Introduction and Basic Concepts

(i) Historical Development and Model Building

Objectives

- Understand the need and origin of the optimization methods.
- Get a broad picture of the various applications of optimization methods used in engineering.

Introduction

- Optimization : The act of obtaining the best result under the given circumstances.
- Design, construction and maintenance of engineering systems involve decision making both at the managerial and the technological level
- Goals of such decisions :
  - to minimize the effort required or
  - to maximize the desired benefit

Introduction (contd.)

- Optimization : Defined as the process of finding the conditions that give the minimum or maximum value of a function, where the function represents the effort required or the desired benefit.

Historical Development

- Existence of optimization methods can be traced to the days of Newton, Lagrange, and Cauchy.
- Development of differential calculus methods of optimization was possible because of the contributions of Newton and Leibnitz to calculus.
- Foundations of calculus of variations, dealing with the minimizations of functions, were laid by Bernoulli, Euler, Lagrange, and Weistrass

Historical Development (contd.)

- The method of optimization for constrained problems, which involve the inclusion of unknown multipliers, became known by the name of its inventor, Lagrange.

- Cauchy made the first application of the steepest descent method to solve unconstrained optimization problems.

Recent History

- High-speed digital computers made implementation of the complex optimization procedures possible and stimulated further research on newer methods.

- Massive literature on optimization techniques and emergence of several well defined new areas in optimization theory followed.

Milestones

- Development of the simplex method by Dantzig in 1947 for linear programming problems.
- The enunciation of the principle of optimality in 1957 by Bellman for dynamic programming problems.
- Work by Kuhn and Tucker in 1951 on the necessary and sufficient conditions for the optimal solution of problems laid the foundation for later research in non-linear programming.

Milestones (contd.)

- The contributions of Zoutendijk and Rosen to nonlinear programming during the early 1960s
- Work of Carroll and Fiacco and McCormick facilitated many difficult problems to be solved by using the well-known techniques of unconstrained optimization.
- Geometric programming was developed in the 1960s by Duffin, Zener, and Peterson.
- Gomory did pioneering work in integer programming. The most real world applications fall under this category of problems.
- Dantzig and Charnes and Cooper developed stochastic programming techniques.

Milestones (contd.)

- The desire to optimize more than one objective or a goal while satisfying the physical limitations led to the development of multi-objective programming methods; Ex. **Goal programming.**
- The foundations of game theory were laid by von Neumann in 1928; applied to solve several mathematical, economic and military problems, and more recently to engineering design problems.
- Simulated annealing, evolutionary algorithms including genetic algorithms, and neural network methods represent a new class of mathematical programming techniques that have come into prominence during the last decade.

Engineering applications of optimization.

- Design of structural units in construction, machinery, and in space vehicles.
- Maximizing benefit/minimizing product costs in various manufacturing and construction processes.
- Optimal path finding in road networks/freight handling processes.
- Optimal production planning, controlling and scheduling.
- Optimal Allocation of resources or services among several activities to maximize the benefit.

Art of Modeling : Model Building

- Development of an optimization model can be divided into five major phases.
  - Collection of data
  - Problem definition and formulation
  - Model development
  - Model validation and evaluation or performance
  - Model application and interpretation of results

Data collection

- **Data collection**
  - may be time consuming but is the fundamental basis of the model-building process
  - extremely important phase of the model-building process
  - the availability and accuracy of data can have considerable effect on the accuracy of the model and on the ability to evaluate the model.

Problem Definition

- Problem definition and formulation, steps involved:
  - identification of the decision variables;
  - formulation of the model objective(s);
  - the formulation of the model constraints.
- In performing these steps one must consider the following.
  - Identify the important elements that the problem consists of.
  - Determine the number of independent variables, the number of equations required to describe the system, and the number of unknown parameters.
  - Evaluate the structure and complexity of the model
  - Select the degree of accuracy required of the model

Model development

- **Model development** includes:
  - the mathematical description,
  - parameter estimation,
  - input development, and
  - software development
- The model development phase is an iterative process that may require returning to the model definition and formulation phase.

Model Validation and Evaluation

- This phase is checking the model as a whole.
- **Model validation** consists of validation of the assumptions and parameters of the model.
- The performance of the model is to be evaluated using standard performance measures such as Root mean squared error and R^2 value.
- Sensitivity analysis to test the model inputs and parameters.
- This phase also is an iterative process and may require returning to the model definition and formulation phase.
- One important aspect of this process is that in most cases data used in the formulation process should be different from that used in validation.

Modeling Techniques

- Different modeling techniques are developed to meet the requirement of different type of optimization problems. Major categories of modeling approaches are:
  - classical optimization techniques,
  - linear programming,
  - nonlinear programming,
  - geometric programming,
  - dynamic programming,
  - integer programming,
  - stochastic programming,
  - evolutionary algorithms, etc.
- These approaches will be discussed in the subsequent modules.

Thank You