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Gurobi
2nd Special Edition

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As the leader in decision intelligence, Gurobi delivers easy-to-integrate, full-featured software and best-in-class support, with an industry-leading 95 percent customer satisfaction rating.

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Optimization

Gurobi 2nd Special Edition

by The Gurobi Team

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Optimization For Dummies®, Gurobi 2nd Special Edition

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Introduction

Welcome to *Optimization For Dummies*, Gurobi 2nd Special Edition! If you're considering optimization for your business, you may have a lot of questions. What exactly is optimization? Is it different from other software technology you use today, and if so, how? What kind of problems can it tackle? What sort of return on investment have other adopters seen? And if you do decide to explore optimization, how should you go about it? This book helps you answer these questions, and more.

About This Book

To make the content of this book easily accessible, we divided it into the following six short chapters:

- **Chapter 1: Getting Started with Optimization** brings you up to speed on optimization basics: what it is, how it works, and how it can benefit your organization.
- **Chapter 2: Piecing Together the Optimization Puzzle** breaks down the optimization process into four approachable steps.
- **Chapter 3: Putting Optimization into Action** explores how optimization has helped real organizations streamline their operations. We also introduce tools to help you implement optimization in your organization.
- **Chapter 4: Overcoming Common Pitfalls** examines common obstacles you may face as you embark on your optimization journey and offers tips for overcoming them.
- **Chapter 5: Looking to the Future** explores what's on the horizon for optimization and what other fast-evolving technologies may mean for its trajectory.
- **Chapter 6: Ten Reasons to Solve with Gurobi** presents ten good reasons to choose Gurobi as your optimization solver.

We wrote each of these chapters to stand on its own, so feel free to start anywhere and skip around to chapters that interest you.

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Foolish Assumptions

To best meet your needs and interests, we assumed that you're a professional looking for ways to make your organization run more efficiently and effectively, you're familiar with data-driven decision-making or process improvement (but you're not necessarily a mathematician or efficiency expert), or you're looking to grow your knowledge and understanding of optimization, as well as gain practical, actionable insights to help you implement it.

Icons Used in This Book

To identify key pieces of information and guidance, look for the following icons:

TIP

The Tip icon highlights quicker, easier, or better ways to do things.

REMEMBER

The Remember icon calls attention to the most critical information and insights.

TECHNICAL STUFF

The Technical Stuff icon highlights more specialized information that you may find interesting but can safely skip.

Where to Go from Here

Hey, it's your book! Dive in anywhere or simply turn the page. If you finish reading the book and you're craving more information and guidance, visit us at `www.gurobi.com`.

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IN THIS CHAPTER

- Understanding what optimization is (and isn't)
- Recognizing the value of optimization in the real world
- Identifying opportunities for optimization in your organization

Chapter 1
Getting Started with Optimization

You've probably heard the old saying that information is power. But that holds true only if insights can be extracted from that information. How can a business turn data into profitable action?

Artificial intelligence (AI) is one possibility. AI has been the center of much hype for the past several years — particularly generative AI (GenAI) and predictive analytics. Many companies lean on analytics and reporting to understand what happened in the past or what may happen next. These tools are useful, but they stop short of answering the most important question: "What should we do *right now?*" That's where mathematical optimization comes in.

Optimization has been quietly delivering value for decades — and it's playing an increasingly important role in helping companies make smarter, more confident decisions while improving their operational efficiency. Unlike other tools that leave the actual decision up to intuition, optimization gives you a defensible, best-possible answer to complex business questions — helping you move from information overload to confident action.

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This chapter explains the nature of mathematical optimization, how it may help with your business challenges, and how you can best harness its potential.

Understanding Optimization and Related Concepts

Mathematical optimization (which we refer to throughout this book as simply "optimization") encompasses an array of computational techniques that use data — predicted store-level sales, estimated machine uptimes, even the price of tea in China, you name it — to solve decision models, resulting in recommendations for common business processes (for example, price promotions, production planning, or material procurement).

REMEMBER

Optimization is simply a mathematically sophisticated way to describe a decision situation with all its relevant elements. Built well, an *optimization model* uses relevant data and rules to identify solutions that lead to the best possible result. The three key elements of an optimization model are as follows:

REMEMBER

- **Objectives:** Objectives are your quantified business goals. They can include goals such as maximizing profit, compressing the quote-to-cash cycle, reducing shipment costs, or lowering emissions, to name a few.

  Objectives often conflict. For example, when you're setting up a stock portfolio, maximizing your expected return will most likely produce a very risky portfolio. In this case, you'd want to create a *multi-objective* model that maximizes return while mitigating risk. Most businesses optimize for one objective at a time — choosing which one to focus on first is a very human task, one based on perspective.
- **Variables:** Variables are geek-speak for factors you control. Suppose you manage a refinery. Do you control the price of crude oil? Um, no, no matter how much you may wish you could. How about the quantity of West Texas Intermediate Crude you refine? Yes. In your production model, the amount of crude oil you choose to refine will be a variable. The forecasted oil price? That's simply data. Variables capture your degrees of freedom — they are the factors you can adjust in an optimization model.

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» **Constraints:** Think of constraints as restrictions relevant to the optimization model. A factory has only so many workers on the swing shift. A portfolio manager is not allowed to invest more than a certain fraction of an investment portfolio in the tech sector. An arriving aircraft requires so many minutes for cleaning and refueling, so any valid plan will have to respect this necessary ground time. All of these are examples of constraints.

Put these three elements together and you have your optimization model. A model with its data completely available is called an *instance.* Assign values to all variables in an instance, and you have a *solution.* If the solution satisfies all constraints, it is called *feasible.* If no better solution exists, it's called *optimal.*

After building your model, you program it into a computer and integrate with a solver and a user interface to build an *optimization system.* The *solver* is the computational engine that takes an optimization model and attempts to find the *best feasible solution* — if one exists.

REMEMBER

Best feasible has two parts: *best* and *feasible. Best* means that no other decisions can yield a better objective. And *feasible* means the decision does not conflict with any of the business rules encoded in the constraints.

REMEMBER

Solving isn't always as straightforward as "model in, optimal solution out." In many real-world problems, intermediate solutions found early in the process may be nearly as attractive or spark new ideas. Modern solvers like Gurobi provide not only intermediate solutions, but also valuable information, such as the *mixed-integer programming (MIP) gap* — a measure of how close the current solution is to the theoretical best.

Differentiating descriptive, predictive, and prescriptive analytics

Optimization's value comes from its ability to provide you with the best feasible solution to a problem, or the best business decision. It goes beyond helping you understand the past or predict future events by telling you *what you should do* to minimize your exposure to future risk, make the most of emerging opportunities, maximize efficiency, and so on.

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REMEMBER

Here's a quick rundown of the differences between descriptive, predictive, and prescriptive analytics:

- **Descriptive analytics:** Uses data aggregation and statistical analysis to derive insights into what happened and why
- **Predictive analytics:** Uses machine learning, statistical models, and simulation to predict what will likely happen
- **Prescriptive analytics:** Uses optimization and *heuristics* (computational or algorithmic shortcuts that simplify problem-solving) to identify decisions that will achieve a desired future outcome

Going beyond analytics and automation

Now, you may be thinking, "This sounds good, but aren't my analytics systems already doing all this? Isn't that what I should expect from my company's customer relationship management (CRM) or enterprise resource planning (ERP) or business process management (BPM) system?" No. Not really.

