake an appropriate analysis and systematic evaluation of various alternatives
- Provide training for engineers to play an increasingly more prominent role in the decision making processes in their work environment

# THE UNDERLYING BASIS

- Decisions are made by selecting from possible alternatives with reference to the future which is inherently ***uncertain***
- A common basis is set up by formulating the decisions in ***economic*** terms
- A key aspect is the ***assumptions*** introduced to enable the undertaking of the analysis and the evaluation of alternatives

# PRODUCT MIX OPTIMIZATION PROBLEM

- A factory manufactures three different products requiring various levels of resources and providing different benefits (profits)
- The constraints on resources are given
- Problem: determine the optimal daily mix, i.e., the production schedule that maximizes profits without violating any constraints

# PRODUCT MIX OPTIMIZATION PROBLEM

| *product* | | *A* | *B* | *C* | *limit* |
|---|---|---|---|---|---|
| *resources required per unit of product* | *labor* (*h*) | 1 | 1 | 1 | 100 |
| | *material* (*lb*) | 10 | 4 | 5 | 600 |
| | *A&G* (*h*) | 2 | 2 | 6 | 300 |
| *profits per unit of product* ($) | | 10 | 6 | 4 | —— |

# PRODUCT MIX OPTIMIZATION PROBLEM

- We formulate the decision problem by introducing the decision variables:

  $x_i =$ daily production level of product $i$, $i = A, B, C$

- We construct a programming problem for the schedule by expressing
  - the objective function
  - the constraints
  - the common sense requirements

  in *mathematical* terms

# PRODUCT MIX OPTIMIZATION PROBLEM

$$\max Z = 10\,x_A + 6\,x_B + 4\,x_C \quad \textit{objective}$$

$$x_A + x_B + x_C \leq 100 \quad \textit{labor}$$

$$10x_A + 4x_B + 5x_C \leq 600 \quad \textit{A \& G}$$

$$2x_A + 2x_B + 6x_C \leq 300 \quad \textit{material}$$

$$x_A, x_B, x_C \geq 0 \quad \textit{reality check}$$

*constraints*

# PRODUCT MIX OPTIMIZATION PROBLEM

- The optimal solution is

$$x_A^* = 33.33 \qquad x_B^* = 66.67 \qquad x_C^* = 0$$

corresponding to maximum profits

$$Z^* = \$\ 733.33$$

- The shadow prices corresponding to the constraints give the change in profits for additional resources:

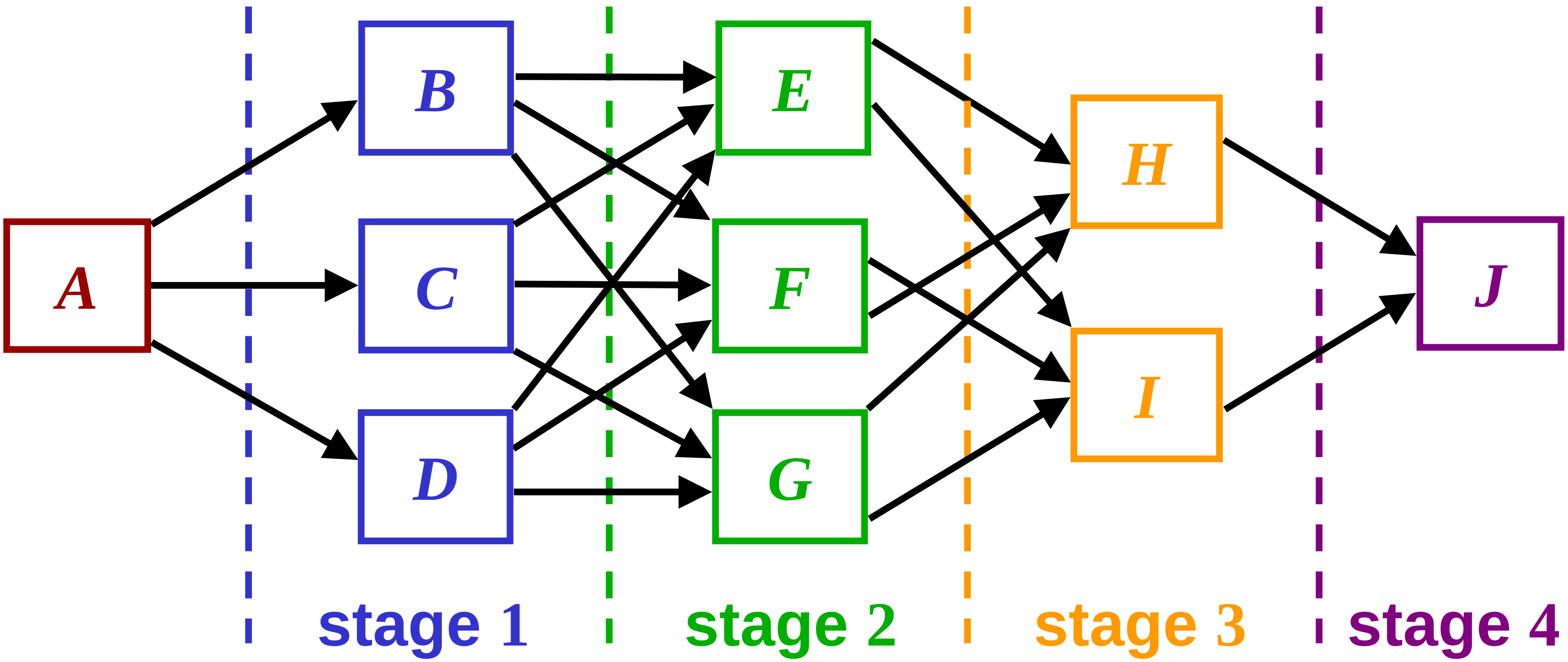
*labor* : $ 3.33 *material* : $ 0.67 *A&G* : $ 0

