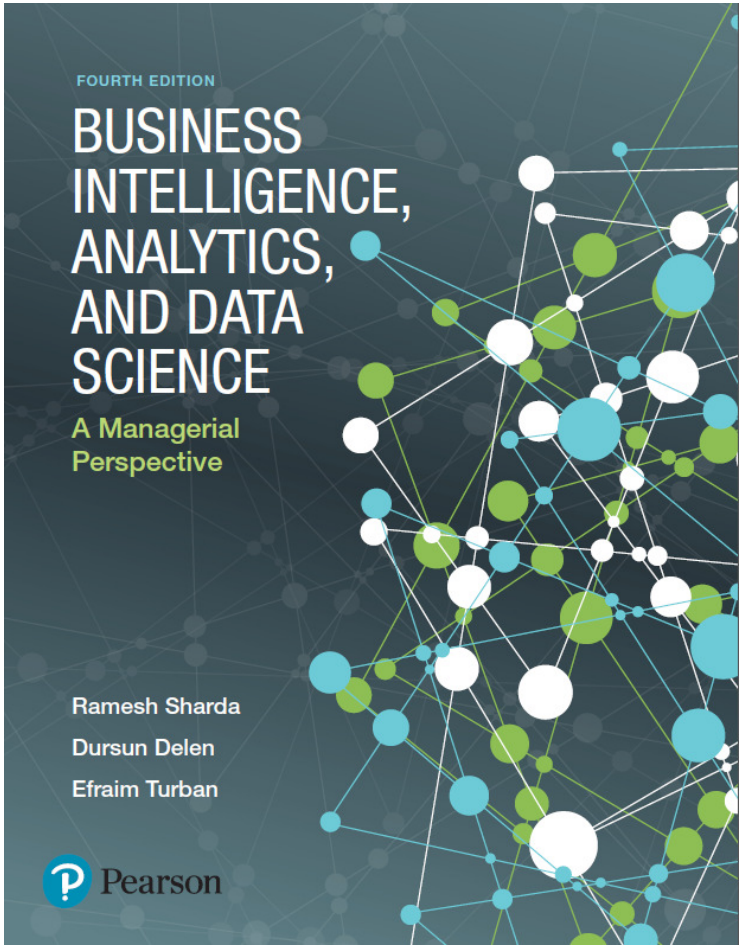
Business Intelligence, Analytics, and Data Science: A Managerial Perspective

Fourth Edition



Chapter 6 – Part B

Prescriptive Analytics: Optimization and Simulation

Pearson

Optimization via Mathematical Programming

- 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.

Application Case 6.6

Mixed-Integer Programming Model Helps the University of Tennessee Medical Center with Scheduling Physicians

Questions for Discussion

1. What was the issue faced by the Regional Neonatal Associates group?
2. How did the HPSM model solve all of the physician's requirements?

LP Problem Characteristics

1. Limited quantity of economic resources
2. Resources are used in the production of products or services
3. Two or more ways (solutions, programs) to use the resources
4. Each activity (product or service) yields a return in terms of the goal
5. Allocation is usually restricted by constraints

Linear Programming Steps

1. Identify the …
   - Decision variables
   - Objective function
   - 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

Modeling in LP - An Example

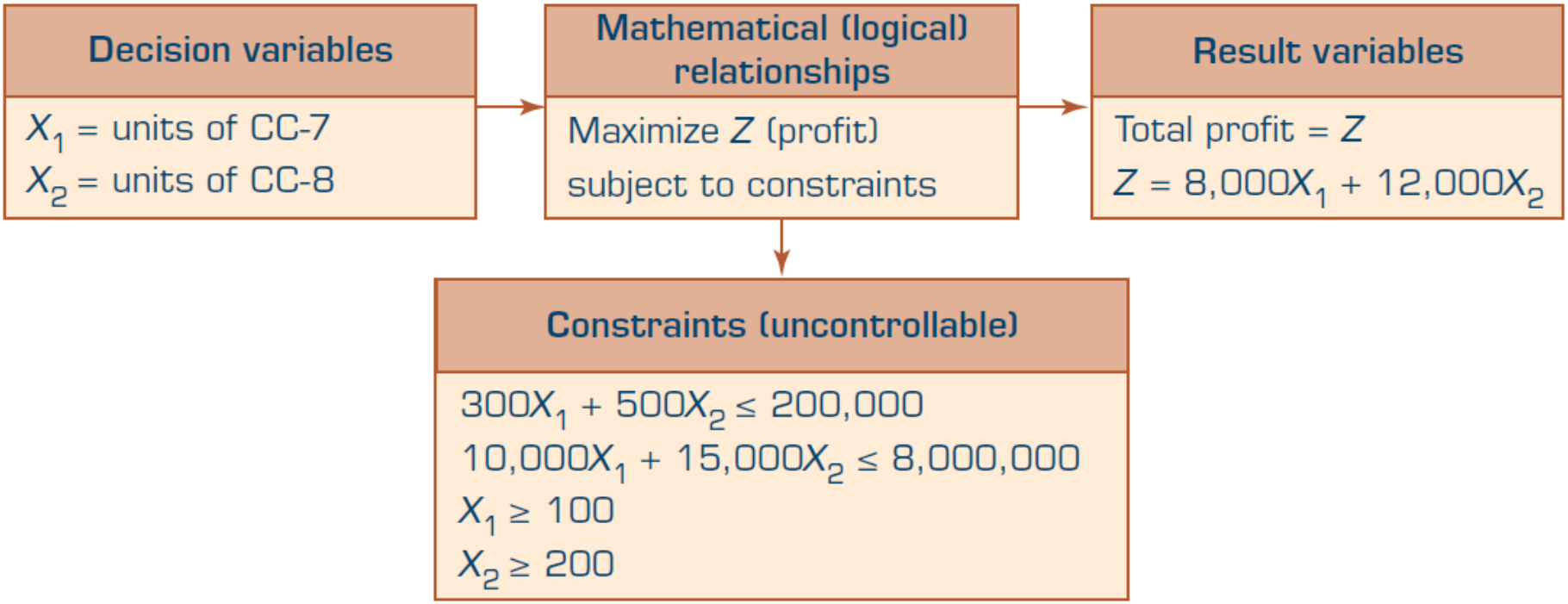
The Product-Mix Linear Programming Model (for MBI Corporation)

