GUROBI
OPTIMIZATION

Combining Predictive and Prescriptive Analytics for Better Decision-Making

By adding prescriptive analytics to your data analytics toolbox, you can go beyond predictions—to optimized decisions.

As a data professional, you know how to extract the most value from your data and model. And your business leaders depend on your insights for making critical business decisions.

But what if you could do more to drive the decision-making process? What if, instead of delivering machine learning insights alone, you could include explainable decision recommendations, based on your real-world constraints and predicted future?

With Gurobi's prescriptive, decision intelligence technology, you can do just that.

As a result, your decision-makers will know exactly how to achieve their business objectives—rather than resorting to gut instinct or "what's worked in the past."

Let's dig into the details, including the difference between predictive and prescriptive, how the two work together, and the impact this can make for your organization.

What is the Difference Between Predictive and Prescriptive Analytics?

Predictive analytics tools, including machine learning, seek to find patterns in data, in order to predict what might happen in the future. For example, predictive analytics can predict who will launch which cyberattack, which experiments are more likely to prove the hypothesis, imminent machine failure, supply chain issues, infrastructure maintenance needs, and price movements—all before they happen.

Prescriptive analytics tools, including Gurobi's decision intelligence technology, help you make decisions based on your real-world goals ("objectives") and limitations ("constraints.") This can be especially useful when you're facing a business problem with multiple, conflicting goals (such as cutting spending while increasing production) and multiple constraints (such as time, distance, product availability).

What Is an Example of Prescriptive Analytics?

Although there are countless ways to use prescriptive analytics, here are some real-world examples from Gurobi customers:

- Transportation providers, such as Air France, Swissport, and Uber, use prescriptive analytics to create optimal routing, staffing, and maintenance plans.

- Professional sports leagues, including the National Football League and Beko BBL, plan their game schedules using prescriptive analytics.

- Manufacturers use prescriptive analytics to plan and manage the procurement, production, and distribution of their products.

What Is the Goal of Prescriptive Analytics?

Prescriptive analytics tools provide a detailed set of recommendations for how you can best achieve your goals, given your limitations. Although you can use it to automate decision-making, you can use it to inform your traditional decision-making processes. Its ability to explore what-if scenarios can be particularly helpful.

What Is an Advantage of Prescriptive Analytics?

Prescriptive analytics doesn't rely on historical data—which means you can make decisions for the future, even when it doesn't look like your past. To use prescriptive analytics, you need to know three things:

- The goals you need to achieve ("objectives"). For example:
  - Minimizing product costs
- The limitations you're facing ("constraints"). For example:
  - Minimum production of a given product
  - Required manufacturing time and cost of a particular machine
  - Raw material inventory
- The questions you're asking ("decision variables"). For example:
  - In which order should we produce which products?
  - In which manufacturing facilities?
  - On what product lines?
  - In what quantities?

With this information, the prescriptive analytics tool can generate a detailed action plan for achieving your goals, given your limitations.

How Can Prescriptive Analytics Be Used with Predictive Analytics?

Say you were planning a trip. Predictive analytics can predict what you may encounter along your journey (weather, traffic, engine trouble), and prescriptive analytics can, given those predictions, identify the route that best helps you achieve your goals (fastest, cheapest, safest route), given your constraints (time, budget, speed limits).

Here are some more examples:

Use predictive analytics to:	Use prescriptive analytics to:
Predict supply chain issues	Identify the least costly way to reroute shipments
Predict which cyberattacks are coming, and when	Identify the right investigators to assign, based on cost and skill
Predict imminent machine failure	Identify the best time to shut down the production line
Predict customer likelihood to buy more with targeted offers	Identify how many discount coupons to offer, to maximize revenue
Predict price movements before the market does	Decide how to allocate capital across all investment vehicles

```
# Set objective
    m.setObjective(x + y + 2 * z, GRB.MAXIMIZE)

# Add constraint: x + 2 y + 3 z <= 4
    m.addConstr(x + 2 * y + 3 * z <= 4, "c0")

# _
```

Is Prescriptive Analytics Hard to Learn?

Prescriptive analytics involves mathematical programming, but you don't have to be a math whiz.

Gurobi comes with a Python extension module called "gurobipy" that offers convenient object-oriented modeling constructs and an API to all Gurobi features.