# PRODUCT MIX OPTIMIZATION PROBLEM

- We next examine a sensitivity case corresponding to the use of overtime labor
- We are interested in determining how many overtime hours would be profitable to schedule without impacting on the optimal product mix
  - 20 hours of labor overtime increases profits by (20) (3.33) = $ 66.6
  - as long as the cost of overtime labor does not exceed $ 66.6 it is worthwhile to use it
  - the optimal product mix remains unchanged: since we only produce products *A* and *B* and no product *C*

# OPTIMAL TRAJECTORY PLANNING

- Mr. Jones has to travel from a fixed starting point *A* to a fixed destination point *J* with a choice in the intermediate points he goes through



# OPTIMAL TRAJECTORY PLANNING

- The relative "costs" for the various possible paths are given by

| | *B* | *C* | *D* |
|---|---|---|---|
| *A* | 2 | 4 | 3 |

| | *E* | *F* | *G* |
|---|---|---|---|
| *B* | 7 | 4 | 6 |
| *C* | 3 | 2 | 4 |
| *D* | 4 | 1 | 5 |

| | *H* | *I* |
|---|---|---|
| *E* | 1 | 4 |
| *F* | 6 | 3 |
| *G* | 3 | 3 |

| | *J* |
|---|---|
| *H* | 3 |
| *I* | 4 |

- The problem is to select the route that *minimizes* the total costs of the trip

# OPTIMAL TRAJECTORY PLANNING

- **Solution approaches:**
  - **enumerate all possibilities: this is, in general, too time consuming since we need to consider**

    $$3 \times 3 \times 2 = 18$$

    **different routes for this simple case**
  - **select the best for each successive stage: myopic decision making solution leads to the path**

    $$A \rightarrow B \rightarrow F \rightarrow I \rightarrow J$$

    **with costs of 13**

# OPTIMAL TRAJECTORY PLANNING

- **use some *heuristic* approach which allows to sacrifice a little at one stage in the hope of attaining savings thereafter: for example, the path *A* → *D* → *F* has costs of 4 which are less than those of the path *A* → *B* → *F*, which are 6**

