Handbook of Research on

Data Science for Effective Healthcare Practice and Administration

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The **Advances in Healthcare Information Systems and Administration (AHISA) Book Series** aims to provide a channel for international researchers to progress the field of study on technology and its implications on healthcare and health information systems. With the growing focus on healthcare and the importance of enhancing this industry to tend to the expanding population, the book series seeks to accelerate the awareness of technological advancements of health information systems and expand awareness and implementation.

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Preface

The quantity of available healthcare data is increasing at a phenomenal rate, in structured and semi-structured formats. With this growth, there is an obvious need to develop efficient tools, skills and techniques for analyzing this data for useful and actionable knowledge. Since healthcare data is characterized by its complexity, high volume and high dimensionality, extensive use of data science is needed for managing and analyzing this data.

"Data science" is an interdisciplinary field of science and technology, used to extract novel and useful information from large volumes of data. Techniques and theories are drawn from many fields within mathematics, statistics, information science, and computer science, including signal processing, probability models, machine learning, statistical learning, data mining, database systems, data engineering, pattern recognition and learning, visualization, predictive analytics, uncertainty modeling, data warehousing, data compression, computer programming, artificial intelligence, and high performance computing. Data science applications span a wide range in engineering (examples include intrusion detection and network security, flow classification, web mining), business (fraud detection, decision support systems, risk analysis, market trend forecasting), medicine (population health, study of drug implications, epidemiology), bioinformatics (protein interactions, gene sequence analysis), and environmental science (flood prediction).

Methods for understanding, analyzing, and managing healthcare systems include data preparation, statistics, predictive modeling and machine learning. The healthcare industry can reap significant benefits from such efforts. Examples: healthcare insurers detecting fraud; healthcare organizations making decisions for better patient relationship management; physicians evaluating the effectiveness of treatment for specific diseases; early prediction of medical conditions; detecting multi-morbidity and complications of diseases, and identifying and controlling chronic diseases. Data science can also be helpful in managing problems associated with delivering hospital services, such as patient recovery, resource planning, facility utilization, logistics, vaccination, and emergency response, including dealing with bioterrorism. The cumulative result is people receiving better and more affordable healthcare services.

Despite the important current and potential value of data science in healthcare and medical decision-making, thus far there is a lack of an organized textbook in this area. Accordingly, this handbook provides healthcare professionals and practitioners a systematic framework with practical examples and solutions on how to use data science methods and tools. Readers can use this knowledge and experience to gain useful insights and novel actionable information from their own vast amounts of data.

In this handbook, the contributing authors survey various techniques and tools of data science, and explain application in the domains of healthcare and medical decision-making. The methods are illus-

trated with case studies, and the implementation of common relevant tools and software programing frameworks are discussed in some chapters.

The Handbook will help healthcare professionals and practitioners to understand the benefits of data science in healthcare, and understand where a particular method or tool would be useful.

The main value and contribution of this handbook lies first in its comprehensive presentation of a framework of the field. Second, it is suitable for training and supporting healthcare professionals to become intelligent users and consumers of various data science methods, and thus bridge the gap between technical specialists and healthcare managers. Our hope is that the Handbook can be a source of encouragement and guidance for healthcare students, professionals and practitioners, providing them with a better understanding of the applications of data science in healthcare.

TARGET AUDIENCE

This handbook is designed for those who are interested in applying data science to improve healthcare and medical decision-making. In particular, the Handbook focuses on developing skills and techniques for improvement in the domain of healthcare. The Handbook is suitable as a reference for a course on data science in healthcare and medical decision-making at the graduate level (master's or doctoral), particularly for medical or health systems students. In addition, the Handbook is a valuable source for self-study in data science, and as a learning tool for healthcare and medical practitioners, academics and managers in public health, research, governmental agencies, and the pharmaceutical industry. Students of data science, computer science, information technology, mathematics and statistics who would like to conduct research in healthcare are also a target audience of this handbook.