- Decision variable: How many computers to build?
- Two types of mainframe computers: CC-7 and CC-8
- Constraints: Labor, Materials, and Marketing limits

	CC-7	CC-8	Rel	Limit
Labor (days)	300	500	<=	200,000 /mo
Materials ($)	10,000	15,000	<=	8,000,000 /mo
Units	1		>=	100
Units		1	>=	200
Profit ($)	8,000	12,000	(Max)	

Objective: Maximize Total Profit / Month

LP Solution – Algebraic Formulations



LP Solution with Excel

Decision Variables:

X_1: unit of CC-7

X_2: unit of CC-8

Objective Function:

Maximize Z (profit)

$Z=8000X_1+12000X_2$

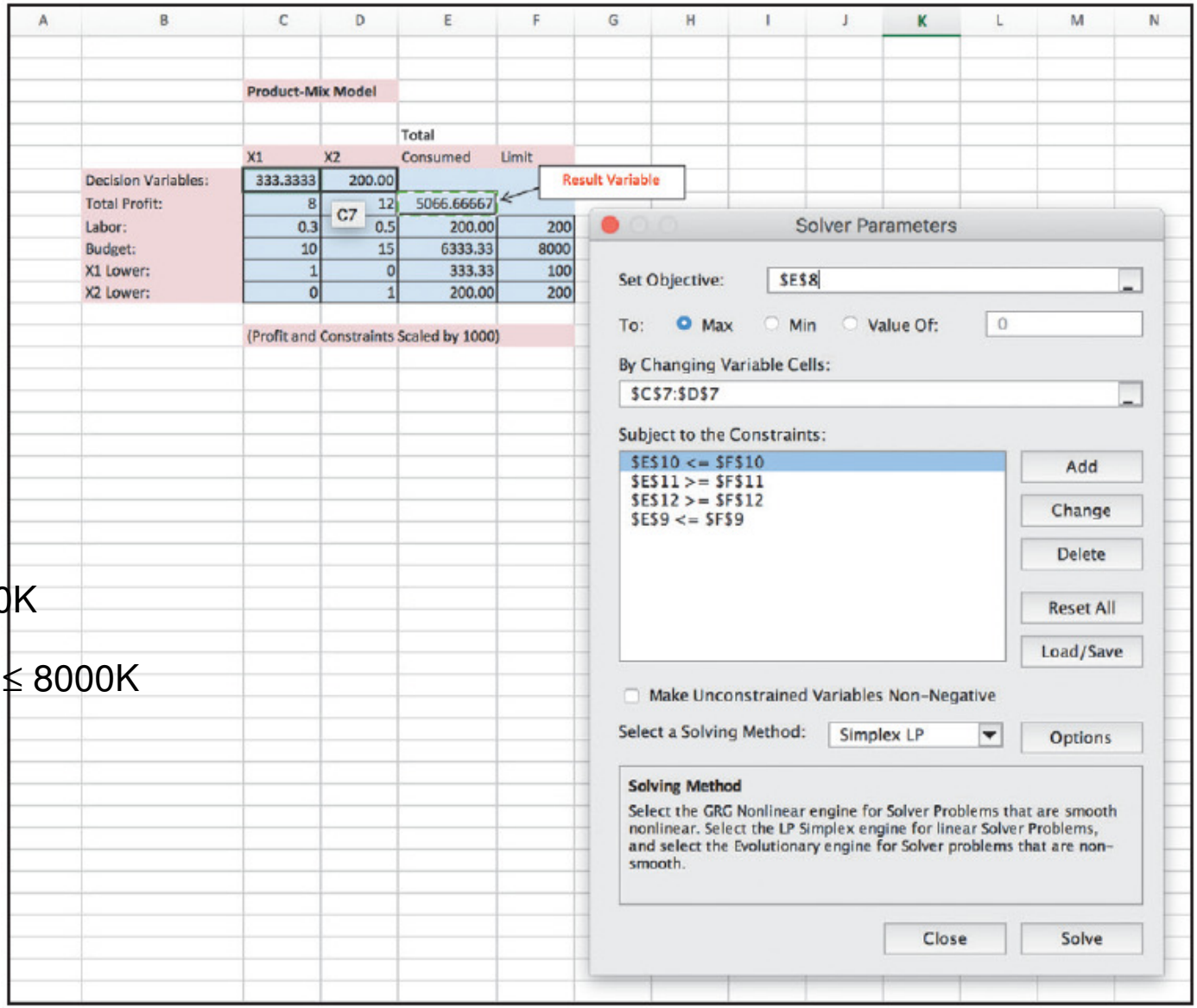
Subject To

$300X_1 + 500X_2 \leq 200K$

$10000X_1 + 15000X_2 \leq 8000K$

$X_1 \geq 100$

$X_2 \geq 200$



Illustrating the Power of Spreadsheet Modeling

- Election Resource Allocation Problem (Data)

