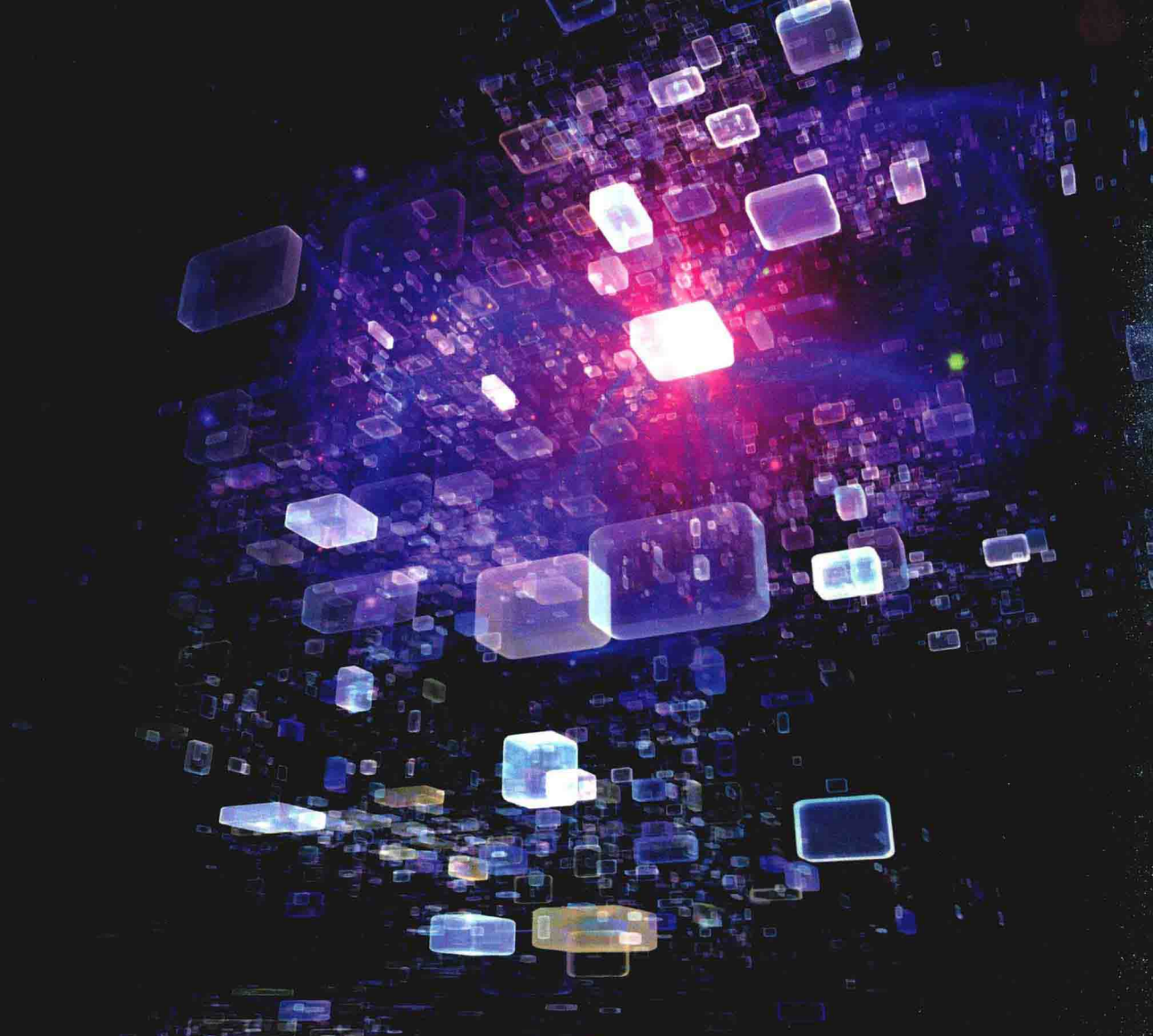


The background of the cover is a dark, deep blue space filled with numerous glowing, translucent cubes and rectangular prisms of various sizes. These shapes are scattered throughout, with a higher concentration towards the top center where they appear to be more densely packed and brighter, some emitting a soft red or orange glow. The overall effect is a sense of depth and digital complexity, reminiscent of a data center or a virtual space.