REMEMBER

Most business IT systems — such as CRM and ERP — are essentially data repositories with a light sprinkling of analytics or rule-based automation. For example, the Salesforce Automation capability in your CRM may assign new leads to salespeople. That's decision-making of a sort. But such assignment rules must be defined up front, such as: "Calls from Canada are routed to Tracy." The CRM can't tell you which salesperson *should* be assigned the lead to maximize profitability, but an optimization-based system can.

BPM systems — including workforce automation or process orchestration tools — are more sophisticated in terms of decision-making. But even they rely on predefined business rules that can make recommendations only as good as the intuition behind them. In effect, the analyst needs to pre-specify all possible situations that may occur — a challenging and time-consuming task.

Making better business decisions

The business environment today obviously poses unique and unprecedented opportunities and challenges. Geopolitical and economic uncertainty, the rapid advancement of AI, and shifting

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global supply chains have created a cut-throat business environment. There are more opportunities than ever — but also more risks for businesses to navigate. In this climate, decision-making tools that are proven, reliable, and adaptable are not just nice-to-haves, but must-haves.

Just a few decades ago, only a handful of "civilians" were discussing web marketing analytics, supply chain planning, or revenue management. But with the rise of search engine giants, retail powerhouses, low-fare airlines, real-time pricing, and AI-driven personalization, these terms have become an essential part of the conversation.

What do these organizations and technologies have in common? They all use data in large volumes to drive profitable decisions. And in many of them, optimization is the "secret sauce" that enables businesses to minimize risks while making the most of emerging opportunities.

Appreciating the Vital Importance of Optimization

If your business is doing just fine, you may be wondering, "Why do I need the headache of adding a new tool to my tech stack now?" The answer comes in two parts.

Optimization users often experience double-digit improvements in their key performance indicators (KPIs) when they move away from legacy systems and other methods (we take a closer look at this benefit in Chapter 3). To ignore a technology with that much potential is to leave money and efficiency gains on the table.

REMEMBER

Just think of all the ways optimization impacts your life daily — every time you price a weekend flight, withdraw money from an ATM, or order groceries expecting them to be delivered on time, you rely on optimization. Airlines, banks, and delivery services have long used optimization to price seats, stock ATMs with cash, and sort and route orders.

Virtually no business today is sheltered from the flow of information, goods, and services across the global economy. Sudden supply chain disruptions, geopolitical tensions, and other unexpected events can turn any business upside-down. But when you have

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a proven optimization model in place, you'll be in a much better position to react quickly and confidently to changes. You can even use optimization to run what-if scenarios ahead of time, to better manage uncertainties.

REMEMBER

Optimization doesn't simply add intelligence to existing business processes; it changes them.

As an example, consider scheduling power generators at an electric utility. The business issue seems fairly straightforward: Schedule a power plant operation for the week to get the lowest cost while meeting anticipated demand and regulatory requirements.

Complex scheduling like this is impossible to do well without using optimization. But wait, there's more! With an optimal scheduling system in place, a utility can also use it to track and control emissions. Planners can even simulate operations over longer periods — months or years — helping them find ways to be "green" without negatively impacting productivity.

In short, optimization isn't merely about one-upping competitors. It's also about helping businesses pivot from complexity to innovative practice.

In Chapter 3, we examine the powerful real-world impact optimization can have on businesses.

Knowing When to Optimize

When you know what optimization entails, you can start to consider how it fits into a typical business process flow in your organization. Specifically, consider which processes are likely to benefit the most from optimization.

The first characteristic of an "optimizable" process is the availability of accurate data. Optimization perfectly illustrates the adage "garbage in, garbage out." The more accurate your data, the greater your potential to improve in that area.

For example, global freight and logistics companies minimize operation costs in large part through optimization. As part of their rich data collection, they track turn-by-turn locations of

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each vehicle, real-time traffic, operating costs, and continuously refreshed pickup and drop-off information.

Another key factor for applying optimization is *repeatability.* Although optimization has been applied with success to one-off decisions — a U.S. federal agency for communications' repurposing of wireless spectrum to generate nearly $20 billion in revenue comes to mind — it's more typically used to improve decisions that occur regularly, even frequently. For example, airlines use it to save on annual fuel costs, hotel chains use it to optimize their room inventory, and technology hardware companies use it to plan and run manufacturing. These are all repetitive processes, where squeezing out even a 0.1 percent gain in efficiency can translate to millions of dollars.

Finally, optimization is best suited for complex, resource-constrained situations — helping airlines to make the most of their seat inventory, tech companies to maximize their cloud computing resources, and hospitals to efficiently schedule healthcare professionals.

Further, in such situations, when the overall structure of the process may stay constant over time, ever-changing operating conditions — such as a major retail sale during the holidays, or an unexpected surge in ride-share requests after a concert — can drastically change the economics from day to day, or even minute to minute. Optimization is built for exactly this kind of environment: structured, but constantly shifting. And when applied correctly, it delivers consistent, measurable improvements.

REMEMBER

Optimization is deeply embedded in many systems governing business processes, from airline reservations to lumber harvesting to online advertising. Yet, its full potential is still often underutilized or misunderstood. To gain a better understanding of optimization, turn to Chapter 2.

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IN THIS CHAPTER

- Approaching optimization as a four-step process
- Getting up to speed on solver basics
- Choosing the right solver for your needs
- Getting started with an open-source solver or a free trial

Chapter 2
Piecing Together the Optimization Puzzle

If you're considering optimization for your business, you may be wondering where to begin. The good news is that you don't need an advanced degree in mathematics or computer science to get started. In this chapter, we outline the basic steps involved in using optimization and offer tips for ensuring optimal results.

REMEMBER

Chapter 3 introduces you to additional training resources for beginners that can help you get up to speed on the basics and gain valuable hands-on experience. This chapter focuses more on laying the groundwork for a foundational understanding of optimization.

Optimizing: Simple as 1-2-3-4

Optimization is a multistep process (with some tuning and adjustments sometimes required to find the best solution). That is, it's not always a neat, straightforward procedure. However, when you're getting started, approaching optimization as a linear process is often best. This section leads you through the complete four-step optimization workflow, from start to finish, as shown in Figure 2-1.

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FIGURE 2-1: Optimization is a four-step process.

Step 1: Develop a problem statement

No math or computer programming is needed for this step — simply identify a business problem to be solved or a process that can be improved, define an objective, and list the relevant variables and constraints (see Chapter 1 for details on objectives, variables, and constraints). In addition to defining an objective, this step involves identifying relevant variables and constraints and composing a succinct problem statement.

REMEMBER

As explained in Chapter 3, the potential use cases for optimization are many — as we like to say, "If you can model it, you can optimize it."

Identifying a problem or opportunity for improvement

What do you want to maximize? For example:

- Operational efficiency
- Output (quantity produced)
- Resource capacity
- Resource utilization
- Revenue
- Sales or service potential
- Website traffic

Or minimize? For example:

- Costs
- Downtime
- Greenhouse gas emissions
- Power consumption

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- Risks
- Service time
- Travel distance
- Waste

Listing the decision variables

What are the *decision variables* in your problem — in other words, the factors you can control? Some examples include the following:

- The budget you allocate to each project or department
- The capital you invest in each asset in a portfolio
- The number of employees you schedule for each shift
- The number of units you produce each week
- The routes your delivery trucks take

Listing all constraints

What *constraints* (rules) does your solution need to follow? Some examples include the following:

- Compliance requirements (rules and regulations)
- External or internal demand
- Limited resource availability (time, capacity, budget)
- Logical conditions
- Precedence constraints (for example, Task B cannot begin until Task A is completed)

Writing your problem statement

After you've identified the three key components of an optimization problem (objective, variables, and constraints), you're ready to write your problem statement. For example, suppose you're trying to maximize your profit from two products; that's your objective. Your variables are the quantities of the two products — cogs and sprockets, for example. Your constraints

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include available machine time and customer demand for the products. Your problem statement may look something like this:

> My factory is looking to maximize profit from cogs and sprockets while meeting customer demand, and machine access is limited.