State	Electoral Votes	W/E	N/S	Influence Function
NV	6	West		F1
CO	9	West		F2
IA	6	West	North	F3
WI	10	West	North	F1
OH	18	East	North	F2
VA	13	East	South	F2
NC	15	East	South	F1
FL	29	East	South	F3
NH	4	East		F3

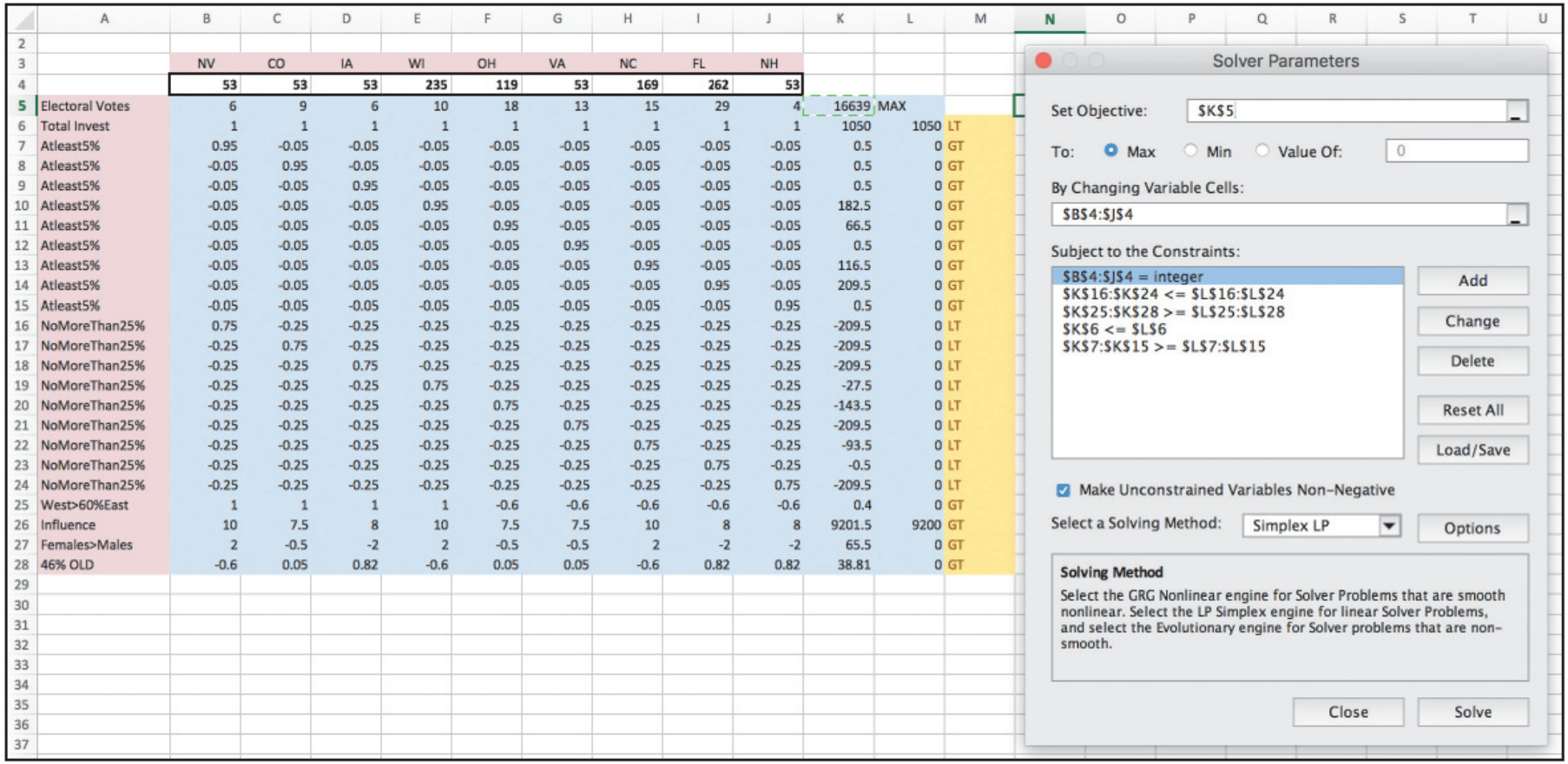
F1	Young	Old		
Men	3	1	4	
Women	3	3	6	
	6	4	10	Total

F2	Young	Old		
Men	1.5	2.5	4	
Women	2.5	1	3.5	
	4	3.5	7.5	Total

F3	Young	Old		
Men	2.5	2.5	5	
Women	1	2	3	
	3.5	4.5	8	Total

Illustrating the Power of Spreadsheet Modeling

- Election Resource Allocation Problem (Formulation)