CLOUD DATA CENTERS AND COST MODELING

A complete guide to planning, designing and building a cloud data center

MK
MORGAN KAUFMANN

Caesar Wu
Rajkumar Buyya

Cloud Data Centers and Cost Modeling

A Complete Guide To Planning,
Designing and Building a
Cloud Data Center

Caesar Wu

Rajkumar Buyya



AMSTERDAM • BOSTON • HEIDELBERG • LONDON
NEW YORK • OXFORD • PARIS • SAN DIEGO
SAN FRANCISCO • SINGAPORE • SYDNEY • TOKYO

Morgan Kaufmann is an imprint of Elsevier



Acquiring Editor: Todd Green
Editorial Project Manager: Lindsay Lawrence
Project Manager: Punithavathy Govindaradjane
Designer: Matthew Limbert

Morgan Kaufmann is an imprint of Elsevier
225 Wyman Street, Waltham, MA 02451, USA

Copyright © 2015 Elsevier Inc. All rights reserved.

No part of this publication may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopying, recording, or any information storage and retrieval system, without permission in writing from the publisher. Details on how to seek permission, further information about the Publisher's permissions policies and our arrangements with organizations such as the Copyright Clearance Center and the Copyright Licensing Agency, can be found at our website: www.elsevier.com/permissions.

This book and the individual contributions contained in it are protected under copyright by the Publisher (other than as may be noted herein).

Notices

Knowledge and best practice in this field are constantly changing. As new research and experience broaden our understanding, changes in research methods, professional practices, or medical treatment may become necessary.

Practitioners and researchers must always rely on their own experience and knowledge in evaluating and using any information, methods, compounds, or experiments described herein. In using such information or methods they should be mindful of their own safety and the safety of others, including parties for whom they have a professional responsibility.

To the fullest extent of the law, neither the Publisher nor the authors, contributors, or editors, assume any liability for any injury and/or damage to persons or property as a matter of products liability, negligence or otherwise, or from any use or operation of any methods, products, instructions, or ideas contained in the material herein.

ISBN: 978-0-12-801413-4

British Library Cataloguing-in-Publication Data

A catalogue record for this book is available from the British Library

Library of Congress Cataloging-in-Publication Data

A catalog record for this book is available from the Library of Congress

For information on all Morgan Kaufmann publications
visit our website at www.mkp.com



Working together
to grow libraries in
developing countries

www.elsevier.com • www.bookaid.org

Preface

How can we measure the sky? This question sometimes refers to how to measure the cost of cloud computing. For many people, it is a very challenging and tough question. And yet, many C-class senior executives (CEO, CFO, and CIO), stakeholders, and cloud investors would not only want to know “how” (cost model assumptions and calculations), but also want to know “why” (logic behind these assumptions).

Why is this so important? The simple answer is it is too big to be ignored. We have heard many stories about how some decision makers just throw big money into cloud projects without proper understanding of cloud technology and expect to catch up to the “wind” (win). This book will lay out the basic concepts and foundation of cloud computing and data center facilities and then provide tools and practical approaches for decision makers to make the right strategic investment decisions. It will help the decision maker to not only rely on “gut feelings” or previous experiences but also count on the scientific method.

One of the goals of this book is to establish a practical framework to enable IT executives to make a rational choice when they are facing a multimillion-dollar investment decision for a cloud project, which is to determine whether IT workloads should stay local or fly to a cloud. (inhouse or cloud computing).

Almost five years ago, this challenging task was assigned to us because a senior IT executive wanted to justify a multimillion investment decision that he had already made but he was not sure whether the decision was a rational choice or not. The original idea of this exercise was to check his intuition, estimate the strategic value, communicate with all the stakeholders, and change the scope of the cloud investment project if necessary.

At that time, many trial projects of cloud computing, server virtualization, and software multitenancy had just taken off. Various companies made different investment decisions in order to test the water or get a foothold on the cloud market.

With these intentions in our mind plus many years’ practical experience in cost modeling of utilities and grid computing, hosting services management, network design, construction, operation, lifecycles, and service delivery, we elicited eight basic questions about this cost modeling exercise:

- What is the ultimate goal of measuring the sky?
- How many cost models are there?
- How can we make a logical and rational comparison with different models?
- Why is the TCO/ROI model so popular? If we use TCO/ROI, would it be the right choice?
- What are the assumptions of these models?
- How can I select the right model to fit a particular business need?
- How can we establish both revenue- and nonrevenue-based cost models?
- What are the risks of keeping the IT workload in house versus migrating to the cloud?

