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What Is Mixed Integer Programming?

Mixed integer programming (MIP) is a mathematical optimization technique that solves problems involving a mix of continuous variables (which can have any value, including decimals and fractions), discrete variables (which must be countable whole numbers), and binary variables (which can only take values 0 or 1).

Why Is Mixed Integer Programming Useful?

MIP is a powerful tool widely used in operations research and decision science to solve complex optimization problems. It can help in scenarios with constraints, limited sources, and discrete decisions.

For business decision-makers and data scientists, MIP provides a structured way to make the best decisions for real-world challenges, like resource allocation, production planning, workforce scheduling, and facility placements.

For developers, MIP models provide a systematic and structured approach to optimization, enabling the encoding of real-world constraints, objectives,

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workforce planning to shop. This approach
empowers businesses to make data-driven,
optimal decisions quickly and accurately.

By adopting MIP, businesses can:

- **Ensure Optimal Decision-Making:** MIP doesn't just provide "a solution"—it guarantees the best solution possible within defined constraints, making decisions data-driven and efficient.
- **Achieve Better Resource Utilization:** From minimizing shipping costs to maximizing production throughput, MIP ensures resources like time, money, and manpower are allocated optimally, enabling businesses to do more with less.
- **Evaluate Trade-Offs Systematically:** MIP enables scenario analysis at scale, helping businesses evaluate critical trade-offs (cost versus speed, staff versus service levels) rather than relying on heuristics or gut instinct.
- **Enhance Resilience Under Constraints:** In a dynamic business environment, MIP models can be updated with new data, allowing businesses to adapt to disruptions (e.g., supply chain issues, labor shortages, or regulatory changes) and find the best possible solutions

When businesses use MIP, they can optimize their processes and increase profitability by making more informed, data-driven decisions faster and effectively. For developers, MIP offers a powerful framework for representing and solving complex decision problems with precision and structure. For businesses, it's a strategic tool that transforms complexity into clarity, enabling optimized decisions under real-world constraints

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MIP is a two-step process: problem modeling and problem solving, which allow businesses and developers to optimize decision-making across various complex scenarios.



Figure 1. Steps in mixed integer programming (MIP) problem-solving

Problem Modeling

In the first step, users—such as developers, analysts, or data scientists—formulate the real-world problem by identifying key components and expressing them mathematically. This is known as problem modeling.

Key model components are:

- > **Decision Variables:** These represent the choices to be made. They can be:
 - > **Binary:** 0 or 1 decisions (e.g., whether to open facility or not)
 - > **Discrete:** Countable values (e.g., number of items to produce)
 - > **Continuous:** Any real value (e.g., amount of raw material used)
- > **Objective Function:** This is the goal of the optimization. The objective could be:
 - > **Single-Objective:**
 - > **Maximization:** E.g., maximizing profit or revenue

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> **Represented as Constraints:** Objectives are framed as constraints on target goals.

> **Constraints:** These are the boundaries within which the decision variable must operate. Constraints can be:

- > **Logical:** E.g., total number of stored items can't exceed warehouse capacity
- > **Physical:** E.g., material or space limitations
- > **Capacity-Based:** E.g., labor hours or machine capacity
- > **Policy-Driven:** E.g., company or regulatory rules

$$\begin{aligned} \max z &= 4x + 5y \\ \text{s.c. } &2x + y \leq 8 \\ &x + 2y \leq 7 \\ &y \leq 3 \\ &x, y \geq 0, \text{ integers} \end{aligned}$$

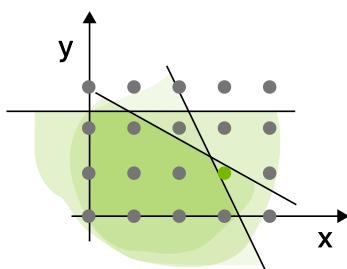


Figure 2. Example of a mixed integer programming (MIP) model and its solution space: x and y are the decision variables, and z is the objective function. The inequalities form the constraint boundaries, represented as lines. Blue dots indicate feasible (valid) solutions that satisfy all constraints, while the green dot marks an optimal solution that maximizes the objective.