		NV	CO	IA	WI	OH	VA	NC	FL	NH			
		53	53	53	235	119	53	169	262	53			
5	Electoral Votes	6	9	6	10	18	13	15	29	4	16639	MAX	
6	Total Invest	1	1	1	1	1	1	1	1	1	1050	1050	LT
7	Atleast5%	0.95	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	0.5	0	GT
8	Atleast5%	-0.05	0.95	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	0.5	0	GT
9	Atleast5%	-0.05	-0.05	0.95	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	0.5	0	GT
10	Atleast5%	-0.05	-0.05	-0.05	0.95	-0.05	-0.05	-0.05	-0.05	-0.05	182.5	0	GT
11	Atleast5%	-0.05	-0.05	-0.05	-0.05	0.95	-0.05	-0.05	-0.05	-0.05	66.5	0	GT
12	Atleast5%	-0.05	-0.05	-0.05	-0.05	-0.05	0.95	-0.05	-0.05	-0.05	0.5	0	GT
13	Atleast5%	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	0.95	-0.05	-0.05	116.5	0	GT
14	Atleast5%	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	0.95	-0.05	209.5	0	GT
15	Atleast5%	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	0.95	0.5	0	GT
16	NoMoreThan25%	0.75	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25	-209.5	0	LT
17	NoMoreThan25%	-0.25	0.75	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25	-209.5	0	LT
18	NoMoreThan25%	-0.25	-0.25	0.75	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25	-209.5	0	LT
19	NoMoreThan25%	-0.25	-0.25	-0.25	0.75	-0.25	-0.25	-0.25	-0.25	-0.25	-27.5	0	LT
20	NoMoreThan25%	-0.25	-0.25	-0.25	-0.25	0.75	-0.25	-0.25	-0.25	-0.25	-143.5	0	LT
21	NoMoreThan25%	-0.25	-0.25	-0.25	-0.25	-0.25	0.75	-0.25	-0.25	-0.25	-209.5	0	LT
22	NoMoreThan25%	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25	0.75	-0.25	-0.25	-93.5	0	LT
23	NoMoreThan25%	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25	0.75	-0.25	-0.5	0	LT
24	NoMoreThan25%	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25	0.75	-209.5	0	LT
25	West>60%East	1	1	1	1	-0.6	-0.6	-0.6	-0.6	-0.6	0.4	0	GT
26	Influence	10	7.5	8	10	7.5	7.5	10	8	8	9201.5	9200	GT
27	Females>Males	2	-0.5	-2	2	-0.5	-0.5	2	-2	-2	65.5	0	GT
28	46% OLD	-0.6	0.05	0.82	-0.6	0.05	0.05	-0.6	0.82	0.82	38.81	0	GT

Solver Parameters

Set Objective: $K$5

To: Max Min Value Of: 0

By Changing Variable Cells: $B$4:$J$4

Subject to the Constraints:

$B$4:$J$4 = integer
$K$16:$K$24 <= $L$16:$L$24
$K$25:$K$28 >= $L$25:$L$28
$K$6 <= $L$6
$K$7:$K$15 >= $L$7:$L$15

