

Analytics, Data Science and AI: Systems for Decision Support

Eleventh Edition, Global Edition

GLOBAL
EDITION



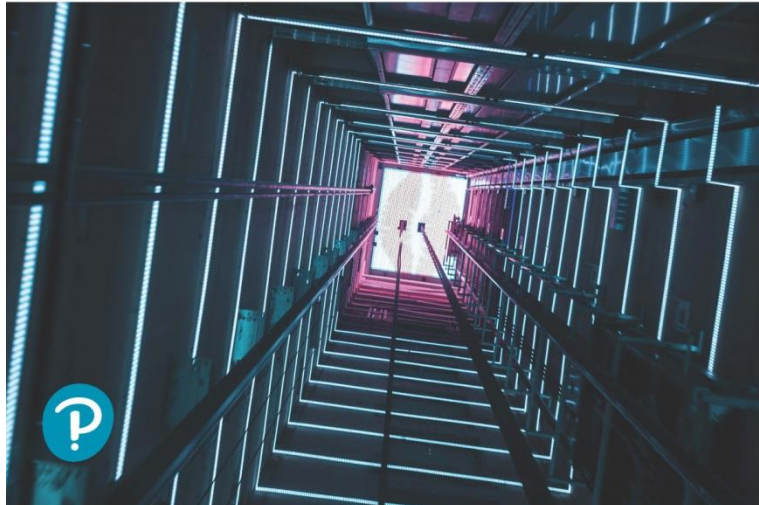
Analytics, Data Science,
& Artificial Intelligence
Systems for Decision Support

ELEVENTH EDITION

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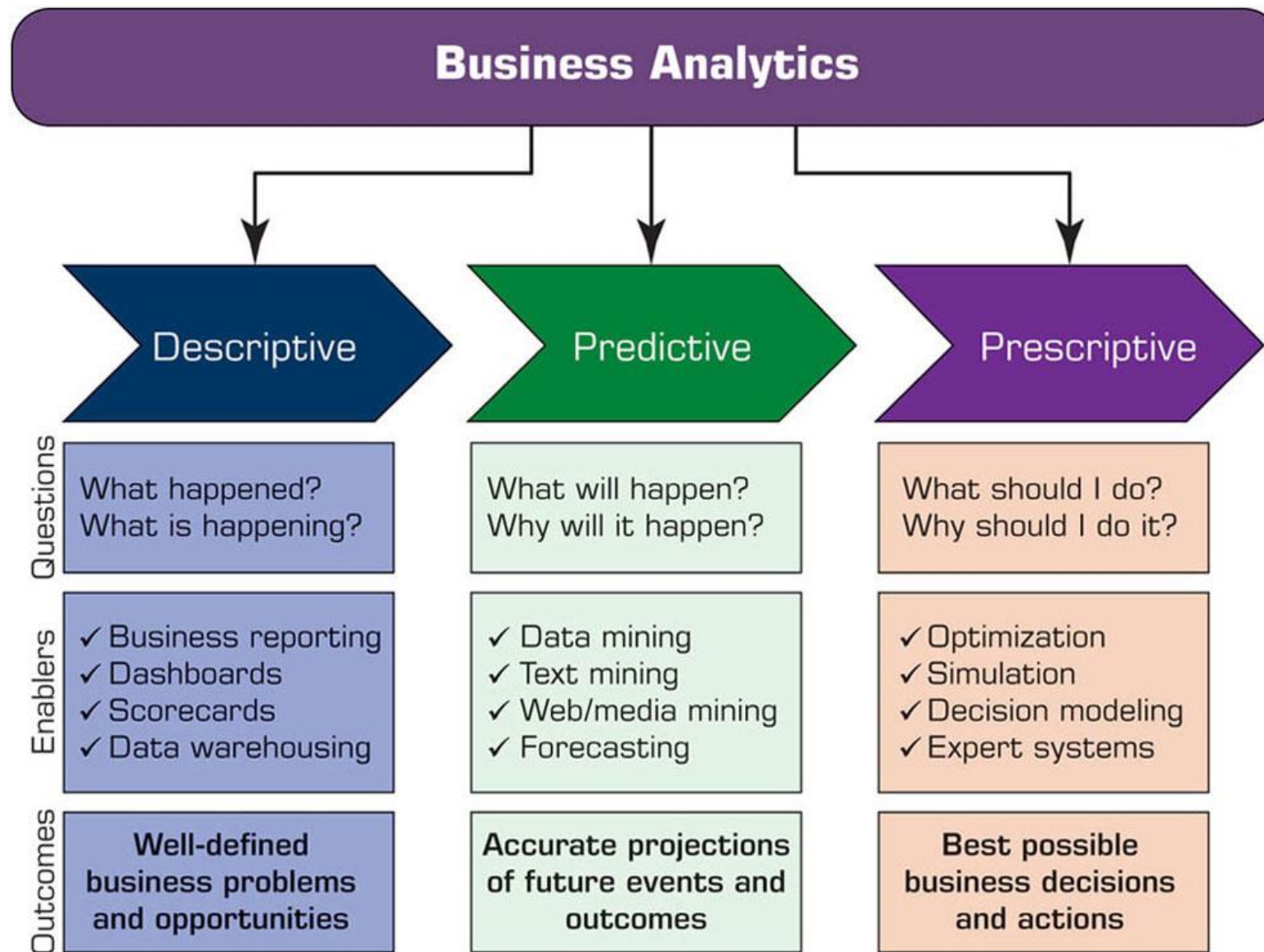
Chapter 8