Step 2: Describe your problem in mathematical terms

After writing your problem statement (which describes your objective, variables, and constraints), you're ready to express it in mathematical terms. Translating your problem into mathematical terms brings you one step closer to being able to feed your problem to an optimization *solver* (an application that computes the solution to the problem).

This step requires some mathematical know-how. You need to write mathematical expressions that accurately represent your problem statement. Building on the problem statement given in the previous section, the math looks like this:

Objective

> Maximize profit (P): $P = 5x_1 + 3x_2$ (assuming $5 per unit of cogs and $3 per unit of sprockets)

Variables

> x_1 = Quantity of cogs
>
> x_2 = Quantity of sprockets

Constraints

> **Machine hours:** $1.0x_1 + 0.5x_2 \leq 80$ (It takes 1 hour of machine time per cog and ½ hour per sprocket, and your machine time is limited to 80 hours per week.)
>
> **Demand:** $x_1 \geq 10$, $x_2 \geq 20$ (You need to produce at least 10 cogs and 20 sprockets per week.)

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When expressing a problem in mathematical terms, you need some basic knowledge of mathematical properties and optimization models, as explained in the following sections.

The basics: Mathematical properties

How a solver works depends on the properties of the objective, variables, and constraints of the model it's meant to solve. The two most basic properties are linearity and integrality:

- **Linearity** is a simple concept: A relationship between variables is *linear* if a change in one variable results in a proportionate change in the other. For example, if one widget costs $100, two widgets cost $200. And if a dongle costs $150, two widgets and five dongles cost (2 × $100) + (5 × $150) = $950. A relationship between variables is *nonlinear* if a change in one variable can result in a disproportionate change in the other; for example, the price of each widget decreases based on the quantity you order.
- **Integrality** determines whether a value is necessarily expressed in whole units or can be a fraction or decimal (continuous). For instance, you can produce 4 widgets or 5, but not 4.3, so the number of widgets must be an integer. One powerful example of integrality is the binary variable, which represents yes-or-no decisions. Many real-world choices are binary, and integrality allows you to model these logical constraints — for example, "*X* can happen only if *Y* happens." In contrast, an airplane may fly 18.25 hours in a day — it isn't limited to 18 or 19 hours. Its daily utilization corresponds to a *continuous* variable.

Types of models

An *optimization model* is a mathematical framework used to find the best solution to a problem by maximizing or minimizing an objective function within specified constraints. The main types of optimization models are as follows:

- **Linear programming (LP):** These optimization models are appropriate when the objective, variables, and constraints have linear relationships, and the variables are continuous (non-integers). For example, if you want to minimize shipping

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costs, while meeting customer demand, without exceeding warehouse supply, the objective function, variables, and constraints all form linear relationships; any change in one (objective, variable, or constraint) will produce a proportionate change in the other.

- **Integer programming (IP):** These optimization models are LP models whose variables are exclusively integers (not continuous).
- **Mixed-integer programming (MIP):** MIP optimization models can accommodate both continuous and integer variables. Both MIP and IP models require more effort to solve compared to LP models.
- **Quadratic programming (QP):** A QP optimization model is used when the objective function includes quadratic terms (such as x^2) and constraints are linear. It's often applied in finance (for example, portfolio optimization), energy systems, and certain machine learning models.
- **Quadratically constrained programming (QCP):** A QCP optimization model is even more complex than its QP counterpart, with both the objective function and some constraints involving quadratic functions.

TECHNICAL STUFF

- **Nonlinear programming (NLP):** In situations where a linear approximation doesn't correctly capture the relationship between decision variables in the constraints and/or objective function, an NLP optimization model may be required. One example of this is grocery pricing: As prices increase, demand often decreases. This relationship is not linear: A price increase of 10¢ may have a negligible effect on demand, while a $1 increase could have a more substantial effect. However, that $1 increase may not correlate to a tenfold decrease in demand compared to the 10¢ scenario — hence, the nonlinear relationship. For example, one retail price optimization platform used optimization to solve large-scale nonlinear problems, helping grocery retailers determine the optimal price for thousands of products. This enabled retailers to maximize profits and adjust to changing conditions in real time.

REMEMBER

NLP models require *algorithms* (sets of mathematical instructions) that may demand more computational effort than algorithms used in LP, IP, and MIP models.

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Step 3: Translate your problem into code

Translating your problem into code involves writing your problem in a programming language that your solver can understand using an *optimization library* (a toolkit in a programming language, such as Python, that helps you describe your optimization problem in code). Yes, this step involves programming.

Using the math from Step 2, the code for minimizing the production costs of cogs and sprockets may look like this when using Gurobi (in Python):

```
import gurobipy as gp
from gurobipy import GRB

# Create environment and model
with gp.Env() as env, gp.Model(env=env,
        name="Cogs-and-sprockets") as m:
    # Decision variables
    x1 = m.addVar(name="x1")
    x2 = m.addVar(name="x2")

    # Set objective function
    m.setObjective(5 * x1 + 3 * x2, GRB.MAXIMIZE)

    # Add constraints
    m.addConstr(x1 + 0.5 * x2 <= 80)
    m.addConstr(x1 >= 10)
    m.addConstr(x2 >= 20)
```

Step 4: Feed your problem to a solver

After the problem is defined, running the solver is the easiest step in the process. Continuing the example, the code would look something like this:

```
m.optimize()
if m.status == GRB.OPTIMAL:
    print("Optimal solution found:")
    print(f"x1 = {x1.x:.2f}")
```