Add | Change | Delete | Reset All | Load/Save

Make Unconstrained Variables Non-Negative

Select a Solving Method: Simplex LP | Options

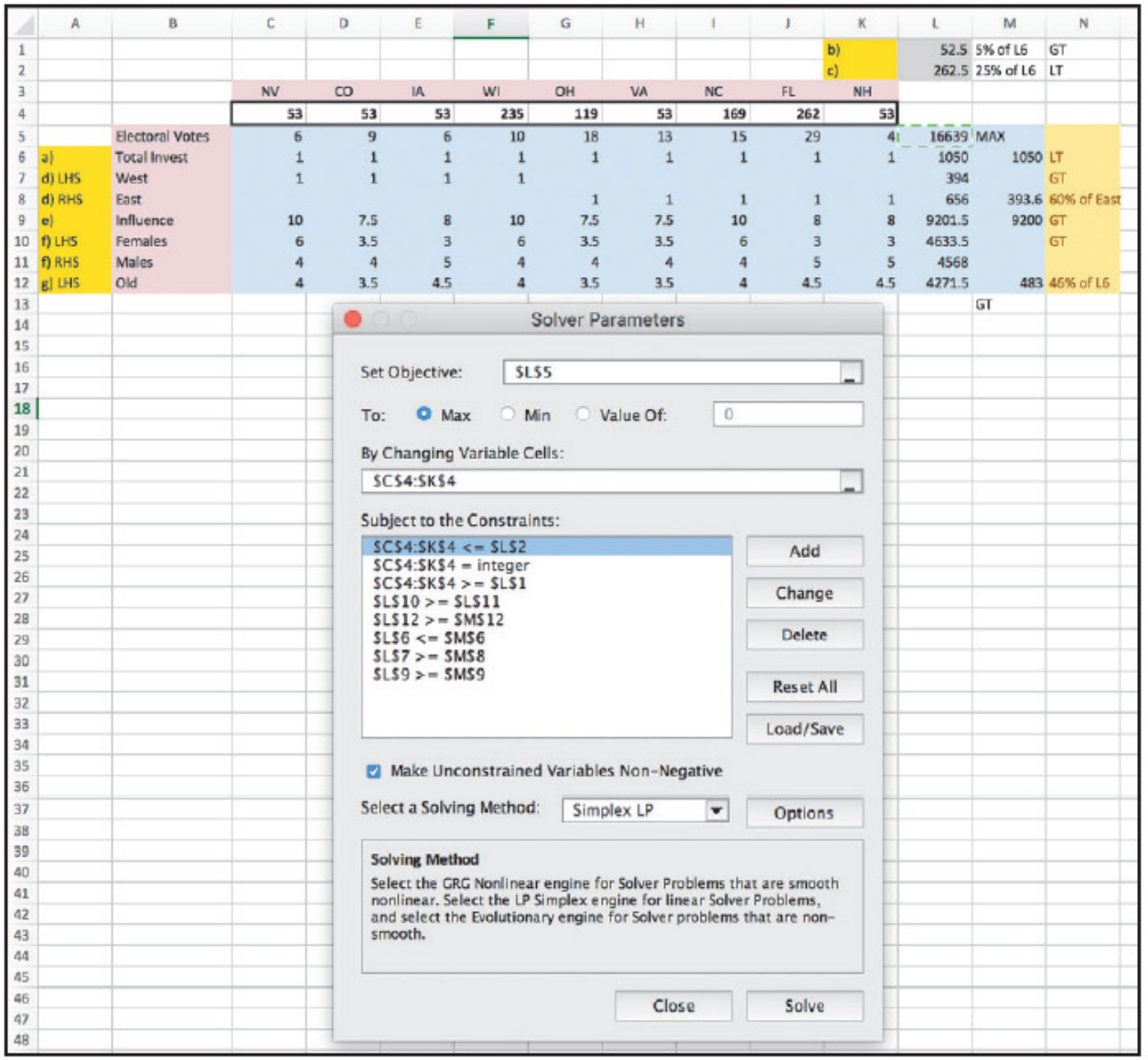
Solving Method

Select the GRG Nonlinear engine for Solver Problems that are smooth nonlinear. Select the LP Simplex engine for linear Solver Problems, and select the Evolutionary engine for Solver problems that are non-smooth.

Close | Solve

Illustrating the Power of Spreadsheet Modeling

- Election Resource Allocation Problem (Compact Formulation)



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

- Multiple Goals
  - Simple-goal vs. multiple goals
  - Vast majority of managerial problems has multiple goals (objectives) to achieve
    - Attaining all goals *simultaneously*
- 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

- Certain difficulties may arise when analyzing multiple goals:
  - Difficult to obtain a single organizational goal
  - The importance of goals change over time
  - Goals and sub-goals are viewed differently
  - Goals change in response to other changes
  - Dynamics of groups of decision makers
  - Assessing the importance (priorities)

Multiple Goals, Sensitivity Analysis, What-If Analysis, and Goal Seeking

- 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

- 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 on output?]
- 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 (profit = 0), how many products do we have to sell each month?

What-If Analysis Example in Excel

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

Change intitial 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 intitial sales of 120 growing at 4%/qtr.

Cash Flow Model for 1996

	Qtr1	Qtr2	Qtr3	Qtr4	Annual Total
Sales	120	125	130	135	510
Revenue	$ 144	$ 150	$ 156	$ 162	$ 611
Variable cost	$ 72	$ 75	$ 78	$ 81	$ 306
Fixed cost	$ 30	$ 31	$ 31	$ 32	$ 124
Net profit	$ 42	$ 44	$ 47	$ 49	$ 182

Goal Seeking Example in Excel

Investment Problem
Example of GoalSeeking

Find the Interest Rate (the Internal Rate of Return-IRR) that yields an NPV of $0

Initial Investment:	$ 1,000.00
Interest Rate:	10%

Year	Annual Returns	NPV Calculations
1	$ 120.00	$109.09
2	$ 130.00	$118.18
3	$ 140.00	$127.27
4	$ 150.00	$136.36
5	$ 160.00	$145.45
6	$ 152.00	$138.18
7	$ 144.40	$131.27
8	$ 137.18	$124.71
9	$ 130.32	$118.47
10	$ 123.80	$112.55

The NPV Solutions:	$261.55

Decision Analysis with Decision Tables and Decision Trees

- 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: Possible Situations

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: Decision Table

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

TABLE 6.3 Investment Problem Decision Table Model

	State of Nature (Uncontrollable Variables)		
Alternative	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 vs. pessimistic approach
- Treating Risk/Uncertainty:
  - Use known probabilities (expected values)
- Multiple goals: yield, safety, and liquidity

TABLE 6.4 Multiple Goals

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

Decision Trees

- Graphical representation of relationships
  - Can be induced (driven) from data [data mining]
  - Can be driven from experts [knowledge-driven]
- Multiple criteria approach
- Demonstrates complex relationships
- Cumbersome, if many alternatives exist
- Many tools exist:
  - Mind Tools Ltd., mindtools.com
  - TreeAge Software Inc., treeage.com
  - Palisade Corp., palisade.com

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
- Descriptive, not normative tool
- Often to "solve" [i.e., analyze] very complex systems/problems
- Simulation should be used only when a numerical optimization is not possible

Application Case 6.7
Simulating Effects of Hepatitis B Interventions

Questions for Discussion

1. Explain the advantage of OR methods such as simulation over clinical trial methods in determining the best control measure for Hepatitis B.
2. In what ways do the decision and Markov models provide cost-effective ways of combating the disease?
3. Discuss how multidisciplinary background is an asset in finding a solution for the problem described in the case.

Advantages of Simulation

- The theory is fairly straightforward
- Great deal of time compression
- Experiment with different alternatives
- The model reflects manager's perspective
- Can handle wide variety of problem types
- Can include the real complexities of problems
- Produces important performance measures
- Often it is the only DSS modeling tool for non-structured problems