The Gurobi distribution also includes a Python interpreter and a basic set of Python modules, which are sufficient for building and running simple optimization models. You can also install gurobipy into an existing Python installation or virtual environment.

We recommend jumping in with our functional code examples for commonly used features and our Jupyter Notebook library, which walks you through common optimization problems in Python.

You can find links to everything you need on our dedicated Data Science page.

Is Prescriptive Analytics Worth Learning?

Absolutely! Without it, you're not working with a complete data analysis toolbox. Perhaps you've heard of the Abraham Maslow quote, "If all you have is a hammer, everything looks like a nail." Well, if all you have is machine learning, you can sometimes forget that there are other ways to solve problems. And depending on the problem, there are definitely better tools.

Plus, as a data scientist, you're a natural learner. You're curious. And you're hardworking. You have what it takes, to add prescriptive analysis into your personal skill set.

Machine Learning + Gurobi at Work

Keep reading to discover how companies are combining predictive and prescriptive analytics to drive better business decisions, leading to millions in annual cost savings.

GUROBI OPTIMIZATION

![SAP]

With a global network of customers, partners, employees, and thought leaders, SAP helps the world run better and improves people's lives. Its end-to-end suite of applications and services enables customers to operate profitably, adapt continuously, and make a difference worldwide.

Industry: Software, Supply Chain
Location: Europe
Use Cases: Inventory Optimization, Logistics, Resource Planning, Supply Chain
Website: www.sap.com

Results

- 1.7 billion variables managed for supply chain customers

- Help customers automate enterprise resource planning and optimize supply chain networks

- Deliver optimal outcomes for any variety of scenarios within seconds

Mastering Supply Chain Challenges Through Complex Scenario Planning

Gurobi helps SAP deliver a powerful planning solution for today's challenges.

As the market leader in enterprise application software, SAP helps companies across all industries create networks of intelligent enterprises that provide transparency, resiliency, and sustainability across supply chains. Their original SAP R/2 and SAP R/3 software established the global standard for enterprise resource planning, and today they boast the largest cloud portfolio of any provider.

To offer their customers the most powerful planning solutions, SAP decided to officially partner with Gurobi in 2015. After four successful years, the partnership was significantly extended in 2019. This move allowed SAP to integrate Gurobi into even more product lines.

Working with the world's fastest mathematical optimization solver means SAP can leverage cutting-edge decision intelligence technology to help its customers automate complex planning tasks. Planners benefit from the ability to compute optimal outcomes for any variety of scenarios in the shortest possible time.

Planning efficiency is greatly improved through proven optimality and the ability to look at more scenarios in the same time. Furthermore, a holistic end-to-end optimization of production and logistics enables SAP customers to archive ambitious sustainability goals.

What SAP Needed

To meet their goal of a 99% success rate for their optimization runs, SAP needed a powerful and reliable solver. After comparing several options, they chose Gurobi for its outstanding performance and reliable team of experts.

"Over the last two and a half years, we've moved from a demand-driven supply chain to a supply-driven supply chain. And because we have constraints in the supply, it's even more important to find the right solution. That's where we need a solver like Gurobi," explained Franz Hero, Senior Vice President and Head of Developmental Digital Supply Chain at SAP.

"The best solution involves effective and sustainable supply chain management,

> **" We made the decision to form this partnership [with Gurobi] years ago, and I really can say that it was the right decision."**
>
> **Franz Hero**
> *Senior Vice President and Head of Development Digital Supply Chain, SAP*

because it saves resources and transportation capacity, brings down the inventory levels, and optimizes the complete chain—the complete material flow from the supplier through the different production steps, all the way down to the customer," said Hero.

Gurobi's growth potential was another key factor that attracted SAP.

"We chose Gurobi because they have a superior solver, but also because they're also scaling. In the beginning, we had customers with 20 million supply chain variables; now we have customers with 1.7 billion supply chain variables. On the other side, [Gurobi] is also supporting our strategies. Our supply chain solutions are built on HANA, an in-memory database, and Gurobi can use this database in the most optimal way," said Hero of the decision to partner with Gurobi.

Around 25% of SAP's customers already use the company's Gurobi-backed solution instead of heuristics or manual planning methods.

Finding Solutions to Complex Planning Challenges

Depending on the structure and complexity of the underlying business planning situation, SAP uses Gurobi either as a straightforward model solver, or inside their own heuristic and decomposition techniques.