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```
    print(f"x2 = {x2.x:.2f}")
    print(f"Objective value = {m.objVal:.2f}")
else:
    print(f"Status was {m.status}")
```

This code simply tells the solver to solve your problem, checks whether an optimal solution was found, and "prints" (outputs) the results — the values for x_1 and x_2 that maximize the profit, along with what that maximum profit is.

Understanding the Role of the Solver: From Models to Solutions

To turn your models into solutions (and optimal decisions you can act on), you need a solver — the heavy lifter that can help you make optimal decisions in seconds.

What is a solver?

An *optimization solver* is a type of specialized software that finds the best solution (or sometimes several optimal solutions) to your mathematical model. Given your constraints (and using the mathematical models described in the "Types of models" section, earlier in this chapter), the solver determines which values your decision variables should take to optimize your objective.

The result? An optimal plan that you can put into action.

How exactly does it work?

Think of a solver as the engine of a car. You may not see it, but it's constantly working hard "under the hood" to:

- **Choose the right set of algorithms to fit your model type.** The solver interprets the mathematical expressions of your problem; recognizes whether they are linear or nonlinear, whether they involve integers or allow for continuous variables, and so on; and chooses the algorithms that are best suited to solving the problem.

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- **Explore and analyze all the possible solutions.** The solver analyzes all possible solutions — potentially numbering in the millions or more. It then completes a mathematical proof internally to validate optimality (demonstrating that better options do not exist).
- **Return optimal solutions.** You get the answer to your question or the solution to your problem — not just any answer or solution, but the *best possible* one, given your objectives and constraints.

How well the solver performs these tasks is typically measured by the time it takes to find a feasible solution, prove optimality, or achieve a certain solution quality.

Comparing solver types

Different types of solvers are built for different kinds of problems — some handle problems with simple, linear relationships, while others are designed for more complex, nonlinear, or uncertain situations. Choosing the right solver type matters because it directly affects how efficiently and accurately your problem is solved. Using an unsuitable solver can lead to slow performance, poor results, or even failure to find a solution.

Solvers come in many flavors. The four main types are LP, MIP, NLP, and QP.

REMEMBER

Note that the types of solvers match the different mathematical model/problem types described in the earlier section "Types of models." You want to choose a solver that matches the problem type (model) you're trying to solve.

Linear programming

LP solvers solve problems in which all relationships between the objective, variables, and constraints are straight-line and values are continuous (not integers). They usually use one (or a combination) of the following methods:

- **Simplex method:** This classic algorithm, developed in 1947, works reliably to solve most LP problems.

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- **Interior point method:** Developed in the mid-1980s, this method often works particularly well for solving large, sparse LP problems — those with very large numbers of variables and constraints, but with relatively few variables per constraint.
- **Primal-dual hybrid gradient (PDHG):** A modern iterative method well-suited for solving extremely large-scale LP problems, particularly when high precision is not essential.

REMEMBER

LP solvers are typically very fast. They can solve LP problems with thousands of variables almost instantly. The largest LP problems may include variables in the millions or more.

Mixed-integer programming

MIP solvers are designed to solve problems that involve linear relationships when some variables must be *integers* (whole numbers). These solvers typically use a method called *branch-and-cut*, which relies on LP solvers to do part of the work.

REMEMBER

MIP solvers are slower than their LP counterparts, because they're having to process integers, but MIP problems containing millions of variables have been solved.

Quadratic programming

QP solvers are a subtype of NLP solvers that allow the use of quadratic terms, such as x^2, in the objective function. QP problems are more difficult to solve than LP problems, but they're easier than most other types of NLP problems. Although QPs are nonlinear, most MIP solvers include a QP solver.

Nonlinear programming

NLP solvers require algorithms for handling nonlinear relationships, which makes them substantially different from LP and MIP solvers, both mathematically and in their computer implementation.

REMEMBER

In terms of performance/speed, NLP solvers lag behind LP and MIP solvers. Nonlinear equations are more difficult to solve.

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Implementation considerations

Optimization is not a one-size-fits-all technology. Implementing it in any given situation requires forethought, planning, and creativity. In particular, you must carefully consider the problem scope, your data needs and availability, and the provider you choose to develop your application:

- **Problem scope:** Process improvement efforts often arise from insightful observations — for instance, "Our hydro turbine utilization is too low." But going from that to "Let's reengineer our generation dispatch process using MIP technology" is quite a leap for a novice. And even if you clear that hurdle, you face the challenge of identifying all relevant variables and constraints, describing your problem in mathematical terms, and then writing the code to feed your problem to a solver. That's why using the best optimization experts you can find and afford is critical. Optimization modeling isn't standard IT.
- **Data needs and availability:** Because optimization is driven entirely by numeric computation rather than by rule-based inferences, it's highly susceptible to data availability and quality shortfalls. As you begin your optimization project, allocate resources to assess your data needs — and ensure that you set up the needed business processes to maintain data quality over time.
- **Solution provider:** After you identify an opportunity and develop a preliminary model, you may want to develop the application using internal resources. This approach can work, *if* you have in-house optimization experts. If, on the other hand, you decide to outsource application development, make sure that your service provider staffs your project team with optimization-savvy programmers.

  Quality solver vendors invest considerable time developing competence networks of optimization experts. Because their business is selling solvers, not labor hours, they can provide objective advice in all project phases. Don't hesitate to use them.

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Knowing What to Look for in a Solver

When you're in the market for a solver, you have several factors to consider. As with the selection of any other enterprise software, you'll want to know whether it's reliable, scalable, and supported, and whether others in your industry are using it successfully.

Open-source versus commercial solutions

Organizations that employ optimization experts often create their own in-house software applications. For others, the main options are choosing between a free, open-source solver or investing in a commercial optimization solution. Which is the right choice for your organization?

Open-source solvers offer zero up-front costs and are maintained by a community of users and developers. This can be a viable option for academic research, experimentation, and noncritical applications. However, free solvers often come with fewer features and less robust support compared to commercial options, which can make them difficult to scale for enterprise use cases.

In addition, free solvers typically deliver only a small percentage of the performance quality that commercial options can offer. Companies that are considering the open-source path should be aware of the hidden costs of internal expertise, because troubleshooting and performance tuning may require significant expertise and effort from in-house teams.

Commercial solvers do come with licensing costs, but they often deliver significantly faster solve times with reliable performance, better scalability, and advanced features. (Some commercial solvers, including Gurobi, offer free licenses for academics.)

For businesses in which decision speed, solution quality, and reliability drive competitive advantage, commercial solvers often deliver a better return on investment.

Unfortunately, when users experience slow or suboptimal performance with free solvers, they may give up on optimization technology altogether.

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REMEMBER

Open-source tools can be very useful for introducing you to optimization and providing you with some hands-on training, but keep in mind that if an open-source tool is unable to solve your model, you shouldn't assume that optimization doesn't work for your problem.

Performance

A solver's performance significantly impacts your outcomes, whether you're looking to better manage supply chains, optimize financial portfolios, or improve manufacturing processes.

A solver's ability to quickly find a feasible solution, prove optimality, and achieve a certain solution quality is critical to most optimization applications, but robustness and efficiency are equally important aspects of performance.

A robust solver maintains numerical stability, behaving reliably even when pushing the accuracy limits of the underlying hardware. Reliable performance under challenging conditions helps to ensure predictability and allows for the inclusion of more complex and accurate models — which can capture a higher degree of granularity and lead to better, more realistic solutions.