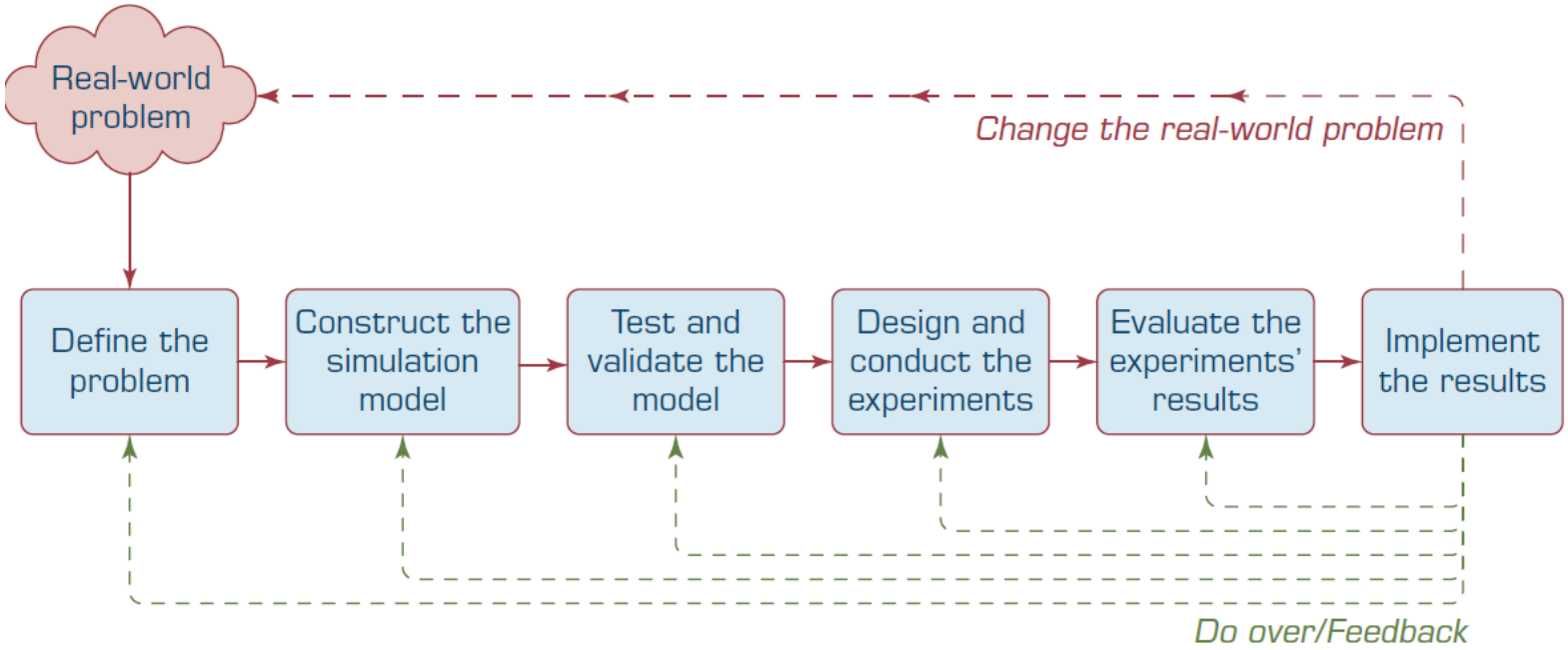
Disadvantages of Simulation

- Cannot guarantee an optimal solution
  - It is a descriptive model that can help develop prescriptive outcomes
- Time-demanding and costly construction process
- Cannot transfer solutions and inferences to solve other problems (models are problem specific)
- So easy to explain/sell to managers, may lead to overlooking analytical/optimal solutions
- Software may require special skills/experience

Simulation Methodology

Model Development 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

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

Application Case 6.8

Cosan Improves Its Renewable Energy Supply Chain Using Simulation

Questions for Discussion

1. What type of supply chain disruptions might occur in moving the sugar cane from the field to the production plants to develop sugar and ethanol?
2. What types of advanced planning and prediction might be useful in mitigating such disruptions?

Visual Interactive Simulation (VIS)

- Visual interactive modeling (VIM), also called Visual Interactive Simulation or Visual Interactive Problem Solving
- Goal is to address conventional simulation modeling inadequacies
- Uses computer graphics and animation
- Often integrated with RFID and GIS
- Allows for interactive/immersive sensitivity analysis
- Virtual reality
- Immersive presence

Application Case 6.9 (1 of 4)