Prescriptive Analytics: Optimization
and Simulation



Learning Objectives

- 8.1 Understand the **applications of prescriptive analytics** techniques in combination with reporting and predictive analytics
- 8.2 Understand the **basic concepts of analytical decision modeling**
- 8.3 Explain the basic concepts of **optimization** and when to use them
- 8.4 Describe how to structure a **linear programming model**
- 8.5 Explain what is meant by **sensitivity analysis, what-if analysis, and goal seeking**
- 8.6 Understand the concepts and applications of different types of **simulation**

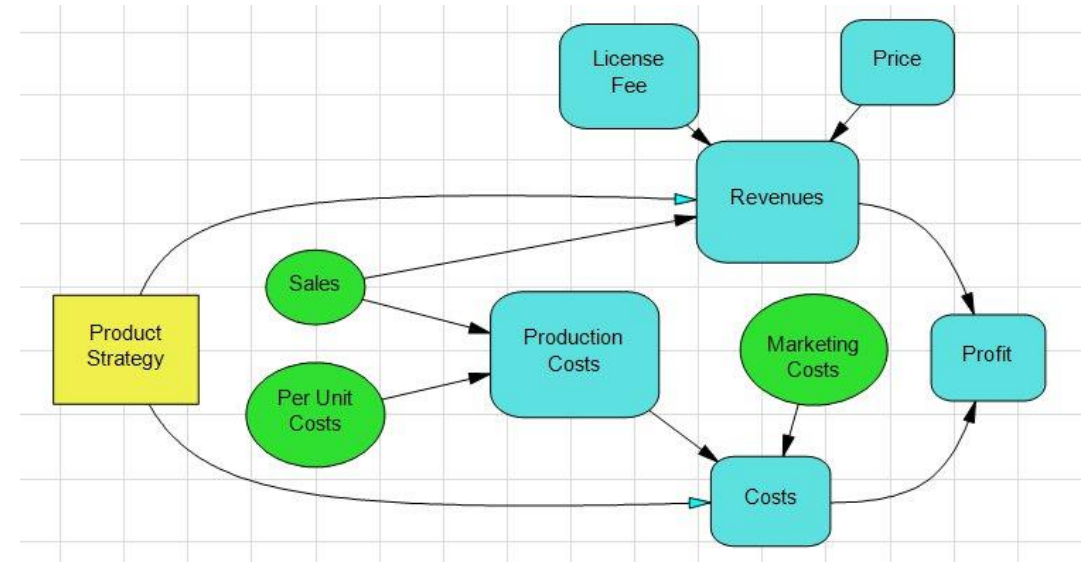


Model Based Decision Making (1 of 2)

- **Use models/representations of real-world to make decision on real-world situations:**
 - Goal: provide a decision or a recommendation for a specific action.
 - Yes/no decision – a specific amount – a set for production plan.
- **Plenty of examples exist in many domains:**
 - Route selection, Airline pricing, COVID-19 simulation, Arrival patterns.
- Its name changes but the purpose stays the same: support the decision-making process

Model Based Decision Making (2 of 2)

- Prescriptive analytics model examples
 - Mathematical models for decision recommendation
- **Identification of the problem**
 - **Environmental scanning and analysis:**
 - Monitoring, scanning and interpretation of collection information.
 - **Variable identification**
 - What variables to include, and how they are related.
 - Influence diagram.



Model Categories

- **Static versus dynamic models**
 - Time dependent / time independent
- **Model management**
 - To maintain integrity and applicability.
- **Knowledge-based modeling**
- **Current trends in modeling**
 - Model libraries (codes – packages).
 - Cloud-based modeling tools/platforms
 - Model transparency / multi-dimensional modeling
 - Influence diagrams for better modeling

