Solve your Toughest Planning and Scheduling Problems: How Business Managers can use Mathematical Optimization Technology

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ILOG Optimization Product Marketing

Application and Integration Middleware Software

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"By maximizing its use of network capacity, the company has increased profitability and reduced operating costs while maintaining high service levels. In 2002 alone, Menlo Worldwide Forwarding reduced operating costs 21 percent, increased operating margin by 41 percent, and improved financial results by US$80 million in the North American aircraft transportation operation. Moreover, management used the optimization model to facilitate Menlo's transition from a heavily asset-based, integrated airfreight company to an asset-light, freight forwarding business. This created a flexible operating environment and a competitive advantage for future operations."

2003 Finalist Team for the Franz Edelman Award for Achievement in Operations Research and Management Sciences Menlo Worldwide Forwarding (now part of Con-Way Transportation)

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Overview

What Makes Optimization Special

Optimization is unique simply by being the mathematical discipline focused on efficiency. Along with statistics and predictive analytics, it is one of the two mathematical disciplines used most frequently in the world of business. It applies mathematics and logic to the pursuit of objective efficiency. It does not concern itself with probability or attempt to predict the future by looking at what happened in the past. It takes facts—costs and yields, available resources and demand, goals and constraints—and finds the best possible plan or schedule of activities using mathematics and logic. And this is why the Institute for Operations Research and the Management Sciences (INFORMS) calls OR/MS the "Science of Better."

Statistics and predictive analytics help people make smarter decisions by helping them play the odds. Optimization helps people make smarter decisions by finding efficiencies that they could not find on their own. This is why optimization is as widely used as predictive analytics. It is hard to imagine a bank or insurance company without sophisticated predictive analytics to manage risk and profitability. It is just as difficult to imagine a manufacturing or transportation company without optimization in the planning or scheduling of its resources.

Optimization also keeps us in touch with the history of mathematics. For over 2,000 years, humans have been working with geometry, algebra and logic to find better ways to make things. Since Descartes unified algebra and geometry over 300 years ago, we have been trying to work out solutions to our most challenging problems by using analytic geometry, graphing equations on an X-Y grid. World War II, however, was the beginning of the development of optimization in its present form. Techniques that came to be called Operations Research (OR) were used by both the British Navy and the U.S. Navy to determine the best locations for radar stations and anti-submarine resources. They worked very well and a profession was born.

Where Optimization is Used

Optimization is used in most major industries—more in some than in others—but ubiquitous, nevertheless. Examples of common business applications can be seen below:

Table 1: Applications

Manufacturing	Transportation and Logistics	Financial Services	Utilities, Energy and Natural Resources	Telecom	Multiple/Other
• Inventory optimization • Supply chain network design • Production planning • Detailed scheduling • Shipment planning • Truck loading • Maintenance scheduling	• Depot/warehouse location • Fleet assignment • Network design • Vehicle and container loading • Vehicle routing and delivery scheduling • Yard, crew, driver and maintenance scheduling • Inventory optimization	• Portfolio optimization and rebalancing • Portfolio in-kinding • Trade crossing • Loan pooling • Product/price recommendations	• Supply portfolio planning • Power generation scheduling • Distribution planning • Water reservoir management • Mine operations • Timber harvesting	• Network capacity planning • Routing • Adaptive network configuration • Antenna and concentrator location • Equipment and service configuration	• Workforce scheduling • Advertising scheduling • Marketing campaign optimization • Revenue/Yield management • Appointment and field service scheduling • Combinatorial auctions for procurement

Most of these applications produce plans or schedules. Some produce optimal prices, store layouts, stock trades or other sets of decisions. In the majority of cases, analysts and managers get these solutions through packaged applications that make decisions based on a generic optimization model, one that is intended to fit a large number of organizations. In other cases, managers use a custom optimization model built by in-house OR professionals or an outside consultant with OR skills and domain expertise in their industry.

The business problems addressed above can be thought about using a three-category framework—long-term economic planning, short-term production/delivery planning, and detailed scheduling. This framework is helpful in discussing the types of complexity found in various optimization problems, the difficulties associated with solving them, and the ease-of-use requirements for each. Within the world of optimization, these categories are often used when discussing problem types and requirements.

Table 2: Categories of Economic Analysts

	TYPICAL FREQUENCY	EXAMPLES
LONG-TERM PLANNING	• Annual • Quarterly • Occasional	• Whether to expand a plant or open a new one • How many distribution centers to have • What's the value of additional equipment over time
SHORT-TERM PLANNING	• Monthly • Weekly	• How much should we produce this week • How many shifts should we have • How many resources will we need • Which marketing campaigns will provide the most impact for a set budget
DETAILED SCHEDULING	• Weekly • Daily • Hourly	• Which activity should be done when • Which resource should be assigned when • When can maintenance or any special task be most efficiently schedules

How Optimization Works

An optimization model is a carefully defined set of inputs—demand, resources, costs, assumptions, constraints, preferences and goals—expressed in equations, matrices and logic statements that find the best solution to a business planning or scheduling problem. The output is an optimized plan or schedule with information about the best possible solution, its binding constraints, and the underlying economics and operational efficiency. Here are some examples for the structural components of a model:

- **Resources Available:** trucks, containers, airplanes, rail cars, people of various skills or seniority, machines, assembly or packaging lines, hospital beds, inventories (raw materials, work in process, finished goods), just-in-time (JIT) deliveries, consumers who could buy a product and so on.
- **Demand To Be Filled or Services To Be Performed:** products to be built, customer orders to be filled, patients to be cared for, marketing offers to make, classes to be scheduled, and so on.. Sometimes this requires forecasting the best case, worst case and most-likely case over one or multiple time periods.
- **Operating and Capital Costs:** hourly labor rates, overtime premiums, mileage costs, depreciation expense, supply costs, switchover costs, inventory carrying costs, shrinkage costs, marginal costs, cost of capital for new equipment purchases, and so on.
- **Yield/Throughput Assumptions:** average driving speed between Warehouse A and Customer B, minutes to dock and unload a truck, cars painted per hour, regular patients served safely by a nurse, percent of customers who will agree to accept a marketing offer in exchange for a discount, revenue per customer at different times of the day, and so on
- **Global Operating Constraints:** rail yard A is 500 miles from rail yard B, a worker can work no more than 20 hours of overtime in a week, a worker must have a one-hour break no more than four hours from the beginning or end of a shift, the Intensive Care Unit must have at least two nurses with X certification, 50 percent of the nurses on a shift must be fully credentialed, no more than 5 percent of homeowner policies in X state should be from Y county, fund position weights may not be more than 0.5 percent from index weights, the production of Product A requires five activities in sequence (each with resource consumption, cost and time properties), truck drivers must end their routes in the same town they started from, the call center can only call 10,000 people for this marketing campaign, employees can be rotated from day shift to evening shift and evening to night, but not day to night, and so on.
- **Individual Operating Constraints and Preferences:** Customer A will not take deliveries between 11:30 a.m. and 1:00 p.m., Nurse B wants a two-and-a-half-week vacation from X date to Y date, Doctor C requires Nurse D and Nurse E to be assigned to his Operating Room team, orders for top accounts are always prioritized for fulfillment and shipment, transition time of Product A from Machine A to Machine B is nonstandard, and so on.