Ability to solve your model type

A solver is helpful only if it can handle your particular model types. Depending on the complexity of your model, a straightforward, open-source, LP solver may do the job.

However, if you're dealing with more complex problems, you will likely need a solver that can also handle MIP or NLP models.

TIP

When evaluating a solver, talk with the provider about your specific use case, the problems/models you work with, and other specific requirements to ensure alignment.

Global optimality

Solvers differ based on whether the solutions they produce are locally or globally optimal. A *locally* optimal solution is the best solution compared to those around it (within a certain area or context). In contrast, a *globally* optimal solution is the best solution of *all* possibilities. So, if you want the best of the best solutions, look for a solver that can solve to global optimality.

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Support

Organizations often have a lot riding on optimization outcomes — from profits to customer satisfaction and much more.

With that much at stake, you shouldn't need to embark on your optimization journey alone — even if you're an experienced operations research professional. Look for a solver that offers a dedicated and experienced support team that will be there to answer your questions, help tune your models, and guide you on the path to an optimal decision or solution.

TIP

Consider each vendor's business drivers when choosing a solver, especially if you're engaging the same vendor for implementation services. You want a vendor whose sole line of business is optimization, not one that's focused on selling a broader range of products and services.

Try Before You Buy

TIP

If you're curious about what a commercial solver can do for your optimization projects, we recommend starting with a free trial or evaluation, so you can see the solver in action and make a confident, informed decision — without the pressure of a long-term, up-front commitment. Be sure to make a list of questions and key requirements to discuss with the vendor, including your use cases, goals, and KPIs.

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IN THIS CHAPTER

- Seeing optimization in action
- Exploring optimization resources for beginners
- Getting some hands-on experience

Chapter 3
Putting Optimization into Action

Mathematical optimization is interesting in theory and even more compelling in practice. In this chapter, you see optimization in action through five diverse real-world case studies. You also discover how to start producing extraordinary results of your own, with some user-friendly resources that enable nearly anyone to start optimizing.

Checking Out Five Real-World Use Cases

Optimization has been used to lower costs and improve operations across the business spectrum for decades. In fact, 70 percent of today's leading enterprises use optimization to make better business decisions. We selected the following success stories from a variety of business settings, industry sectors, and applications to represent the diverse applications of mathematical optimization:

- Scheduling the perfect season
- Optimizing tail assignments for an international airline
- Delivering robust portfolios for a major asset management firm

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- Optimizing schedules for smarter workforce management
- Supplying humanitarian aid before disaster strikes

REMEMBER

These brief case studies represent only the tip of the iceberg of possibilities.

Game plan: Scheduling the perfect season

Each year, a small group of people at a major American professional sports league must schedule 272 games for an 18-week season while working with thousands of constraints around stadium availability, travel considerations, competitive equity, and TV viewership.

For decades, this task was executed using a 6-foot-square pegboard that mapped out who would play whom, when, and where. The board enabled planners to get the job done, but the organization strove to create the *best possible* schedule. Creating a full season's worth of matchups that satisfy not only all constraints but also teams, broadcasters, and fans is a task that demands the power of optimization.

With trillions of possible schedules to consider, the league's planners use mathematical optimization to generate and further analyze more than 50,000 feasible schedules, while adding more constraints to the process every year.

With optimization, instead of working for months to manually create just one or two feasible schedules, the planners can focus on evaluating and comparing completed schedules produced by optimization to determine the single *best* plan. Humans are still involved, carefully reviewing the recommended schedules in detail. But with optimization as their assistant, the schedulers no longer need to spend months rearranging items on a board.

Optimizing tail assignments for a major airline

One of the world's largest air carriers sought to build the most efficient schedule for its entire fleet in order to save on fuel and operational costs, while also reducing delay propagation. They turned to mathematical optimization to help solve what they call

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the "tail assignment problem" — modeling the entire aircraft planning process, from fleet assignment to the day of operation.

The carrier's operations research team built a decision support tool to recommend a solution that internal users can use to fit their specific needs. The tool provides an optimal solution with respect to the given constraints and the criteria, but the user still has the flexibility to make decisions based on experience, if needed.

After implementing this optimization-powered solution, the carrier saw a 1 percent reduction in fuel costs, on top of what they thought was an optimal fuel bill. Delay propagation and operational costs were also reduced.

Generating optimal fixed-income portfolios

The success of an asset management firm rests, in large part, on the strength of its investment portfolios.

To design and deliver robust portfolios that consistently produce healthy returns for individual and institutional investors, asset managers must consult the right experts, use the right tools, and put in place the right processes.

In the case of one international asset management firm, mathematical optimization allows their fundamental and quantitative portfolio managers and researchers to efficiently allocate assets for fixed-income portfolios in a way that maximizes risk-adjusted returns, minimizes risk, and ensures compliance with industry regulations and investment guidelines.

Furthermore, because they can now quickly construct optimal fixed-income portfolios, the firm's portfolio managers and researchers have enough time to carefully analyze and evaluate these portfolios, making any necessary adjustments to the proposed allocation before executing trades and rebalancing.

Optimizing rosters for smarter workforce management

The way a business manages its workforce affects much more than just the hours employees work. It ultimately impacts customer service, legal compliance, and the bottom line.

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One personnel scheduling company aims to change the way businesses engage their workforces by applying sophisticated mathematics, optimization, and machine learning. These methods provide accurate daily forecasts to help organizations across industries avoid the wasted costs associated with over-coverage, as well as the poor customer service that can result from gaps in coverage.

Clients who use the platform can maximize profits simply by having the right people working at the right time. With an innovative, optimization-driven approach, these businesses no longer need to build rosters from scratch, and they can be confident that their employees are paid correctly and in compliance with government regulations.

Delivering the right humanitarian aid before disaster strikes

Optimization isn't just for businesses looking to cut costs or maximize profits. As one international humanitarian logistics and preparedness project has demonstrated, optimization can significantly improve disaster response.

The project aims to minimize gaps and redundancies in emergency response planning while improving coordination among humanitarian actors to ensure that aid is delivered where and when it's needed most.

By applying mathematical optimization, the working group of member states, nongovernmental organizations, academics, United Nations (UN) agencies, and regional organizations can strategically determine the best locations and quantities for essential items — such as blankets, tents, clothing, hygiene kits, sleeping mats, and kitchen supplies — before disasters occur. In doing so, they ensure that critical resources are readily available and positioned to provide timely support to impacted communities.

The organization's stock mapping and analysis tool also tells users how much stock they should have in a particular location, as well as where there may be too much stock that could be relocated. Users can also get an idea of how much time and money they could save by implementing the system's recommendations.

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The user-friendly platform not only makes the deployment of humanitarian aid more efficient, but also empowers the individuals and organizations within the affected countries to take charge of their disaster response efforts.

Getting Started: Tools and Software for Beginners

Unless you have a mathematical background, many of the optimization concepts introduced so far probably seem intimidating. You may be wondering how you could possibly replicate the success of the organizations mentioned here without a PhD in a mathematical field.

The good news is that mathematical optimization is getting more accessible each year, with new tools and technologies designed to help users master best practices for modeling.

This section introduces you to several resources that can help you get up and optimizing quickly with some basic models.

Getting started with Python and optimization libraries