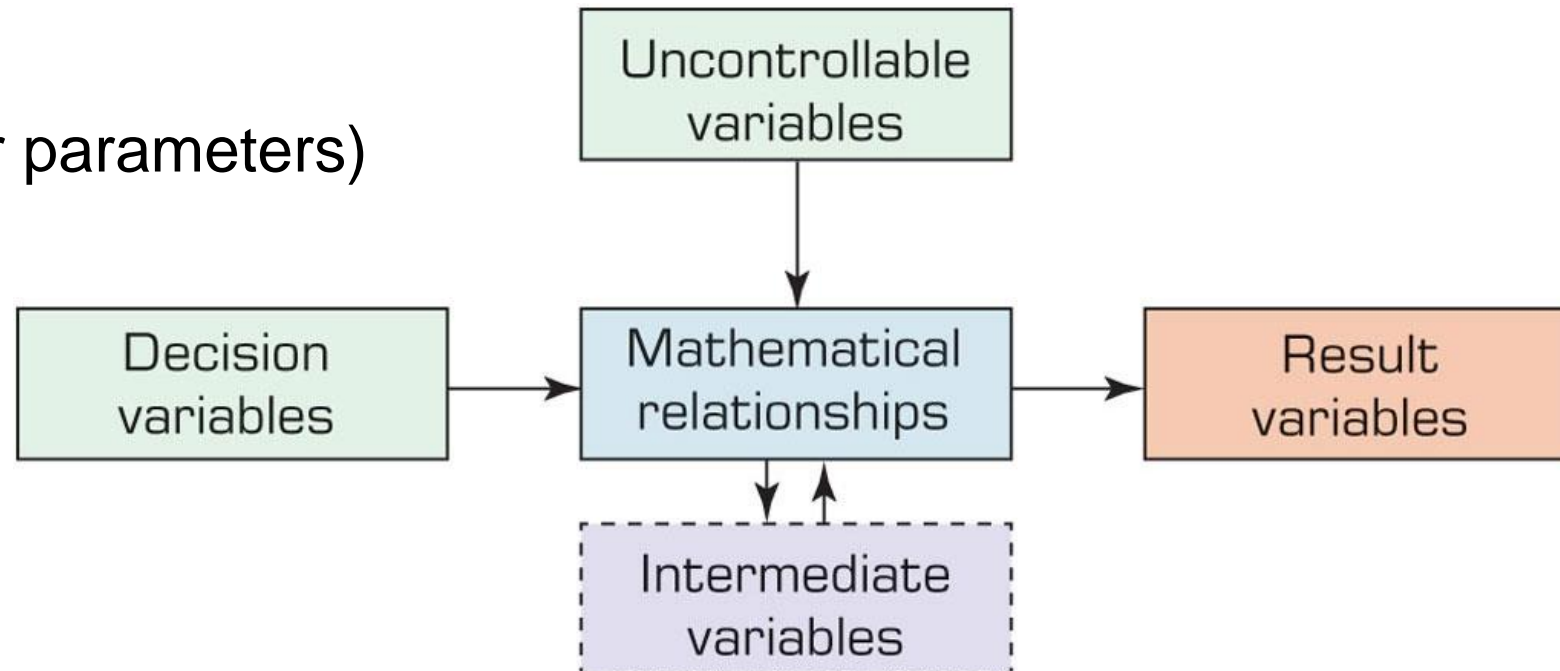
Categories of Models

Table 8.1 Categories of Models.

Category	Process and Objective	Representative Techniques
Optimization of problems with few alternatives	Find the best solution from a small number of alternatives	Decision tables, decision trees, analytic hierarchy process
Optimization via algorithm	Find the best solution from a large number of alternatives, using a step-by-step improvement process	Linear and other mathematical programming models, network models
Optimization via an analytic formula	Find the best solution in one step, using a formula	Some inventory models
Simulation	Find a good enough solution or the best among the alternatives checked, using experimentation	Several types of simulation
Heuristics	Find a good enough solution, using rules	Heuristic programming, expert systems
Predictive models	Predict the future for a given scenario	Forecasting models, Markov analysis
Other models	Solve a what-if case, using a formula	Financial modeling, waiting lines

Structure of Mathematical Models for Decision Support

- **Quantitative Models:** Mathematically links decision variables, uncontrollable variables, and result variables
 - Non-quantitative models: qualitative models
- **Components:**
 - Result (outcome variable)
 - Decision variables
 - Uncontrollable variable (or parameters)
 - Intermediate results



Examples of Components of Models

Table 8.2 Examples of Components of Models.

Area	Decision Variables	Result Variables	Uncontrollable Variables and Parameters
Financial investment	Investment alternatives and amounts	Total profit, risk Rate of return on investment (ROI) Earnings per share Liquidity level	Inflation rate Prime rate Competition
Marketing	Advertising budget Where to advertise	Market share Customer satisfaction	Customer's income Competitor's actions
Manufacturing	What and how much to produce Inventory levels Compensation programs	Total cost Quality level Employee satisfaction	Machine capacity Technology Materials prices
Accounting	Use of computers Audit schedule	Data processing cost Error rate	Computer technology Tax rates Legal requirements
Transportation	Shipments schedule use of smart cards	Total transport cost Payment float time	Delivery distance Regulations
Services	Staffing levels	Customer satisfaction	Demand for services

The Structure of a Mathematical Model

- The components of a quantitative model are linked together by mathematical (algebraic) expressions—equations or inequalities.