Problem-Solving

Once the problem is modeled, it must be solved using algorithms that navigate through the solution space to find the optimal solution.

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2. Solving the Model

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The solver interacts with the encoded model either through standard formats (e.g., [LP](#), [MPS](#), [NL](#)) or APIs like [solver.solve\(model\)](#).

The solver performs several steps.

- **Parsing the Model:** Understanding the structure of the problem
- **Pre-Solving:** Using techniques like [linear relaxations](#), constraint tightening, and bound propagation to simplify the problem
- **Solving:** Applying algorithms such as [branch-and-bound](#), [cutting planes](#), and [heuristics](#) to efficiently navigate the solution space and solve the model efficiently

The solver's output will include:

- **Optimal Decision Variables Values:** E.g., the best values for production quantities or resource allocation
- **Optimal Objective Function Value:** E.g., the best profit or minimum cost
- **Solver Status:** E.g., optimal, infeasible, unbounded

3. Solution Interpretation:

Once the solution is found, the user interprets the output by analyzing the results (e.g., determining the best routes to take or how much to produce). Additionally, the user may examine [dual values](#), [slack](#), or solve multiple scenarios to assess different trade-offs and solutions.

4. Deployment and Automation:

The MIP solution is often integrated into a larger decision system, such as supply chain planning, workforce allocation, or production

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Enabling automated responses based on
constantly changing inputs (e.g., in logistics
or emergency services)



What Are Popular Algorithms Used for Mixed-Integer Programming?

To tackle real-world problems efficiently, various algorithms are employed to find the best solutions while managing constraints and resources.

One such technique is the linear programming (LP) relaxation of an MIP model, where the integrity requirement for integer variables is relaxed (i.e., removed). This provides an upper bound for a maximization problem or a lower bound for a minimization problem, which can then be used in combination with the branch-and-bound technique to guide the search for an optimal solution.

The table below outlines some of the most widely used algorithms in MIP, explaining the core principles, typical use cases, and their impacts on improving the efficiency of solving MIP problems.

Algorithm	Description	Use Case/Impact
Branch-and-Bound	A tree search method that divides a problem into a smaller subproblems (branching), bounds the solution space, and prunes unpromising branches	Used for solving large MIP problems by exploring feasible solutions more efficiently

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Cutting Planes

remove parts of the solution space that cannot contain optimal solutions without affecting feasible ones

Heuristics

Approximation methods or shortcuts that find “good enough” solutions quickly, particularly when finding the perfect solution is computationally expensive

Interior-Point Methods (Barrier Method)

Algorithms that solve linear programming problems by traversing the interior of the feasible region instead of along the boundary like the Simplex method

Lagrangian Relaxation

A technique where difficult constraints are relaxed by incorporating them into the objective function, simplifying the problem

Simplex

An optimization algorithm that solves linear programming problems by moving along the edges of a feasible region to find the optimal solution

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methods like branch-and-bound to speed up solving and reduce computational time

Useful for getting near-optimal solutions quickly when time or computational power is limited, and for performing quick what-if analysis or real-time adjustments on the original model

Useful for large-scale problems, particularly in cases with a large number of constraints or variables

Effective for decomposing complex MIP problems into a set of simpler subproblems that are easier to solve independently

Primarily used for the continuous part of MIP problems, and often used as a subroutine in MIP solvers

What Are the Applications of Mixed Integer Programming?

