Chapter 7

Alternative and Models in Decision Making

Alternative and Models in Decision Making

- A ***methodology*** for structuring alternatives and a general decision evaluation approach using models are presented to ***facilitate decision making*** in both design and operations
- Decision models are only intended to take the decision maker part way to the point of decision
- Chapter topics study and consideration will impart a general understanding of the following concepts:
  - Alternatives and their equivalent comparison for going beyond the known to explore opportunities for technological progress
  - A classification of models, models experimentations, and the formulation and validation of decision models
  - Two related paradigms for decision evaluation theory, money flow modeling, and economic optimization modeling
  - Multiple criteria considerations and some classical methods for choosing from among alternatives
  - The decision evaluation display
  - A number of classical approaches approaches and rules for dealing with risk and uncertainty in decision making

Alternative in Decision Making

- It is better to consider all the alternatives than overlook one that might be preferred

Limiting and Strategic Factors

- An ***important element*** of the systems engineering process is the ***identification*** of the ***limiting factors*** restricting accomplishment of a desired objective
- Once the the limiting factors have been identified they are examined to ***locate strategic factors to make progress possible***
- Strategic factors can be altered in a ***cost-efficient way*** so that a selection from among the alternatives may be made

Comparing Alternatives Equivalently

- To compare alternatives equivalently it is important that they be converted to a ***common measure***
- ***Money flow models*** and ***economic optimization models*** are ***central*** to the conversion process
- On completion of the conversion step, quantitative and qualitative outputs and inputs for each alternative form the basis for comparison and decision
- A decision is made by customer alone or by producer jointly with customer

Models in Decision Making

- A ***methodology*** for structuring alternatives and a general decision evaluation approach using models are presented to ***facilitate decision making*** in both design and operations
- ***Models*** and ***the process of simulation*** are useful tools in systems analysis
- A ***model*** may be used as a representation of a system to be brought into being or to analyze a system already in being

Classification of Models

  - Aeronautics – Wooden model for a proposed aircraft
  - Architecture – scale of model of the building
  - Industrial systems – model of layout of tools in a factory
  - **Model Types:**
    - **Physical Models –** geometric equivalent or miniatures
    - **Analogue Models –** The focus is on similarity in relations such as electric circuits sre used to represent mechanical systems, hydraulic systems
    - **Schematic Models –** Reducing a state or event to a chart or diagram such as an organization chart
    - **Mathematical Models**

Decision Evaluation Theory

- ***Evaluation*** is needed as **a basis** for choosing among the alternatives as well as for **optimizing** systems already in operation
- **Equivalency** provides the ***common evaluation measures*** on which choice can be based
- Two general categories of decision evaluation models:
    - ***Money flow modeling***
    - ***Economic optimization modeling***

