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Supply Chain Planning Optimization: Just the Facts

Supply Chain Planning Optimization: Just the Facts

by Larry Lapide

Since the 1960s artificial intelligence (AI) research has sought to enable computers to replicate the thinking processes of the human brain. But many efforts have failed to produce useful results. One visible "big win" for the computer versus the human recently occurred when IBM's Deep Blue finally beat chess master Garry Kasparov. Can computers out-think people? Probably not! Deep Blue was able to beat Kasparov because the computer's logic was tailored to its opponent's way of thinking, based on his prior games and strategies. Thus, the computer logic was focused on tackling a particular problem area, not on general thinking processes. Ultimately, the computer won because it could dispassionately, tirelessly, and mechanically sort through many combinations of potential board situations extremely fast. Thus, the computer does not replicate the thinking process, but it can improve decision-making and strategy.

In the area of supply chain planning, advanced planning and scheduling (APS) vendors have put together solutions that help planners make better decisions. For planners, APS quickly analyzes the implications of alternative decisions. By performing what-if simulation analyses, APS systems provide information about whether plans are reasonable or if they, for example, exceed resource constraints or result in inadequate performance.

Recently, in a fashion similar to the AI efforts, there has been a trend to embed sophisticated optimization logic into APS suites to improve decisions of supply chain planners. If used successfully, this type of optimization promises to drastically improve a company's supply chain performance in a variety of areas:

- Reduced supply chain costs
- Improved product margins
- Lower inventories
- Increased manufacturing throughput
- Better return on assets

This potential for improvement is generating a great deal of interest in supply chain optimization. Many established and startup APS vendors

SNAPSHOT

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are now using the concept as a selling point, and in some cases, as a key marketing differentiator. While optimization methods have been around since post World War II—with the advent of operations research and management sciences—there has been only a marginal interest in applying these concepts to supply chain planning. Will companies embrace these newer versions of optimization technology? The answer is yes. What company would not want to optimize its supply chain? These solutions, however, are expensive. Do all buyers really understand how to apply these solutions and what they are getting for their money? Is optimization worth the cost? Does it really work? AMR addresses these questions by focusing on supply chain optimization technology from leading APS providers. The Report covers the following topics:

- The growing optimization technology market and reasons for its growth
- The supply chain planning optimization framework
- The importance of data, models, and solvers in optimization
- The holistic optimization approaches vendors use within applications
- Optimization technology design issues
- Guidelines for the use of optimization in supply chain planning

THE MARKET FOR OPTIMIZATION IS GROWING

Today's market dynamics have made supply chains extremely complex and planning more difficult. The following true story is a case in point:

ABC Inc., a small, 100-year-old agricultural seed company called in a consultant to work on a production scheduling problem. The consultant talked to upper management and found that over the last couple of years the company was having difficulty meeting increasingly diverse customer needs. The president, who came from a Fortune 500 company, seemed to understand the problem best. One night, he noted his production planning people were working later than usual and he asked them why. They said that they had been working to develop a plan that would meet marketing's forecasts, but they were not able to do it, despite working on it for a couple of weeks! Over the last few years, the business had become very competitive and the company's product line had expanded to several hundred items, making planning much more difficult. The president explained that, while these planners had over 20 years of experience, the complexity of the environment had exceeded their ability to do the production plan on paper and spreadsheets using the guidelines and rules-of-thumb that they had developed over the years. The president stated he wanted the consultant to develop software to help them schedule better. He was familiar with this type of software from his experience at the Fortune 500 company. The consultant said, "Of course, you will want the software to give the planners the

At ABC, Inc. the planners had over 20 years of experience, but the complexity of the environment had exceeded their ability to do the production plan on paper and spreadsheets using the guidelines and rules-of-thumb that they had developed over the years.

optimal lowest cost solution." The president stated: "This would be extremely desirable, but just make sure it gives them a production plan that meets our marketing forecasts, as well as our production and distribution needs. Right now, it is of paramount importance that we generate realistic plans that satisfy our customer demand."

Manufacturers Are Showing a Greater Interest in Optimization

The situation at ABC, Inc., described above, has been happening for many years in all sizes and types of companies throughout the manufacturing industry. Customer demand and competition have made supply chain planning and scheduling more challenging and complex. A number of major trends have contributed to this increasing complexity:

Customer demand and competition have made supply chain planning and scheduling more challenging and complex.