STRUCTURE OF THE HANDBOOK

In this handbook, various topics of data science are categorized into five main sections: "Mathematical Techniques and Operation Research", "Statistical Analysis Techniques", "Machine Learning and Data Mining", "Big Data" and "Other Topics in Data Science". Each section includes overview chapters that present a comprehensive literature review on the application of related techniques in healthcare and medicine. There are also supplementary chapters in each section with original research or case studies discussing the application of a specific technique or group of methods in a specific area of healthcare. The associated tools and software are briefly explained in each chapter, toward helping medical students and practitioners understand the potential benefits, and know when a particular approach would be useful for their specific cases. An overview of the five sections is presented below:

Section 1: Mathematical Techniques and Operation Research

Among the different quantitative methods which have been used in healthcare, mathematical methods and operation research have received considerable attention during the last few decades. Various optimization problems in the field have been addressed. Resource planning, facility utilization, vaccination, bioterrorism, emergency department management, production and distribution management are some examples. The section covers these techniques with seven chapters describing the application of different

methods of optimization, multi-criteria decision-making, simulation and the use of nonlinear dynamic models in healthcare (e.g. maintenance in healthcare systems, production and distribution management of pharmaceutical products, and management of an emergency department) including:

Benchmarking of Maintenance Service in Health Care Organizations

It is of a great interest to healthcare organizations to apply benchmarking to their maintenance processes in order to determine the quality of the provided services, and improve it further. In this chapter, Carnero uses a collection of fuzzy Analytic Hierarchy Process (AHP), utility theory and Monte Carlo simulation together with a benchmarking approach to evaluate the maintenance service of a healthcare organization.

Optimization of Maintenance in Critical Equipment in Neonatology

Maintenance decisions by medical staff play an essential role in achieving availability, quality and safety and affect the quality of services. Nonetheless, despite its importance, there is a serious deficiency in models facilitating optimization of maintenance decisions. In this regard, the chapter proposes a decision support system (DSS) for choosing the best combination of maintenance policies and improvement actions in the neonatology services of a hospital. The DSS combines Markov Chains and Categorical Based Evaluation Technique (MACBETH) methods. The result is a ranking of various maintenance alternatives and real implications of applying the best solution.

Applications of Operations Research in Production and Distribution Management of Pharmaceutical Products

Pharmaceutical industry is considered as a global industry because of its effects on the human life. Many researchers have used optimization tools to manage the pharmaceutical supply chain (PSC) efficiently. The issue of PSC, which includes strategic, tactical and operational decisions, is an active research area. In this chapter, Sarmad and Pishvaee introduce and discuss the recent developments of procurement, production and distribution management of pharmaceutical products. The main focus is on quantitative Operation Research (OR)-based models which enable the decision makers to appropriately coordinate and manage the whole pharmaceutical industry.

A Simulation Model for Resource Balancing in Healthcare Systems

In this chapter, Şenaras and Sezen aim to analyze resource effectiveness and identify efficient hospitalization admission policies for an emergency department in Turkey. They test different scenarios by using the discrete event simulation modeling to design the effective policy. The developed model could be used as a base for new implementations in other hospitals and clinics.

The Applications of Simulation Modeling in Emergency Departments: A Review

Emergency Departments (EDs) are the busiest units of healthcare system. This review chapter presents a comprehensive overview of the applications of simulation modeling in the management of EDs. The

authors study the potential problems of emergency departments and discuss how simulation modeling can interfere in order to solve these problems, improve patient satisfaction and reduce cost.

Analyzing Interval Systems of Human T-Cell Lymphotropic Virus Type I Infection of CD4+ T-Cells

Human T-cell lymphotropic virus type I (HTLV-I) infects a type of white blood cell called T lymphocyte. In this chapter, T-cell dynamics in HTLV-I infection are studied which were proposed by Stilianakis and Seydel (1999). This model is defined by a system of ordinary differential equations. Then, dynamical behaviors of this system with interval uncertainties are studied. To achieve this objective, interval analysis and Kharitonov's stability theorem are used.