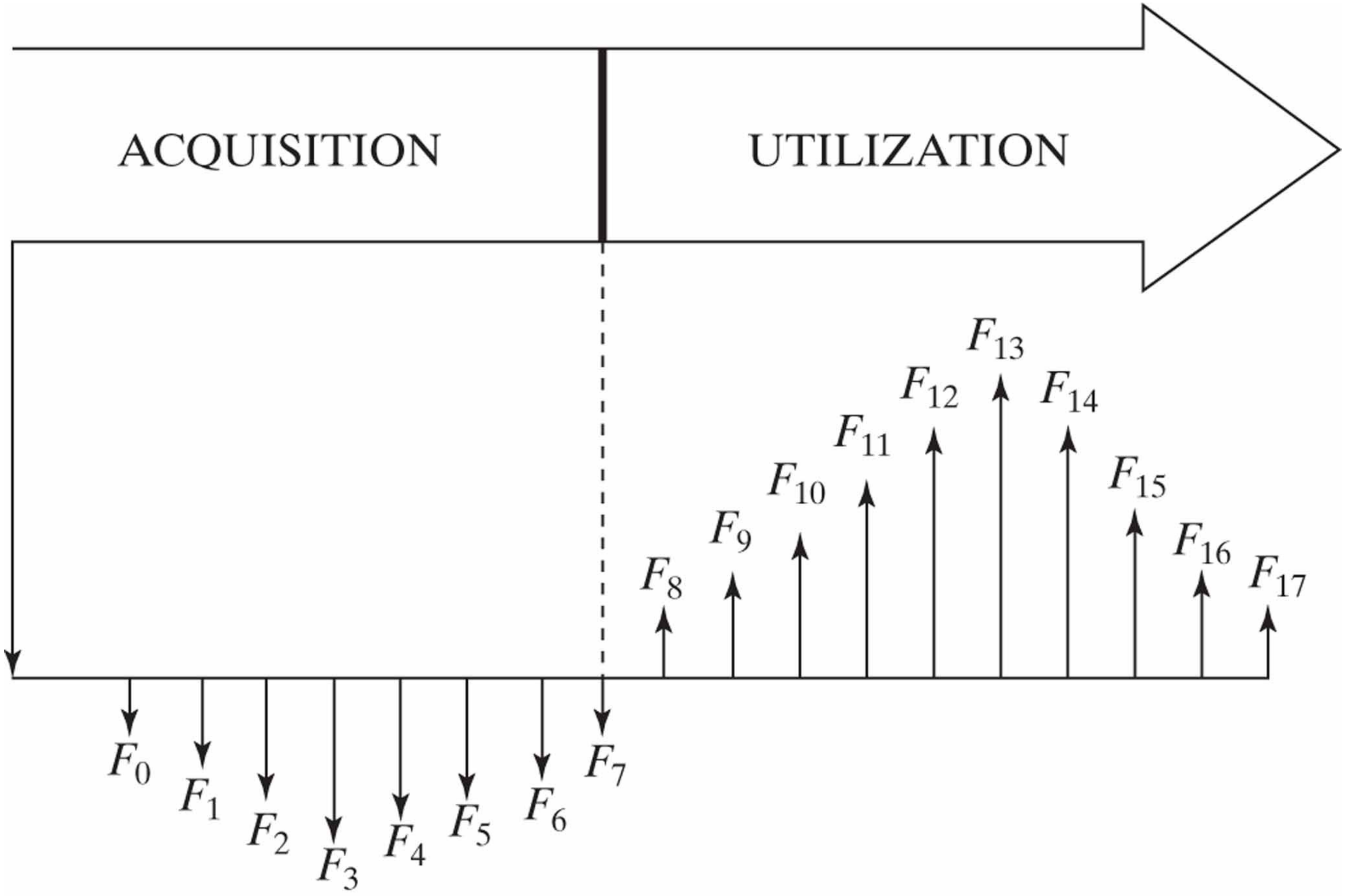
Evaluation by Money Flow Modeling

- Economic equivalence is expressed as the **present equivalent (**PE), **annual equivalent (AE),** or **future equivalent (FE)**

PE, AE, or FE = *f(F, I, n),*

F positive or negative money flow at the end of year *t, i* annual rate of interest*, n* number of years

Figure 7.1 Money flows for acquisition and utilization.



Decision Evaluation Theory

- The life cycle is the underlying money flow generator over its acquisition and utilization phases for 17-year life cycle Fig. 7.1
    - Expenditures composed of F0 through F7 (F0 – F2 conceptual and preliminary design, F3 – F4 for detail and development, F5 – F7 for production and/or construction
    - Net benefits or revenues occur at the end of each year for 10 years, F8 – F17