- **Goals (Individual or In Combination):** minimize empty or total mileage, one cost or total costs, handling, idle or total cycle time, particular risks or total risk. Maximize revenue, throughput, profitability, customer satisfaction, or employee preferences.
- **Key Performance Indicators (KPIs):** metrics about the solution that supplement the optimized plan or schedule, or "meta data" about the solution. The complete profile of a solution includes these calculations summarizing how efficient the plan or schedule is in operational, financial or hybrid terms.

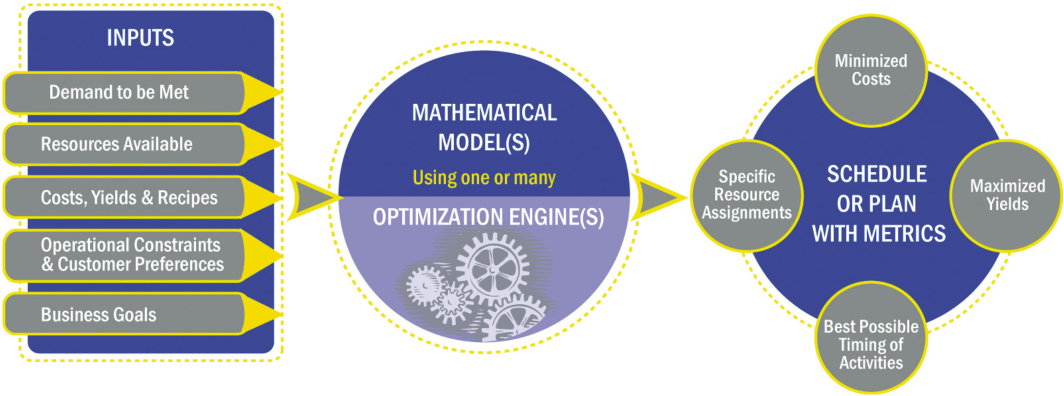


Figure 1: The Structure of Optimization Models

When these components are put together into an optimization model and executed using one or multiple optimization engines, the result is the best possible plan, schedule or set of schedules to achieve the goal or set of goals. For example, the final output could be a supply chain network design; a multiyear production plan; a detailed, to the minute, production schedule for the week; a one-month workforce schedule; a set of routes to deliver a day's worth of goods or services; a set of trades to bring a stock index fund back into compliance; a set of price offers or marketing offer assignments that will produce the best results, and so on.

Two Key Optimization Technologies

Optimization problems come in many forms and there are two distinct ways to approach solving them.

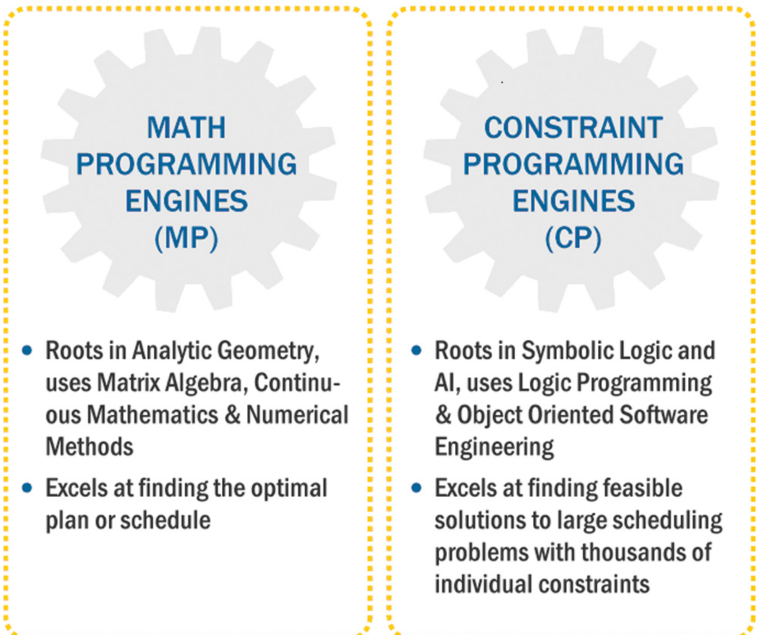


Figure 2: Optimization Technologies

Mathematical Programming (MP)

The first optimization technology is Mathematical Programming (MP), which is a branch of Applied Mathematics. It finds mathematical optimality by applying equations to a large search space of potential solutions. Algebra and analytical geometry form the core, but they are assisted by a large number of algorithms and heuristics (rules of thumb) that take advantage of concepts and methods developed in both mathematics and computer science over the past 20 years.

Linear equations are the dominant language of optimization, which is why the term Linear Programming (LP) is used interchangeably when talking about MP; however, some models also require the use of quadratic equations ($ax^2 + bx + c = 0$) which are not linear. More important, most business problems can only be solved if you can adjust all or some of the solution recommendations to whole numbers—because in the real world, most machines, people and activities come in whole numbers. These two extensions may sound like simple adjustments, but it has actually taken over 50 years of continuous effort for LP to fully support Quadratic Programming (QP) and Mixed Integer Programming (MIP or MIQP).

Given the number of constraints that need to be satisfied, the decisions that need to be made, and the goals that need to be balanced, optimization as we know it today would not be possible without modern computing power. With today's computing power, it is now possible to execute millions of calculations and generate thousands of trial solutions on the road to finding the optimal solution.