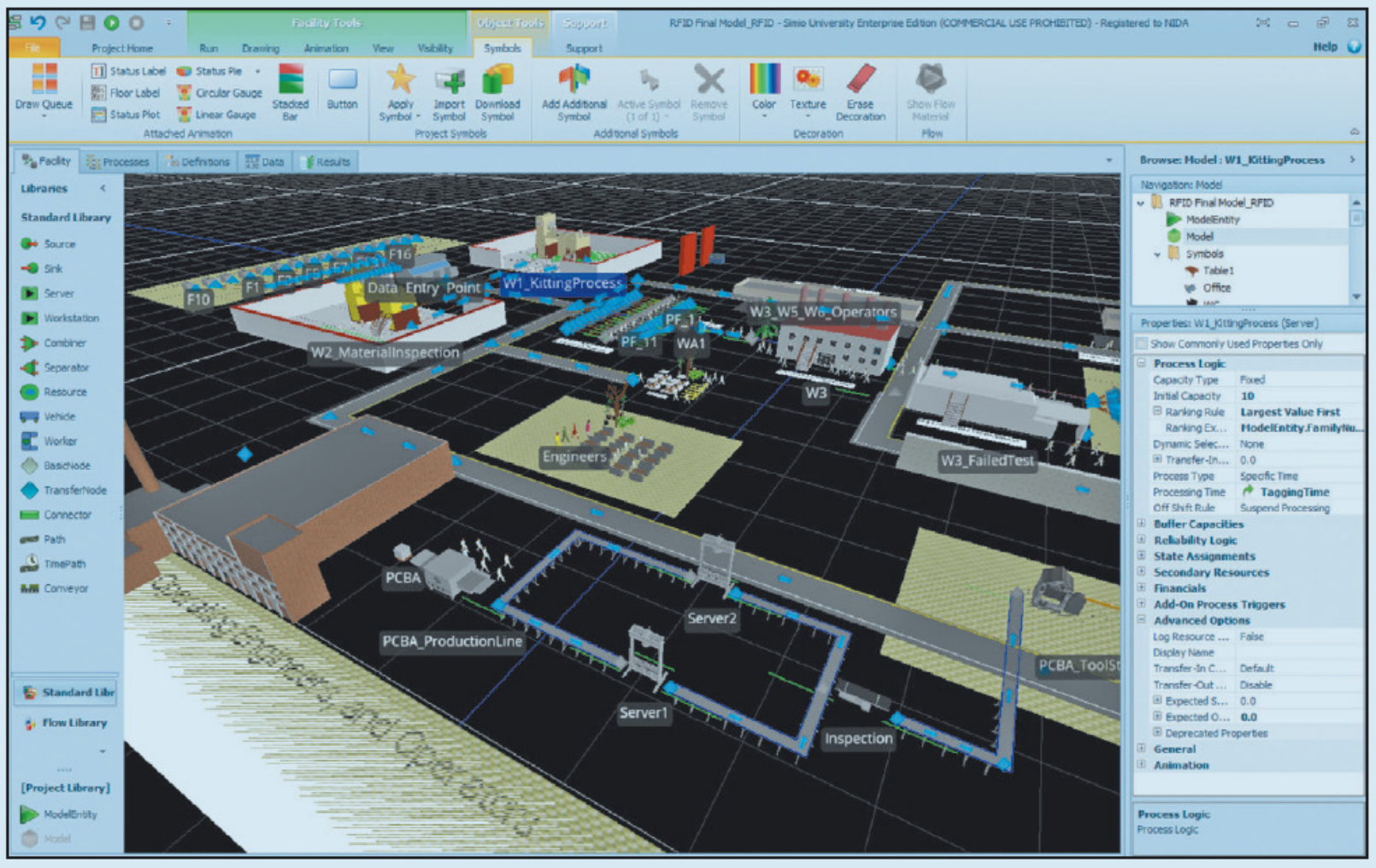
Improving Job-Shop Scheduling Decisions through RFID: A Simulation-Based Assessment

Questions for Discussion

1. In situations such as what this case depicts, what other approaches can one take to analyze investment decisions?
2. How would one save time if an RFID chip can tell the exact location of a product in process?
3. Research to learn about the applications of RFID sensors in other settings. Which one do you find most interesting?

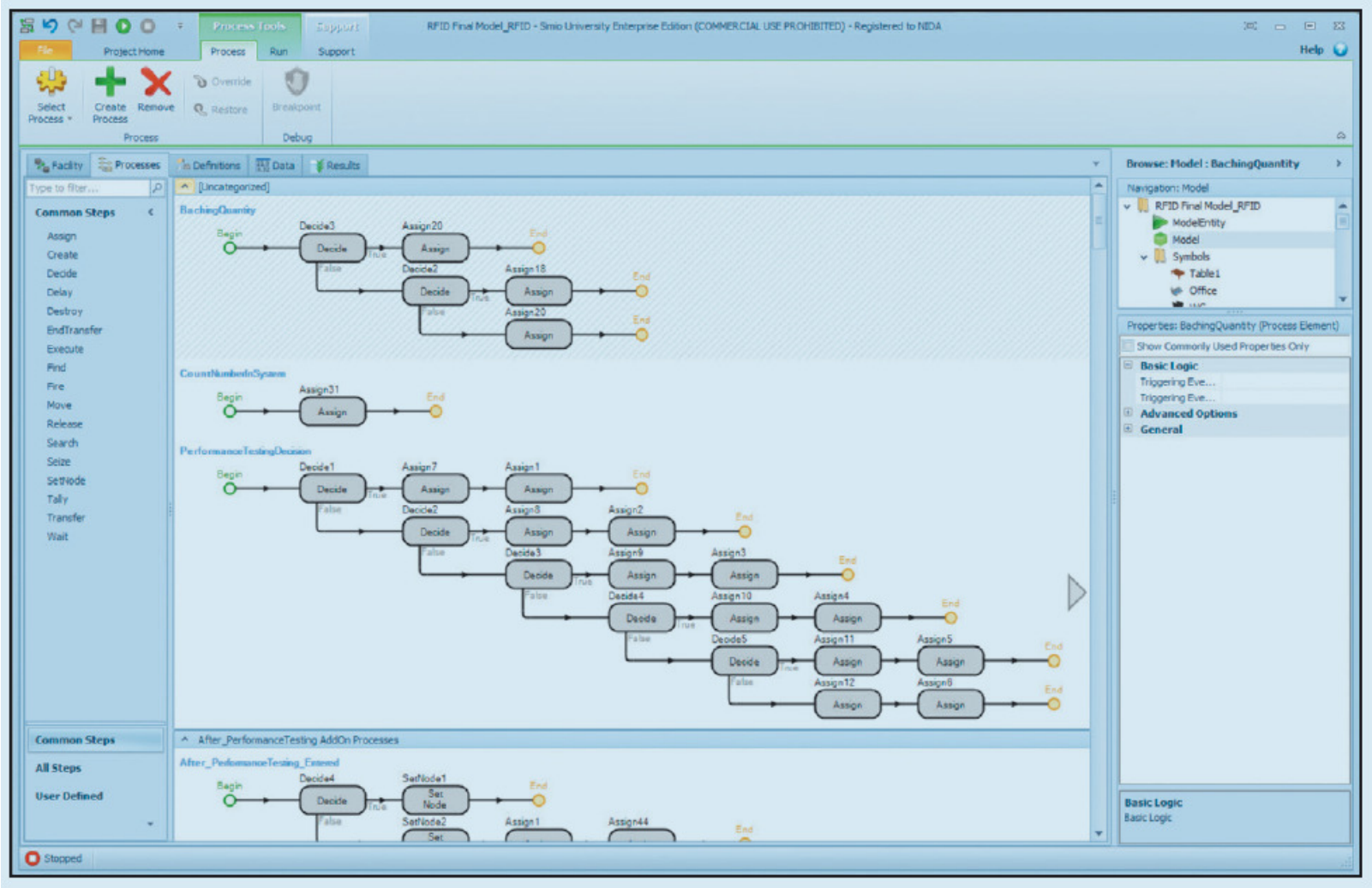
Application Case 6.9 (2 of 4)