Evaluation by Economic Optimization Modeling

- Decision evaluation often requires a combination of both money flow modeling and economic optimization approaches
- An economic optimization function is a mathematical model formally linking an evaluation measure *E* with:
    - controllable decision variables *X*, and
    - System parameters *Y* cannot be directly controlled by the decision maker

$$E = f(X, Y)$$

Decision Evaluation Theory

Example: Optimal procurement quantity for inventory operations

- The **evaluation measure is cost** and **the objective** is to choose a **procurement quantity** in the face of demand, procurement cost, and holding cost so that the total cost is **minimized**
- The procurement quantity is the variable directly under the control of the decision maker
- Demand, procurement cost, and holding cost are not directly under his/her control
- **Holding costs** are those associated with storing inventory that remains unsold
- Use of **optimization function** allows to arrive at **a value for the variable under his/her control** and allows for **trade-off of conflicting cost elements**
- **Extension of equation 7.2**

$$E = f(X, Yd, Yi)$$

This extension involves the identification and isolation of design- or decision-dependent system parameters Yd, from the design- or decision-independent system parameters Yi

Decision Evaluation Theory

Terms are defined as follows:

- *Design-dependent parameters* – under the control of the designer(s). A design-dependent parameters set represents a distinct design alternative – Design-dependent parameters: reliability, maintainability, etc.
- *Design-independent parameters* – these factors are beyond the control of the designer(s) but impact the effectiveness of design alternatives: labor rates, material cost, energy cost.
- *Design variables (X)* – define the design optimization space. Each candidate system is optimized over a set of design variables before being compared with other alternatives

A **summary** of the evolution and development of the decision evaluation function **Table 1**

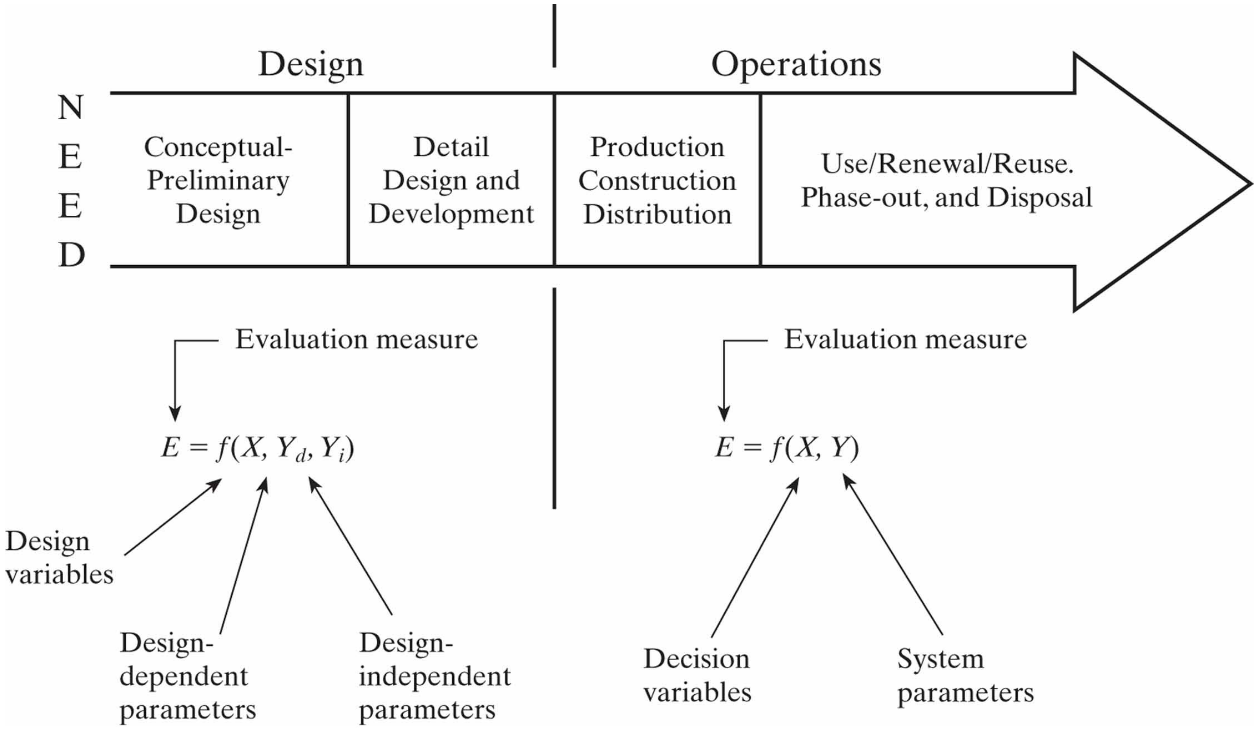
TABLE 7.1 Forms of the Decision Evaluation Function (References in Appendix G)