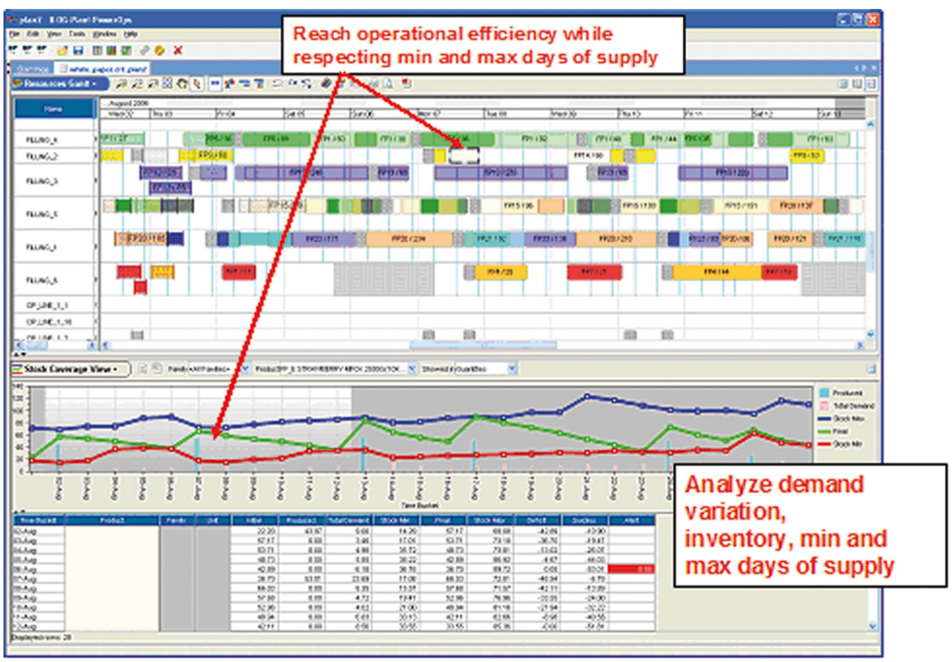
Constraint Programming (CP)

The second major technology for optimization is Constraint Programming (CP), which is a branch of Computer Science (also known as Logic Programming) with roots in the Artificial Intelligence (AI) and Expert System efforts of the 1980s and the move to object-oriented approaches to software development in the 1990s. Its approach to optimization is completely different from the approach of MP. Simply put, CP finds feasible solutions by rapidly eliminating possibilities, zeroing in on feasible combinations of resource assignments and activities—when there are too many possible combinations or too many individual constraints regarding sequence and timing for MP to find a solution in an acceptable timeframe. This is sometimes referred to as coping with the "combinatorial explosion" of possibilities.

CP approaches optimality via a continuous improvement process based on the systematic comparison of new solutions to a base feasible solution. As a result, CP can find good solutions to large, intricate scheduling and routing problems in minutes when MP would take hours or even days, assuming that an MP model could even find a solution. Note that when you run either a CP or MP model, you can instruct the solving engine to give you its best result after a set time limit—often the extra time the engine spends searching is only gaining you a small additional improvement.

The easiest way to understand the sort of problem CP technology is good at solving is to think of a Gantt chart. It is a time-honored way to visualize "what is being done where" on a project—a complete picture of all of the available resources and all of the necessary activities done using the available resources over a period of time. It is no surprise that when there are many interdependencies between activities and numerous operating constraints, it can be very difficult to find a feasible solution, much less an optimal one. Add the pursuit and balancing of multiple goals, and it becomes even more difficult. CP technology was designed to handle these tough scheduling problems, finding feasibility first and then polishing the solution to near optimality.

The Gantt chart below shows a detailed manufacturing schedule for finished goods production in a process manufacturing environment that has tanks filled with intermediate products, equipment connections, mandatory cleaning activities, batch tracing, and shelf-life management challenges. This schedule was generated using CP technology.



To appreciate the range of problems that exist in the world of scheduling, consider the following examples. Some of these can be more efficiently solved with either MP or CP.

Example 1 – Production Planning

You run a large paper mill that makes standard and specialty papers. The production process involves a variety of specialized equipment and each product must be made in fairly large batches on six-meter-long rolls weighing several tons. Individual customer orders can be accommodated by making rolls of different diameters and by cutting the rolls into segments of varying widths.

Goal – Maximize margin dollars given that:

- Production must be scheduled by machine and sequenced, respecting different switchover costs (the setup time for a product varies from 15 to 120 minutes)
- Rolls must be cut with minimum scrap loss (waste)
- Paper rolls are sent to cutters, coaters and sheet-cutting machines to produce the various individual products for customer orders, and there are different setup times for each product on each downstream machine
- The entire schedule should minimize idle time

Example 2 – Nurse Scheduling

You need to schedule staff for a large operating room environment at a major hospital. There are 40 individual operating rooms scheduled 12 hours per day. Over 350 people are scheduled in a month to do all the different jobs. Most are fully credentialed nurses, but there are also other, less-broadly trained people. In addition, many of the nurses must have specializations in specific clinical areas or procedures. Surgeons are assigned operating room time in blocks that do not align perfectly with staff shifts. The schedule is a monthly schedule and is posted one month in advance, although adjustments are made after posting.

Goal – Minimize labor costs while satisfying the following constraints:

- A nurse's weekly schedule must be for one and only one shift (day, evening or night)
- A nurse's weekly schedule can only be one shift away from his/her previous weekly schedule and it must support circadian rhythms (Week Two can be evening if Week One was day, but it cannot be night)
- A nurse's shift can be for 6, 8, 10 or 12 hours
- A nurse may not work more than three 12-hour shifts in a row within a week
- There must be at least 24 hours between the end of the last shift in a week and the start of a new one in the next week
- Clinical certification requirements must be respected
- Nurse shift and vacation requests should be respected based on seniority
- Surgeon A requires Nurse D and Nurse F to be on his operating room team

Example 3 – Truck Loading

You are a planner/dispatcher at a major manufacturing plant with nine packaging lines that produce finished product for inventory and immediate shipment. You need to schedule the loading and departure of 1,200 trucks a week to get 4,000 deliveries made to 150 distributors and 10 regional warehouses. The plant makes 125 individual products that are shipped on pallets in five different cubic shapes. Individual customer deliveries can be for as many as 40 different products, but the average is 10. The plant can make a lot more product than it can warehouse on site.

Goal – Maximize truck capacity utilization while satisfying the following constraints and sub-goals:

- Maximize the percentage of product that is loaded directly from the packaging lines vs. from warehouse inventory
- Maximize the percentage of orders that are shipped 100 percent complete for a single delivery
- Minimize truck time at loading dock
- Minimize the number of different products on a truck to minimize handling costs
- Ensure that no truck is loaded with more weight than can be safely carried

- Ensure that loading instructions respect the three truck sizes with their individual lengths, capacities and weight restrictions
- Customer A's delivery dock cannot handle Truck Type 2
- Customer B's delivery dock is not available between 11:00am and 1:00pm
- Customer C is a regional warehouse that wants to ship excess inventory back to the main

The Business Value of Optimization

When we talk about the business value of optimization, we mean finding the best balance between conflicting goals. We often want to maximize customer service, profitability and employee satisfaction or fairness at the same time. Optimization can find this balance. More specifically, optimization can help organizations:

- Lower unit operating costs
- Postpone capital expenses
- Increase asset utilization
- Shorten production and service delivery cycle times
- Provide better, more flexible and precise service to customers
- Provide more flexible and personalized schedules to employees
- Manage risk
- Reduce inventories
- Maximize profitability
- See into the future

The value of using optimization technology is twofold – it helps you gain a better understanding of your business' economics and operational options while it helps you actually generate the best possible plans and schedules. And the combination of these two things is very powerful for any organization.