Global Dynamics of an Immunosuppressive Infection Model Based on a Geometric Approach

In this chapter, an immunosuppressive infection model is considered which was studied by Dadi and Alizade (2016) from the view point of bifurcation theory. The authors investigate the global dynamics of antiviral immune response in this model. To this end, Poincare-Bendixon property, the properties of monotone dynamical systems and a geometric approach are used.

Section 2: Statistical Analysis Techniques

Statistical analysis has been extensively applied in many areas of health studies. Three chapters are included in this section discussing the statistical analysis techniques. The first two chapters of this section present the application of time-series analysis and other analytic methods, as well as non-parametric statistical analysis in the cases of provincial capacity-planning for dialysis and histologic outcomes of kidney transplantation, respectively. The section concludes with an overview chapter on the applications of regression-based methods in monitoring surgical performance.

Strategic Analytics to Drive Provincial Dialysis Capacity Planning: The Case of Ontario Renal Network

This chapter discusses applications of analytics at the strategic level of health system planning in the province of Ontario, Canada. To supplement the strategic priorities of the Ontario Renal Plan I, a roadmap and an interactive user-friendly analytical capacity planning model were developed to forecast the growth of the prevalent chronic dialysis patient population and estimate consequent future need for hemodialysis stations at Ontario's dialysis facilities. The model uses a variety of analytical methods including time series analysis, mathematical optimization, geo-spatial analysis and Monte Carlo simulation.

Non-Parametric Statistical Analysis of Rare Events in Healthcare: Case of Histological Outcome of Kidney Transplantation

This chapter recommends using non-parametric tests in the statistical analysis of health studies as the assumption of the Gaussian distribution of population may not hold strongly in such cases. The authors

present a non-parametric single-center retrospective analysis of kidney transplants to compare histological outcomes among different deceased donors, based on consecutive biopsies. A total of 310 surveillance biopsies were taken, and classified based on the Banff 97 adequacy assessment. It is concluded that the recipient's physiological condition after kidney transplant is as important as the donor's risk factors.

Regression-Based Methods of Phase-I Monitoring Surgical Performance Using Risk-Adjusted Charts: An Overview

This chapter focuses on monitoring phase-I risk-adjustment models in surgical context which have been presented in medical setting and discuss the unique properties of each method. Results show that the overall probability of Type-I error has affected from the number of hypothesis tests for each patient. Furthermore, ignoring the important categorical operational covariates may lead to poorer performance in detecting possible changes in the reviewed models.

Section 3: Machine Learning and Data Mining

Artificial intelligence techniques have been implemented in recent years. Among these tools, machine learning and data mining are becoming increasingly popular, if not increasingly essential. These techniques are becoming of interest and importance for healthcare practice and research. Various descriptive and predictive methods are effetely employed in the areas of clinical decision making, public health, and administration and policies. This section includes two survey and two supplementary chapters:

Machine Learning Applications in Cancer Therapy Assessment and Implications on Clinical Practice

In personalized cancer therapy, tailored optimal therapies are selected depending on patient response to treatment. In this regard, significant advances in cancer response monitoring early after the start of therapy administration have been emerged. This chapter elaborates recent advances in the design and development of computer-aided-theragnosis (CAT) systems based on quantitative ultrasound (QUS) technologies in conjunction with advanced texture analysis and machine learning techniques. The purpose is providing a framework for the early assessment of cancer responses that can potentially facilitate switching to more efficacious treatments in refractory patients.

Application of Data Mining Techniques in Clinical Decision Making: A Literature Review and Classification

With regards to the benefits of data mining techniques in clinical decision making, Ameri, Alizadeh and Akhond Zadeh Noughabi present a systematic literature review in the field. The applications of data mining techniques in clinical decision making are classified into two main categories including diagnosis and treatment and discussed in the detected sub-categories. The results of review indicate that the majority of the articles are related to diagnosis; the classification model is also the most commonly practical model in clinical decision making.