References	Functional Form	Application
Churchman, Ackoff, and Arnoff (1957)	$E = f(x_i, y_j)$ $E =$ system effectiveness $x_i =$ variables under direct control $y_j =$ variables not subject to direct control	Operations
Fabrycky, Ghare, and Torgersen (1984)	$E = f(X, Y); g(X) \lesseqqgtr B$ $E =$ evaluation measure $X =$ controllable variables $Y =$ uncontrollable variables	Operations
Banks and Fabrycky (1987)	$E = f(X, Y_d, Y_i); g(X, Y_d) \lesseqqgtr C$ $E =$ evaluation measure $X =$ procurement level and procurement quantity $Y_d =$ source-dependent parameters $Y_i =$ source-independent parameters	Procurement operations
Fabrycky and Blanchard (1991)	$E = f(X, Y_d, Y_i); g(X, Y_d) \lesseqqgtr C$ $E =$ evaluation measure $X =$ design variables $Y_d =$ design-dependent parameters $Y_i =$ design-independent parameters	Design optimization

Decision Evaluation Theory

Models in Design and Operations

- **Equ. 7.2** is applicable to the optimization of operations already in being
- **Equ. 7.3** is useful for choosing from among mutually exclusive design alternatives based on design-dependent parameters.



Decision Involving Multiple Criteria

In most cases, a decision must be made in the face of multiple criteria that jointly influence the desirability of the alternatives under consideration.

Multiple criteria considerations

Choice of is not easy when multiple criteria are present and this difficulty is perpetuated if a decision maker sidesteps basic concepts and guidelines

- **Selecting the criteria to be considered** –

It is important that alternatives to be compared after criteria of importance are identified, selected, and characterized

  - The most import is that criteria or attributes be independent
  - Independence should be sought as a first step
  - The number of criteria selected should be kept to a reasonable minimum. Unfortunately, there is no other way to determine the ideal number of criteria
  - It is to start with one, or a few criteria and subject them to to preliminary evaluation to gain insight in the decision situation. Then other criteria can be added incrementally

Decision Involving Multiple Criteria

Direct Ranking Methods

A direct method for choosing from among alternatives is simply to present to the decision maker for ranking

Method of paired comparisons – Five important criteria for an office appliance. They are designated 1 – 5

1- Better, 2- cheaper, 3- faster, 4- repairable, 5- disposable

Note: When there are *N* criteria or alternatives to be ranked, *N(N-1)/2* pairs must be compared.

>“preferred to”, = “equally preferred to”.

For the five appliance design criteria, assume that the results are as follows – Page 182

Table 7.2 – A display of the pairwise comparisons is given in Table

For this example, the rank order of preference is **2>1>3>4=5**

TABLE 7.2 Exhibit of Preference Comparisons

Criteria	1	2	3	4	5	Times Preferred
1	–		*P*	*P*	=	2+
2	*P*	–	*P*	*P*	*P*	4
3			–	*P*	=	1+
4				–	*P*	1
5	=		=		–	++

Decision Involving Multiple Criteria

Systematic elimination methods

Systematic elimination methods are among the simplest approaches available for choosing from among alternatives in the face of multiple criteria

- These methods are applicable when values and /or outcomes can be specified for all criteria and all alternatives.
- The values should be measurable or at least rank orderable (ordinal)

