Operations Research and its Industrial Applications

Introduction

- **Operations Research** is an Art and Science
- It had its early roots in World War II and is flourishing in business and industry with the aid of computer
- Primary applications areas of Operations Research include forecasting, production scheduling, inventory control, capital budgeting, and transportation.

What is Operations Research?

Operations

The activities carried out in an organization.

Research

The process of observation and testing characterized by the scientific method. Situation, problem statement, model construction, validation, experimentation, candidate solutions.

Operations Research is a quantitative approach to decision making based on the scientific method of problem solving.

What is Operations Research?

- Operations Research is the scientific approach to execute decision making, which consists of:
  - The art of ***mathematical modeling*** of complex situations
  - The science of the development of ***solution techniques*** used to solve these models
  - The ability to effectively ***communicate*** the results to the decision maker

What Do We do

1. OR professionals aim to provide rational bases for decision making by seeking to understand and structure complex situations and to use this understanding to predict system behavior and improve system performance.

2. Much of this work is done using analytical and numerical techniques to develop and manipulate mathematical and computer models of organizational systems composed of people, machines, and procedures.

Terminology

- The British/Europeans refer to “**Operational Research**", the Americans to “**Operations Research**" - but both are often shortened to just "OR".

- Another term used for this field is “**Management Science**" ("MS"). In U.S. OR and MS are combined together to form "OR/MS" or "ORMS".

- Yet other terms sometimes used are “**Industrial Engineering**" ("IE") and “**Decision Science**" ("DS").

Operations Research Models

Deterministic Models

- Linear Programming
- Network Optimization
- Integer Programming
- Nonlinear Programming
- Inventory Models

Stochastic Models

- Discrete-Time Markov Chains
- Continuous-Time Markov Chains
- Queuing Theory (waiting lines)
- Decision Analysis
- Game Theory
- Inventory models
- Simulation

Deterministic vs. Stochastic Models

Deterministic models

assume all data are known with certainty

Stochastic models

explicitly represent uncertain data via random variables or stochastic processes.

Deterministic models involve optimization

Stochastic models

characterize / estimate system performance

History of OR

- OR is a relatively new discipline.
- 85 years ago it would have been possible to study mathematics, physics or engineering at university it would not have been possible to study OR.
- It was really only in the late 1930's that operation as research began in a systematic way.

1890
Frederick Taylor
Scientific Management
[Industrial Engineering]

1900
- Henry Gannt [Project Scheduling]
- Andrey A. Markov [Markov Processes]
- Assignment [Networks]

1910
- F. W. Harris [Inventory Theory]
- E. K. Erlang [Queuing Theory]

1920
- William Shewart [Control Charts]
- H.Dodge – H.Roming [Quality Theory]

1930
Jon Von Neuman – Oscar Morgenstern [Game Theory]

1940
- World War 2
- George Dantzig [Linear Programming]
- First Computer

1950
- H.Kuhn - A.Tucker [Non-Linear Prog.]
- Ralph Gomory [Integer Prog.]
- PERT/CPM
- Richard Bellman [Dynamic Prog.]

ORSA and TIMS

1960
- John D.C. Litle [Queuing Theory]
- Simscript - GPSS [Simulation]

1970
- Microcomputer

1980
- H. Karmarkar [Linear Prog.]
- Personal computer
- OR/MS Softwares

1990
- Spreadsheet Packages
- INFORMS

2022
- You are here

Problem Solving and Decision Making

- 7 Steps of Problem Solving

  (First 5 steps are the process of decision making)

  - Identify and define the problem.
  - Determine the set of alternative solutions.
  - Determine the criteria for evaluating the alternatives.
  - Evaluate the alternatives.
  - Choose an alternative.

  - Implement the chosen alternative.
  - Evaluate the results.