Improving Job-Shop Scheduling Decisions through RFID: A Simulation-Based Assessment (Simio - Modeling Interface)



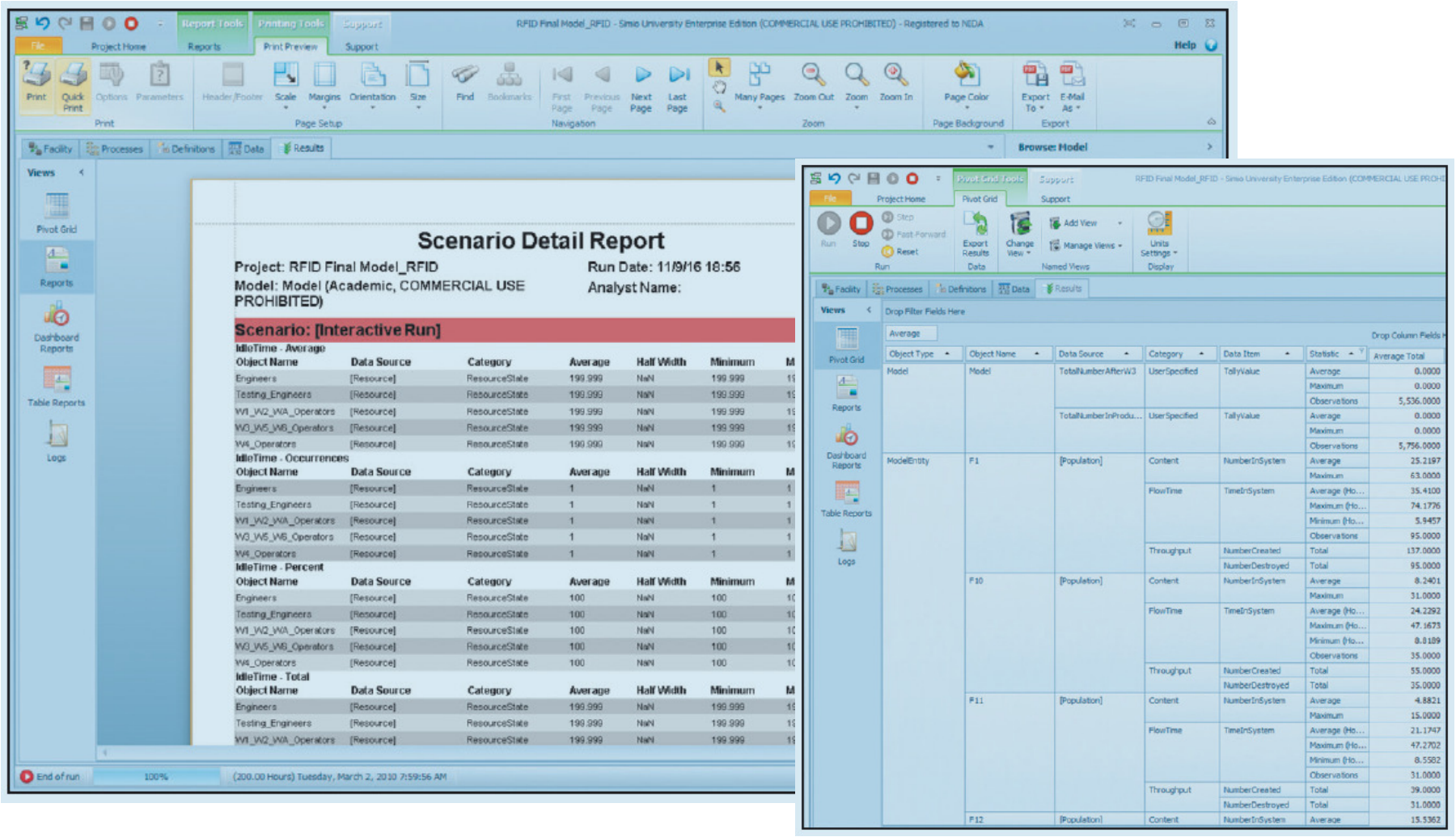
Application Case 6.9 (3 of 4)

Improving Job-Shop Scheduling Decisions through RFID: A Simulation-Based Assessment (Simio - Process Definition)



Application Case 6.9 (4 of 4)

Improving Job-Shop Scheduling Decisions through RFID: A Simulation-Based Assessment (Simio – Result Reporting)



Simulation Software

- A comprehensive list can be found at
  - orms-today.org/surveys/Simulation/Simulation.html
- Simio LLC, simio.com
- SAS Simulation [SAS OR], sas.com
- Lumina Decision Systems, lumina.com
- Oracle Crystal Ball, oracle.com
- Palisade Corp., palisade.com
- Rockwell Software, arenasimulation.com …