- Example: Profit (P) = $R - C$

where P = profit, R = revenue, and C = cost

- Example - Simple Present-Value -

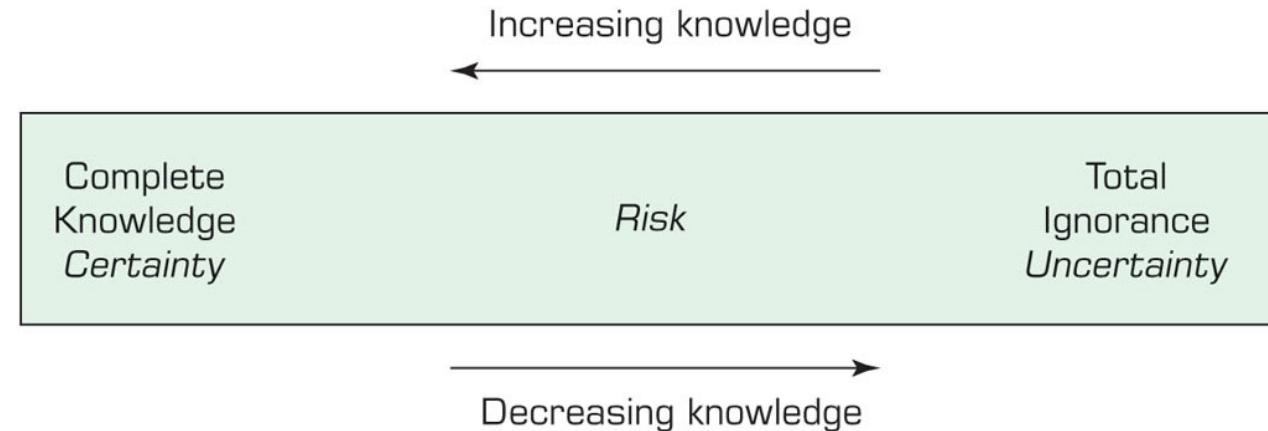
$$P = \frac{F}{(1+i)^n} = \frac{100,000}{(1+0.1)^5} = 62,092$$

where P = present value, F = future cash-flow, i = interest-rate, and n = number of period

Modelling and Decision Making - Under Certainty, Uncertainty, and Risk (1 of 2)

Decision situation is classified on the basis of the decision-maker's knowledge:

- **Certainty**
 - Assume complete knowledge
 - All potential outcomes are known
- **Uncertainty**
 - Lack/insufficient information
 - Probability of each outcome is unknown
- **Risk analysis** (probabilistic decision making)
 - Partial information
 - Probability of each outcomes is known
 - Level of uncertainty → Risk (expected value)



Decision Modeling with Spreadsheets

- Spreadsheet
 - Most popular end-user modeling tool
 - Flexible and easy to use
 - Powerful functions (add-in functions)
 - Programmability (via macros)
 - What-if analysis and goal seeking
 - Simple database management
 - Incorporates both static and dynamic models
 - Examples: Microsoft Excel (with Solver add-in)

Excel Spreadsheet - Static Model Example

(Simple loan calculation of monthly payments)

	A	B	C	D	E	F	G	H
1								
2								
3		Simple Loan Calculation Model in Excel						
4								
5								
6		Loan Amount			\$150,000			
7		Interest Rate			8.00%			
8		Number of Years			30			
9						=E8*12		
10		Number of Months			360			
11		Interest Rate/Month			0.67%	=E7/12		
12								
13		Monthly Loan Payment			\$1,100.68	=PMT (E11, E10, E6, 0)		
14								
15								
16								
17		Excel Spreadsheet Static Model Example of a Simple Loan						
18								
19								
20								
21								
22								

$$F = P(1+i)^n$$

$$A = P \left[\frac{i(1+i)^n}{(1+i)^n - 1} \right]$$

Excel Spreadsheet - Dynamic Model Example

(Simple loan calculation – effect of prepayment)

	A	B	C	D	E	F	G	H	I	J	K
1											
2											
3		Dynamic Loan Calculation Model with Prepayment in Excel									
4											
5											
6		Loan Amount			\$150,000						
7		Interest Rate			8.00%						
8		Number of Years			30						
9						=E8*12					
10		Number of Months			360						
11		Interest Rate/Month			0.67%						
12						=E7/12					
13		Monthly Loan Payment			\$1,100.65						
14						=PMT (E11, E10, E6, 0)					
15											
16											
17		Excel Spreadsheet Dynamic Model Example of a Simple Loan									
18											
19											
20											
21											
22		Month	Normal Payment	Prepay Amount	Total Payment	Principle Owed					
23		0				\$150,000					
24		1	\$1,100.65	\$100.00	\$1,200.65	\$149,799					
25		2	\$1,100.65	\$100.00	\$1,200.65	\$149,597					
26		3	\$1,100.65	\$100.00	\$1,200.65	\$149,394					
27		4	\$1,100.65	\$100.00	\$1,200.65	\$149,189					
28		5	\$1,100.65	\$100.00	\$1,200.65	\$148,983					
29											
30											

A \$100 Prepayment every Month--Loan is paid off in Month 270

Copy the Cells in Row 24 into Rows 25 through Row 383 to get 360 Months of Results

Mathematical Programming Optimization

- **Mathematical Programming**

A family of tools designed to help solve **managerial problems** in which the decision maker must allocate **scarce resources** among competing activities to **optimize a measurable goal**

- **Optimal solution:** The best possible solution to a modeled problem

- **Linear programming (LP):** A mathematical model for the optimal solution of resource allocation problems. All the relationships are linear.