Python is the go-to programming language for optimization. It's widely used for a number of reasons:

- **It's easy to use.** Python's simple syntax and readability make formulating and solving optimization models a straightforward, intuitive process.
- **It integrates well with data science workflows.** If you're already using Python for data analysis or machine learning, adding mathematical optimization to your workflow is a natural next step.
- **It offers access to powerful optimization solvers.** With libraries like Gurobi, you can access a powerful optimization solver capable of handling large, complex problems.

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The following sections describe several Python libraries that make modeling optimization problems more approachable for those who can code but may not have experience with optimization. We also provide a general overview of the steps for using Python and your library of choice to solve linear programming problems.

PuLP

PuLP is an open-source library that provides a simple interface for formulating and solving both linear and mixed-integer linear programming problems. It can generate mathematical programming system (MPS) or linear programming (LP) files and call a variety of solvers, including Gurobi, to solve linear problems, making it a versatile tool for Python users.

Here are the advantages of PuLP:

- It's a simple and intuitive library for linear programming — great for learning the basics.
- It works well for small to medium-sized models.
- It uses a syntax that feels close to math.

SciPy

SciPy is another open-source Python library containing diverse algorithms for solving scientific, technical, and financial optimization problems. Though it's not as specialized as Gurobi or PuLP, it's robust and suitable for solving simple problems.

The advantages of SciPy include the following:

- It's ideal for engineering, economics, and scientific applications.
- It can offer a quick way to prototype optimization problems (especially if your model has no integer or binary variables and you're already using SciPy or NumPy for analysis).

Gurobi Python API

Gurobi comes with a Python extension module, gurobipy, that features convenient object-oriented modeling constructs and an application programming interface (API) to all Gurobi features. It offers advanced algorithms, powerful modeling tools, and

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excellent support for large-scale problems. However, it's important to note that, unlike the other two libraries listed here, it's part of a commercial product.

The advantages of the Gurobi Python API include the following:

- It's a powerful, industrial-strength solver with a Python interface.
- It's able to handle large, complex models at top speed.
- It comes with numerous learning resources for beginners and expert support (plus free licenses for academics).

Solving a linear problem with Python

After you've chosen the right library for your needs, you're ready to get started with linear programming in Python. The following steps provide an overview of the process:

1. **Install the chosen library (PuLP, SciPy, or Gurobi).**
2. **Define your objective, variables, and constraints and use them to formulate your LP problem statement (see Chapter 2).**
3. **Translate your LP problem statement into mathematical terms (see Chapter 2).**
4. **Use the library-specific syntax to translate your problem statement into computer code (Python).**

   You need some programming knowledge to perform this step. In the following sections, we direct you to resources that can bring you up to speed on the basics.
5. **Feed the model into your solver to identify the optimal solution.**

   In practice, this usually means calling the solver directly on the model object you created in Step 4. You can also export the model to an LP file, which is useful for debugging, or to an MPS file, which is useful for sharing. However, you don't typically need to create these files just to solve a model.
6. **Analyze and interpret the results.**

   The results may deliver the ideal decision or solution, or they may reveal a need to revise the model.

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Running a simple optimization model

TIP

Looking for a step-by-step walk-through of the modeling process? Here you'll find a Jupyter notebook that outlines the basics and enables you to write and execute Python code through your browser: `www.gurobi.com/jupyter_models/introduction-to-mathematical-optimization-modeling/`.

Exploring hands-on learning resources

One of the biggest myths about optimization today is that it's only for math experts.

Thanks to interactive tools, user-friendly tutorials, and communities of like-minded users who are eager to help, modeling and solving optimization problems is more accessible than ever. In fact, Gurobi offers a range of free, high-quality educational resources designed specifically for beginners. This section steers you to several resources to help you get started.

TIP

You can access all of these tools and more at `www.gurobi.com/learn`. Happy optimizing!

OptiMods

No modeling experience? No problem. This open-source library of ready-to-use optimization models provides Python users with high-level access to optimization capabilities for common business problems, such as workforce scheduling, production planning, and vehicle routing.

TIP

Ready to jump in? Start fine-tuning your modeling skills for free at `www.gurobi.com/features/gurobi-optimods/`.

No need to start from the scratch — you can load a model, plug in your data, and see optimization in action. Each "Mod" (model) comes with explanatory documentation of the problem it's intended to solve, as well as runnable example codes and data sets.

REMEMBER

For many practical applications, you'll need to understand and extend the implementation of the Mod to tailor it to your use case.

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Opti Training Series for Data Scientists

Gurobi offers on-demand, self-paced tutorials designed for data scientists, machine learning enthusiasts, analysts, academics, and professionals seeking to elevate their skills. Featuring hands-on examples, real-world use cases, and more, these expert-led trainings guide you through the basics, offering the tools you need to formulate and code your own comprehensive application while demonstrating how optimization integrates with machine learning.

TIP

Start here: `www.youtube.com/playlist?list=PLHiHZENG6W8B_65-Unq-G59PtQtEc1Xj4`.

Free online course: Introduction to Optimization Through the Lens of Data Science

In this free massive open online course (MOOC), Dr. Joel Sokol, Harold E. Smalley Professor at Georgia Tech, provides a unique opportunity for data scientists to enhance their skill sets with optimization.

Tailored specifically for students and professionals in data science, this in-depth course makes optimization accessible by focusing on practical, actionable skills, instead of taking a deep dive into theory.

TIP

Enroll today at `www.gurobi.com/resources/intro-to-optimization-through-the-lens-of-data-science/`.

Jupyter notebooks

If you're looking to try out Gurobi's Python interface, one of the best ways to get started is through Gurobi's Jupyter Notebook library. These notebooks offer interactive coding environments to help you develop your knowledge and skills and experiment with optimization. Included are dozens of examples designed specifically for beginners.

TIP

Dive into hands-on examples at `www.gurobi.com/jupyter_models/`.

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Large language models for optimization

Generative artificial intelligence (GenAI)–based tools are being positioned to transform the workflows surrounding mathematical optimization, making it more accessible to a broader range of users. In fact, we've already seen several of our customers successfully build simple models with help from GenAI.

TIP

You can explore some of Gurobi's latest AI-powered innovations, including Gurobot, our AI-powered expert agent, at `www.gurobi.com/gurobi-innovation-lab/`.

REMEMBER

At Gurobi, we're constantly looking to leverage new opportunities in this space while still honoring the importance of classical model development techniques.

The Burrito Optimization Game

Who says math has to be boring? Remember to save time for a little hands-on fun — and a few burritos! The Burrito Optimization Game is an interactive, web-based game that introduces the concepts of mathematical optimization in a fun and engaging way.

Players manage burrito food trucks and make decisions about how many burritos to make, where to position their trucks, and what prices to set, with the goal of maximizing profit. The game also features a championship mode that allows instructors and trainers to create a fun competition that reinforces the value of optimization. It includes a full teaching guide and supplementary resources.

TIP

Start playing here: `www.gurobi.com/burrito-optimization-game/`.

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IN THIS CHAPTER

- Exploring common reasons optimization models fail
- Figuring out what went wrong
- Persisting in the face of early failures

Chapter 4 Overcoming Common Pitfalls

Suppose you've built your model and hit Solve with eager anticipation. But instead of an optimized solution, you get an error. Don't panic — even experienced teams encounter this. It doesn't mean optimization won't work for you; it usually just means your data or setup needs a small adjustment.

In this chapter, we walk you through some common reasons optimization models fail, share useful troubleshooting tips, and — most important — explain why you shouldn't give up on optimization just because it doesn't solve your problem the first time.

Understanding Why Optimization Models Sometimes Fail

Failure to optimize may manifest in various ways, ranging from the results not being physically meaningful or not making sense, to a technical inability to complete the optimization process. In this section, we explore a few common obstacles that may stand in the way of turning an optimization model into a useful solution.

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Your data quality is poor