Note:

- Elimination methods have two limitations:
    - Do not consider ***weights*** applicable to criteria or attributes
    - ***Noncompensatory*** – they do not consider ***trade-offs among criteria*** across alternatives
- Example **Table 7.3**

TABLE 7.3 Estimated Criterion Values for Alternatives

	Alternative					
Criterion	*A*	*B*	*C*	*D*	Ideal	Minimum Standard
1. Better	40	35	50	30	50	30
2. Cheaper	90	80	75	60	100	70
3. Faster	6	5	8	6	10	7
4. Gone	*G*	*P*	*VG*	*E*	*E*	*F*

Decision Involving Multiple Criteria

Comparing alternatives against each other

The most obvious one is to check for **dominance**

Alternative **A dominates** alternative **B**

Comparing alternatives against a standard

- Rule 1 – Retain only if it meets the **standard** for at **least one criterion**
- Rule 2 – Retain only if it meets the **standard** of **all the criteria**

Table 7.4

Alternative C is the only retained

TABLE 7.4 Alternatives Not Meeting Criteria Standards

Alternative	Criterion 1	Criterion 2	Criterion 3	Criterion 4
A			*X*	
B			*X*	*X*
C				
D		*X*	*X*	

Decision Involving Multiple Criteria

Weighting Methods of Evaluation

- Weighted importance rating can extend the ranking and elimination methods.
- The extension will explicitly recognize the higher importance that some criteria would assume

Weighting of criteria or attributes – Table 7.5

The tabular additive method – Table 7.6

TABLE 7.5 Additive Weights from Importance Rating

Criterion	Importance Rating	Additive Weight
Better	7	7/20 = 0.35
Cheaper	9	9/20 = 0.45
Faster	4	4/20 = 0.20
		1.00

TABLE 7.6 Tabular Additive Method

Criterion	Weight (W)	Alternative A Rating (R)	Alternative A $W \times R$	Alternative B Rating (R)	Alternative B $W \times R$
Better	0.35	6	2.10	7	2.45
Cheaper	0.45	10	4.50	6	2.70
Faster	0.20	5	1.00	3	0.60
	1.00		7.60		5.75