"The latter is especially of interest to us because it allows us to exploit problem structures that cannot be used without expert knowledge," explained Dr. Jakob Witzig, Senior Developer of Optimization at SAP.

According to Dr. Thomas Engelmann, Product Owner Optimization, the company currently uses Gurobi in three main ways:

- To help their customers identify the best planning options with Gurobi embedded in their library solution
- As a separate service available on their SAP business technology platform, to make it even easier to build new optimization applications
- In their own business operations, to optimize the utilization of their servers and databases

"Due to the size of our models, we need to apply decomposition techniques and hierarchical optimization. Because of this, numerically stable solutions are

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>
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> *Senior Vice President and Head of Development Digital Supply Chain, SAP*

very important," explained Witzig. "Based on our feedback, Gurobi implemented a feature that can be explicitly enabled to improve the numerical properties of the solutions. With this possibility, solving a set of small optimization problems, we can see both improved running times and much better solutions compared to solving the optimization problem in a single shot."

The relationship between machine learning and mathematical optimization is also critical to SAP's operations—as machine learning helps them to prepare scenarios from customer data before using optimization technology in the decision-making process.

For example, SAP uses machine learning in their Integrated Business Planning (IBP) product to clean up master data and detect data issues like outliers. They are even able to repair it automatically, and then use Gurobi to optimize the complete supply chain.

As for their future plans, SAP is working to give customers greater influence over the optimization process by allowing them to add new planning constraints or decision variables themselves, for a solution that is even more customizable to individual needs.

A Mutually Beneficial Partnership

"Because our partnership allows us to implement Gurobi's solver in almost all of our new products, our end users are provided with new optimization and planning solutions for their most important decisions," said Dr. Sabine Seelenmeyer, Head of Optimization. "This is an important step towards the intelligent enterprise."

But this is a mutually beneficial partnership—by working closely with SAP's research and development teams, Gurobi has been able to constantly improve the product to address issues and new requirements encountered by SAP's customers.

SAP has a talented team of in-house mathematical optimization specialists who meet at least once a month with Gurobi's experts to discuss customer challenges and come up with innovative solutions together. Many features and enhancements in Gurobi's product were developed as a result of this regular exchange to benefit both SAP's and Gurobi's customers.

With the fantastic results that this partnership has yielded so far, both parties look forward to a bright future.

"We made the decision to form this partnership years ago, and I really can say that it was the right decision," said Hero. "They are a really reliable partner. And not only that, but they are bringing a lot of benefits to our solution portfolio. We look forward to the years to come—I know we will do great things together."

Machine Learning + Gurobi at Work

SAP uses machine learning in their Integrated Business Planning product to clean up master data and detect data issues like outliers. They are even able to repair it automatically, and then use Gurobi to optimize the complete supply chain.

GUROBI OPTIMIZATION

Identifying Optimal Product Price Points

Blue Yonder makes real-time price adjustments—leading to a 5% increase in product sales and a 20% reduction in inventory.

BlueYonder

Blue Yonder is the world leader in digital supply chain transformations and omni-channel commerce fulfillment. Its end-to-end, cognitive business platform enables retailers, manufacturers and logistics providers to best fulfill customer demand from planning through delivery.

Industry: Retail and Consumer Products
Location: Europe
Use Cases: Sales Optimization
Website: blueyonder.com

Results

- 5% increase in product sales
- 20% reduction in inventory

"What is the right price?" – This is a key question with enormous impact on profitability of retail companies. If the price is too high, you cannot achieve the desired sales volume. If set too low, the lack of product availability will result in missed sales opportunities and an overall decrease in profitability. In this scenario, Blue Yonder offers its customers Price Optimization – as a SaaS solution – to support price adjustments.

The Business Segment

Blue Yonder is the leading provider of cloud-based artificial intelligence solutions for the retail industry. The world's leading machine learning algorithms are used to deliver decisions that increase sales, reduce write-off rates and increase profits. The company assists in the automation of pricing decisions that are influenced by historical data and other critical factors such as weather, public holidays, or competitor information.