Models rely on data, so if your data is inaccurate or incomplete, the model will produce poor results. To obtain quality solutions from your optimization model, start with quality data.

Testing was insufficient

No matter how confident you are in your model, it's always important to test it in a realistic environment. Insufficient testing can lead to unexpected issues when the model is deployed, and you may miss critical gaps between the model's assumptions and actual conditions.

The model is infeasible

If your model is *infeasible*, it means there is no way to satisfy all your constraints at once. As a simple example, if your model requires the addition of ten units of your resources but your budget constraints allow for only eight, the solver won't be able to find a solution — because there isn't one. This doesn't mean optimization "failed"; it simply means that the rules you set up conflict with each other.

The model is unbounded

In optimization, infinite solutions aren't something you hope to find — but that's what you could end up with if your model lacks the right constraints. For example, without a limit to how many units you can produce, your model may project infinite profits.

It's also possible that you unintentionally omitted some important real-world constraints, such as resource limitations or regulatory requirements. That's why thorough testing is so important.

Open-source solvers may not be sufficient

If you run into trouble using an open-source solver, the issue may be that the computational software isn't powerful enough to handle your model. For example, maybe the solver wasn't able to complete the optimization process within the required timeframe, or maybe it ran into numerical issues that couldn't be remedied.

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REMEMBER

Open-source solvers can be a great way to get started with optimization — but if they can't solve your problem, don't assume that your model is unsolvable. Give the process another try with an evaluation trial of a commercial solver.

Debugging and Troubleshooting Your Optimization Model

When your optimization model fails to deliver the desired answer or solution, naturally you want to know what went wrong. Here's a simple, systematic approach to identifying the root cause of the failure:

- **Audit your data.** Data quality has a major impact on a model's performance. Make sure your units are consistent and check for anything that may be missing or is obviously incorrect. Sometimes, simply cleaning up your data can resolve your issues entirely.
- **Validate your modeling assumptions.** Before you dive deeper into troubleshooting, take a step back and carefully review the assumptions you made when building your model. Are your constraints too tight (or too loose)? Does your model accurately capture the real-world business logic — such as the relationships, dependencies, and priorities that exist in practice?

  To validate your assumptions, consider consulting with subject matter experts or stress-testing your model using edge cases. This validation process ensures that your model not only solves correctly but also provides solutions that are relevant, feasible, and actionable in the real world.
- **Run an infeasibility analysis.** Many solvers offer features or tools for conducting an infeasibility analysis. For example, Gurobi offers irreducible inconsistent subsystem (IIS) infeasibility analysis, as well as a feasibility relaxation framework, which enable you to track down the source of any constraint conflicts and fix the problem in your model.
- **Tune your optimization run or reduce the complexity of your model.** With Gurobi's automatic parameter tuning and expert support, you can adjust the settings of the solver

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algorithms to find the best configuration for your problem. Although the default parameter choices are quite powerful, they may not be optimal for every case. Instead, you can experiment with different combinations and see how they impact performance and quality.

TIP

If you're having trouble finding a solution, try stripping your model back to a very basic version. Then gradually add back in more constraints or decision variables, testing along the way, until you identify the source of the issue. You can also try to resolve the discovered bottleneck from an alternative modeling perspective.

- **Ask the community.** The optimization community is full of brilliant people who are eager to share their knowledge and happy to help someone who's struggling. In addition to your solver's support team, optimization forums, user communities, and learning platforms are all great resources. Ask questions, share your own experience, and learn from others.

Committing to Success: Why You Shouldn't Give Up on Optimization

Even for seasoned optimization professionals, challenges with models are bound to arise every now and then. Experienced teams know these are normal, solvable bumps in the road — not signs that optimization doesn't work. With the right guidance, most organizations move from challenges to measurable wins quickly.

The optimization community is growing rapidly, and new resources are emerging every day to support both beginners and experts. From free online courses to solver-specific documentation, artificial intelligence (AI)–powered tools, and vibrant forums, the guidance you need is often right at your fingertips.

REMEMBER

You're not alone on this journey, and you don't have to start from scratch.

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IN THIS CHAPTER

- Tracking developments in optimization and AI
- Looking into how emerging technologies are driving change
- Capitalizing on the surge in demand for optimization talent

Chapter 5
Looking to the Future

Optimization has been around for decades, but it's growing and evolving at a rapid pace. This chapter gives you a sneak peek into the future of optimization, explores factors that are driving its evolution, and shares insight into how to prepare for the growing demand for optimization expertise.

Exploring Trends in Optimization and AI

As you're no doubt aware, artificial intelligence (AI) is ubiquitous — it plays a role in everything from making product recommendations to providing tech support to running smart homes. But what you may *not* know is that optimization can make other AI techniques like machine learning more useful, efficient, and scalable.

Machine learning extracts insight from data, while optimization prescribes the best course of action based on that data. Together, these technologies create smart, data-driven systems that not only predict what may happen but also help you decide what to do next.

For example, in supply chain management, machine learning can help predict future demand patterns, but optimization can help determine how to best meet that demand given available

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resources, while minimizing costs and maximizing service levels. For business leaders, this means fewer surprises, more resilient operations, and faster response times.

Similarly, in workforce scheduling, machine learning can forecast the busiest hours (when more employees are needed), but optimization can ensure that schedules are adjusted accordingly based on your constraints, in real time, to maintain productivity. As machine learning unlocks new insights, optimization ensures that organizations can act on those insights in the smartest possible way.

Figure 5-1 shows common AI techniques and illustrates the key differences between generative AI (GenAI), machine learning, and optimization, and how the options can be used together as a powerful tool for driving decisions, solving problems, and boosting productivity.

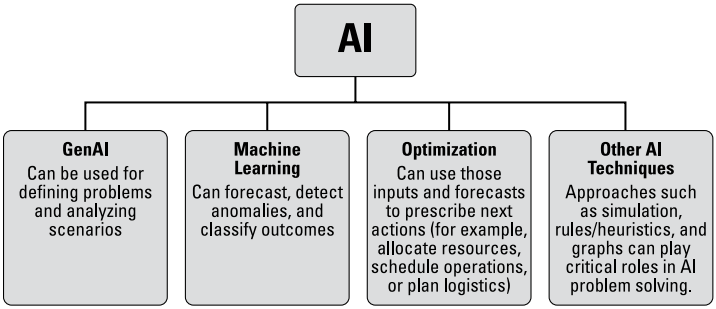

FIGURE 5-1: GenAI, machine learning, and optimization can be combined in powerful ways.

REMEMBER

According to Gurobi's survey of optimization users, 81 percent reported that their organization combines machine learning with mathematical optimization for at least one project. This relationship between machine learning and optimization is expected to grow even closer, opening the door to new possibilities. Their combined use empowers human decision-makers with even smarter, more actionable recommendations in real time.

Explainable decision-making

Unlike some "black box" AI systems, optimization provides clear, explainable decisions. This isn't just a technical detail — it's a major business advantage. Optimization models are not open for

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interpretation, so they make it 100 percent clear what defines a valid solution, while the algorithms provide a mathematical proof of the solution quality that can be fully trusted. Because of this, organizations can use optimization to comply with audit requirements and foster greater trust in automated systems. As more AI regulations are put in place worldwide, optimization's ability to deliver transparent, defendable decisions will only become more valuable.

Making optimization more accessible with Gurobot

Optimization is already more accessible than ever, and new AI capabilities are helping to democratize it even further. GenAI can help users understand their models by explaining constraints, surfacing errors, and clarifying how different parts of a model impact the final decision.

Conversational agents — such as Gurobi's own Gurobot — make it easier to get started with optimization by answering detailed questions, identifying coding issues, and guiding users toward best practices in modeling and solver usage. This empowers more business users to confidently leverage optimization in their daily decision-making.

You can learn more about Gurobot at `www.gurobi.com/solutions/gurobot/`.

Understanding the Role of Emerging Technologies

As if optimization weren't already a powerful tool for making data-driven decisions, solving problems, and boosting productivity, a couple other technologies hold the promise of turbocharging optimization. Here, we look at two technologies that are likely to drive the future development of optimization.

GPU-enabled optimization