- **The optimal route is**

$$A \rightarrow C \rightarrow E \rightarrow H \rightarrow J$$

**with costs of 11**

# OPTIMAL TRAJECTORY PLANNING

- There are two additional routes whose costs are 11:

$$A \rightarrow D \rightarrow E \rightarrow H \rightarrow J$$

$$A \rightarrow D \rightarrow F \rightarrow I \rightarrow J$$

- Thus, this problem does not result in a *unique* optimum

# BUSING PROBLEM

- **Three school districts in *Busville* have a distribution of *Caucasians* (*C*) and *African Americans* (*A*) as shown in the table**

| district | number of students | |
|---|---|---|
| | *C* | *A* |
| 1 | 210 | 120 |
| 2 | 210 | 30 |
| 3 | 180 | 150 |

# BUSING PROBLEM

- **Implementation of the Supreme Court ruling on racial balance requires that each of the three districts have exactly 300 students with identical racial make-up, i.e., that**

$$\left(\frac{A}{C}\right)_1 = \left(\frac{A}{C}\right)_2 = \left(\frac{A}{C}\right)_3$$

**and the only means of attaining the racial balance goal is through busing**

# BUSING PROBLEM

- Given the distances between the districts, determine the total minimum distance that students must be bussed to satisfy the racial balance requirements

| district | number of students | | distance to district | |
|---|---|---|---|---|
| | *C* | *A* | 2 | 3 |
| 1 | 210 | 120 | 3 | 5 |
| 2 | 210 | 30 | — | 4 |
| 3 | 180 | 150 | 4 | — |

# THE ENVELOPE QUESTION

- On a television game show, the host subjects contestants to unusual tests of mental skill
- On one, a contestant may choose one of two identical envelopes – labeled $A$ and $B$ – each of which contains an unknown amount of money
- The host reveals, though, that one envelope contains twice as much money as the other
- After choosing $A$, the host suggests that the contestant might want to switch; the host states:

# THE ENVELOPE QUESTION

"Switching is clearly advantageous. Suppose you have amount $x$ in your envelope $A$. Then $B$ must contain either $x/2$ or $2x$ (with probability $0.5$). In fact, now that I think about it, I'll only let you switch if you give me a $10\%$ cut of your winnings. What do you say? You'll still be ahead."

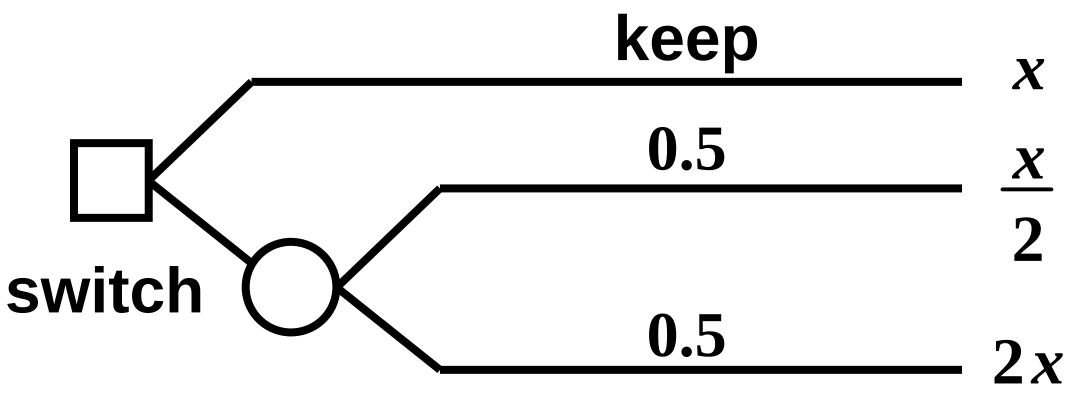
- The contestant replies:

  "No deal. But I'll be happy to switch for free. In fact, I'll even let you choose which envelope I get. I won't even charge you anything!"

- Who is right?