We believe that most people, whether they are cloud service providers or cloud service consumers, will also face similar questions if they are asked to measure “the sky” or to prepare a business case for a cloud investment project. From this perspective, this book is also targeted for IT business analysts and MBA students as reference material.

In essence, the core objective of this book is to demonstrate how to build a cloud cost model. It will illustrate the process of establishing the cost framework and calculating the costs. One of the main reasons to address the cloud cost modeling issue is that many ordinary people have two popular misconceptions:

1. The cloud is free.
2. My data is stored anyway up in the air.

If this is so, why should we bother to measure the sky? The answer is dependent on who you are. If you are just an individual consumer and require very limited cloud resources, it is quite clear that you can obtain nearly free cloud resources. However, if you are a business consumer, especially for medium- and large-scale businesses, there will be no free lunch. You have to pay for what you have consumed. This leads to the issue of how to make the rational investment decision for the usage of IT resources.

For most small or medium size companies, the investment decision would be relatively simple. The decision criteria could be mainly based on financial or economic returns plus a decision maker's intuition or personal satisfaction. However, for a large enterprise, the strategic investment decision (very often involving millions of dollars) is not a simple intellectual exercise but rather than process of negotiation and compromise among different Line of Business (LoB) units.

However, to some degree, all models are subjective because cost modeling involves many subjective assumptions and selection of raw data and material. It would be impossible to avoid subjective assumptions and personal opinions. Strictly speaking, any data selected and assumption made are subjective. It is based on personal experiences and intuition or perhaps, a gut feeling.

Many people think a gut feeling is negative or nonscientific. As a matter of fact, a gut feeling is kind of a super-logic or sixth sense or recognition of a subconscious pattern. It gives us a shortcut to quickly reach a solution. Sometimes, this shortcut serves us quite well, especially if we do not have enough time to analyze the circumstances surrounding us or do not have enough information available. In this case, the sixth sense would be the only choice for us to reach a self-satisfactory conclusion. It is not purely arbitrary or an illogical guess but rather meta-knowledge built upon the subconscious mind. Actually, people's minds are always searching for a recognised pattern based on available information, knowledge, experiences and most importantly, wisdom. Perhaps that is why a gut feeling is very often called an "educated guess," self-learning, working experience, or armchair thinking.

Many strategic investment decisions made by IT legends such as Steve Jobs and Marc R. Benioff [1] led to great success for their companies. Why did they achieve what most people cannot achieve? Is it because they not only have years of working experiences and cumulative knowledge, but also have "gut feelings" or wisdom? People speculate that they may have absorbed wisdom from Eastern philosophy and religion because they both went to India for enlightenment. In Steve Jobs' own words, "Trust in destiny" and "Follow your heart." Walter Isaacson, the exclusive biographer of Steve Jobs, wrote it this way:

Jobs's interest in Eastern spirituality, Hinduism (Krishna/God Consciousness), Zen Buddhism, and the search for enlightenment was not merely the passing phase of a nineteen-year-old. Throughout his life he would seek to follow many of the basic precepts of Eastern religions, such as the emphasis on experiential prajñā, wisdom or cognitive understanding that is intuitively experienced through concentration of the mind. Years later, sitting in his Palo Alto garden, he reflected on the lasting influence of his trip to India [2].

For the East, it is the soul. The soul did not come with body nor die with the body. The body is just a temporary home for the soul. The soul can be enlightened by many sophisticated methodologies and practices that have been developed by Eastern philosophy, religion, and culture for many thousands of years or by messages delivered by the Supreme God personally (e.g., Lord Krishna's teachings compiled as Bhagavad Gita) or his incarnations.

For the West, it is subconsciousness. In Sigmund Freud's teachings, it is the unconscious mind beneath consciousness and awareness. It is a repository of idea, desire, memories, and emotion. It consists of any information and data the mind collects from five senses but cannot consciously process to make meaningful sense of. However, it can be retrieved or recalled to consciousness by the simple direction of attention.

In order to make the right decision at the right time, the spiritual mind constantly needs not only information and knowledge but also wisdom. Without that, a strategic decision may just be a tactical one. Long-term success would be dependent on pure luck rather than a strategy. Here, wisdom means abstract pattern recognition at hierarchical level. It is the experience of cumulative knowledge. Cumulative knowledge has four different levels:

- Level 1: You do not know what you do not know (ignorance).
- Level 2: You know what you do not know (know unknowns).
- Level 3: You know what you know and what you do not know (know your boundaries).
- Level 4: You know all — knowledge of knowledge or meta-knowledge, wisdom (wizard).