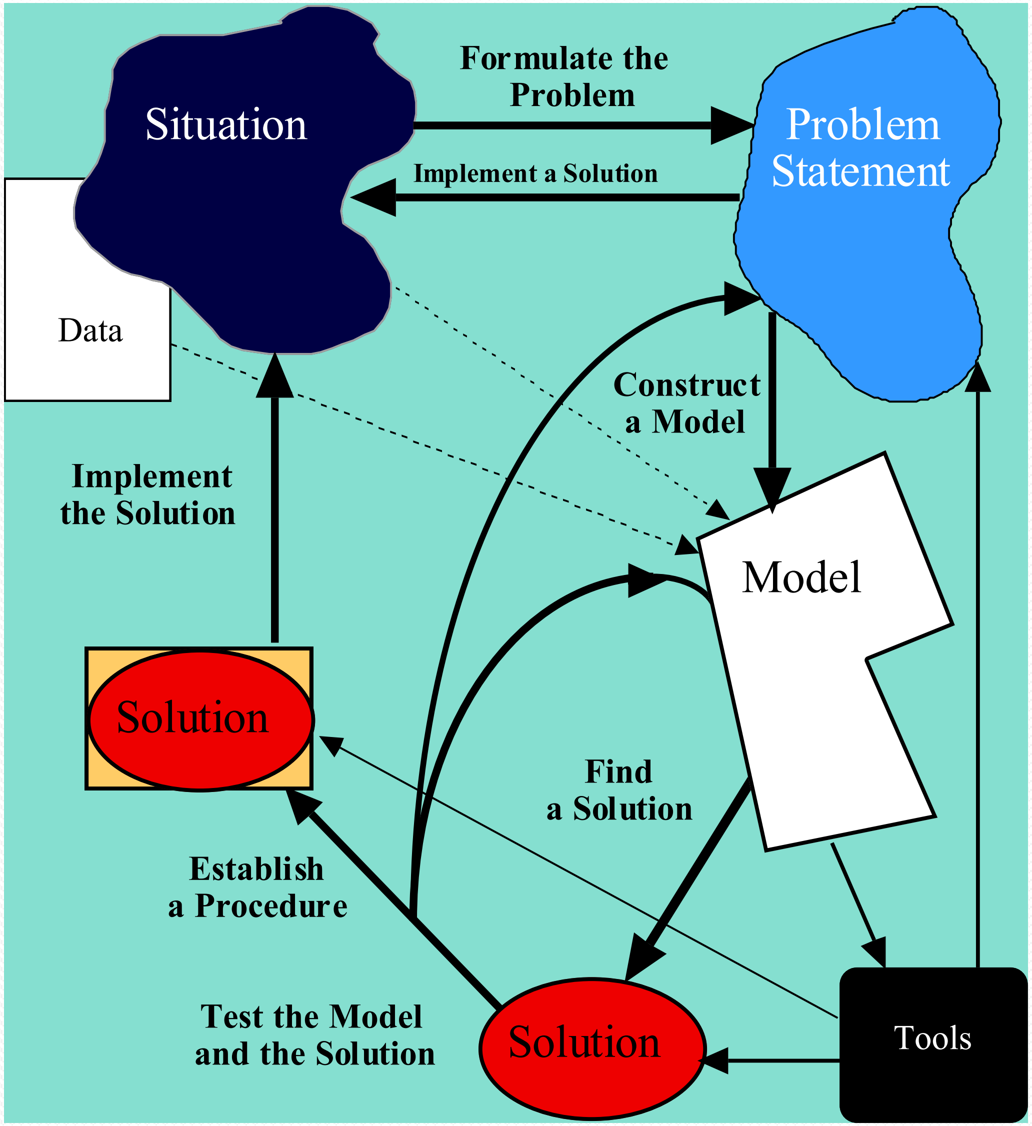
Quantitative Analysis and Decision Making

- Potential Reasons for a Quantitative Analysis Approach to Decision Making
  - The problem is complex.
  - The problem is very important.
  - The problem is new.
  - The problem is repetitive.