Graphics processing units (GPUs) are highly efficient at processing large amounts of data in parallel. New developments in GPU-enabled optimization algorithms are making it possible to solve some very large linear programming problems with greater speed.

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At the time of this writing, GPU-enabled optimization applies to just a handful of use cases. However, research and testing are ongoing, and we expect GPU-enabled algorithms to open new opportunities in some real-world optimization applications.

Quantum optimization

Quantum optimization has the potential to drive some major developments in the coming years, including for optimization algorithms. By leveraging the power of subatomic phenomena, quantum computing could solve some of the world's greatest challenges — and companies and governments want to be ready to take full advantage of these capabilities.

However, while quantum computing is understood from a theoretical point of view, it has yet to scale to an industrial-size machine. Even so, the race to develop quantum-ready algorithms is well underway. By implementing optimization into their workflows and decision-making processes now, organizations can benefit from optimized outcomes today, while preparing for the quantum possibilities of tomorrow.

Preparing for the Growing Demand for Optimization Skills

As additional resources become available to make optimization more approachable, the demand for optimization skills continues to rise. In fact, the Bureau of Labor Statistics projects an additional 24,100 operations researchers (who traditionally are optimization modelers) and 82,500 data scientists will be needed by 2034. This growth is fueled by the rapidly increasing adoption of advanced analytics, AI, and data-driven decision-making across nearly every industry.

Organizations are looking not only for technical experts who can analyze data, but also for professionals who can translate that data into a functional model (potentially leveraging GenAI to do so) and drive actionable business strategies. As more businesses discover the transformative power of optimization technology, those with relevant skills will find an abundance of opportunities in the job market.

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IN THIS CHAPTER

- Reaping the benefits of versatility and performance
- Getting expert advice from a supplier focused solely on optimization
- Using your solver however and wherever you want

Chapter 6
Ten Reasons to Solve with Gurobi

In the *For Dummies* tradition, here are the top ten reasons to select Gurobi for your optimization needs:

- **World-class performance:** Having developed the fastest linear programming/mixed-integer programming (LP/MIP) solver available, Gurobi's engineers strive to maintain the solver's pole position with each new release by leveraging the latest technologies and approaches. For business leaders, this speed means answers in minutes instead of days — enabling faster response times, reduced costs, and the ability to act while opportunities are still relevant.

  Nearly as important as solution time is numerical stability. An LP/MIP solver relies on finite-precision arithmetic; this means that there are limited bits to represent numbers, but mathematically, you need to compute in an infinite space. If you can't represent all numbers at 100 percent accuracy, small errors are normal, but they need to be handled to ensure robust operation. Without numerical stability, even highly respected solvers can produce solutions that are simply incorrect. Or, they slow down. In the worst case,

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the solver is unable to complete the calculations because the computer can't deliver the required accuracy.

REMEMBER

Stability is among Gurobi's widely recognized strengths, and it's a primary reason why Gurobi has been adopted extensively by the most demanding users of optimization tools: researchers.

- **Laser focus on optimization:** A key consideration when adopting a new technology is the nature of your vendor's commitment to the market. Gurobi began as, and steadfastly remains, an optimization-technology-focused company. That focus manifests itself in everything from Gurobi's product design to its licensing policies — and it's important to understand, before making your technology choice, that such tight focus is not a given.

REMEMBER

Gurobi pours a tremendous amount of its resources into improving its main product, the solver, and developing innovative ways to help users get the most from it.

- **Expert advice:** Gurobi's globally distributed, PhD-level optimization experts work one-on-one with users to diagnose complex modeling and tuning challenges, offering tailored guidance to help users fully leverage the capabilities of Gurobi's optimization tools. Additionally, they take the time to respond thoughtfully in detail to every inquiry, as well as to many of the questions asked in our user forum.

  The Gurobi experts are deeply integrated with both the development and technical account management teams, ensuring fast, knowledgeable, and context-aware responses. With a 99 percent customer satisfaction rating, they're committed not only to solving problems, but also to empowering users with the confidence and insight they need to succeed.

  In other words, you don't need to hire all the expertise yourself — Gurobi's team becomes an extension of your own, helping you see results faster and with less risk.

- **Versatile solving:** Admittedly, versatile solving is a technical issue, but one critical to IT developers. The bedrock of optimization is a class of models and algorithms called LP. However, most real-world applications result in MIP models. In finance and pricing applications, among others, quadratic programming (QP) models also arise.

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Gurobi can handle LP, MIP, nonlinear programming (NLP), QP, mixed-integer quadratic programming (MIQP), mixed-integer quadratically constrained programming (MIQCP), non-convex models, and more — usually faster and more robustly than any competing product. (See Chapter 2 for details about LP, MIP, NLP, and QP.)

REMEMBER

The ability to solve such a broad array of models within a single solver reduces integration complexity and eliminates vendor sprawl, or the need to switch tools or vendors mid-project.

For users, this means less time spent learning new software and more time focusing on their problem. For business decision-makers, the takeaway is simple: Whatever your challenge — scheduling, pricing, resource planning — Gurobi can handle it in a single, reliable solution.

- **Flexible licensing:** Gurobi's flexible approach to licensing means you can use Gurobi how and where you want, for any number of users — for both development and deployment. You can scale up to add new projects easily, without undue administrative burdens.

REMEMBER

This flexibility protects your investment — whether your IT landscape shifts to the cloud, stays hybrid, or evolves in unexpected ways.

- **Built for parallelism:** Engineered from the ground up as parallel code, Gurobi scales efficiently across multi-core central processing units (CPUs) — no extra cost or configuration needed. Recent updates have significantly improved parallel processing efficiency and memory usage, further reducing solve times for large-scale models. These improvements matter in real-world scenarios, where even small reductions in solution time can have significant economic impact on time-sensitive decision situations.

  For your business, that means even large-scale, time-sensitive problems can be solved faster — keeping operations running smoothly and costs under control.

- **Multi-objective and scenario analysis:** Gurobi supports *multi-objective optimization* (models with competing objectives) using a number of techniques, including blended objectives, hierarchical objectives, and a hybrid approach that combines these two. In addition, Gurobi supports flexible prioritization, what-if scenario evaluation, solution pools, and automated parameter tuning.

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- **Robust infeasibility diagnostics:** Gurobi includes tools to help you quickly pinpoint where infeasibility exists in your model, enabling faster debugging and model refinement so you can get back up and running faster and easier.
- **Easy-to-use high-level application programming interfaces (APIs):** Gurobi features lightweight, intuitive APIs for Python (gurobipy), C/C++, Java, .NET, MATLAB, and R, as well as interfaces for AMPL, GAMS, AIMMS, and Microsoft Excel. No matter which programming language you prefer, Gurobi ensures a seamless, user-friendly experience.
- **Proven track record:** Used by more than 1,200 organizations across more than 40 industries — including transportation, financial services, supply chain management, and power and utilities — Gurobi has a proven ability to meet diverse needs.

TIP

Ready to see Gurobi in action? Request a free, 30-day evaluation license to test our solver and get access to our team of optimization experts, who will help you fine-tune and benchmark your models: `www.gurobi.com/free-trial`.

Academics: You may qualify for a free, full-featured Gurobi license. Explore our academic program at `www.gurobi.com/academia`.

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Uncover what you need to know about mathematical optimization

If you're exploring how to bring the power of artificial intelligence into your organization, mathematical optimization is the key to making AI results actionable, reliable, and trustworthy. But what kind of problems can optimization solve? How does optimization support better business decisions, and how is it different from other AI technologies? Can it really transform the way your business plans, allocates, and competes? This book can help you find the answers to all of these questions and more.

Inside...

- See how optimization can help your business become more successful
- Choose the best optimization software for your needs
- Recognize where optimization creates the most value
- Understand how optimization and generative AI can work together
- Explore real-world success stories

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