Creating a great optimization model will always require a deep understanding of the business – its products and services, and its goals and operational processes. Fortunately, optimization technology now provides a complete set of tools to help companies develop powerful and flexible planning and scheduling applications based on that deep understanding. These applications not only help find the best approach to sometimes extremely complex problems, but they also make it possible for operations managers, planners and strategists to explore the entire universe of possible scenarios and solutions. Now, a wider range of personnel can take greater advantage of the power of optimization technology, without becoming mathematicians or programmers.

The ROI of Optimization

One of the great things about optimization technology is that its use is measurable. It is either making you more efficient with demonstrable financial and operational results or it isn't. The business benefits are measurable. The gains can be significant and the return on investment (ROI) large. The next figure shows the ROI achieved and documented by a set of INFORMS Franz Edelman Award finalists. This award is given annually to the most successful and innovative use of OR techniques in industry. Finalists must submit papers that document the business benefits realized and the mathematical models built. Papers are available at the INFORMS "Science of Better" website for business people.

Table 3: Documented ROI INFORMS Edelman Award Finalists Using IBM ILOG CPLEX

COMPANY	BUSINESS PROCESS	ROI
UPS	• Air Network design	• US$87m/2yrs + 10 percent fewer planes
Motorola	• Procurement Management	• US$100-150 million/year
Samsung Electronics	• Semiconductor Manufacturing	• Fifty percent reduction in cycle times
Continental Airlines	• Crew Re-scheduling	• US$40 million in one year
AT&T	• Network Recovery	• Thirty five percent reduction spare capacity
South African Defense	• Force/Equipment Planning	• US$1.1 billion/year
SNCF (French RR)	• Scheduling and Pricing	• US$1.1 billion/year
Grant Mayo van Otterloo	• Portfolio Optimization	• US$4 million/year
2 Chilean Forestry firms	• Timber Harvesting	• US$20 million/year + 30 percent fewer trucks

ROI can be especially high in capital-intensive situations, where optimization can result in large savings for money not spent. Given the cost of capital, these savings will often exceed the margin improvements from greater efficiency in the use of existing assets. Note that operating efficiencies can result in both lower unit costs and increased revenues. Let's look at three examples in more detail.

Japanese Carmaker

Considered among the most efficient automobile plants in Europe, this carmaker's UK factory was able to make more than 200,000 cars per year, building two models on two different production lines. Despite this outstanding record, top management wanted to begin production of a third model – without constructing a third production line.

Ordinarily, a demand like this would seem impossible. But by building a custom scheduling system, the factory was able to accomplish the goal. In addition, the "straight-through ratio"—the percentage of cars produced on schedule—jumped from 3 to 95 percent. Productivity increased by 30 percent without a major investment in plant retooling.

The project also reduced the time needed to produce a schedule by a factor of 10—from one week to four person-hours. Needless to say, the value of the efficiency gains was dwarfed by the savings associated with avoiding the US$500 million cost of a third production line.

Package Delivery Company

A subsidiary of the package delivery company operates as one of the largest airlines in the world. The airline is the backbone that enables the package delivery company to provide expedited package delivery services.

Here, the optimization problem was to determine the minimum-cost set of routes, fleet assignments and package flows that still satisfied a number of key operating constraints, including:

- Limits on the number and capacities of each type of aircraft
- Landing restrictions at airports
- Aircraft operating characteristics, such as range, speed and load capacity

- Continuous aircraft flow requirements (that is balance of flow)
- Time windows for pickup and delivery
- Sorting capacities and hours of operation for each hub

In addition, packages needed to arrive at the hubs in a staggered manner so that package volume could be spread across the entire sorting period, and the next-day-air network flying at night needed to interface with the daytime aircraft network used for the standard second-day-air network.

The optimization model the company built had a direct financial impact:

- Operating costs in the first two years were reduced by US$87 million.
- Major additional aircraft ownership costs were avoided. In early results, the optimization model reduced by 16 the number of aircraft needed to operate the network. With each plane costing in excess of US$100 million, the long-term savings in aircraft ownership costs exceeded the savings in operating costs.

Broadcasting Company

A U.S. television network had an advertising inventory management problem and a pricing problem. Advertising slots on certain television shows are always more or less valuable than slots on other shows. And certain weeks are more or less valuable than others. Individual advertisers purchase blocks of advertising time and have negotiated terms and demographic coverage requirements. The newtwork needed a scheduling system that would fill contractual obligations at lowest cost in terms of slot inventory consumption. The effect of the system was to enable the network to maintain or even raise prices while preserving some of the best slots for enticing new customers.

By generating better ad schedules, the network increased revenues by over US$50 million per year. The sales staff, backed by an efficient and nimble pricing and allocation system, was able to compete for new customers while meeting contractual obligations to existing customers.

Why Business Managers Should Look at Optimization Technology Now

Most business managers and financial analysts have a general idea of what optimization is about—that it somehow concerns planning or scheduling and efficiency. Some managers may even remember something about linear programming from college or business school. But few know how it really works, and most are unaware of recent developments in the field.

There are four key reasons why business managers and planners should take a look at the current state-of-the-art in optimization technology:

- **Changes in the economy and in business process management are making smart, agile economic planning and scenario comparison a necessity.** Mergers and acquisitions are on the rise, forcing the integration and rationalization of supply chains. The growth of Asian manufacturing and the emergence of the European Union are completely changing transportation networks in North America and Europe. Every company is fighting to keep or gain share in an increasingly flat world. Finance professionals are expected to manage increasingly international portfolios with a finely tuned balance between risk and return. The list goes on.
- **The efficient use of resources has never been more critical in terms of impact on profitability. And the need to reschedule is constant.** The demand for electricity grows every year, requiring more careful management of generation and distribution. The explosion of healthcare costs from advances in drugs, technology and procedures is increasing pressure to maximize hospital throughput. Demand-driven manufacturing initiatives coupled with the constant manufacturing imperative to be the low-cost producer are making detailed scheduling an area of increasing focus. Almost every organization of any size can find some process that can benefit from more efficient scheduling of certain resources.
- **Advances in computer hardware and optimization software have made it possible to evaluate large planning and scheduling problems that were too difficult for computers as recently as five years ago.** Some problems involve thousands of individual decisions with many more constraints. Others involve tens or hundreds of thousands of decisions that create millions of possible combinations. Think of a marketing campaign aimed at 200,000 consumers, each with a probability of acceptance and a probability of lifetime customer value. If

there are five offers that can be made to the consumers, there are hundreds of millions of possible offer combinations that need to be evaluated for overall profitability and revenue impact. Even if you replace the 200,000 consumers with 50 marketing segments, it is a very big problem. The possibilities must be narrowed systematically.