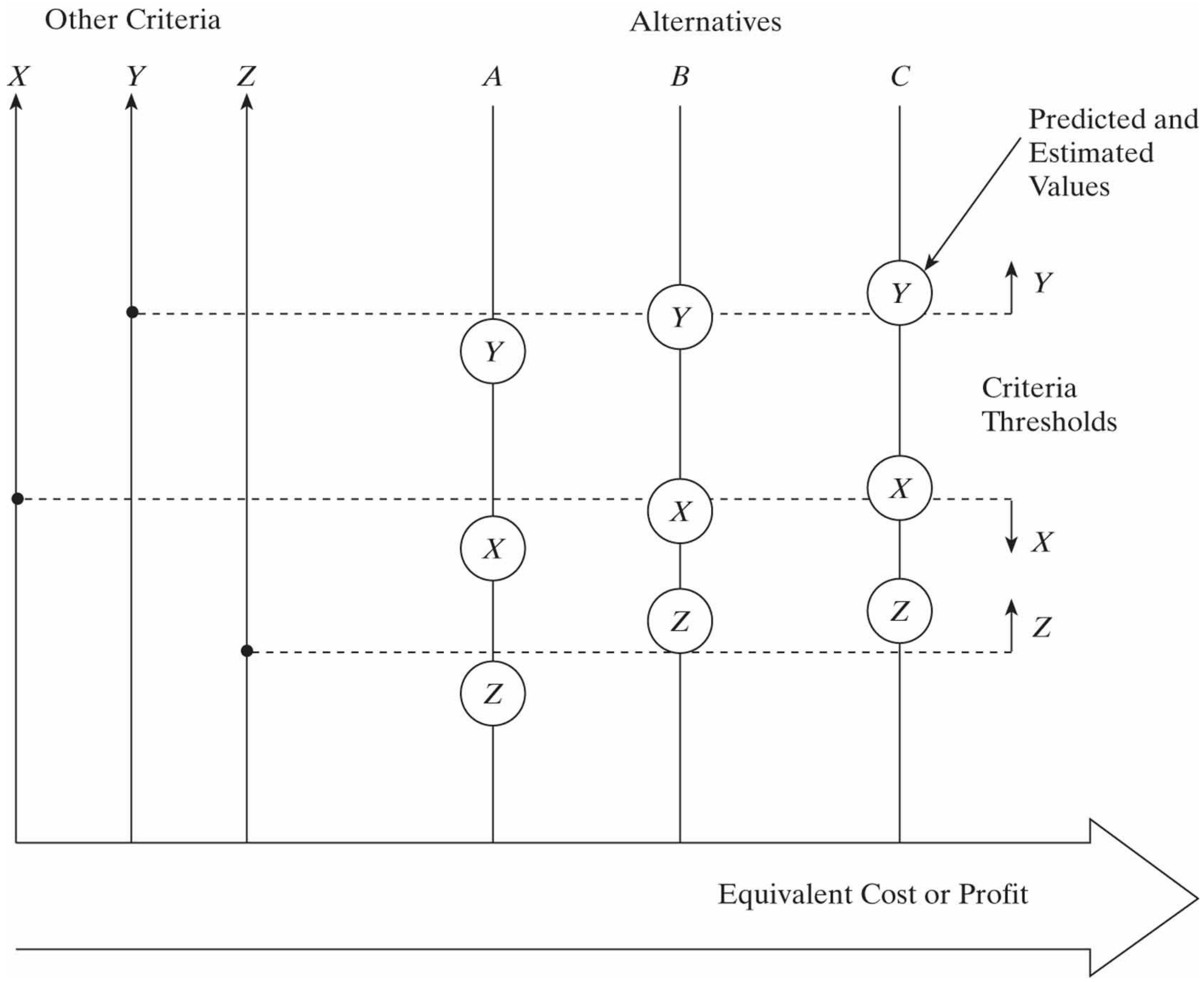
The Decision Evaluation Display

- Put emphasis on communicating only the differences upon decision depends, leaving the remaining path to a decision maker

- The basic structure and general form of the decision evaluation display is illustrated in **Fig. 7.4**

  - *Alternatives (A, B, C)* – alternatives appear as vertical lines
  - *Equivalent cost or profit*
  - *Other criteria (X, Y, Z)* – Each axis has its own scale and noneconomic
  - *Other criteria thresholds*
  - *Predicted and/or estimated values*

Figure 7.4 General decision evaluation display.



Decision under Risk and Uncertainty

The Decision Evaluation Matrix

- It is a formal way of exhibiting the interaction of ***finite set of alternatives*** and ***a finite set of possible futures*** (states of nature)
- The states are not normally **natural events** but future outcomes over which the decision maker has **no direct control**
- Its symbols are defined as follows: Page 189

- Fig. 7.6: one would choose the alternatives that minimizes cost or maximizes profit

Cost: mi{*Ei*} for i=1, 2, 3,…, m

Profit: maxi{*Ei*} for I = 1, 2, 3,.., m

Figure 7.5 The decision evaluation matrix.

$$
\begin{array}{c|cccc}
P_j & P_1 & P_2 & \cdots & P_n \\
F_j & F_1 & F_2 & \cdots & F_n \\
A_i & & & & \\
\hline
A_1 & E_{11} & E_{12} & \cdots & E_{1n} \\
A_2 & E_{21} & E_{22} & \cdots & E_{2n} \\
\vdots & \vdots & \vdots & & \vdots \\
A_m & E_{m1} & E_{m2} & \cdots & E_{mn}
\end{array}
$$

Figure 7.6 Decision evaluation vector.