- Customer demand for shorter cycle times and specialized packaging/delivery requirements
- Mass customization of products
- Product line and stock keeping unit (SKU) proliferation
- Globalization of operations—including sourcing, production, sales and marketing
- Greater outsourcing of manufacturing operations
- Increased use of third party logistics (3PL) providers
- Implementation of co-managed inventory programs with both suppliers and customers, such as vendor managed inventory (VMI) and continuous replenishment programs (CRP)
- Implementation of agile manufacturing initiatives
- Implementation of supply chain integration concepts
- Company mergers, acquisitions, and consolidations

These trends are contributing to an explosion in the number of entities that have to be planned for, driven by increases in the number of the following elements:

- Items
- Production and distribution facilities
- Functions
- Customers and suppliers

For many years manufacturers have been moving toward improved use of technology to support complex, diverse planning processes. Some, such as ABC, Inc., are doing it largely to maintain control of their operations in order to meet customer demand. Having already achieved control, many manufacturers are using APS technology to increase the productivity of planning processes and to lower supply chain costs.

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Generally, companies are looking for planning solutions that consider major supply constraints, which leads them to constraint-based optimization. Supply chain planning optimization techniques and solutions attempt to accomplish the following tasks:

- Determine a feasible plan that meets all demand needs and supply limitations
- Optimize the plan in relation to corporate goals such as low cost and profitability

While a feasible, realistic plan is of paramount importance, an optimized plan is better. It is the need for realistic, optimized plans that is driving many manufacturers away from classic materials requirements planning (MRP)-based planning solutions, which do not consider supply constraints (especially material constraints) and frequently generate an unrealistic supply plan.

Vendors Are Embedding Optimization in Their Planning Applications

While the APS market has increased dramatically over the last decade, only within the last two to three years has optimization been widely incorporated into APS suites.

Consistent with this corporate trend toward greater need for supply chain planning technology, the APS market is increasing dramatically. While this has happened over the last decade, only within the last two to three years has optimization been widely incorporated into APS suites. Examples include the following events:

- Slightly over one year ago, **Manugistics** (Rockville, MD) embedded various optimization solution methods into its integrated supply chain planning suite, especially its *Supply Chain Navigator* product.
- In 1997, **i2 Technologies** (Irving, TX) extended its optimization capabilities by purchasing the **CSC Operations Planning Group** (Austin, TX), which developed customized optimization solutions for the consumer packaged goods (CPG) market. i2 Technologies also purchased **Optimax Systems**, a pioneer in the use of genetic algorithms to optimize the scheduling of assembly lines. Lastly it introduced its *Global Decision Support Architecture* to lay the framework for enhanced optimization functionality across diverse environments.
- Recently, **Logility** (Atlanta, GA) announced plans to embed optimization software technology from **INSIGHT, Inc.** (Manassas, VA), a provider of supply chain optimization software for over 20 years.
- In 1997, **SynQuest** (Atlanta, GA), a production scheduling solution provider, acquired **Bender Management Associates** (Arlington, VA), which has a long history of customized supply chain optimization solutions. This purchase added to the optimization functionality acquired in 1996 from **Log'In**, a developer of simulation and optimization software.

- **InterTrans Logistics Solutions** (Toronto, ON), an i2 Technologies company and a provider of transportation management software, acquired **Strategic Decisions, Inc.**, the developer of *Supply Chain Strategist*, a supply chain network design tool, to help its 3PL customers optimize their distribution networks.
- **ILOG, Inc.** (Mountain View, CA), a supplier of supply chain optimization software components to APS vendors, purchased **CPLEX Optimization, Inc.** (Incline Village, NV), a supplier of linear and mixed integer programming tools.

Enterprise resource planning (ERP) vendors have also noted the dramatic growth in the supply chain planning market and some have announced plans to add optimization functionality:

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- **PeopleSoft** (Pleasanton, CA) leveraged its purchase of the Red Pepper APS optimization functionality to create what it calls *Enterprise Resource Optimization (ERO).*
- **SAP** (Walldorf, Germany) announced an initiative to develop supply chain planning functionality, which it calls *Supply Chain Optimization, Planning and Execution (SCOPE).* A key component of *SCOPE* will be *Advanced Planner and Optimizer* (*APO*), which will use optimization techniques.
- **Baan** (EDE, The Netherlands) acquired **Berclain** (Toronto, Ontario), a production planning and scheduling vendor, and has since developed *Baan SYNC*, which will include constraint-based planning and scheduling functionality.
- **J.D. Edwards** (Denver, CO) announced plans to embed optimization technology from ILOG into its future APS solution to be offered as part of its *OneWorld* ERP system.