MIP is extensively applied across both business and non-business sectors to solve high-stakes optimization problems. It provides a powerful framework for making decisions involving limited

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Business Use Case	Description	Optimization Focus	Relevant Industry
Resource Allocation	Optimizing the distribution of limited resources to maximize efficiency or minimize costs	Allocation of raw materials, budget distribution, workforce assignment	Manufacturing, financial services, healthcare and life sciences, and retail: Optimizing resource and budget allocation for production, investments, medical staff, and marketing campaigns
Production Planning	Designing efficient production schedules to meet demand while minimizing costs and resource usage	Production scheduling, inventory levels, machine utilization	Manufacturing, automotive, and food and beverage: Optimizing production schedules, reducing downtime, and aligning production with demand fluctuations
Workforce Scheduling	Assigning shifts and tasks to employees to meet operational needs, considering labor regulations and employee preferences	Shift assignments, workload balancing, compliance with labor laws	Retail, healthcare and life sciences, logistics, and hospitality: Optimizing staff scheduling for peak hours, shift rotations, and high-demand periods
Route Optimization	Finding the most efficient paths for transportation and delivery while	Travel distance, fuel consumption, delivery time	Logistics and transportation, public transit, utilities,

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Non-Business Use Case	Description	Optimization Focus	Relevant Field
Facility Placement	Deciding the optimal placement of facilities to minimize costs and maximize accessibility	Facility placement, distance to customers, supply chain efficiency	Retail, logistics, healthcare and life sciences, and manufacturing: Optimizing facility placement to maximize customer access, reduce shipping costs, and improve service efficiency
Wild Habitat Conservation	Planning and optimizing the allocation of resources and land for the protection and preservation of wildlife habitats	Resource allocation, land use, habitat preservation	Conservation biology: Protecting endangered species and optimizing resource use
Disaster Responses and Emergency Resource Allocation	Optimizing the distribution of resources during disaster situations, ensuring fast and effective emergency responses	Resource distribution, response time, deployment efficiency	Emergency management: Coordinating resources in disaster scenarios (e.g., wildfires, earthquakes)

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Organ Matching and Cold Chain Routing

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Optimizing the allocation of organs for transport and routing of cold chain transportation for organ transport

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Resource allocation, route optimization, time sensitivity

Logic-Based Puzzles

Solving puzzles or problems where constraints must be satisfied, such as sudoku or other constraint satisfaction problems

Placement of numbers or items based on logical constraints

Healthcare and logistics:
Optimizing organ matching systems and ensuring timely, temperature-controlled transportation

Recreational mathematics:
Solving logic puzzles that involve multiple constraints, like sudoku

What Are Mixed-Integer Programming Challenges?

While mixed-integer programming (MIP) offers powerful optimization capabilities, its implementation and adoption come with several challenges across technical, implementational, and adoption areas. Below are key challenges that may arise when integrating MIP into business processes and the potential areas where innovation and evolution may emerge:

Technical Challenges

- > **NP-Hard Problems:** Many MIP problems are NP-hard, meaning they are computationally difficult and can take a long time to solve, especially for large datasets.
- > **Solver and Model Sensitivity:** The solution quality depends on the solver chosen and the model formulation. While selecting the right

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and the use of heuristics to improve solutions,
and solve problems within a reasonable time
frame.

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Implementation Challenges

- > **Solver Selection:** Choosing the appropriate solver (e.g., open source versus commercial) based on business needs, available resources, and desired performance can be complex. This decision impacts both cost and solution quality.
- > **Integration:** Integrating MIP models into existing data pipelines or production systems can be technically challenging, especially when aligning optimization models with operational workflows.
- > **Modeling Complexity:** Building MIP models requires both domain knowledge (understanding the business context) and mathematical expertise to correctly capture the constraints, variables, and objectives.

Adoption Challenges

- > **High Licensing Costs:** Commercial solvers often come with high licensing fees, which can be a significant barrier to adoption for smaller companies or those with limited budgets.
- > **Optimization Expertise:** Successful implementation requires specialized expertise in optimization, which may require investing in training or hiring professionals who understand the complexities of MIP.
- > **Explaining Results:** Communicating the results of MIP optimization to stakeholders who are unfamiliar with optimization methods can be challenging. It is important to provide clear, actionable insights that align with business goals.

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Dive into how GPU-accelerated linear programming (LP), a key enabler for mixed integer programming (MIP), is transforming large-scale optimization tasks with unmatched speed and scalability.

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Learn More About NVIDIA cuOpt

Explore NVIDIA cuOpt—an open-source decision optimization solver pushing the boundaries of optimization and delivering business-critical insights.

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