Linear Programming (LP) Steps

1. Identify the ...

- Decision variables (unknown values)
- Objective function (to be optimized)
- Objective function coefficients
- Constraints
 - Capacities / Demands / ...

2. Represent the model

- LINDO: Write mathematical formulation
- EXCEL: Input data into specific cells in Excel

3. Run the model and observe the results

LP Modeling – Example (1 of 3)

The Product-Mix Linear Programming Model

MBI Corporation needs to make a decision: How many computers should it produce.

- MBI is considering two types of computers:
 - the CC-7, which requires 300 days of labor and \$10,000 in materials, and
 - the CC-8, which requires 500 days of labor and \$15,000 in materials.

PROFIT: The profit contribution of CC-7 is \$8,000, and CC-8 is \$12,000.

CONSTRAINTS:

- The plant has a capacity of 200,000 working days per month, and
- the material budget is \$8 million per month.
- at least 100 units of the CC-7 and at least 200 units of the CC-8 be produced each month.

LP Modeling – Example (1 of 3)

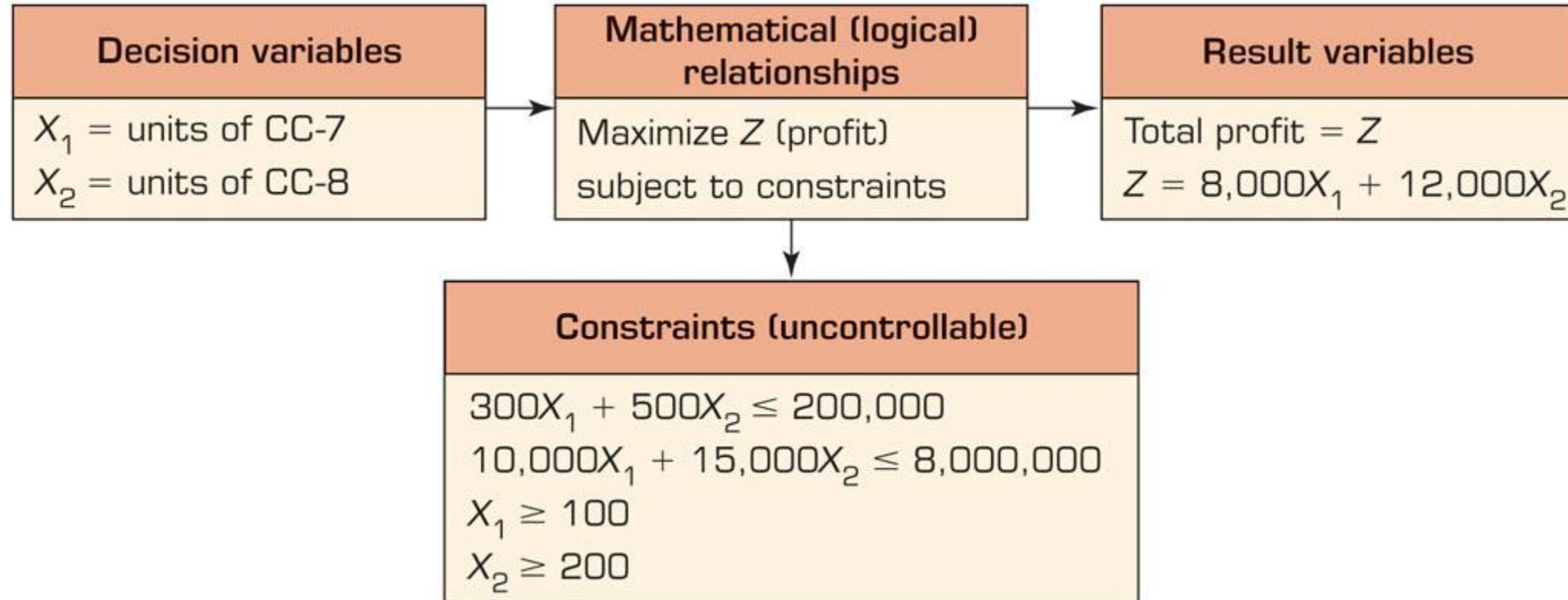
The Product-Mix Linear Programming Model

- MBI Corporation
- **Decision: How many computers to build?**
- Two types of mainframe computers: CC-7 and CC-8
- Constraints: Labor limits, Materials limit, Marketing lower limits

	CC-7	CC-8	Relationship	Limit
Labor (days)	300	500	\leq	200,000 /mo
Materials (\$)	10,000	15,000	\leq	8,000,000 /mo
Units	1		\geq	100
Units		1	\geq	200
Profit (\$)	8,000	12,000		Max