Renewed Interest in a Mature Market

Despite the recent flurry created by the APS and ERP providers, it should be noted that supply chain planning optimization technology solutions are not new. There has been a market for optimization solutions for over 30 years. The market has slowly evolved from toolkit-based products to a packaged application market. Early adopters of optimization technology tended to be quantitative analysts, usually with degrees in operations research, who worked in the corporate world. Many worked in process industries such as Chemical, Paper, and Steel. These early adopters used general-purpose optimization tools (e.g., linear programming packages) purchased from software vendors to develop custom planning tools that typically ran in a batch mode. Early optimization tool vendors include the following companies:

Despite the recent flurry created by the APS and ERP providers, it should be noted that supply chain planning optimization technology solutions are not new.

- **IBM** (Armonk, NY), which provided the *Optimization Solutions and Library* (*OSL*) suite of optimization tools
- **Lindo Systems, Inc.** (Chicago, IL), which marketed a set of optimization tools, including one of the first spreadsheet-based user interfaces
- **Ketron Management Sciences** (Arlington, VA), which, in addition to operations research consulting services, sold optimization software

Few if any of the customized planning solutions developed by early adopters dealt with large portions of a company's total supply chain.

Few if any of the customized planning solutions developed by these early adopters dealt with large portions of a company's total supply chain. They usually focus on one important aspect of it. Some of the early applications dealt with specialized optimization problems:

- *Blending*—involves determining the best mix of raw materials required to form a product with specific characteristics. Blending optimization is important in some businesses where raw materials with different compositions can be obtained from multiple sources. For example, various crude oil supplies are blended to produce certain types of gasoline or oil products with specific viscosity grades. There is no fixed bill-of-material or recipe for a blended product. The planning problem is how to determine the optimal mix of constrained raw materials that are needed to produce specified amounts of finished product, often at a target or lowest price.
- *Trim or Cutting Stock*—involves the cutting, according to size—of semi-finished products to form a finished product. Examples of this type of planning occur in the Paper and Steel industries. Typically, large rolls of semi-finished products need to be cut to order. The planning problem is how to develop a cutting plan that satisfies customer orders while minimizing the amount of waste or "trim."
- *Network Flow or Transportation*—involves shipping products from a number of origins to a number of destinations. This was one of the earliest approaches for supply chain design or tactical planning, used to determine inbound or outbound shipments. The objective is to develop a shipping plan that minimizes transportation costs between origins and destinations.

General-purpose optimization applications made it easier for corporate users to develop supply chain planning solutions on their own or working with the vendor's consultants.

As this market progressed, a few early supply chain planning vendors started to sell general-purpose optimization applications. These applications made it easier for corporate users to develop supply chain planning solutions on their own or working with the vendor's consultants. Two such vendors are **Chesapeake Decision Sciences** (New Providence, NJ) and **Numetrix** (Toronto, ON). As general-purpose optimization applications, these types of solutions allowed users not only to model specialized planning problems like trim, blending, and network flow, but they also allowed users to model more general planning problems, such as combining blending with production scheduling.

Despite some early success in the use of optimization, the market was relatively stagnant until recently. Advances in powerful computer technology have helped to accelerate the growth of the APS market. The technology has also allowed APS vendors to embed optimization into their solutions more seamlessly and transparently. This has made it easier for users to model their planning environment, even those users not trained in optimization techniques.

Advances in powerful computer technology have helped to accelerate the growth of the APS market, allowing APS vendors to embed optimization into their solutions more seamlessly and transparently.

Today there are many popular APS solutions with embedded optimization. Despite this, the optimization aspect of the market carries a certain amount of mystery. Optimization is difficult to understand because of the jargon used by practitioners on both the user and vendor side. To many non-practitioners this is a very confusing, but seemingly intriguing and important area. The sidebar entitled "What is an Optimization Problem?" below should clear up some of the confusion. A short primer on the concepts and language behind optimization techniques and methods, it provides the context for the remainder of this Report.