A_i \ F_j	F
A_1	E_1
A_2	E_2
$\vdots$	$\vdots$
A_m	E_m

Decision Making under Risk

The Decision Evaluation Matrix

- Before proceeding to the application of criteria for the choice among alternatives, the decision should be examined for ***dominance***
- Eliminate *A*5 from consideration because it is dominated by all other alternatives
- **Aspiration level criterion**

  An aspiration level is some desired level of achievement such as profit

  The profit level is set to be at least $400k and the loss is set to be no more than $100k – Choice between *A1* and *A3*
- **Most probable future criterion**

  The most probable criterion is (C1 + C2), would choose alternative *A3*
- **Expected value criterion – see below**

TABLE 7.7 Decision Evaluation Matrix (Profit in Thousands of Dollars)

	Probability:	(0.3)	(0.2)	(0.5)
	Future:	C_1	C_2	$C_1 + C_2$
	A_1	100	100	400
	A_2	−200	150	600
Alternative	A_3	0	200	500
	A_4	100	300	200
	A_5	−400	100	200

TABLE 7.9 Computation of Average Profit (Thousands of Dollars)

Alternative	Average Payoff
A_1	(\$100 + \$100 + \$400) ÷ 3 = \$200
A_2	(−\$200 + \$150 + \$600) ÷ 3 = \$183
A_3	(\$0 + \$200 + \$500) ÷ 3 = \$233
A_4	(\$100 + \$300 + \$200) ÷ 3 = \$200

Decision Making under Risk

Comparison of decisions:

Aspiration level criterion	A1 or A3
Most probable future criterion	A2
Expected vales criterion	A3

A3 is the best alternative

Decision Making under Uncertainty

Often no meaningful data are available from which probabilities could be developed

- **Laplace criterion** - Under Laplace principle, the probability of occurrence is assumed to be *1/n*, where *n* is the number of possible future states
- Using **Table 7.8**, one can compute the following **Table 7.9 –** Decision is *A3* ($233K)

TABLE 7.9 Computation of Average Profit (Thousands of Dollars)

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A_3	($0 + $200 + $500) ÷ 3 = $233
A_4	($100 + $300 + $200) ÷ 3 = $200

Decision Making under Uncertainty

Maximin and Maximax criterion –

The maximin rule based on an extremely pessimistic view – A1 or A4 profit $100k regardless of the future

The Maximax rule is based on extremely optimistic view - A2 profit of $600k if the future is benevolent

TABLE 7.10 Profit by the Maximin Rule (Thousands of Dollars)

Alternative	$\min_j E_{ij}(\$)$
A_1	100
A_2	−200
A_3	0
A_4	100

TABLE 7.11 Profit by the Maximax Rule (Thousands of Dollars)