# THE ENVELOPE QUESTION

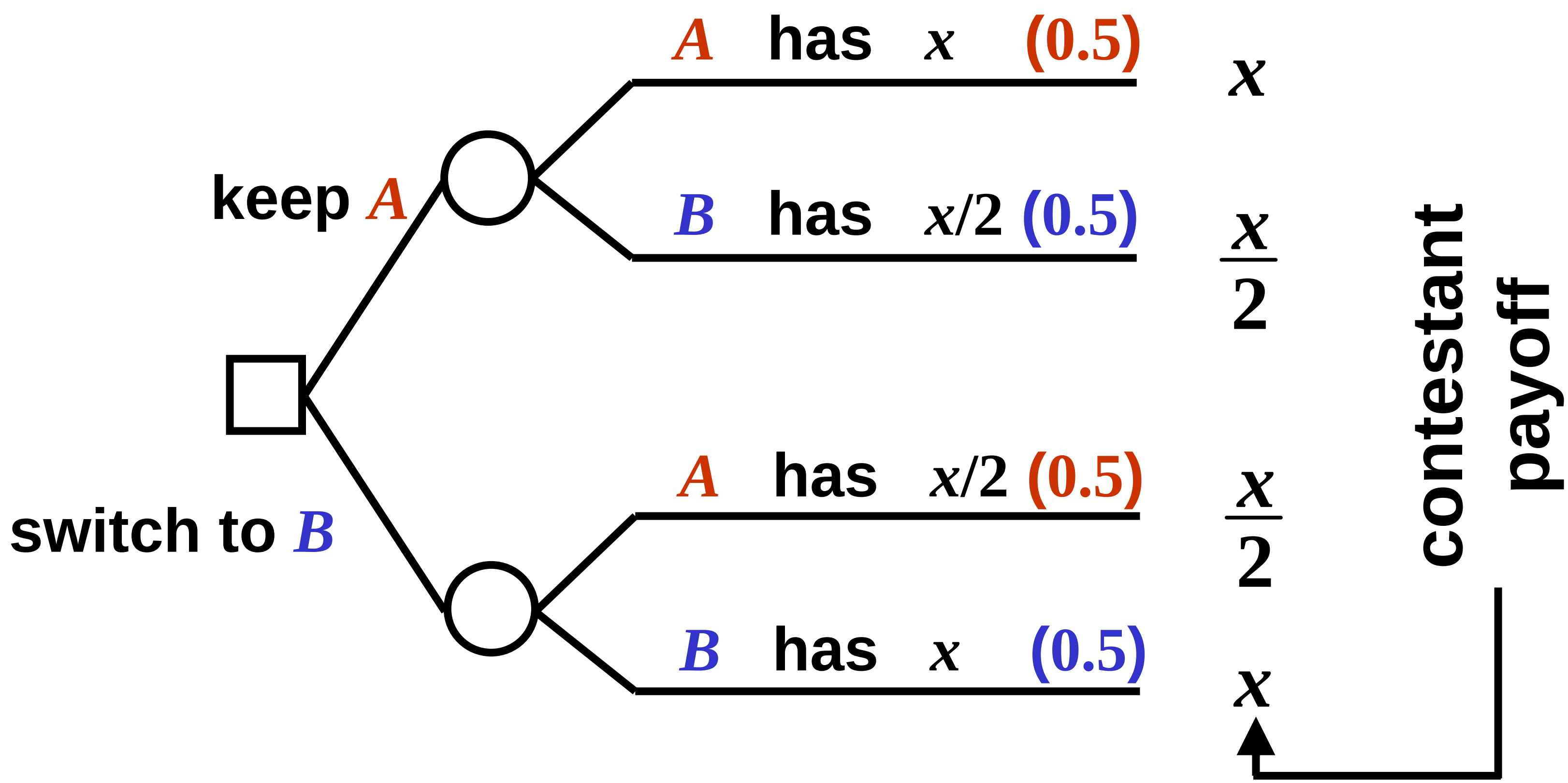
- The host is proposing a decision tree that looks like this:




which does not correctly represent the situation

# THE ENVELOPE QUESTION

- Rather, we have for the two envelopes *A* and *B*




- The two decision branches are identical from the view of the decision maker

# DECISION ANALYSIS PROTOTYPE EXAMPLE

- **The *Greazy Company* owns a tract of land that may contain oil; the report of a consulting geologist indicates that there is one chance in four that oil exists**
- **Because of this prospect, another oil company has offered to purchase the land for $\$90{,}000$ but Greazy is considering holding the land in order to drill for oil itself: if oil is found, the profits are expected to be $\$700{,}000$ but if land is dry, the losses are expected to be $\$100{,}000$**