For many people and under many circumstances, they are just wandering around at knowledge level 1. If we borrow the Indian philosophy term, it is so-called "ignorance." There are two different scenarios when people face the unknown. One is either leaving to chance or pretending to know. The other is to wonder about the unknown and continuously search for knowledge and wisdom. That is why people often say wondering is the beginning of wisdom.

Unfortunately, we have witnessed many IT strategic decisions made by some wayward people subject to purely static analysis, shallow observation, personal opinion, preference, taste and prejudice and, above all, ignorance. The results of these decisions often led to great fiascos or disaster.

Certainly, this book does not intend to tell readers how to make a particular decision or to enlighten readers on how to search for wisdom, but rather to share some common experiences that we have learned from previous lessons of cloud investment projects. By Buddhist philosophy, enlightenment depends only on oneself. Wisdom cannot be taught or demonstrated but one can only be shown the path to be followed.

This book will provide analytic tools and some practical processes of decision making for people to follow. It will not only provide readers with knowledge and analytic methods to establish a cost framework for strategic decision making but also will help readers to understand the logic behind the strategic decision making for cloud computing investment in practice.

We think it is important because not all decisions can be made by "gutfeelings," especially for a multimillion-dollar strategic investment decision that is made in a complex and dynamically changing environment. It requires hard mental work and comprehensive analysis. Gut feelings and educated guesses may add some value but not enough. Perhaps we can summarize the main point by altering the old English proverb "Look before you jump" as "Analyze before you decide."

ORGANISATION OF THE BOOK

This book is organized into five major parts:

- I. Cloud Computing Foundations and Business Requirements (Introduction)
- II. Cloud Data Center Facility (Below the Floor)
- III. Cloud Infrastructure and Management (Above the Floor)
- IV. Cloud Computing Cost Models and Framework (Framework)
- V. Cloud Strategy and Critical Decisions with Real Option Theory (Example)

The structure of this book is similar to a five-paragraph essay. Actually, the structure of the entire book can be loosely considered a recursive five-paragraph essay.

Part I is made up of three chapters (Chapter 1–3) that offer an introduction to cloud computing, define related computing paradigms such as parallel computing, identify business requirements through a five-phase process for defining business needs, and conclude with a case study.

Part II consists of seven chapters (Chapters 4–10) that cover issues related to data center architecture and key components and elements of data centers including space, power, cooling, fire suppression, and physical security.

Part III consists of three chapters (Chapter 11–13) that focus on cloud physical infrastructure elements namely servers, storage, and networking.

Part IV is made up of three chapters (Chapters 14–16). They cover topics related to the cost modeling framework and associated challenges. They also offer a detailed review of literature on cost modeling and key classifications, and how these concepts are put into practice in the real world.

Part V consists of two chapters (Chapters 17 and 18), which discuss the application of cost modeling to a real-life case scenario and present real option theory as one of the effective strategic methodologies for a decision maker to steer the business based on three basic elements: planning, opportunities, and decision making.

Caesar Wu and Rajkumar Buyya
Melbourne, Australia, 2014

Acknowledgments

First and foremost, we are grateful to all the researchers, industrial developers, and organizations worldwide for their contributions to the various concepts and technologies discussed in the book. Special thanks to all of our colleagues at Telstra and the CLOUDS (Cloud Computing and Distributed Systems) Lab at the University of Melbourne who have influenced our experience.

We thank all of our colleagues at the University of Melbourne, especially Professors Rao Kotagiri, Iven Mareels, and Glyn Davis for their mentorship and positive support for our research and knowledge transfer efforts.

We thank the members of the CLOUDS Lab for proofreading one or more chapters. They include Rodrigo Calheiros, Nikolay Grozev, Amir Vahid, Maria Rodriguez, Adel Toosi, Atefeh Khosravi, Yaser Mansouri, and Jungmin Jay Son.

We thank our colleagues Guoqi Qian, Kerry James Hinton, Peter Hormann, Joe Disisto, Sascha Suesseck, Tao Lin, and Arash Tayebi for their support.

We thank our family members, including Summa Wu, Smrithi Buyya, Soumya Buyya, and Radha Buyya, for their love and understanding during the preparation of the book.

We sincerely thank external reviewers commissioned by the publisher for their critical comments and suggestions on enhancing the presentation and organization of many chapters to a finer level. This has greatly helped us in improving the quality of the book.