New Features Extracted From Renal Stone NCCT Images to Predict Retreatment After Shock Wave Lithotripsy (SWL)

In this chapter, novel features are proposed which are automatically extracted from Non-Contrast Computed Tomography (NCCT) images to describe morphology and location of renal stones and kidneys to predict retreatments after Shock wave lithotripsy (SWL). Novel image segmentation and feature selection methods are implemented to obtain this objective.

Applications of Image Processing in Laparoscopic Surgeries: An Overview

Khatibi, Sepehri, Shadpour and Zegordi discuss the applications of image processing in laparoscopic surgeries through a review study. The various applications include preprocessing video frames by laparoscopic image enhancement, telescope related applications (telescope position estimation, telescope motion estimation and compensation), surgical instrument related applications (surgical instrument detection and tracking), soft tissue related applications (soft tissue segmentation and deformation tracking) and high level applications such as safe actions in laparoscopic videos, summarization of laparoscopic videos, surgical task recognition and extracting knowledge using fusion techniques. The corresponding techniques are also discussed in various applications.

Section 4: Big Data

Using big data analytics in healthcare is a nascent field. The emergence of massive datasets in the healthcare sector and advances in information technology offer great opportunities for the use of big data analytics in healthcare. This section presents two overview chapters on the advantages and applications of big data analytics in healthcare:

Leveraging Applications of Data Mining in Healthcare Using Big Data Analytics: An Overview

There are many prospective applications of data mining in healthcare. In this chapter, the authors investigate whether health data exhibits characteristics of big data, and accordingly whether big data analytics can leverage data mining applications in healthcare. To answer this interesting question, potential applications of data mining in healthcare and the available types of health data are specified, with a discussion of the applicable dimensions of big data for each category of applications. The results indicate that big data analytics can provide more advantages for the quality of analysis in particular categories of data mining applications in healthcare, while having less efficacy for other categories.

Overview of Big Data in Healthcare

Zarandi and Gamasaee review big data applications in healthcare in this chapter. The focus is on two major applications including "understanding disease outcomes" and "genetics, biological, and molecular fields". Moreover, characteristics and challenges of big data analysis in healthcare, as well as its technologies and soft wares are discussed.

Section 5: Other Topics in Data Science

Finally, this section discusses additional related topics of data science in healthcare in three chapters:

Notifiable Disease Databases for Client Management and Surveillance

The requirement to report cases of infectious diseases has been embedded in public health laws since the 1800s. Documenting client management and monitoring numbers of cases are the primary goals in collecting these data. In this chapter, a sample notifiable disease database is presented, including database structure, elements and rationales for collection, sources of data, and tabulated output. This study is a comprehensive guide to public health professionals on the content, structure, and processing of notifiable disease data for regional, provincial, and federal use.

Brain-Machine Interface: Human-Computer Interaction

Many patients who become afflicted with neurological conditions or neurodegenerative diseases may lose all their abilities to control their muscles. One option to address this problem is to provide the brain with a new and non-muscular output channel, a brain–computer interface (BCI) for conveying the user's intent to the external world. This chapter discusses the advantages of using data analytics methods in this area. The results indicate that the neural activity of the human brain recorded non-invasively is sufficient to control the external machine, if advanced methods of signal processing and feature extraction are used in combination with the machine learning techniques.

A Case-Based-Reasoning System for Feature Selection and Diagnosing Asthma

The differentiation between asthma as a chronic disease, COPD and bronchiectasis in the early stage of disease is very important for the adoption of appropriate therapeutic measures. In this research, a case-based-reasoning (CBR) model is proposed to diagnose the disease and assist a physician to therapy. The most important risk factors for asthma were detected as symptoms hyper responsive, frequency of cough and cough.

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We hope that this handbook stimulates the development of new ideas and efficient solutions in the area of data science for effective healthcare practice and administration.

Section 1

Mathematical Techniques and Operation Research

List of Contributors