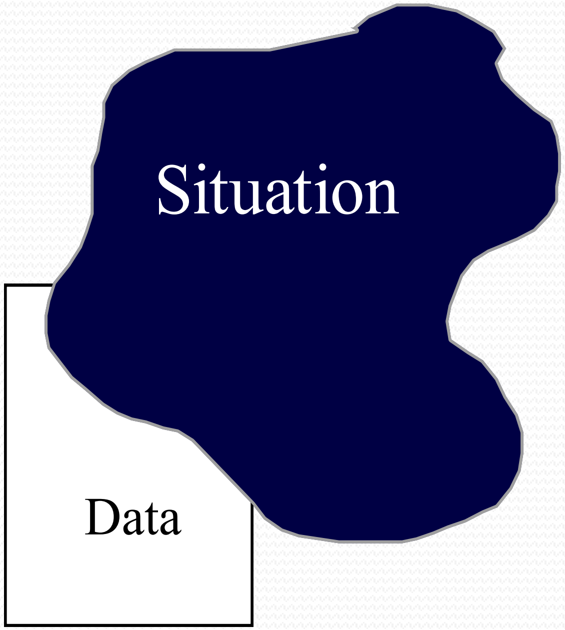
Problem Solving Process

Goal: solve a problem

- Model must be valid
- Model must be tractable
- Solution must be useful



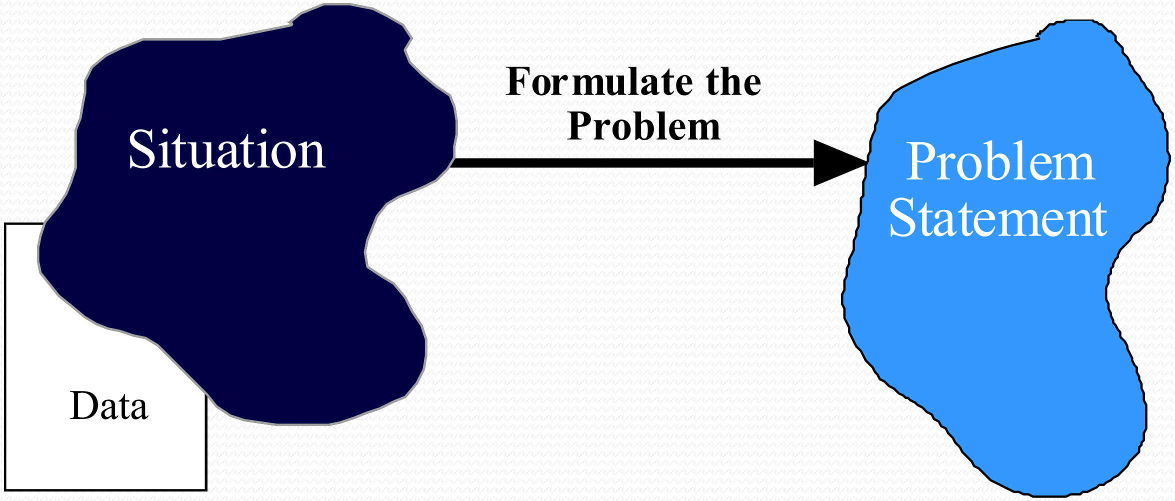
The Situation



- May involve current operations or proposed expansions due to expected market shifts
- May become apparent through consumer complaints or through employee suggestions
- May be a conscious effort to improve efficiency or response to an unexpected crisis.

Example: Internal nursing staff not happy with their schedules; hospital using too many external nurses.

Problem Formulation



- Describe system
- Define boundaries
- State assumptions
- Select performance measures

