Preface

MOTIVATION

Graph Theory as a well-known topic in discrete mathematics, has become increasingly under interest within recent decades. This is principally due to its applicability in a wide range of research fields ranging from chemical and electrical engineering to social sciences and management sciences, and of course industrial engineering. Regarding the variety of disciplines encompassed by industrial engineering, including operations management, decision making, operations research, management decision making science, et cetera, it is not hard to imagine the spectrum of graph theory applications in this field.

Despite this, industrial engineering applications can be only found as chapters among other fields of application in graph theory books and there is no book with special orientation to industrial engineering topics in graph theory. Motivated by this fact, the present book attempts to cover essential graph theory concepts and their various industrial engineering oriented applications. As the book title suggests, in this book, contributors primarily address readers with industrial engineering background such as undergraduate and graduate students, and researchers. However, the text can be used by any other groups of readers in the related research fields, who may find the topics and their applications interesting for their own purpose.

ORGANIZATION OF THE BOOK

The book comprises 24 chapters organized in two sections. The first section discusses the basic concepts of graph theory ranging from essential definitions to the advanced topics such as networks and artificial neural networks. The second section covers various industrial engineering related applications of the concepts discussed in the first part. Each section covers 13 and 11 chapters, respectively. Due to the diversity of topics that come under the name of industrial engineering, a variety of application can be found which some of them may overlap with other fields of study. Following, each chapter is described individually.

Section 1: Basic Concepts of Graph Theory

• Chapter 1 introduces preliminary concepts and definitions of graph theory. It starts with the history of graph theory and introduces some of the most known problems, terminology and the notations.
Chapter 2 is about matrices as tools for representing graphs and their applications in graph theory. Notions such as adjacency, incidence, cycle, and cut-set and some other advanced topics on matrices are discussed in this chapter. Also applications of the discussed matrices are addressed in this chapter.

Chapter 3 deals with isomorphism in graph theory. It discusses variations of isomorphism such as automorphism and homomorphism. It gives explanations of how to reject or accept isomorphism of graphs.

Chapter 4 discusses the connectivity in graph theory. It introduces the basic connectivity related definitions, such as components and connected graphs. Then it covers two distinct variations of connectivity, namely vertex and edge connectivity. It also discusses connectivity in directed graphs. Finally, it explains the methods to identify the connectivity in various types of graphs.

Chapter 5 focuses on trees as special and important type of graphs. Starting with the introduction and the primitive definitions, it describes the concepts of rooted and spanning trees. It discusses issues such as Caylay’s formula, Steiner tree problem, and fundamental cycles and bounds in trees. It reviews and explains tree search algorithms including methods of tree search, spanning tree construction algorithms and minimum weighted spanning tree algorithms. It also discusses algorithms for branching search, such as shortest path algorithms. Finally, it defines binary trees and explains about finding optimal binary trees.

Chapter 6 is about a topological notion in graph theory, called planarity. After defining planarity and plane graphs and the related theorems, it addresses the algorithms to recognize planarity of a graph. Then it covers duality, as the twin notion of planarity. Finally, it discusses notions of thickness and crossing numbers for drawing of graphs.

Chapter 7 is devoted to famous graph concept of Eulerian trails and tours. After introducing the basic definitions and the theorems of such trails and tours, it reviews famous puzzles and applications related to this notion. It discusses the algorithms and methods to find Eulerian tours and trails. Next, it addresses the issue of counting the number of such tours and trails in a graph. It also covers concepts such a Kotzig transformations and Eulerian orientation.

Chapter 8 deals with Hamiltonian paths and cycles. It begins with giving historical background and necessary definitions of the notion, and it reviews Hamiltonian graph problems. It discusses the conditions for existence of Hamiltonian cycles, and addresses the relationship between Hamiltonian and Eulerian graphs. At the end, it focuses on algorithms of finding Hamiltonian cycles in a graph.

Chapter 9 addresses the issue of graph coloring which is a particular type of labeling of graphs. After giving information on historical background of graphs, it focuses on edge and vertex coloring as the two concepts of this notion. For each type of coloring, it covers the related definitions, theorems, and the existing algorithms for the particular types of coloring. Also, it discusses some helpful concepts such as chromatic number, critical graphs, list coloring, and edge and vertex decomposition.

Chapter 10 focuses on matching theory. It discusses the two closely related concepts of covering and matching, including vertex and edge covering, and vertex and edge independent sets. It addresses the problem of finding maximal matching, their basic concepts, and matching algorithms. It briefly reviews some applications of matching algorithms in industrial engineering problems.
• Chapter 11 is about digraphs i.e. directed graphs. It gives basic definitions of digraphs and presents classifications of digraphs, such as strong, tournament, acyclic, Eulerian, transitive, and quasi-transitive digraphs. Then it discusses the issue of connectivity and reachability in digraphs. Finally, it addresses some applications including directed Chinese postman problem and Markov digraph.

• Chapter 12 is devoted to networks. After introducing definitions and concepts of networks, it discusses fundamental definitions and elements of the theory of network flows. It reviews some of the most important and famous network flow problems, including the shortest path problem, the maximum flow problem, the minimum-cost flow problem, the multi-commodity flow problem, the matching problem, and the transportation problem. Finally, it focuses on the most important algorithms and solutions techniques for network flow problems.