The Challenge

An efficient interplay of algorithmically-demanding disciplines is required to determine dynamic price adjustments. Powerful machine learning models that can take into account extremely diverse influences in a dynamic market environment are required to automatically determine reliable sales forecasts. In addition, several other requirements must be met. For example, the price trend in a product life cycle is subject to many rules. Local factors such as time period and cost of price changes must be taken into account as well as price developments in the competitive environment. Adjustment of prices in the network allow for consideration of reciprocal dependencies in the overall offer and the proactive implementation of strategic objectives.

The Solution

Blue Yonder Price Optimization automatically sets the optimal price to deliver the best bottom line without compromising the brand's promise to its consumers. Our solution delivers optimized prices for every channel and every product according to consumer demand, brand loyalty and competitive advantage. The solution "learns" the relationship between price changes and demand while incorporating a retailer's business strategy. Blue Yonder's Price Optimization solution rapidly senses vital demand signals from changing market conditions and data such as sales, promotions, weather and other events. It serves a retailer's pricing strategy along the product's life cycle and provides a measurable impact on revenues and return on investment. The Gurobi Optimizer is used to help solve this complex mathematical optimization model and provide the company with optimal prices for each product at each location. The prices can be calculated quickly and models can be solved reliably with the use of Gurobi.

The Result

With the use of Gurobi and Price Optimization, Blue Yonder's customers saw a boost in profitability and an increase of 5% in product sales. The price adjustments now take place in real-time, based on current data, considering company objectives and the cost of changing prices, with minimum effort. In addition, inventories can now be reduced by 20% by means of price reduction optimization.

How Gurobi Is Used

Time is the most critical resource. New forecasts have to be calculated overnight from the most recent data, and up-to-date price strategies have to be generated. Retail companies need the results by the next morning. To generate the optimization models, product quantities are divided into suitable clusters. About 50,000 variables are generated for each cluster for the price decisions, and numerous rules are converted into approximately one million constraints. For specific optimization processes over the entire product lifecycle, MIP models, with more than 1.2 million variables, are created. Depending on the uncertainties in the input data, the termination criteria of the optimization also change. A trade-off between available time and the desired solution quality is thus defined for each customer. There is not much more than an hour available per night to complete the overall process on time. With Gurobi, a stable solution time and quality can be achieved consistently even when changing the input data. Usability was also a point in favor of the Gurobi Optimizer. Using the Gurobi Python API, a prototype could be developed in a very short time during the solver selection process. In addition, due to the use of Gurobi Compute Server, the optimization functionality was able to be seamlessly integrated into the service infrastructure.

- Founded in 2008
- Leading provider of cloud-based artificial intelligence solutions for retail
- Blue Yonder solutions for supply chain and merchandising are based on innovative machine learning algorithms developed by highly qualified Data Scientists specifically for retail
- Blue Yonder provides retail companies with the best solutions to increase their sales and margins daily

Machine Learning + Gurobi at Work

Blue Yonder uses machine learning and Gurobi together to deliver decisions that increase sales, reduce write-off rates, and increase profits.

GUROBI OPTIMIZATION

arute solutions

Arute Solutions develops advanced enterprise software for Cash and Route Optimization via Machine Learning and Operations Research algorithms for financial Institutions and cash service providers. Their product and service portfolio helps clients to drive up process optimization and brings tangible cost reduction throughout the Cash Supply Chain with highly advanced forecasting and optimization algorithms.

Industry: Financial Services
Location: Americas
Use Cases: Cost Reduction, Forecasting, Inventory Optimization, Logistics, Operations, Supply Chain
Website: arutesolutions.com

Results

Arute Solution's Cash+, powered by Gurobi, enables customers to minimize total operational costs, while conforming to the constraints of each ATM or CMC—with 22% less cash and the same number of CITs.

Cash+ Keeps ATMs Optimally Stocked

Arute Solutions helps banks deliver the right cash, at the right time, to the right ATMs, while minimizing costs.

Contrary to popular belief, the need for cash is on the rise for businesses and individuals alike. Despite recent technological and financial developments in cashless payments, cash is proving that it is indeed still king.

To keep up with demand, banks keep their ATMs stocked with massive amounts of cash. But the key is to stock the right amount of cash to meet demand, without letting cash sit idle—where it can rack up interest costs.

Plus, there are operating expenses to consider, such as the costs of carrying the cash between cash management centers (CMCs) and ATMs, preparing cassettes or cash bags, counting collected cash, maintaining ATMs, and paying Cash-in-Transit (CIT) staff.