# DECISION ANALYSIS PROTOTYPE EXAMPLE

| *decision alternative* | *payoff ($)* | |
|---|---|---|
| | *land has oil* | *land is dry* |
| *drill for oil* | 700,000 | (100,000) |
| *sell the land* | 90,000 | 90,000 |
| *probability* | 0.25 | 0.75 |

# DECISION ANALYSIS PROTOTYPE EXAMPLE

- Evaluation of the two alternative actions

| *action* | *expected payoff* (*k$*) |
| --- | --- |
| 1 | 0.25 (700) + 0.75 (-100) = 100 |
| 2 | 0.25 (90) + 0.75 (90) = 90 |

and the better choice is to drill for oil

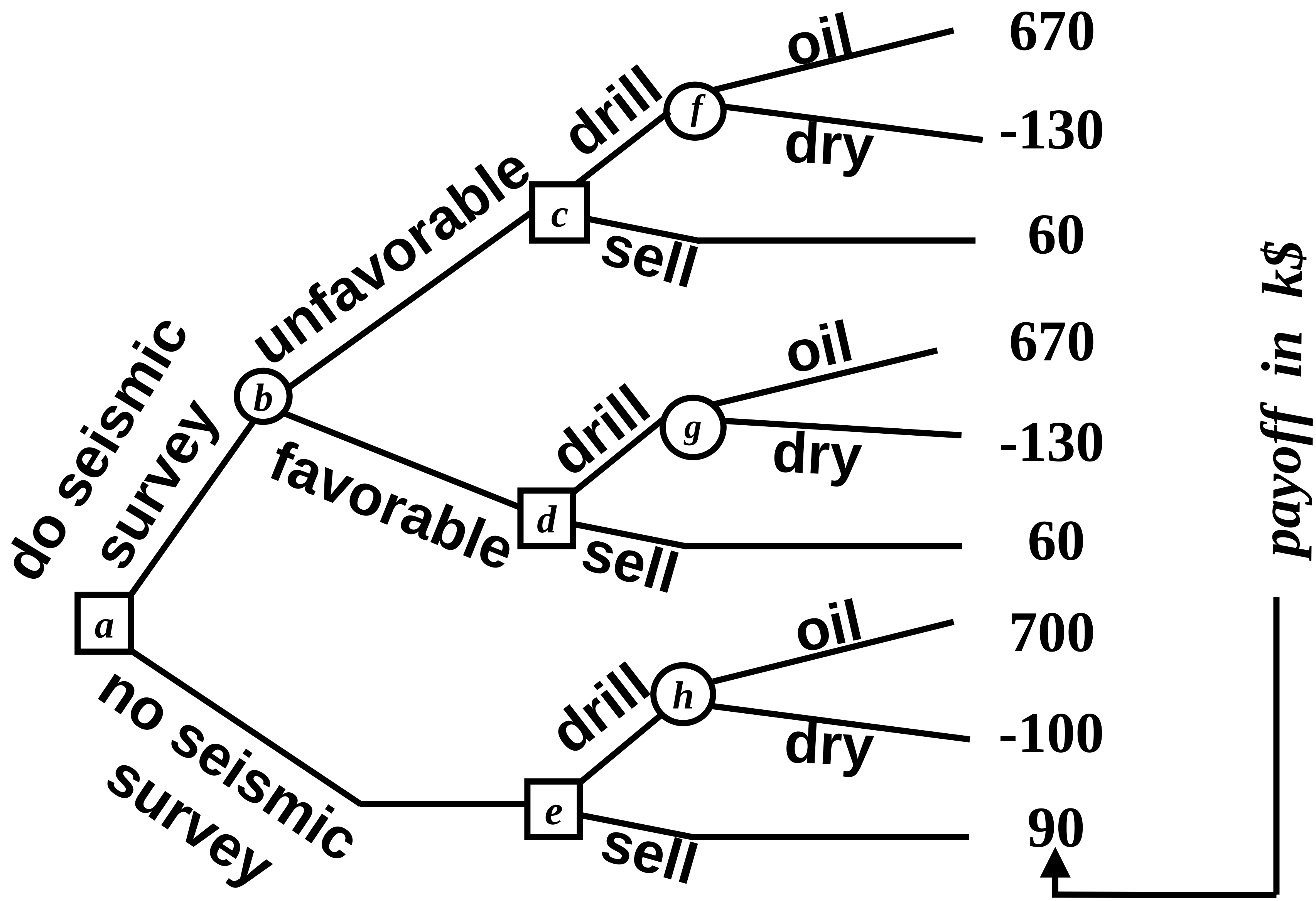
- The decision is strongly dependent on how good is the knowledge of the probabilities