Finally, we would like to thank the staff at Elsevier Inc. for their enthusiastic support and guidance during the preparation of the book. In particular, we thank Todd Green for inspiring us to take up this project and set the process of publication in motion. They were wonderful to work with!

Contents

Preface	xvii
Acknowledgments	xxi

PART I CLOUD COMPUTING FOUNDATIONS AND BUSINESS REQUIREMENTS

CHAPTER 1 Cloud Computing.....	3
1.1 Introduction	3
1.1.1 Operation Cost Rationalization	3
1.1.2 Revenue Estimation for Emerging Products	5
1.2 Cloud Computing at a Glance	7
1.3 Right Approach to Definition	8
1.4 A Brief History of Cloud Computing Definitions.....	9
1.5 Parallel Computing.....	16
1.5.1 Hardware Parallelism	17
1.5.2 Software Parallelism	18
1.5.3 Different Types of Parallel Models	20
1.6 Distributed Computing.....	24
1.7 Grid Computing.....	25
1.8 Utility Computing	27
1.9 Cloud Computing	30
1.10 Summary.....	39
1.10.1 Software (Applications).....	39
1.10.2 IT Infrastructure (Hardware)	40
1.11 Review Questions.....	41
 CHAPTER 2 Business Needs.....	 43
2.1 Introduction.....	43
2.2 Project Contents and Processes	48
2.3 Allocate the Right People for the Right Job.....	49
2.4 Business Analyst Role	51
2.5 Defining Business.....	57
2.6 Business Variables.....	59
2.6.1 Business Entity	59
2.6.2 Business Strategy.....	60
2.6.3 Business Profile (Variety)	62
2.6.4 Business Size (Volume)	62
2.6.5 Business Variation	64

2.7	Classification of Business Requirements	65
2.7.1	Business Requirements	66
2.7.2	Stakeholder requirements	66
2.7.3	Solution Requirements	66
2.7.4	Transition Requirements.....	68
2.8	E2E Process of Business Problem Solving.....	68
2.8.1	Business Problem Definition.....	71
2.8.2	Goals of Defining Business Problems	77
2.8.3	Techniques for Identifying Real Problems	78
2.8.4	Business Requirements Gathering Phase	78
2.8.5	Provide the Right Solution	81
2.9	Managing Expectations	91
2.10	Summary	94
2.11	Review Questions	95
CHAPTER 3	Identifying Business Problems: A Case Study	97
3.1	Case Information Briefing.....	97
3.1.1	Servers	99
3.1.2	Storage	109
3.1.3	Storage Switches	111
3.2	Define the Problems	113
3.2.1	Elicit Multiple Issues.....	116
3.2.2	IT Asset Operation Practice	124
3.2.3	IT Operational Structure	127
3.2.4	Misguided Incentive System	128
3.3	Requirements	130
3.3.1	Business Application Requirements	132
3.3.2	Architecture Requirements.....	135
3.3.3	Operational Requirements.....	137
3.3.4	Vendor Requirements.....	138
3.3.5	Other Stakeholder Requirements	141
3.3.6	Identify Hidden Requirements	141
3.4	Solution	141
3.4.1	Organizational Perspective.....	141
3.4.2	Technical Perspective.....	143
3.5	Summary	148
3.6	Review Questions	150
PART II	DATA CENTER FACILITIES AND COST	
CHAPTER 4	Data Center Facilities	153
4.1	Basic Understanding of a Data Center.....	153
4.1.1	Definition of Data Center.....	153
4.1.2	Data Center Architecture.....	156