- Define variables
- Define constraints
- Data requirements

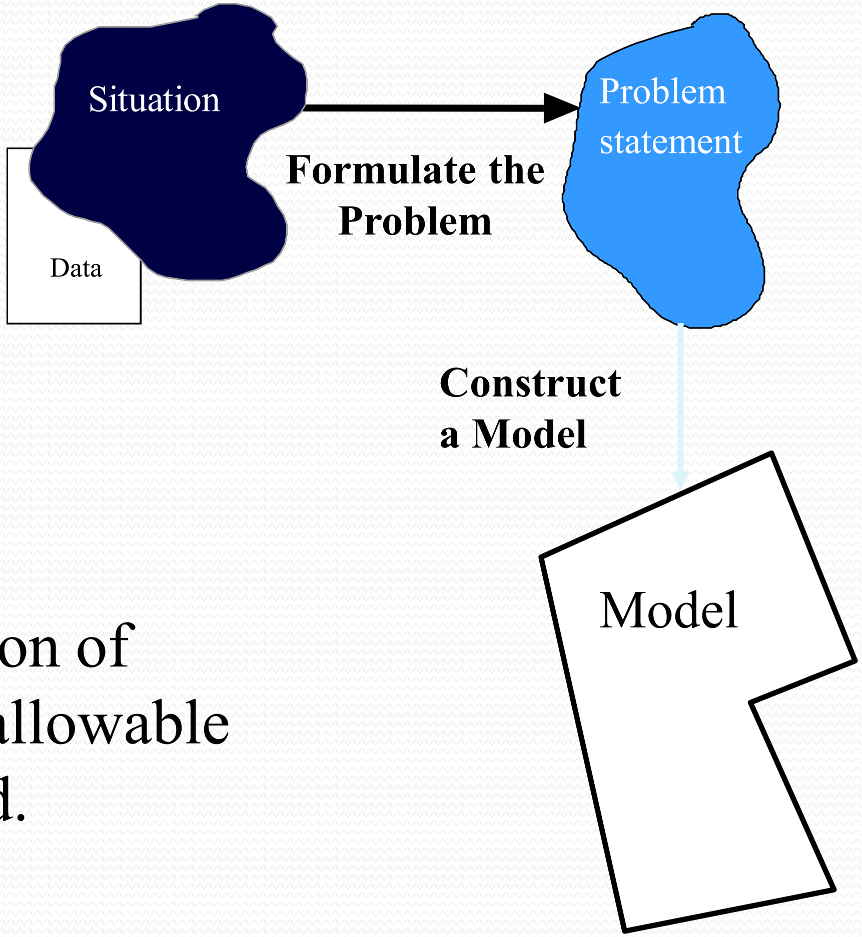
Example: Maximize individual nurse preferences subject to demand requirements.

Data Preparation

- Data preparation is not a trivial step, due to the time required and the possibility of data collection errors.
- A model with 50 decision variables and 25 constraints could have over 1300 data elements!
- Often, a fairly large data base is needed.
- Information systems specialists might be needed.

Constructing a Model

- Problem must be translated from verbal, qualitative terms to logical, quantitative terms
- A logical model is a series of rules, usually embodied in a computer program
- A mathematical model is a collection of functional relationships by which allowable actions are delimited and evaluated.



Example: Define relationships between individual nurse assignments and preference violations; define tradeoffs between the use of internal and external nursing resources.

Advantages of Models

- Generally, experimenting with models (compared to experimenting with the real situation):
  - requires less time
  - is less expensive
  - involves less risk

Mathematical Models

- Cost/benefit considerations must be made in selecting an appropriate mathematical model.
- Frequently a less complicated (and perhaps less precise) model is more appropriate than a more complex and accurate one due to cost and ease of solution considerations.

Mathematical Models

- Relate decision variables (controllable inputs) with fixed or variable parameters (uncontrollable inputs).
- Frequently seek to maximize or minimize some objective function subject to constraints.
- Are said to be stochastic if any of the uncontrollable inputs (parameters) is subject to variation (random), otherwise are said to be deterministic.
- Generally, stochastic models are more difficult to analyze.
- The values of the decision variables that provide the mathematically-best output are referred to as the optimal solution for the model.

LP review: Definitions

Linear programming problem:

- problem of maximizing or minimizing a linear function of a finite number of variables
- subject to a finite number of linear constraints: $\leq$, $\geq$ or $=$ constraints

max/min $\quad f(x) = c_1x_1 + c_2x_2 + \ldots + c_nx_n$

subject to $\quad a_{i1}x_1 + a_{i2}x_2 + \ldots + a_{in}x_n \;\substack{\leq \\ \geq \\ =}\; b_i \quad \forall i=1,\ldots,m$

Feasible point: $x \in \mathcal{R}^n$ s.t. x satisfies all constraints

Feasible region: set of all feasible points

$P = \{x \in \mathcal{R}^n : x \text{ satisfies all constraints}\}$

LP review: more definitions

Decision variables: should completely describe all decisions to be made

Objective function

$$\begin{array}{ll} \text{max/min} & f(x) = c_1x_1 + c_2x_2 + \dots + c_nx_n \\ \text{subject to} & a_{11}x_1 + a_{12}x_2 + \dots + a_{1n}x_n \le b_1 \\ & a_{21}x_1 + a_{22}x_2 + \dots + a_{2n}x_n \ge b_2 \\ & a_{31}x_1 + a_{32}x_2 + \dots + a_{3n}x_n = b_3 \end{array}$$