• Chapter 13 deals with the special topic of artificial neural networks, which has linkages with signal flow graphs, which in turn has connections to graph theory. It describes the linkages to indicate the relations of graph theory and neuronal computation and learning. It introduces signal flow graphs as specific types of directed graphs. Finally, it addresses the training regime, validation regime, testing regime, and measurement of different artificial neural network families.

Section 2: Applications

• Chapter 14 presents the applicability of graph theory in inbound logistics and vehicle routing. It addresses the flow path design of automated guided vehicle systems as a specific problem in the field of inbound logistics. It covers a specific type of path design for such systems, namely unidirectional/ conventional flow path design. It explains the problem in details and presents its mathematical formulation. It presents a novel graph based algorithm to determine the flow paths. The algorithm tries to orient the given block layout graph, such as the total travel of loaded vehicles is minimized. It contains a special branch and bound based on logic of depth fast search method which is based on testing connectivity of the resulting oriented graph.

• Chapter 15 addresses facility layout planning as one of the applications of graph planarity concept. It is based on the application of weighted maximal planar graphs in layout planning, which is very well matched with it. It describes four mathematical models related to facility layout planning based on graph theory concepts, and reviews the solution methods to each presented model. Next, it discusses the greedy search algorithm to obtain weighted maximal planar graph. Finally, it focuses on how to draw a block plant layout, having the adjacency graph of the facilities.

• Chapter 16 discusses the Chinese postman problem, a problem related to finding Eulerian tour. It classifies and discusses different variations of the problem, including undirected, directed, mixed, rural, capacitated, time constrained, hierarchical, and open Chinese postman problem. Then it addresses the undirected version of the problem.

• Chapter 17 is devoted to graph-based offline handwritten image recognition. It presents an application of Eulerian graphs and Eulerian tours/trails. More specifically, it addresses the problem of extracting the trajectory of writing so as to equip the offline handwritten image with temporal information. After identification of the trajectory of writing, application of online recognition methods will be possible. The methods to extract the trajectory are principally based on finding Eulerian trails in semi-Eulerian graphs. It discusses two algorithms to recognize the handwriting trajectory.
Chapter 18 addresses the problem of optimal arrangement of curriculum, specifically for the higher education, which is an application of matching problem in graph theory. It reviews the problem of curriculum design and its various phases, including planning, design, implementation and evaluation. Then, it describes the linkages between the subject and the matching concept, and its related applicable theories.

Chapter 19 is devoted to applications of network flow problems. The discussed applications are classified into three main network flow problems, including the shortest path problem, the maximum flow problem, and the minimum-cost flow problem. For the shortest path problem, it reviews facility location and facility layout, robotic systems, transportation of hazardous materials, and very-large-scale integration problem in circuits. For the maximum flow problem, the covered applications are extraction of web communities, image segmentation, telecommunication, wireless networks, and transportation. For the minimum-cost flow problem, applications in petroleum industry, routing and fleeting problems, and scheduling problems are reviewed.

Chapter 20 presents the problem of phasing of traffic lights in urban intersections. It establishes linkages between the problem and the coloring concept in graph theory. It introduces and defines the related concepts such as traffic streams, vehicle flows, pedestrian flows, compatible streams, and conflicting streams. It discusses two graph theory approaches to model the phasing of traffic streams, including conflict graphs and concepts such as circular chromatic number and star chromatic number of graphs. It presents two procedures for phasing of traffic streams in urban intersections, and compares their performances.

Chapter 21 is about timetabling problem for passenger trains. It introduces periodic and non-periodic train timetabling approaches. Then, it defines the principle elements of infrastructure topology of railway network. It focuses on main characteristics of non-periodic timetabling and the related assumptions. It introduces a graph theory based approach to solve the problem, using the time-space graph notion. It describes the mathematical formulation of the problem, according to the time-space graph.

Chapter 22 addresses the industrial manufacturing and urban applications of Eulerian and Chinese concepts in graph theory. It reviews various applications of this graph theory concept. The industrial manufacturing applications include surface painting, laser/ water cutting, and cutting high precision tools. The urban applications include meter reading, snow removal, waste collection, and milk delivery.

Chapter 23 deals with the practical approach to implementing intelligent solutions with artificial neural networks. In particular, supervised learning based neural methods are implemented within the context of directed graphs. It explains the neural network formation, training, validation and testing regimes of the radial basis function, multi-layer perceptron and recurrent neural networks in practical terms. It discusses the pre-processing steps of selected datasets. Also it gives a description of the datasets, how they are pre-processed and partitioned into training, validation, and test set. It discusses a step-wise approach to constructing neural based intelligent agents. Lastly, it outlines the real life applications of engaged techniques and future directions of neural solutions.
Chapter 24 focuses on reinforcement learning in the context of graphs. It establishes a linkage between reinforcement learning theory and graph theory. Within the context of semi-supervised pattern recognition, it introduces and discusses the reinforcement learning theory in basic steps. It outlines and investigates two real world problems for understanding of the problem. It addresses the motivation leading to learning agent development with reinforcement capabilities for massive data pattern learning.

Elnaz Miandoabchi  
Institute for Trade Research and Studies (ITSR), Iran Ministry of Industry, Mining, and Trade, Iran

Reza Zanjirani Farhani  
Kingston University, UK