4.2	Data Center Capacity Planning	157
4.2.1	Data Center Site Selection	162
4.2.2	Data Center Performance	172
4.2.3	Data Center Resource Ceiling	178
4.3	Data Center Space	180
4.3.1	Five Types of Space	181
4.3.2	Data Center Functional Rooms	185
4.4	How to Estimate Cost of Space	189
4.5	Summary	190
4.6	Review Questions	191
CHAPTER 5	Data Center Power	193
5.1	Introduction	193
5.2	Fundamentals of Power	195
5.2.1	Three Basic Power Metrics	195
5.2.2	Power Factor for AC Power	196
5.3	Power Panel (Circuit Breaker)	198
5.3.1	Type of Circuit Breaker and Selection	198
5.3.2	Circuit Breaker Coordination	200
5.4	Transfer Switches and Generators	200
5.4.1	Static Transfer Switch (STS)	202
5.4.2	Automatic transfer switch (ATS)	202
5.4.3	Generator	202
5.5	Uninterruptible Power Supply (UPS)	207
5.5.1	Different Types of UPS Topologies	210
5.6	How to Select UPS Topologies	213
5.6.1	UPS Redundancy and Cost Efficiency	215
5.7	UPS Batteries	220
5.7.1	Vented (Flooded or Wet Cell) UPS Batteries	220
5.7.2	Valve Regulated (VRLA) UPS Batteries	221
5.7.3	Modular Battery Cartridge (MBC) UPS Batteries	222
5.7.4	Comparison of Three Common UPS Battery Technologies	222
5.7.5	Battery Monitoring	222
5.8	Summary	224
5.9	Review Questions	224
CHAPTER 6	Power Distribution Unit and Cabling	227
6.1	Introduction	227
6.1.1	Basic PDU	227
6.1.2	Metered PDU	228
6.1.3	Switched PDU	228

6.2	Rack Power Distribution Unit and Redundancy	228
6.3	Power Feed to 42RU Rack	231
6.4	Data Center Power Cabling Installation	232
6.4.1	Transformation of the Data Center	232
6.4.2	Under the Floor Cabling	233
6.4.3	Overhead Cabling	234
6.5	Power Cable Layout Architectures	234
6.5.1	Star Topology Cabling Architecture	234
6.5.2	Bus Topology Cabling	235
6.6	Data Center Power Calculation	235
6.6.1	Process of Calculating Data Center Power Requirements	237
6.7	Strategies for Power Saving	242
6.7.1	Improve Efficiency of UPS or Remove Redundant Power Equipment	242
6.7.2	Improve Power Configuration	242
6.7.3	Reducing Data Center Capacity	244
6.8	Summary	246
6.9	Review Questions	246
CHAPTER 7	Data Center Cooling	249
7.1	Introduction	249
7.2	Understanding Cooling, Comfort, and Precision Cooling	249
7.2.1	Understanding Cooling	249
7.2.2	Comfort Cooling	250
7.2.3	Precision Cooling	250
7.2.4	Issues with Not Using Precision Cooling	251
7.2.5	Heat Sources in a Data Center	251
7.3	Temperature, Pressure, and Volume	252
7.3.1	Heat	252
7.3.2	Temperature	253
7.3.3	Humidity	254
7.3.4	Relationship between Temperature and Humidity	255
7.3.5	The Psychometric Chart (Humidity Chart)	257
7.3.6	Refrigeration	258
7.3.7	Refrigeration Unit	259
7.3.8	Refrigeration Cycle	259
7.3.9	Airflow and Airflow Rate	262
7.3.10	Fan Types and Fan Laws	264
7.4	Data Center Cooling Components	267
7.4.1	CRAC	267
7.4.2	CRAH	267
7.4.3	Chiller	267
7.4.4	Humidifier and Dehumidifier	267

7.5	Data Center Cooling Control	268
7.5.1	Demand Fighting Among Different CRAC Units	269
7.5.2	Adopting a Dew Point and Avoiding Relative Humidity Control	270
7.5.3	How to Control Humidity and Temperature	271
7.5.4	Consequences of Under- or Overhumidification	271
7.5.5	Managing the Data Center Temperature.....	272
7.5.6	Making Temperature Changes Based on the Heat Transfer Equation.....	276
7.5.7	Five Different Technologies for Removal of Data Center Heat	277
7.6	Summary.....	281
7.7	Review Questions.....	284

CHAPTER 8 Effective Air Distribution in Data Centers..... 285

8.1	Introduction.....	285
8.2	Methods of Air Distribution	286
8.2.1	Flooded Approach for Hard Floor	286
8.2.2	Targeted or Locally Ducted Approach for Hard Floor	287
8.2.3	Fully Ducted or Contained Approach for Hard Floor.....	287
8.2.4	Locally Ducted for Supply Air with Hard Floor.....	288
8.2.5	Fully Ducted for Both Supply and Return Air with Hard Floor.....	289
8.2.6	Locally Ducted or Targeted Approach with Raised Floor.....	290
8.2.7	Fully Ducted Return Air with Raised Floor	291
8.2.8	Fully Ducted Supply Air with Raised Floor.....	291
8.2.9	Fully Ducted Supply Air and Locally Ducted Return Air with Raised Floor	291
8.2.10	Fully Ducted Supply and Return Air with Raised Floor.....	292
8.3	Guidelines for Air Distribution Methods	293
8.4	Computational Fluid Dynamics (CFD) Analysis.....	294
8.4.1	What Is Data Center CFD Analysis and Simulation?	295
8.4.2	The Process of CFD Modeling and Simulation.....	296
8.5	Data Center Cooling Calculations.....	298
8.5.1	Converting Energy in kW to Tons of Ice Cooling Equivalent	298
8.5.2	IT Load Calculations.....	298
8.5.3	Total Cooling Requirement Calculation	299
8.6	Managing and Optimizing Cooling Systems	303
8.6.1	Resolve Easy Issues Immediately to Improve Cooling Efficiency.....	303
8.6.2	Guidelines to Manage Perforated Tiles and Racks	305
8.6.3	Conditional Monitoring for Cooling System.....	309
8.6.4	Handling High-Density Rack Cooling	309
8.7	Summary	315
8.8	Review Questions	315