This leaves the banks asking an important question: When should we visit an ATM, and how much cash do we need to replenish to its cassettes, subject to all the rules of the operation and the field?

When a bank can identify the optimal answer to that question, they can keep ATMs sufficiently stocked—which increases customer satisfaction—while keeping costs low.

Keeping ATMs Properly Stocked is Complex Business

ATM cash optimization—the process of delivering the right cash, at the right time, to the right ATM—is a highly complex operation, subject to many rules depending on a bank's operational structure. Some banks outsource their
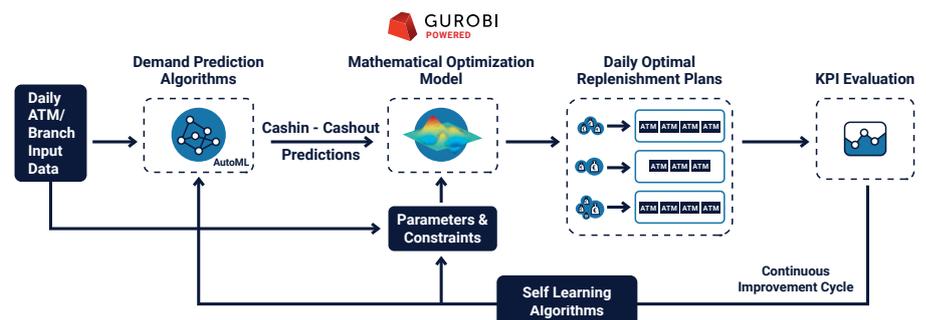
CIT operations, while others use their own resources to transfer cash. Because banks have such wide-ranging operation types, cash optimization techniques need to be robust, reliable, and flexible.

Cash optimization techniques also need to consider an ATM's cash accepting-and-dispensing algorithm to achieve the best results. Depending on its cassette-banknote configuration, each ATM has its own transaction rules, meaning that the ATM decides the cassette-banknote combination of each withdrawal request, which in part might be fulfilled by the recycle cassettes.

Furthermore, ATM replenishments depend on CIT operations. For instance, there might be non-visitable days for ATMs, consecutive day replenishments might be undesirable, or there might be a minimum replenishment amount per ATM. These conditions and constraints create an enormous problem space—requiring a robust mathematical model.

Solving such complexity is a challenge. But solving it quickly enough to generate optimal plans on time for each day's operations—that's the key.

Time is Money: Solving Cash Optimization Models, Fast

To address this challenge, Arute Solutions developed the Cash+ ATM and branch solution, which—using advanced machine learning and mathematical optimization algorithms—generates optimal replenishment and collection plans for the next N days for each ATM and branch (cashpoint).

Figure 1: Arute's Cash+ Optimization Workflow

> **" According to our empirical results, Gurobi is significantly faster than any other solver on MIP models. With Gurobi, we decreased the solution time by half, compared to another commercial solver that we were using previously."**
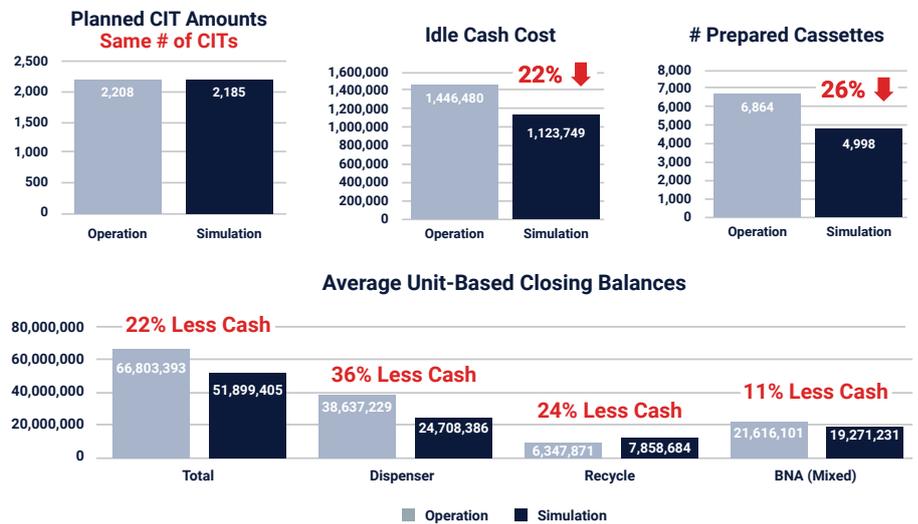>
> **Mehmet Arıkkan**
> *CEO of Arute Solutions*

Figure 2: Arute's Cash+ Simulation Results

"The objective is to minimize total operational costs—including CIT, idle cash, cassette preparation, and cash collecting costs—while conforming to the constraints of each ATM or CMC," explained Mehmet Arıkkan, CEO of Arute Solutions. "Cash+ supports various replenishment and ATM types, as well as ATM-based or CMC-based system parameters that achieve ultimate flexibility for our customers."