Fortunately, between the advances in processing power and memory availability and the improvements in search techniques and algorithms, there are few problems that cannot be solved today within a reasonable timeframe—no matter how many activities must be scheduled, resources assigned or offers made. Still, some problems take less than a minute, others two or three minutes, and still others a few hours. When a major airline schedules crews for a large portion of its entire route system, it can take three or four hours.

- **Advances in software technology are making optimization accessible to nontechnical planners, schedulers and managers who make the decisions in most organizations.** In other words, the use of state-of-the-art optimization technology is no longer restricted to mathematicians and advanced computer scientists. More on this below.

Challenges to Using Optimization

Making the most efficient use of resources and developing the most sophisticated business strategies are obvious goals for most organizations. So, what problems do businesses encounter in practice?

- **Problems building optimal schedules** With complex schedules, businesses can face difficulties when attempting to build models that take into account a wide range of resources with their individual capabilities and costs, and that process a large number of product orders, deliveries, staff assignments, and so on; and that schedule a number of activities over a fine-grained set of time periods. Certainly scheduling to the minute is harder than scheduling to the day.

  Examples of very difficult schedules would be enforcing a shift schedule where assignments must respect complex time-off rules or a manufacturing schedule where Activity Two may not start until Activity One is completed or Tank 3 is cleaned and refilled. If your schedule needs to support precedence constraints for individual resources or activities, such as an individual machine having a particular setup activity for a particular product manufacturing step or an individual customer delivery being before or after lunch, the problem is challenging.

- **Problems building planning applications that effectively compare scenarios** Good planning requires the ability to easily create multiple scenarios that solve a problem with different assumptions and/or goals. And the best planning usually requires the careful review of all of the differences between the scenarios. Even experienced analysts cannot do this in spreadsheets. Managers often face difficulties even creating scenarios, much less comparing them systematically. The decisions that are being made are complex and optimization models are highly structured. Specialized software is needed not only to support what-if analysis and scenario comparison, but also to provide explanations of which constraints are binding and may need to be relaxed.

Options for Planning and Scheduling Solutions

Today, many business managers use the planning and scheduling modules of the applications they are already using to manage daily operations, or they make do with home-grown spreadsheet-based applications. Others employ more flexible and powerful decision-making applications that were built using custom optimization-based models and integrate with the applications that provide the input data or receive the recommended plans or schedules. But historically, most organizations have behaved conservatively in an area as complex as optimization, preferring to accept the limitations of spreadsheets or generic applications to the uncertainties and risks associated with custom application development. The fact that many companies do not have OR experts on staff is another reason people have turned away from this option. But now there are good reasons to take a closer look at custom application development.

The following diagram summarizes the set of choices that are available today with their respective advantages and disadvantages. What is important to note is that there have been significant advances in the ease of model development and the quality of the decision support applications that can be built on top of optimization models.

	PROS	CONS
SPREADSHEET-BASED APPLICATIONS	• Quickly getting started • Familiar tool	• Limited size and complexity • Hard to maintain • Cumbersome what-if analysis
PACKAGED APPLICATIONS Generic Model by a Software Company SAP, ORACLE, IBM, infor, i2, Manhattan Associates	• Out-of-the-box functionality • Packaged best practices	• Difficult to change GUIs • May not capture all costs, constraints or goals
CUSTOM APPLICATIONS Custom Model Old Style	• Tailored to business needs	• Difficult for business managers to participate in model development process • Difficult to build GUIs • Difficult to maintain over time • Obligation to maintain custom model
CUSTOM APPLICATIONS Custom Model New Style	• Tailored to business needs • Easy for business managers to participate in model development process • Easy to build GUIs • More easily maintain application in harmony with optimization model	• Obligation to maintain custom model

Figure 4: Options for Planning and Scheduling Solutions

With spreadsheet-based solutions, it is extremely difficult for anyone other than the spreadsheet author to know what is going on inside the spreadsheet's calculations. Even for the original author, there is little support for documentation. Then there are the well-known size limitations which are a roadblock in many scheduling problems. Finally, the virtues of a spreadsheet are also a danger. It is actually not a good idea for enterprise-class planning or scheduling to be done by any person using any version of a spreadsheet without any documentation or any explanations of the decisions made. Production planning and scheduling are important applications and greater control is necessary in most situations.

Planning and scheduling applications based on generic models can be very effective. Let us look at one example to review the strengths and weaknesses of this approach. SAP's Advanced Production and Optimization (APO) application is a very successful and widely used application that has a generic supply network planning model that optimizes a supply chain using IBM® ILOG CPLEX. Specifically, it optimizes the flow of products through a network of suppliers, manufacturers, distribution centers and even customers. The optimization model built by SAP reduces overall costs (global costs) while respecting operational constraints and customer service goals. A partial summary of this can be seen in this table:

Costs	Constraints	Goals
• Production • Inventory carrying • Transportation between locations • Labor overtime • Non-delivery penalties	• Production capacity • Transportation capacity • Lot sizes • Safety stock requirements • Product shelf life • Product priorities • Customer category priorities	• Minimize costs • Maximize customer service

Two points are worth noting about this very successful and pervasive optimization-based planning application. First, if you need additional costs, constraints, prioritization rules or goals, you are out of luck. Simple examples would be the penalty cost difference between a non-delivery and a late delivery or the service difference between generic product delivery priorities and specific customer product delivery priorities. In both cases, SAP supports the first but not the second. Second, if you need a different application environment and greater ease of use in exercising and understanding the model, it is equally impossible. The optimization model and the style of interaction are both fixed. Certain parameters are exposed for scenario-creation purposes, but that is pretty much it. For many people using SAP APO-SNP, the functionality and ease of use are sufficient. But for others, the limitations are significant. For these people, there are two options: purchase a "best of breed" supply chain network planning application such as IBM ILOG LogicNet Plus XE, which also uses CPLEX, or build a custom decision support application based on a custom model.

Taking maximum advantage of optimization requires having the right optimization model or models to perfectly capture an organization's decision-making parameters. And the models may need to be modified at some point in their service life. Business does not stand still. As a result, custom applications should be considered if they can be based on better models that can be changed over time, and if they can provide the ease of use that people need to take full advantage of the power of optimization.