CHAPTER 9	Cooling Strategy	317
9.1	Cooling Control for Wiring Closets.....	317
9.1.1	Sharing Comfort Cooling System.....	317
9.1.2	Conduction Cooling	318
9.1.3	Conduction, Passive, and Fan-Assisted Ventilation.....	319
9.2	Room-Based Cooling	319
9.3	Row-Based Cooling.....	320
9.4	Rack-Based Cooling	321
9.5	Comparison of Room-, Row-, and Rack-Based Cooling	321
9.5.1	Mixing with Room and Row Based Cooling.....	322
9.5.2	Hot Aisle and Rack Containment for High-Density Zone	324
9.5.3	Uncontained	325
9.6	Rack Rear Door—Based Cooling Strategy	325
9.7	Raising the Data Center Temperature.....	326
9.8	Free Cooling Using Economizers	328
9.8.1	Airside Economizer	330
9.8.2	Waterside Economizer.....	330
9.9	Summary.....	334
9.10	Review Questions	339
 CHAPTER 10	 Fire Suppression and On-Site Security	 341
10.1	Introduction.....	341
10.2	Issues with Traditional Fire Suppression Systems	342
10.3	Fire Classification and Standards.....	343
10.3.1	Fire Detection	343
10.4	Fire Suppression Solution Selection	345
10.4.1	Traditional Fire Suppression Solutions.....	347
10.5	Inert Gases, Halocarbons, and Aerosol.....	350
10.5.1	Inert Gases	350
10.5.2	Halocarbons	350
10.5.3	Aerosol.....	350
10.5.4	Fluorinated Ketone (Liquid) (Novec 1230)	351
10.5.5	Most Commonly Used Agents in Today's Data Center.....	351
10.6	Fire Suppression System Cost for Data Centers.....	351
10.7	Summary of Fire Suppression Selection.....	352
10.8	On-Site or Physical Security	354
10.9	Physical Layers.....	356
10.9.1	Protecting Data Center Perimeters.....	356
10.9.2	Security Envelope.....	358
10.9.3	Access Points and Door Control	358
10.9.4	Camera or CCTV Control	359
10.9.5	Security Guards	359

10.10	Organizational Layer.....	360
10.10.1	People.....	360
10.10.2	Organizational Structure and Policy	362
10.10.3	Security Process.....	363
10.11	Establishing Physical Security	363
10.11.1	Cost Calculations for Physical Security Systems	364
10.11.2	Summary of physical security	366
10.12	Summary.....	366
10.13	Review Questions.....	367

PART III CLOUD INFRASTRUCTURE AND MANAGEMENT

CHAPTER 11	Cloud Infrastructure Servers: CISC, RISC, Rack-Mounted, and Blade Servers.....	371
11.1	Cloud Servers	371
11.1.1	A Client/Server Architecture.....	375
11.2	x86 Server.....	377
11.2.1	CPU.....	381
11.2.2	Server CPU Cache	387
11.2.3	RAM	387
11.2.4	NUMA	388
11.2.5	Server PCI Cards	390
11.2.6	Server Storage.....	391
11.2.7	Server Network.....	392
11.2.8	Server Motherboard	392
11.3	Rack-Mounted Servers and Vendors	392
11.4	Blade Servers.....	395
11.4.1	What Is a Blade Server?.....	395
11.4.2	History of Blade Servers	397
11.4.3	Rack vs. Blade Server	401
11.5	RISC Server.....	402
11.5.1	History of RISC Servers.....	403
11.5.2	CISC vs. RISC.....	404
11.5.3	RISC Server Market Share	408
11.6	Oracle/Sun SPARC Servers	409
11.6.1	Oracle/Sun M-Series RISC Servers	414
11.6.2	Oracle/Sun T-Series RISC Servers	417
11.6.3	SPARC Logical Domain and Virtual Machine (VM)	418
11.7	Summary.....	423
11.8	Review Questions	424

