Optimization in Civil Engineering

Dr. Tanjina Nur, Ph.D.

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Tanjina finished her PhD in Civil and Environmental Engineering in 2014 from University of Technology Sydney (UTS). Now she is working as Post-Doctoral Researcher in the Centre for Technology in Water and Wastewater (CTWW) and published about eight International journal papers with 80 citations. Her research interest is wastewater treatment technology using adsorption process.

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Preface

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INTRODUCTION

Optimization is the process of obtaining the best result under given circumstances. In design, construction and maintenance of any engineering system, engineers have to take many technological and managerial decisions at several stages. The ultimate goal of all such decisions is either to minimize the effort required or to maximize the desired benefit. A number of optimization methods have been developed for solving different types of optimization problems. In this course, after discussing about the optimization problem formulation, Linear Programming, Non Linear Programming, Dynamic Programming techniques are explained in detail along with number of applications in civil engineering. Advanced optimization techniques such as Evolutionary search algorithms, Multi objective optimization are briefly introduced.

A mechanical engineer designs a new engine, or a car suspension or a robot. A civil engineer designs a bridge or a building. A chemical engineer designs a distillation tower or a chemical process. An electrical engineer designs a computer or an integrated circuit. For many reasons, not the least of which is the competitive marketplace, an engineer might not only be interested in a design which works at some sort of nominal level, but is the best design in some way. The process of determining the best design is called optimization. Thus we may wish to design the smallest heat exchanger that accomplishes the desired heat transfer, or we may wish to design the lowest-cost bridge for the site, or we may wish to maximize the load a robot can lift. Often engineering optimization is done implicitly. Using a combination of judgment, experience, modeling, opinions of others, etc. the engineer makes design decisions which, he or she hopes, lead to an optimal design. Some engineers are very good at this. However, if there are many variables to be adjusted with several conflicting objectives and/or constraints, this type of experience-based optimization can fall short of identifying the optimum design. The interactions are too complex and the variables too numerous to intuitively determine the optimum design. In this text we discuss a computer-based approach to design optimization. With this approach, we use the computer to search for the best design according to criteria that we specify. The computer's enormous processing power allows us to evaluate many more design combinations than we could do manually. Further, we employ sophisticated algorithms that enable the computer to efficiently search for the optimum. Often we start the algorithms from the best design we have based on experience and intuition. We can then see if any improvement can be made. In order to employ this type of optimization, several qualifications must be met. First, we must have a quantitative model available to compute the responses of interest. If we wish to maximize heat transfer, we must be able to calculate heat transfer for different design configurations. If we wish to minimize cost, we must be able to calculate cost. Sometimes obtaining such quantitative models is not easy. Obtaining a valid, accurate model of the design problem is the most important step in optimization. It is not uncommon for 90% of the effort in optimizing a design to be spent on developing and validating the quantitative model. Once a good model is obtained, optimization results can often be realized quickly. Fortunately, in engineering we often do have good, predictive models (or at least partial models) for a design problem. For example, we have models to predict the heat transfer or pressure drop in an exchanger. We have models to predict stresses and deflections in a bridge. Although engineering models are usually physical in nature (based on physical principles), we can also use empirical models (based on the results of experiments). It is also perfectly acceptable for models to be solved numerically (using, for example, the finite element method).

Historical Development and Model Building

The existence of optimization methods can be traced to the days of Newton, Lagrange, and Cauchy. The development of differential calculus methods for optimization was possible because of the contributions of Newton and Leibnitz to calculus. The foundations of calculus of variations, which deals with the minimization of functions, were laid by Bernoulli, Euler, Lagrange, and Weistrass. The method of optimization for constrained problems, which involve the addition 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. By the middle of the twentieth century, the high-speed digital computers made implementation of the complex optimization procedures possible and stimulated further research on newer methods. Spectacular advances followed, producing a massive literature on optimization techniques. This advancement also resulted in the emergence of several well defined new areas in optimization theory.

Engineering applications of optimization

To indicate the widespread scope of the subject, some typical applications in different engineering disciplines are given below.

- Design of civil engineering structures such as frames, foundations, bridges, towers, chimneys and dams for minimum cost.
- Design of minimum weight structures for earth quake, wind and other types of random loading.
- Optimal plastic design of frame structures (e.g., to determine the ultimate moment capacity for minimum weight of the frame).
- Design of water resources systems for obtaining maximum benefit.
- Design of optimum pipeline networks for process industry.
- Design of aircraft and aerospace structure for minimum weight
- Finding the optimal trajectories of space vehicles.
- Optimum design of linkages, cams, gears, machine tools, and other mechanical components.
- Selection of machining conditions in metal-cutting processes for minimizing the product cost.
- Design of material handling equipment such as conveyors, trucks and cranes for minimizing cost.
- Design of pumps, turbines and heat transfer equipment for maximum efficiency.
- Optimum design of electrical machinery such as motors, generators and transformers.
- Optimum design of electrical networks.
- Optimum design of control systems.
- Optimum design of chemical processing equipment's and plants.
- Selection of a site for an industry.
- Planning of maintenance and replacement of equipment to reduce operating costs.
- Inventory control.
- Allocation of resources or services among several activities to maximize the benefit.
- Controlling the waiting and idle times in production lines to reduce the cost of production.
- Planning the best strategy to obtain maximum profit in the presence of a competitor.

Optimization Methods: Introduction and Basic Concepts

- Designing the shortest route to be taken by a salesperson to visit various cities in a single tour.
- Optimal production planning, controlling and scheduling.
- Analysis of statistical data and building empirical models to obtain the most accurate representation of the statistical phenomenon.

Art of Modeling: Model Building

Development of an optimization model can be divided into five major phases.

- Data collection
- Problem definition and formulation
- Model development

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