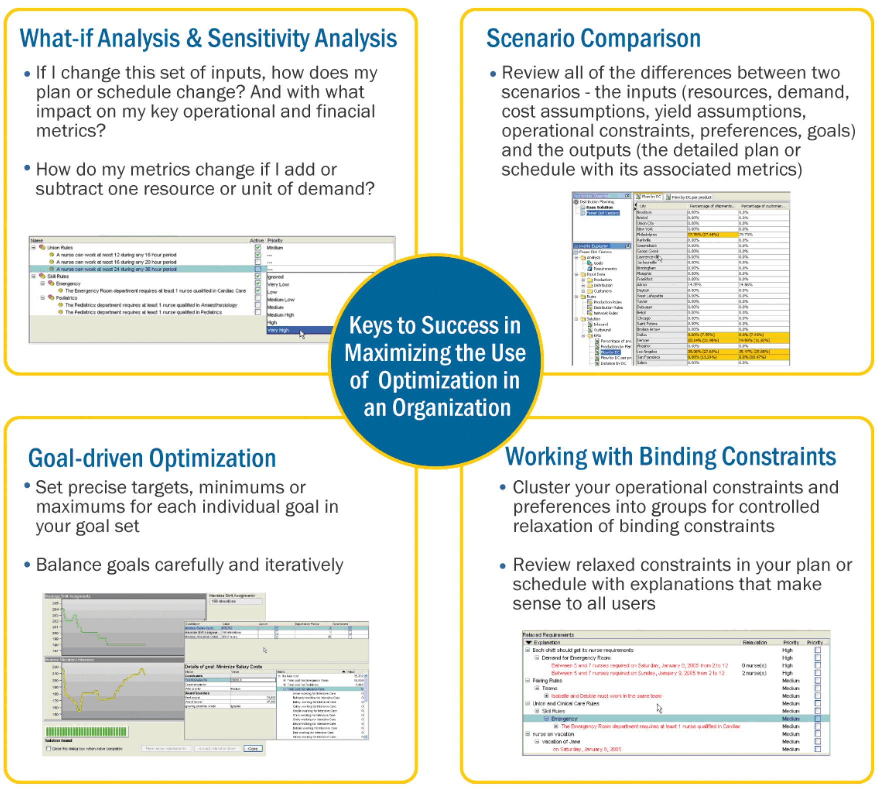
What Business Managers Need in a Planning or Scheduling Application

Let us now review the two foundations for effective optimization-based planning and scheduling applications:

- **Carefully Developed Optimization Models** – Complete sets of equations and instructions that can find the best possible plan or schedule for a set of goals while taking into consideration a large number of costs, constraints and preferences. These models tell the optimization engines what problem to solve.

  Great models are often worth millions of dollars to an organization. But how are great models built? What skills are needed? What does the process look like? It is probably fair to say that the process is 75 percent management consulting and 25 percent optimization expertise. It is fundamentally a management consulting process because many people must be interviewed and many views of a problem assembled and structured. Data must be analyzed to obtain correct costs and yields. The business must be analyzed to define the exact decisions that need to be made and the metrics that should be part of the model. The process involves economic analysis, cost accounting, business strategy and process modeling. When all of this is done, an optimization expert creates mathematical models that capture all of the inputs and generate all of the outputs.

- **What-if Analysis, Sensitivity Analysis and Scenario Comparison** – This is the ability to create a new scenario by modifying the assumptions and/or goals, and then seeing what happens to the solution as a whole and the metrics associated with it. This requires a very specialized type of decision support application—one designed to explore all of the underlying economics of a planning or scheduling problem, and one that interacts with the optimization engines and displays data, explanations and metrics in interesting and useful ways. Achieving excellence in scenario exploration can also be worth many millions of dollars to an organization. Key features include:



To expand on this second success factor a bit further, below is a more detailed list of the specific requirements for effective everyday use of the technology:

- **The visual display of complex data sets** – individually and in relationship to each other
- **Scenario definition:** the ease with which you can build a scenario, without any significant limits on the adjustments that can be accommodated, adjustments to any of the input datasets, constraints, business policies and preferences, costs, assumptions or goals
- **Scenario comparison:** seeing exactly what is different between two solutions in each area of inputs, outputs and output metrics
- **Explanations of binding constraints:** the quality of the messages the user receives when the optimization process hits an infeasibility
- **The controlled relaxation of constraints by group:** the ability to easily organize your operating constraints, business policies and preferences into groups with finely grained priorities that instruct the optimization engine to relax constraints in an order that makes sense to the business; constraint relaxation should be business driven not math driven
- **Manual adjustment:** the ability to modify a recommended plan or schedule, adding human knowledge and judgment to the mathematics and optimization, and then receive useful feedback on the consequences of the changes
- **Interoperability:** the solution can be easily exported to a spreadsheet for further analysis or reporting, or to an operational application that will execute the plan; similarly, input data can be easily imported from spreadsheets, data warehouses or production "system of record" databases
- **Engine visibility:** the ability to monitor the progress of the optimization process (the solution of the model for the dataset provided) and understand the rate of progress

If these usability features are present, nontechnical people will be successful with optimization.

Building Successful Planning and Scheduling Applications

For individuals not familiar with the application development process required for a custom planning or scheduling solution, the following illustration may prove helpful. The process requires both optimization and IT expertise.

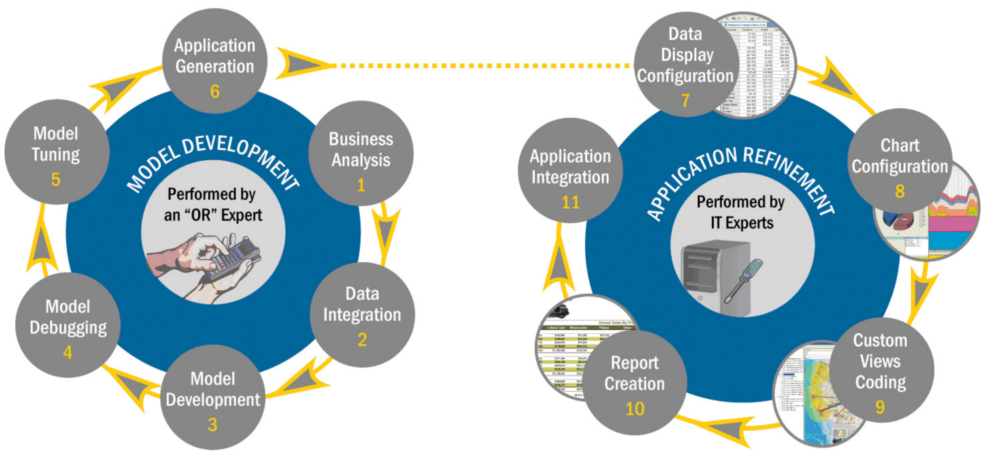


Figure 5: The Complete Custom Planning and Scheduling Application Development Process

The keys to success in developing a custom planning or scheduling application lie in three major areas:

- **Iterative model development** with the full participation of the necessary range of stakeholders from multiple functions
- **An integrated application development system** supporting the entire process from model development to application generation to application refinement and data integration
- **The ability to find and work with experienced people** who have built custom planning and scheduling applications before

An Iterative, Cooperative Modeling Process

To develop good planning or scheduling models, operational managers, financial analysts and business planners all may be required to participate in the modeling process in order to confirm that the operational constraints, costs and yield assumptions are correct, and that the goals are accurately categorized and can be balanced properly. This is not a one-step process and it must be one that allows people with different backgrounds to discuss the data, costs and relationships between variables associated with planning or scheduling problems without being an expert in OR or IT.