CHAPTER 12	Cloud Storage Basics	425
12.1	Storage Hierarchy	425
12.1.1	Hard Disk Drive (HDD) Fundamentals	426
12.1.2	Storage SLA and RAID Architecture	433
12.1.3	Storage LUN	443
12.2	Solid State Disk or Flash SSD	445
12.2.1	What Is an SSD?	448
12.2.2	SSD versus HDD	450
12.2.3	Total Cost of Ownership of SSD	451
12.3	Storage Topologies and Connections	453
12.3.1	Direct Attached Storage (DAS)	453
12.3.2	Storage Area Network (SAN)	454
12.3.3	Network Attached Storage (NAS) and File Storage Protocols	459
12.4	Storage Protocols	464
12.4.1	File-Oriented Protocols	464
12.4.2	Block-Oriented Protocols	467
12.4.3	Storage Interface Protocols Summary	480
12.5	Pros and Cons for Different Storage Topologies	483
12.6	Traditional Storage vs. Cloud Storage	486
12.7	Major Storage Vendors and Market Trends	490
12.8	Summary	493
12.9	Review Questions	494
CHAPTER 13	Data Center Networks	497
13.1	Key Network Terms and Components	497
13.1.1	Network Hardware	498
13.2	Data Center Network Terms and Jargon	516
13.2.1	DCN Terms, Jargon, and Definitions	516
13.3	Metrics of DCN Topology	520
13.4	Types of Network Topology	521
13.4.1	Common DCN Topologies	527
13.4.2	Recursive DCN Topologies	535
13.4.3	Other DCN Topologies	544
13.4.4	Characteristics of Different DCN Topologies	560
13.5	Characteristics of Cloud Data Center Network	560
13.5.1	Management Network	560
13.5.2	Kernel Network	561
13.5.3	Virtual Machine Network	565
13.5.4	Virtualized Storage Network	565
13.5.5	Example of Connection Details	566
13.6	Cloud DCN Summary	570
13.6.1	DCN Component Summary	570

13.6.2 Terms and Definitions Summary	573
13.6.3 Metrics Summary	573
13.6.4 DCN Topology Summary.....	573
13.6.5 Cloud DCN	575
13.7 Review Questions	576

PART IV CLOUD COMPUTING COST MODELS AND FRAMEWORK

CHAPTER 14 Cost Modeling: Terms and Definitions	579
14.1 Concept of Cost Model	580
14.1.1 Definition of Cost.....	580
14.1.2 Capex and Opex Shift in a Cloud Environment.....	585
14.1.3 Benefits	589
14.1.4 Risks and Opportunity	589
14.1.5 Definition of Model.....	590
14.1.6 Model Measurement or Metrics	595
14.1.7 Analysis.....	597
14.1.8 Framework and Methodology	598
14.1.9 Formulating a Cost Model	599
14.2 Purposes of Cost Modeling for Cloud Computing.....	600
14.2.1 Visualize Abstract Structure of the Complex World.....	600
14.2.2 Organize Concepts, Thoughts, and Ideas.....	601
14.2.3 Communicate with Other People	602
14.3 Challenges of Cloud Cost Modeling.....	602
14.3.1 Not All Factors Are within the Framework.....	606
14.3.2 Limitation of Framework Size	607
14.3.3 Objective or Subjective Process of Cost Modeling.....	607
14.3.4 Limitation of Individual Knowledge and Experience	607
14.3.5 A Time Stamp on the Model.....	608
14.4 Summary.....	608
14.5 Review Questions	609
 CHAPTER 15 Cost Model Categories	 611
15.1 Review of Cost Models	611
15.1.1 The Cost Model of the First CPU.....	615
15.1.2 Recent Cloud Computing Cost Models	616
15.2 Cloud Computing Issues, Impacts, the Right Questions for the Cost Model.....	632
15.2.1 Cloud Service Consumers	633
15.2.2 Cloud Service Providers.....	633
15.3 Cost Models over the Last 50 Years.....	633
15.4 Common Financial Cost Models.....	636
15.4.1 Accounting Rate of Return (ARR).....	637