When running a simulation of Arute's plans versus current operations, one customer found they could manage the whole operation—with the same number of CITs—with 22% less cash.

With Cash+, customers have been able to achieve the following outcomes with the same number of CITs:

- 26% decrease in the number of prepared cassettes
- 36% reduction in average dispenser unit closing
- 11% reduction in average BNA unit closing
- 24% more recycled cash at ATMs

Cash+ offers clients more recycled cash and fewer— yet enough—replenishments with a remarkably lower level of total cash, even with the same number of CITs. If the operation allows, even more benefit is possible with a greater number of CITs.

Cash+ was able to provide cost savings for all customers and PoCs. In one of the live PoCs for one month, Arute's Cash+ plans yielded 19% less total cost than a control period.

Powerful Solutions Require a Powerful Engine

To power its Cash+ solution, Arute Solutions needed an advanced mathematical optimization solver, capable of solving real-time models extremely quickly. It would need to solve 5000+ MIP problems in less than 30 minutes, where each model has around 2500+ variables and 5000+ constraints—while ensuring a 0.01% optimality gap at most.

"To generate the best results, we need to have the latest balance information for each ATM just before the planning task starts. On the other hand, CMC staff needs to create the orders as early as possible to prevent any delays in the field. That's why solving a model in a reasonable time is one of the key binding constraints in this business," Arıkkan explained.

To find a solver that would be up for the task, the Arute team tested out nearly all commercial and non-commercial solvers that have a C# interface.

"According to our empirical results, Gurobi is significantly faster than any other solver on MIP models," Arıkkan said. "With Gurobi, we decreased the solution time by half, compared to another commercial solver that we were using previously."

"In addition, Gurobi supports nearly all advanced features such as callbacks and IIS," he added. "Gurobi makes it easy to model an optimization solution."

Machine Learning + Gurobi at Work

Arute Solutions uses advanced machine learning and prescriptive algorithms to generate optimal replenishment and collection plans for ATMs and branches.
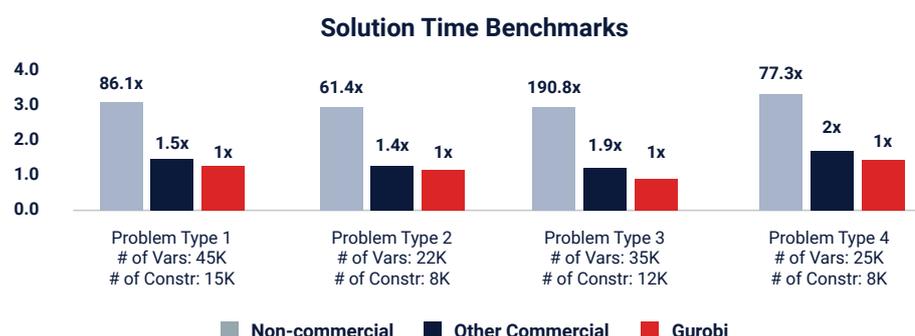
Figure 3: Solution Time Benchmarks on Different MIP Problem Types with Respect to Gurobi

Gurobi Teams Up with Lityx to Accelerate the Adoption of Mathematical Optimization Across the Enterprise

The Gurobi Optimizer will be embedded into Lityx's No-Coding AutoML Platform, giving data scientists and business users the capability to easily and effectively leverage mathematical optimization to solve their most challenging problems.

Founded in 2006, Lityx has delivered market-changing results for customers that lead their categories in data-driven growth and customer experience, including AARP, All American Hearing, The Motley Fool, and more. Lityx develops and delivers solutions directly and through an expanding roster of servicing partners.