In fact, this is such an iterative process that the biggest key to success is application prototyping. This important step allows business people to review the model in a decision support application environment. Instead of reviewing the model's equations, analysts and managers are reviewing the model's inputs and outputs in natural language and in the context of actual decision-making scenarios with real data.

A Complete, Integrated System

A modern optimization-based application development system combines tools for optimization experts with tools for generating the graphical user interfaces (GUIs) that allow nontechnical people to exercise an optimization model fully. These tools work together and ensure that businesses can generate high-quality decision-support applications on top of high-quality optimization models. An obvious additional benefit is that the entire application is more maintainable—more able to grow and change with the organization it serves.

This concept can be visualized in the following diagram depicting IBM ILOG ODM Enterprise, a platform for supporting the entire model and application development process.

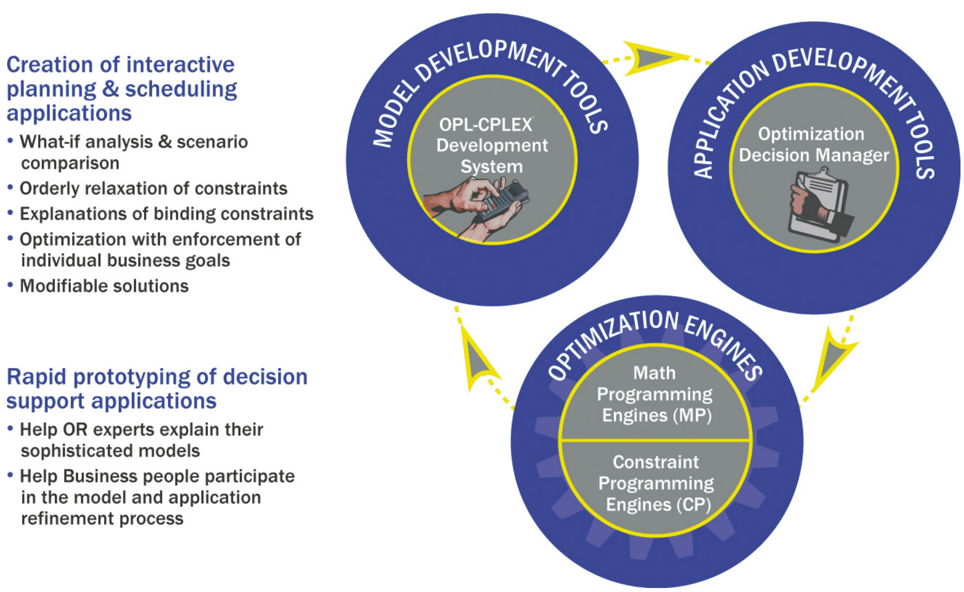


Figure 6: IBM ILOG ODM Enterprise

As can be seen, a complete system features three essential components:

Specialized Application Development Tools

In order to make optimization accessible for analysts and managers without advanced degrees in mathematics or computer science, the system must translate the structure of the optimization models into model input and output displays, and also generate a set of interactive application screens that will satisfy user requirements. In particular, it should allow nontechnical business users to:

- **Participate actively in the model refinement process:** test a model with easily prototyped application forms and displays that help them identify missing inputs or goals, ensuring that costs, yields and other assumptions are accurate and complete
- **Create and store scenarios:** easily modify input data, constraints, costs and/or goals without optimization expertise; they can store multiple scenarios and track input differences, plans or schedules, and metrics over time
- **Compare scenarios:** see exactly what the difference is between two solutions or plans; compare the goals, constraints, assumptions, available resources and recommended solutions with their operational and financial metrics
- **Use recommended plans and schedules as a beginning:** freeze part of a solution, make manual changes, and then regenerate a plan or schedule with information about the impact of these overrides
- **Relax binding constraints in an orderly fashion:** set constraint groupings and constraint enforcement priorities to manage solution generation, and receive straightforward explanations of binding or unsatisfiable constraints
- **Balance goals:** set minimums and maximums for individual goals as well as place different weights on the individual goals in a set
- **Work with spreadsheets:** import input data and export solutions as required

Optimization Model Development Tools for OR Professionals

The "optimization experts," whether they are in-house staff or outside professionals, need a complete, integrated development environment (IDE) designed specifically for optimization model development. This is analogous to the environments provided by SAS Enterprise Miner and SPSS Clementine for the development of models in the arena of predictive analytics. For optimization models, key capabilities can be summarized as follows:

- **A specialized optimization language/syntax:** allowing OR professionals to build models faster with fewer lines of code
- **An IDE for iterative model development:** supporting the visualization of data, performance tuning, debugging, monitoring of engine solving progress, relaxing constraints to force a solution, and an ability to change data sources easily as data is moved from Access or Excel-based data to production data in enterprise databases
- **Scripting capability:** supporting the definition of data preprocessing steps, special optimization solution search instructions, and solution post-processing
- **Integration with the application development process:** allowing the optimization expert to easily identify the portions of the model that need to be exposed to the business user and define the data display column labels, messages, constraint groups, and so on that will make the model accessible to the nontechnical community

A Set of High-Performance Optimization Engines

Of course, none of the models or applications would be operational without the optimization engines that are able to actually solve these complex problems. It is difficult to explain quickly everything that goes into a high-performance optimization engine, but for the nontechnical reader, the following can be easily appreciated:

- **The best possible performance** especially on large problems and on difficult scheduling challenges. Achieving this is a journey. You are always working toward the next step-function improvement in solving power and speed. An optimization engine is a coordinated set of approaches that orchestrate the use of thousands of algorithms and instructions. They are the result of years of focused kaizen by teams of people composed of mathematicians with a flare for software methods and advanced logic programmers with a flare for mathematics. Kaizen is the Japanese word for continuous improvement.
- **The highest quality recommendations** because optimization engines are solving problems that may have never been solved before, it is important for them to be tested and exercised on a wide range of problems as part of an effective QA process. You need a large library of models to test this sort of software properly.
- **The most information possible** to fully trust a recommended solution and to compare options properly, you need detailed explanations of binding constraints, calculated solution metrics and sensitivity analysis. Providing this information is on top of finding the best possible solution to a planning or scheduling problem.