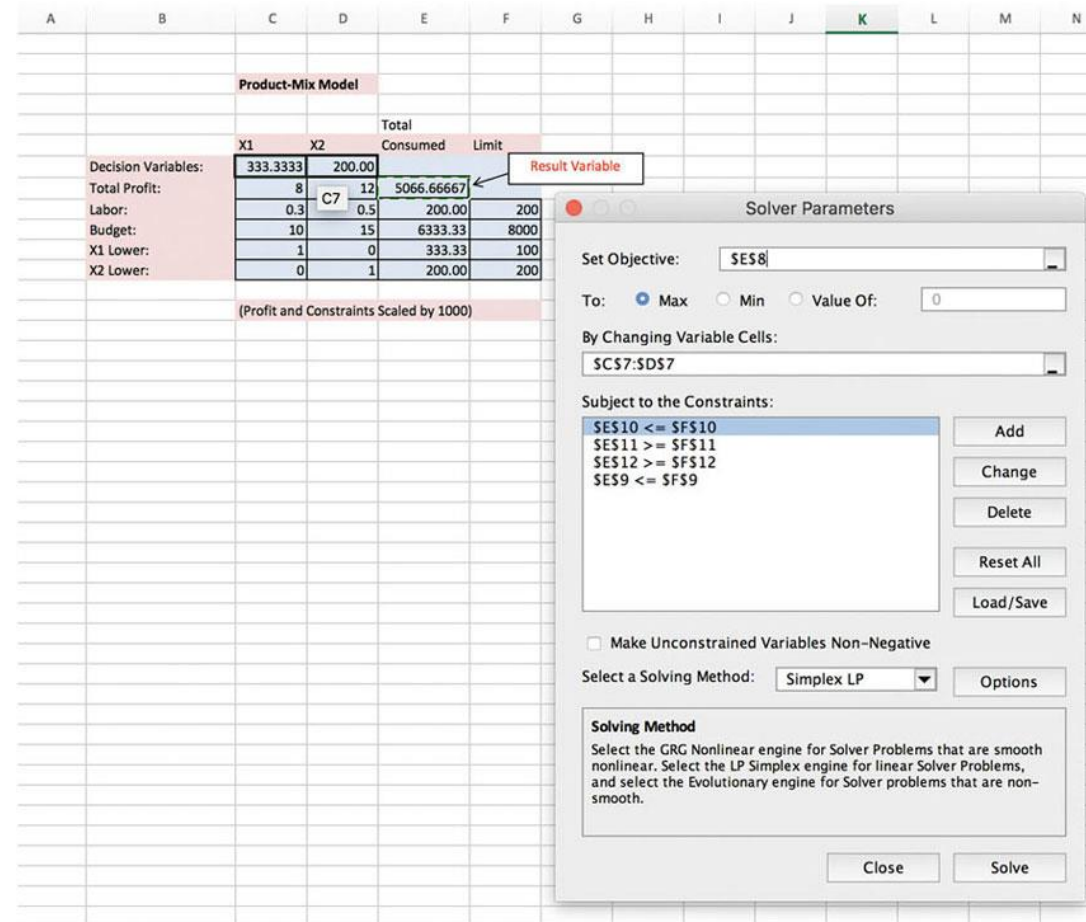
Objective: Maximize Total Profit / Month

LP Modeling – Example (2 of 3)



LP Modeling – Example (3 of 3)

Figure 8.6 Excel Solver Solution to the Product-Mix Example.



Common Optimization Models

- Assignment (best matching of objects)
- Dynamic programming
- Goal programming
- Investment (maximizing rate of return)
- Linear and integer programming
- Network models for planning and scheduling
- Nonlinear programming
- Replacement (capital budgeting)
- Simple inventory models (e.g., economic order quantity)
- Transportation (minimize cost of shipments)

Multiple Goals, Sensitivity Analysis, What-If Analysis, and Goal Seeking (1 of 5)

- **Multiple Goals**
 - Simple-goal vs. multiple goals
 - Vast majority of managerial problems has multiple goals (objectives) to achieve
 - Attaining simultaneous goals
 - Methods of handling multiple goals
 - Utility theory
 - Goal programming
 - Expression of goals as constraints, using LP
 - A points system

Multiple Goals, Sensitivity Analysis, What-If Analysis, and Goal Seeking (2 of 5)

- **Sensitivity analysis**
 - It is the process of assessing the impact of change in inputs on outputs
 - Helps to ...
 - eliminate (or reduce) variables
 - revise models to eliminate too-large sensitivities
 - adding details about sensitive variables or scenarios
 - obtain better estimates of sensitive variables
 - alter a real-world system to reduce sensitivities
 - ...
 - **Can be automatic or “trial and error”**

Multiple Goals, Sensitivity Analysis, What-If Analysis, and Goal Seeking (3 of 5)

- **What-if analysis**

- Assesses solutions based on changes in variables or assumptions (scenario analysis)
- What if we change our capacity at the milling station by 40% [what would be the impact]

- **Goal seeking**

- Backwards approach, starts with the goal and determines values of inputs needed
- Example is break-even point determination
 - In-order to break even ($\text{profit} = 0$), how many products do we have to sell each month

Multiple Goals, Sensitivity Analysis, What-If Analysis, and Goal Seeking (4 of 5)

Figure 8.10 Example of a What-If Analysis Done in an Excel Worksheet.