# DECISION ANALYSIS PROTOTYPE EXAMPLE

- Sometimes it is possible to undertake further work before a decision is taken; for example, an available option before making a decision is to conduct a detailed seismic survey with costs of $\$30,000$ to obtain a better estimate of the probability of oil
- We construct a decision tree to
  - visually display the problem
  - organize systematically the computation

# DECISION ANALYSIS PROTOTYPE EXAMPLE



# A GENERAL FRAMEWORK FOR DECISION MAKING UNDER UNCERTAINTY

- **The decision maker must select an action from a set of possible actions – the set of feasible alternatives**
- **The underlying premise is that the choice of action is made under *uncertainty* because the outcome will be affected by random factors outside the control of the decision maker; this necessitates a classification of the possible *states of nature***

# A GENERAL FRAMEWORK FOR DECISION MAKING UNDER UNCERTAINTY

- **For each contribution of an action and state of nature, the value to the decision maker of the consequences of an outcome is established and quantified in terms of the *payoff***
- **The *payoff* is defined as the quantity measure of the value to the decision maker of the consequences of an outcome**

# A GENERAL FRAMEWORK FOR DECISION MAKING UNDER UNCERTAINTY

- **The *payoffs* are used to select the *optimal action* for the decision maker according to some selected criterion**
- **Example: *Bayes' decision rule* involves the use of the best available estimates of the probabilities of the states of nature to calculate the expected value of the *payoff* for each possible action and then to choose the action with the maximum *expected payoff***

# DECISION ANALYSIS

- We study decision analysis since its application can lead to *better decisions*
- We need to differentiate between *good* decisions and *lucky* outcomes
- Every decision may have a *lucky* outcome or an *unlucky* outcome
- A good decision is one that gives *the best outcome*
- The goal is to make effective decisions *more consistently*

# ECE 307

- **Prerequisite : ECE 210**
- **Corequisite  : ECE 313**
- **Required texts**
  - **A. Ravindran, D. T. Phillips and J. J. Solberg, "*Operations Research: Principles and Practice*," J. Wiley, New York, 1992**
  - **R. T. Clemen, "*Making Hard Decision: An Introduction to Decision Analysis,*" Duxbury Press/Wadsworth Publishing Company, 1995**
- **Course Website**

# GRADING POLICY

- Two exams: midterm and final
- Two team project presentations
- Grade Breakdown

| component | percentage |
|---|---|
| homework | 15 |
| projects | 10 |
| midterm | 25 |
| final | 50 |
| total | 100 |

# ECE 307 TOPICAL OUTLINE

- **Introduction: nature of engineering decisions; structuring of decisions; role of models; interplay of economics and technical/engineering considerations; decision making under certainty and uncertainty; good decisions vs. good outcomes; tools**
- **Resource allocation decision making using the linear programming framework: problem formulation; basic approach; duality; economic interpretation; sensitivity analysis; interpretation of results**

# ECE 307 TOPICAL OUTLINE

- **Scheduling and assignment decisions using network flow concepts:** transshipment problem formulation and solution; application to matching decisions; network optimization; scheduling applications
- **Sequential decision making in a dynamic programming framework:** nature of dynamic programming approach; problem formulation; solution procedures; key limitations
- **Probability theory:** random variables; probability distributions; expectation; conditional probability; moments; convolution

# ECE 307 TOPICAL OUTLINE

- **Statistical concepts:** data analysis; statistical measures; estimation
- **Application of probabilistic concepts to the modeling of uncertainty in decision making:** modeling of the impacts of uncertainty; applications to siting, investment and price volatility problems
- **Decision making under uncertainty:** decision trees; value of information; uses of data; sensitivity analysis and statistics
- **Case studies and presentations**