Alternative	$\max_j E_{ij}$ (\$)
A_1	400
A_2	600
A_3	500
A_4	300

Decision Making under Uncertainty

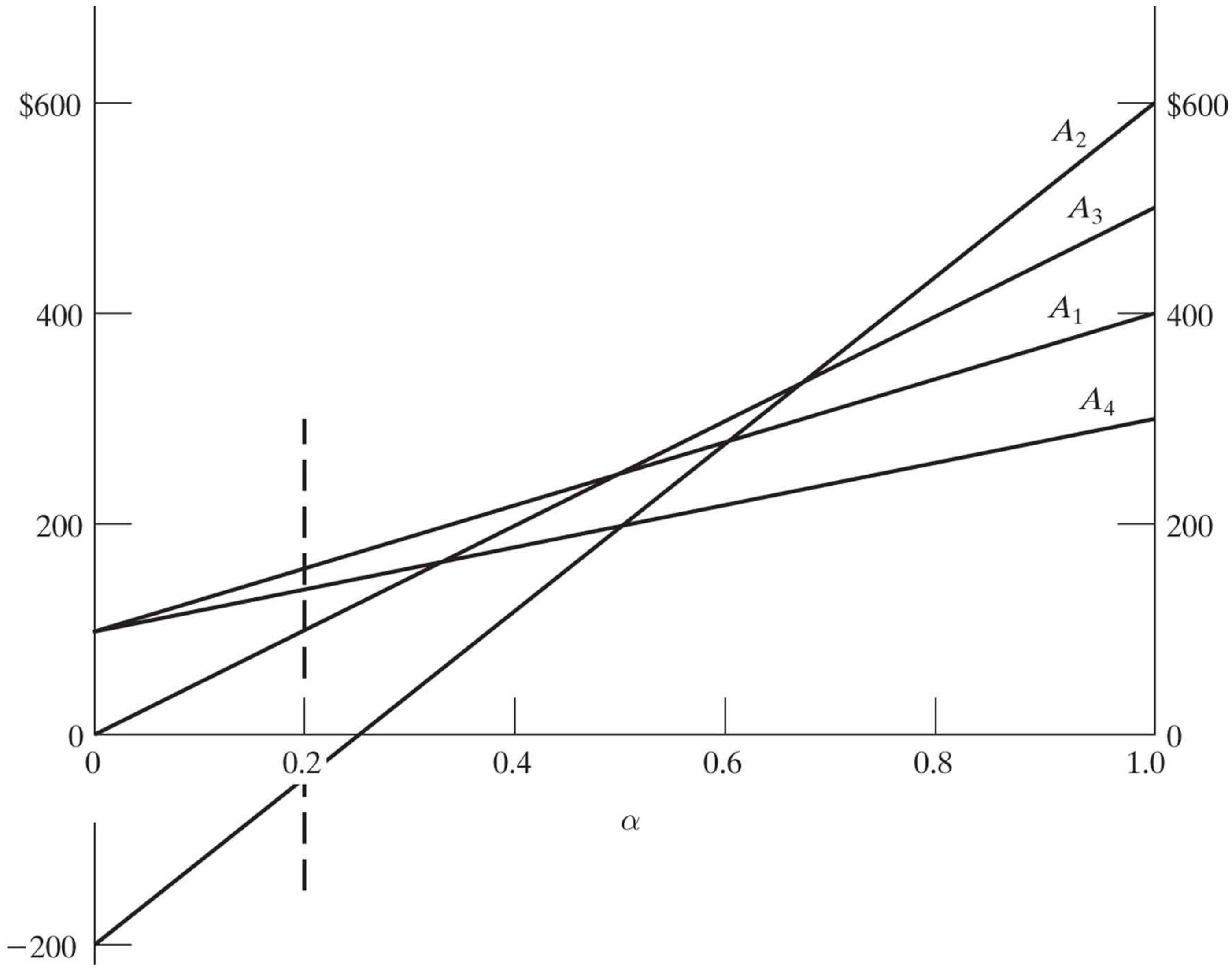
Hurwicz criterion –

For alpha=0 gives the maxmin rule, when alpha=1 gives the maximax rule

TABLE 7.12 Profit by the Hurwicz Rule with $\alpha = 0.2$ (Thousands of Dollars)

Alternative	$\alpha[\max E_{ij}] + (1 - \alpha)[\min E_{ij}]$
A_1	$0.2(\$400) + 0.8(\$100) = \$160$
A_2	$0.2(\$600) + 0.8(\$-200) = \$-40$
A_3	$0.2(\$500) + 0.8(0) = \$100$
A_4	$0.2(\$300) + 0.8(\$100) = \$140$

Figure 7.7 Values for the Hurwicz rule for four alternatives.



Decision Making under Uncertainty

Comparison of decisions:

Laplace criterion	A3
Maximin criterion	A1 or A4
Maximax criterion	A2
Hurwicz criterion	A1

The decision must be based on subjective judgement depending on the decision maker attitude.