4						
5						
6						
7	Unit revenue	\$	1.20			
8	Unit cost	\$	0.60			
9						
10	Initial sales		120			
11	Sales growth rate		0.04			
12						
13	Annual net profit	\$	182			
14						
15						
16						
17	Cash Flow Model for 1996					
18						
19		Qtr1	Qtr2	Qtr3	Qtr4	Annual Total
20	Sales	120	125	130	135	510
21	Revenue	\$ 144	\$ 150	\$ 156	\$ 162	\$ 611
22	Variable cost	\$ 72	\$ 75	\$ 78	\$ 81	\$ 306
23	Fixed cost	\$ 30	\$ 31	\$ 31	\$ 32	\$ 124
24	Net profit	\$ 42	\$ 44	\$ 47	\$ 49	\$ 182
25						

Change initial sales (cell B10) and sales growth rate (cell B11) to evaluate change in annual profit.

Initiate sales of 100 growing at 3%/qtr yields an annual net profit of \$127. Compare to this What-If case of initial sales of 120 growing at 4%/qtr.

Multiple Goals, Sensitivity Analysis, What-If Analysis, and Goal Seeking (5 of 5)

Figure 8.11 Goal-Seeking Analysis.

5									
6									
7	Investment Problem Example of GoalSeeking			Initial Investment:		\$ 1,000.00			
8				Interest Rate:		10%			
9									
10	Find the Interest Rate (the Internal Rate of Return-IRR) that yields an NPV of \$0			Year		Annual Returns		NPV Calculations	
11									
12				1		\$ 120.00		\$109.09	
13				2		\$ 130.00		\$118.18	
14				3		\$ 140.00		\$127.27	
15				4		\$ 150.00		\$136.36	
16				5		\$ 160.00		\$145.45	
17				6		\$ 152.00		\$138.18	
18				7		\$ 144.40		\$131.27	
19				8		\$ 137.18		\$124.71	
20	9		\$ 130.32		\$118.47				
21	10		\$ 123.80		\$112.55				
22									
23				The NPV Solutions:		\$261.55			
24									

Decision Analysis with Decision Tables

- **Decision Tables** – a tabular representation of the decision situation (alternatives)
- Investment Example
 - Goal: **maximize the yield after one year**
 - Yield depends on the status of the economy (the state of nature):
 - Solid growth
 - Stagnation
 - Inflation

Decision Table: Investment Example (1 of 2)

1. If **solid growth** in the economy, bonds yield 12%; stocks 15%; time deposits 6.5%
2. If **stagnation**, bonds yield 6%; stocks 3%; time deposits 6.5%
3. If **inflation**, bonds yield 3%; stocks **lose** 2%; time deposits yield 6.5%

Decision Table: Investment Example (2 of 2)

- Payoff decision variables (alternatives)
- Uncontrollable variables (states of economy)
- Result variables (projected yield)
- Tabular representation:

TABLE 8.3 Investment Problem Decision Table Model

Alternative	State of Nature (Uncontrollable Variables)		
	Solid Growth (%)	Stagnation (%)	Inflation (%)
Bonds	12.0	6.0	3.0
Stocks	15.0	3.0	-2.0
CDs	6.5	6.5	6.5

Decision Table: Investment Example (Treating Uncertainty)

- Optimistic approach: the best possible outcome
- Pessimistic approach: the best of the worst outcome
- Treating Risk/Uncertainty:
 - Use known probabilities
 - Expected values

TABLE 8.3 Investment Problem Decision Table Model

Alternative	State of Nature (Uncontrollable Variables)		
	Solid Growth (%)	Stagnation (%)	Inflation (%)
Bonds	12.0	6.0	3.0
Stocks	15.0	3.0	−2.0
CDs	6.5	6.5	6.5

Decision Table: Investment Example

- **A:** If you are certain that the economic condition is in a *growth* state, which trading alternative would you consider
- **B:** If you are certain that the economic condition is in a *recession* state, which trading alternative would you consider
- **C:** If you are uncertain about the economic condition, which trading alternative would you consider? Use the *optimistic* approach
- **D:** If you are uncertain about the economic condition, which trading alternative would you consider? Use the *pessimistic* approach

Trading Alternative	State of nature			Solution	
	Growth	Stable	Recession	Optimistic	Pessimistic
Import/Export	170	120	90	170	90
Real-Estate	190	150	80	190	80
Transportation	160	110	70	160	70
Used Car Sales	150	100	50	150	50

Decision Table: Investment Example (Under Risk)