Constraints

Optimal solution: feasible solution with best (max/min) objective-function value

Optimal value: objective-f'n. value at an optimal solution

Computer Software

- A variety of software packages are available for solving mathematical models, some are:
  - Spreadsheet packages such as *Microsoft Excel*
  - *The Management Scientist (MS)*
  - *Quantitative system for business (QSB)*
  - *LINDO, LINGO*
  - *Quantitative models (QM)*
  - Decision Science (DS)

Examples of OR Applications

- Rescheduling aircraft in response to groundings and delays
- Planning production for printed circuit board assembly
- Scheduling equipment operators in mail processing & distribution centers
- Developing routes for propane delivery
- Adjusting nurse schedules in light of daily fluctuations in demand

Success Stories of OR

Application Areas

- Strategic planning
- Supply chain management
- Pricing and revenue management
- Logistics and site location
- Optimization
- Marketing research

Applications Areas (cont.)

- Scheduling
- Portfolio management
- Inventory analysis
- Forecasting
- Sales analysis
- Auctioning
- Risk analysis

Examples

- British Telecom used OR to schedule workforce for more than 40,000filed engineers. The system was saving $150 million a year from 1997~ 2000. The workforce is projected to save $250 million.

- Sears Uses OR to create a Vehicle Routing and Scheduling System which to run its delivery and home service fleet more efficiently $42 million in annual savings

- UPS use O.R. to redesign its overnight delivery network, $87 million in savings obtained from 2000 ~ 2002; Another $189 million anticipated over the following decade.

- USPS uses OR to schedule the equipment and workforce in its mail processing and distribution centers. Estimated saving in $500 millions can be achieve.

A Short List of Successful Stories (1)

- Air New Zealand
  - Air New Zealand Masters the Art of Crew Scheduling
- AT&T Network
  - Delivering Rapid Restoration Capacity for the AT&T Network
- Bank Hapoalim
  - Bank Hapoalim Offers Investment Decision Support for Individual Customers
- British Telecommunications
  - Dynamic Workforce Scheduling for British Telecommunications
- Canadian Pacific Railway
  - Perfecting the Scheduled Railroad at Canadian Pacific Railway
- Continental Airlines
  - Faster Crew Recovery at Continental Airlines
- FAA
  - Collaborative Decision Making Improves the FAA Ground-Delay Program

A Short List of Successful Stories (2)

- Ford Motor Company
  - Optimizing Prototype Vehicle Testing at Ford Motor Company
- General Motors
  - Creating a New Business Model for OnStar at General Motors
- IBM Microelectronics
  - Matching Assets to Supply Chain Demand at IBM Microelectronics
- IBM Personal Systems Group
  - Extending Enterprise Supply Chain Management at IBM Personal Systems Group
- Jan de Wit Company
  - Optimizing Production Planning and Trade at Jan de Wit Company
- Jeppesen Sanderson
  - Improving Performance and Flexibility at Jeppesen Sanderson

A Short List of Successful Stories (3)

- Mars
  - Online Procurement Auctions Benefit Mars and Its Suppliers
- Menlo Worldwide Forwarding
  - Turning Network Routing into Advantage for Menlo Forwarding
- Merrill Lynch
  - Seizing Marketplace Initiative with Merrill Lynch Integrated Choice
- NBC
  - Increasing Advertising Revenues and Productivity at NBC
- PSA Peugeot Citroen
  - Speeding Car Body Production at PSA Peugeot Citroen
- Rhenania
  - Rhenania Optimizes Its Mail-Order Business with Dynamic Multilevel Modeling
- Samsung
  - Samsung Cuts Manufacturing Cycle Time and Inventory to Compete

A Short List of Successful Stories (4)

- Spicer
  - Spicer Improves Its Lead-Time and Scheduling Performance
- Syngenta
  - Managing the Seed-Corn Supply Chain at Syngenta
- Towers Perrin
  - Towers Perrin Improves Investment Decision Making
- U.S. Army
  - Reinventing U.S. Army Recruiting
- U.S. Department of Energy
  - Handling Nuclear Weapons for the U.S. Department of Energy
- UPS
  - More Efficient Planning and Delivery at UPS
- Visteon
  - Decision Support Wins Visteon More Production for Less

What you Should Know about Operations Research

- How decision-making problems are characterized
- OR terminology
- What a model is and how to assess its value
- How to go from a conceptual problem to a quantitative solution