Experienced Assistance

It goes without saying that the number one form of assistance that most companies need is optimization expertise – help in building the model of the problem. But for a successful decision-support application project that is based on a custom optimization model and integrated into an ERP environment, you need five key things:

- Expertise in facilitating the cross-functional model definition and refinement process
- OR expertise in building, testing and debugging the model
- Expertise in data preparation, manipulation and testing
- Expertise with mapping optimization data arrays to the tables of SAP, Oracle or others
- Project management

Optimization experts are not common, but they are more widely available than most managers realize. They can be found in universities, consulting firms, and in the Professional Services groups of some software companies. Managers should interview them for industry experience and number of real-world business problems successfully modeled.

Keys to success in the integration of optimization model-based applications into enterprise application architectures are the subject of another white paper. It is mentioned here only in making the general observation that experience—having done it before—is useful. To take one example, a planning or scheduling application might need data from SAP. What is important to understand is that there is a conversion process. In this case, an IBM ILOG SAP Adapter pulls the data out of SAP and converts it into the format needed by the optimization engines. Once the optimization process is completed, the planning or scheduling application can send selected data updates back to SAP via the same adapter, performing the same data mapping in reverse. A real-world example would be getting master data and production orders from SAP and sending updated production orders back to SAP.

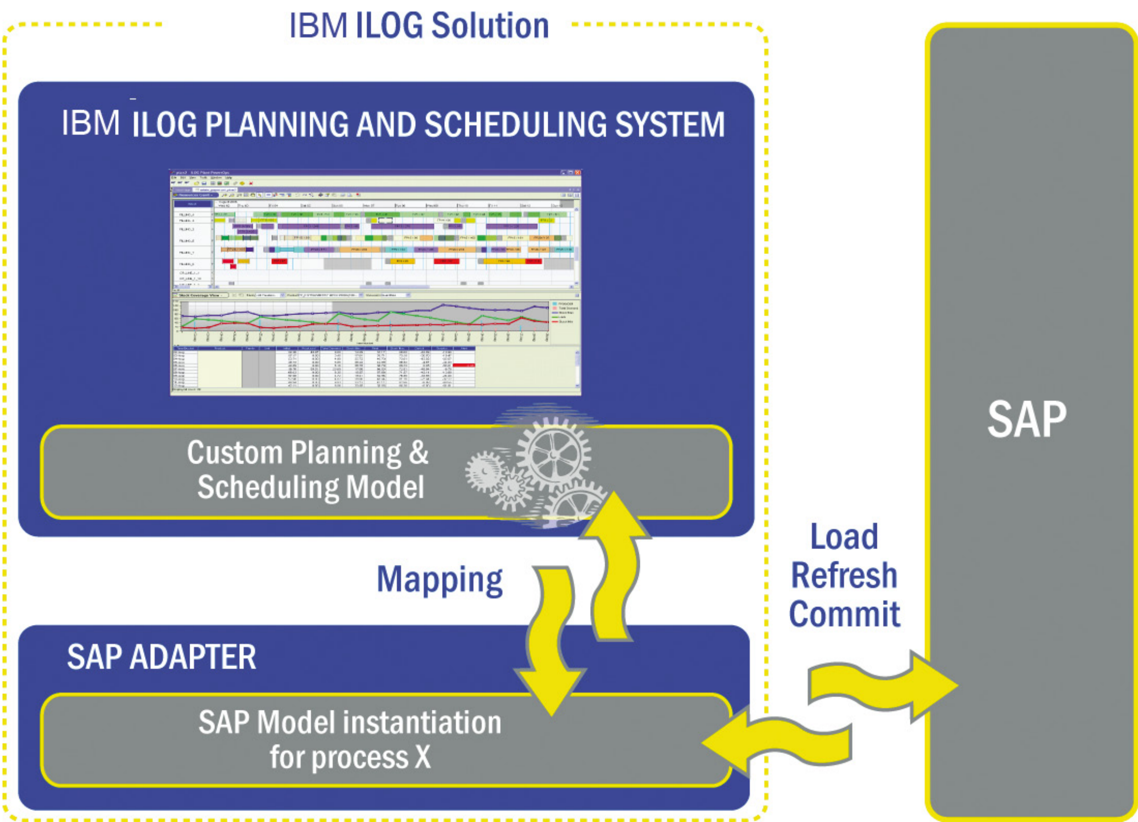


Figure 7: SAP Integration Architecture

For those interested in looking at this process in a bit more detail, the following picture may be helpful. Here the emphasis is on explaining the steps in the process if an SAP user wants to invoke an IBM ILOG analytic application from the SAP environment, taking advantage of NetWeaver and SAP's support for SOA-based interoperability. In current terminology, this picture illustrates how an IBM ILOG analytic application can serve as an "X-App" in the SAP world. Note: an IBM ILOG analytic application generally has no database of its own, although it can be easily set up to store run scenarios in a file system.

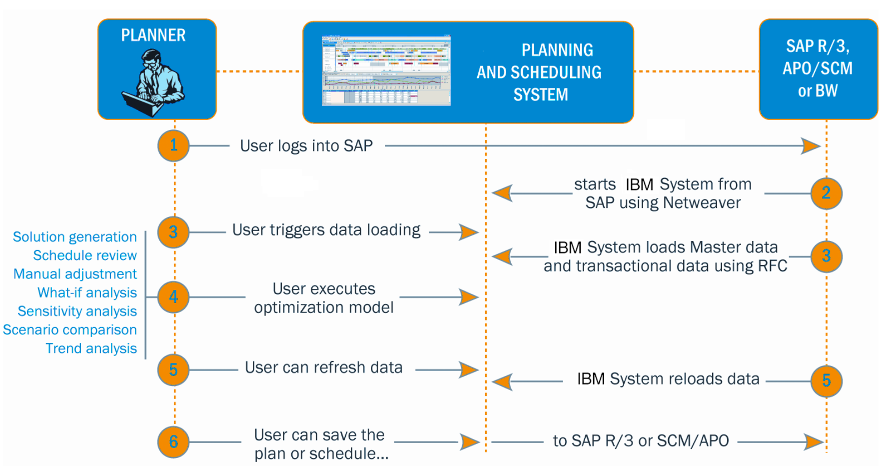


Figure 8: Using IBM ILOG Optimization in an SAP Environment

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