- State of Nature: solid growth (50%), stagnation (30%), inflation (20%)
 - Yield of bonds = $12(0.5)+6(0.3)+3(0.2) = 8.4$
 - Yield of Stocks = $15(0.5)+3(0.3)-2(0.2) = 8.0$
 - Yield of CDs = $6.5(0.5)+6.5(0.3)+6.5(0.2) = 6.5$
- Multiple goals
 - Yield, safety, and liquidity

Alternative	Yield (%)	Safety	Liquidity
Bonds	8.4	High	High
Stocks	8.0	Low	High
CDs	6.5	Very high	High

Simulation

- Simulation is the “appearance” of reality
- It is often used to conduct what-if analysis on the model of the actual system
- It is a popular DSS technique for conducting experiments with a computer on a comprehensive model of the system to assess its dynamic behavior
- Often used when the system is too complex for other DSS techniques

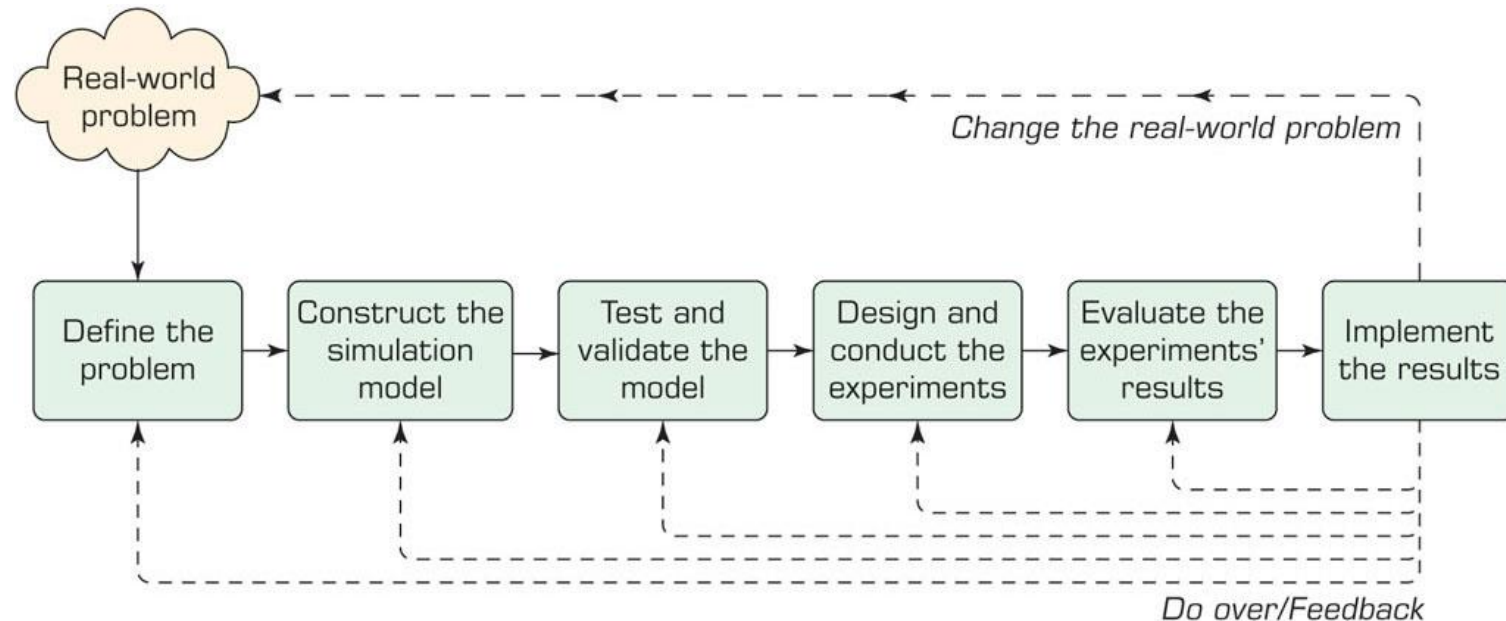
Major Characteristics of Simulation

- **Imitates** reality and captures its richness both in shape and behavior.
- “Represent” versus “Imitate”
- Technique for **conducting experiments**
- Often to “solve” [i.e., analyze] very complex systems/problems
- Simulation should be used only when a numerical optimization is not possible

Simulation Methodology

Steps:

1. Define problem
2. Construct the model
3. Test and validate model
4. Design experiments
5. Conduct experiments
6. Evaluate results
7. Implement solution



Simulation Types

- **Probabilistic/Stochastic vs. Deterministic Simulation**
 - Uses probability distributions
- **Time-dependent vs. Time-independent Simulation**
 - Monte Carlo technique ($X = A + B$)
[A, B, and X are all distributions]
- **Discrete Event vs. Continuous Simulation**
- **Simulation Implementation**
 - Visual Simulation and/or Object-Oriented Simulation

Visual Interactive Simulation (VIS)

- **Visual interactive modeling** (VIM), also called Visual Interactive Simulation or Visual interactive problem solving
 - Uses computer graphics to present the impact of different management decisions
 - Often integrated with 3G and GIS
- Users can perform sensitivity analysis
- Static or dynamic (animation) systems
- Virtual reality

Q & A