Industry: Software
Location: Americas
Use Cases: Supply Chain, Logistics, Workforce Scheduling, Routing
Website: www.lityx.com

Results

Users across the enterprise (including data scientists and business executives) receive the capability to successfully develop and deploy scalable mathematical optimization solutions that deliver significant business value.

PRESS RELEASE:
APRIL 15, 2021

Beaverton, Ore and Wilmington, Del – Gurobi Optimization, LLC – which produces the world's fastest mathematical optimization solver, the Gurobi Optimizer – and Lityx, LLC – which produces the leading no-coding-required automated machine learning (AutoML) platform, LityxIQ – today announced that they are partnering to expand the use of mathematical optimization across the enterprise by empowering a wider cross-section of professionals (including data scientists and business executives) to utilize mathematical optimization to address their most challenging real-world problems and achieve their business goals.

Lityx will embed the Gurobi Optimizer as a key component of the mathematical optimization solution in its LityxIQ platform, thereby enabling both technical and non-technical users to:

- Easily build mathematical optimization models of their organization's complex, mission-critical business problems (such as supply chain and logistics planning, workforce scheduling, product pricing, and shipment routing) using the Lityx platform's modeling tools.

- Automatically and rapidly generate optimal solutions to these problems using Gurobi's state-of-the-art mathematical optimization solver.

" **This integration of the Gurobi Optimizer into LityxIQ will put the power of mathematical optimization at the fingertips of a larger group of users...and will help promote and expand the utilization of mathematical optimization across the enterprise.**"

Duke Perrucci
Chief Executive Officer, Gurobi
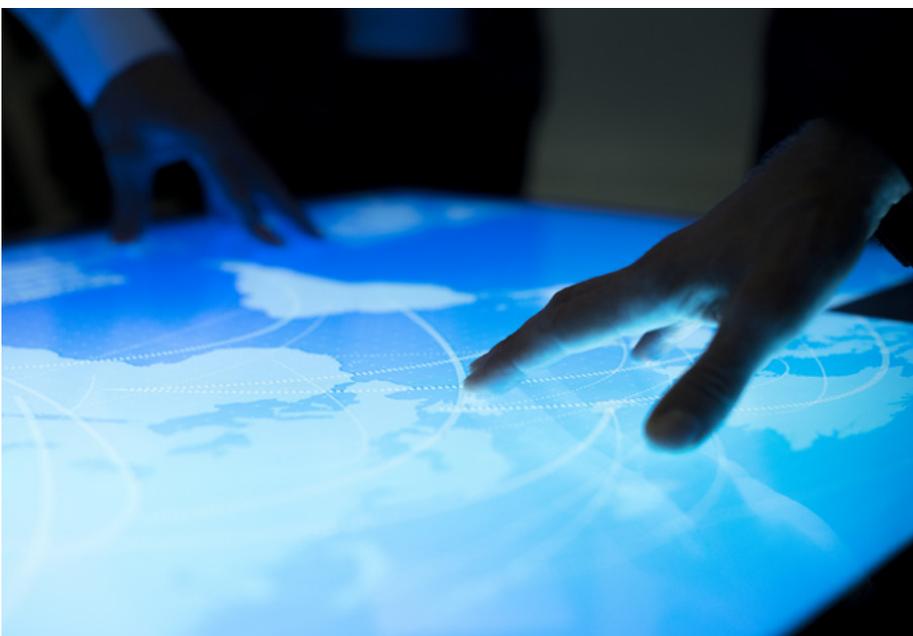
> **" This combination of Lityx's user-friendly, cutting-edge AutoML platform with Gurobi's best-of-breed solver will give users across the enterprise the capability to successfully develop and deploy scalable mathematical optimization solutions that deliver significant business value."**
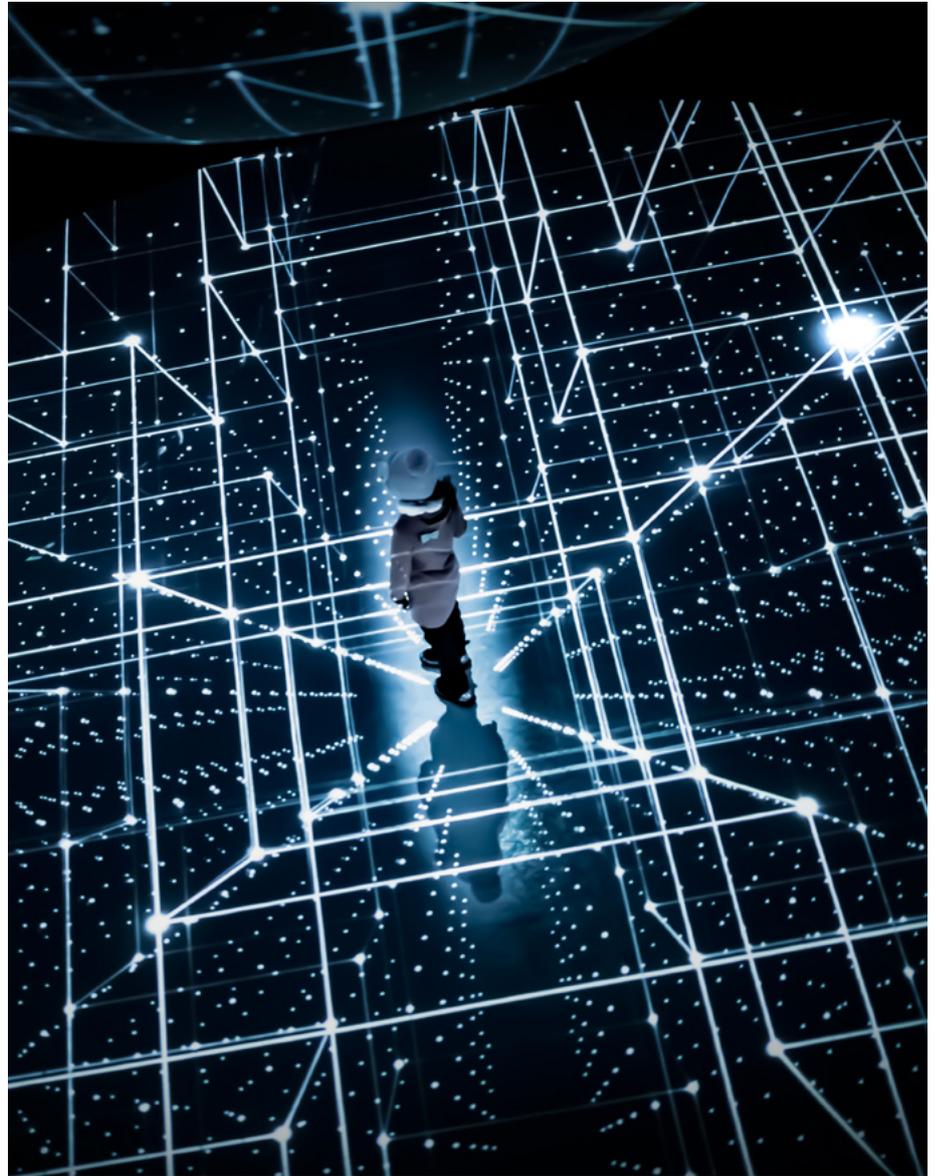
- Utilize these solutions as the basis to make data-driven decisions that optimize operational efficiency, cost savings, and revenue growth.

This combination of Lityx's user-friendly, cutting-edge AutoML platform with Gurobi's best-of-breed solver will give users across the enterprise (including data scientists and business executives) the capability to successfully develop and deploy scalable mathematical optimization solutions that deliver significant business value.

Lityx's Chief Executive Officer Paul Maiste, PhD, commented: "LityxIQ has enabled analysts across a range of experience levels to make use of mathematical optimization without writing code for many years now. Our partnership with Gurobi further bolsters the platform's ability to

solve large and complex business optimization problems. LityxIQ's seamless integration of data, AI and machine learning, and Gurobi-enhanced mathematical optimization capabilities gives our customers access to the full analytics spectrum in a single democratized platform."

Gurobi's Chief Executive Officer Duke Perrucci said: "We're excited that Lityx has selected the Gurobi Optimizer as the preferred mathematical optimization solver for its end-to-end AutoML platform. This integration of the Gurobi Optimizer into LityxIQ will put the power of mathematical optimization at the fingertips of a larger group of users including data scientists and business executives, and will help promote and expand the utilization of mathematical optimization across the enterprise."

Machine Learning + Gurobi at Work

LityxIQ's seamless integration of data, AI and machine learning, and Gurobi-enhanced mathematical optimization capabilities gives customers access to the full analytics spectrum in a single democratized platform.

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