WHAT IS AN OPTIMIZATION PROBLEM?

Generally, optimization problems seek a solution where decisions need to be made in a constrained or limited resource environment. Most supply chain optimization problems require matching demand and supply when one, the other, or both may be limited. By and large, the most important limited resource is the time needed to procure, make, or deliver something. Since the rate of procurement, production, distribution, and transportation resources is limited, demand cannot be instantaneously satisfied. It always takes some amount of time to satisfy demand, and this may not be quick enough unless supply is developed well in advance of demand. In addition to time, other resources, such as warehouse storage space or a truck's capacity, may be constrained in meeting demand. An optimization problem comprises four major components:

Generally, optimization problems seek a solution where decisions need to be made in a constrained or limited resource environment.

Decision Variables are within the planner's span of control:

- When and how much of a raw material to order from a supplier
- When to manufacture an order
- When and how much of the product to ship to a customer or distribution center

Constraints are limitations placed upon the supply plan:

- A supplier's capacity to produce raw materials or components
- A production line that can only run for a specified number of hours per day and a worker that must only work so much overtime
- A customer's or distribution center's capacity to handle and process receipts

Hard constraints, such as the number of working hours in a shift or the maximum capacity of a truck, must be adhered to or satisfied.

Constraints in an optimization problem are either *hard* or *soft*. Hard constraints, such as the number of working hours in a shift or the maximum capacity of a truck, must be adhered to or satisfied. Soft constraints can be relaxed or violated. Examples of soft constraints include customer due dates or warehouse space limitations. Customer due dates can be changed or a product may be squeezed into a warehouse temporarily, making constraints less stringent. Most optimization problem formulations designate cost *penalties* if a soft constraint is not met. The penalties allow constraints to be weighted by importance. For example, missing a customer due date is a more important concern than cluttering a warehouse aisle.

Objectives

Objectives maximize, minimize, or satisfy something, such as the following:

- Maximizing profits or margins
- Minimizing supply chain costs or cycle times
- Maximizing customer service
- Minimizing lateness
- Maximizing production throughput
- Satisfying all customer demand

Those unfamiliar with optimization are often confused about the difference between a constraint and an objective. Fueling this confusion, some factors can be formulated as either an objective or a constraint. For example, in most problems customer due dates are hard constraints. On the other hand, in resource constrained environments, while meeting customer due dates is important, it may not be possible. Therefore, the objective to meet customer due dates is expressed by maximizing customer service.

Models

Generally, the model must represent the "real world" to the degree needed to capture the essence of the problem. It must represent the important aspects of the supply chain.

Models describe the relationships among decisions, constraints, and objectives. These are often expressed in the form of mathematical equations. This is probably the most important but least understood part of an optimization problem. Generally, the model must represent the "real world" to the degree needed to capture the essence of the problem. It must represent the important aspects of the supply chain in order to provide a useful solution. For example, strategic planning typically uses aggregate models, which do not include every factor. On the other hand, operational planning uses models that include almost all factors and require detailed data.

Once an optimization problem is formulated, a *solver* determines the best course of action. A solver comprises a set of logical steps or algorithms embodied in a computer program to search for a solution that achieves the objective. A solver can develop three types of solutions:

- *Feasible Solution*—satisfies all the constraints of the problem.
- *Optimum Solution*—the best feasible solution that achieves the objective of the optimization problem. Although some problems may yield more than one feasible solution, there is usually only one optimum.
- *Optimized Solution*—a solution that partially achieves the objective of the optimization problem. It is not the optimum or best solution, but it is a satisfying or reasonable one. This is usually one of the best feasible solutions. However, for optimization problems that have no feasible solutions, it may be one of the best *infeasible* solutions. For example, in a resource-constrained environment, it may be a solution that is infeasible because it does not meet all customer due dates, but it may minimize operating costs.

Unless a problem has a very specific structure (such as a linear programming problem), an optimized rather than an optimum solution is the best that can be generated.

Figure 1 represents an optimization problem with a generalized set of objectives to maximize. It depicts the different types of solutions that might be developed by a solver. While an optimum solution is intuitively appealing in most cases, it is unattainable in very complex problems. Unless a problem has a very specific structure (such as a linear programming problem), an optimized rather than an optimum solution is the best that can be generated. In some cases a solution may be a local optimized one (see Figure 1).

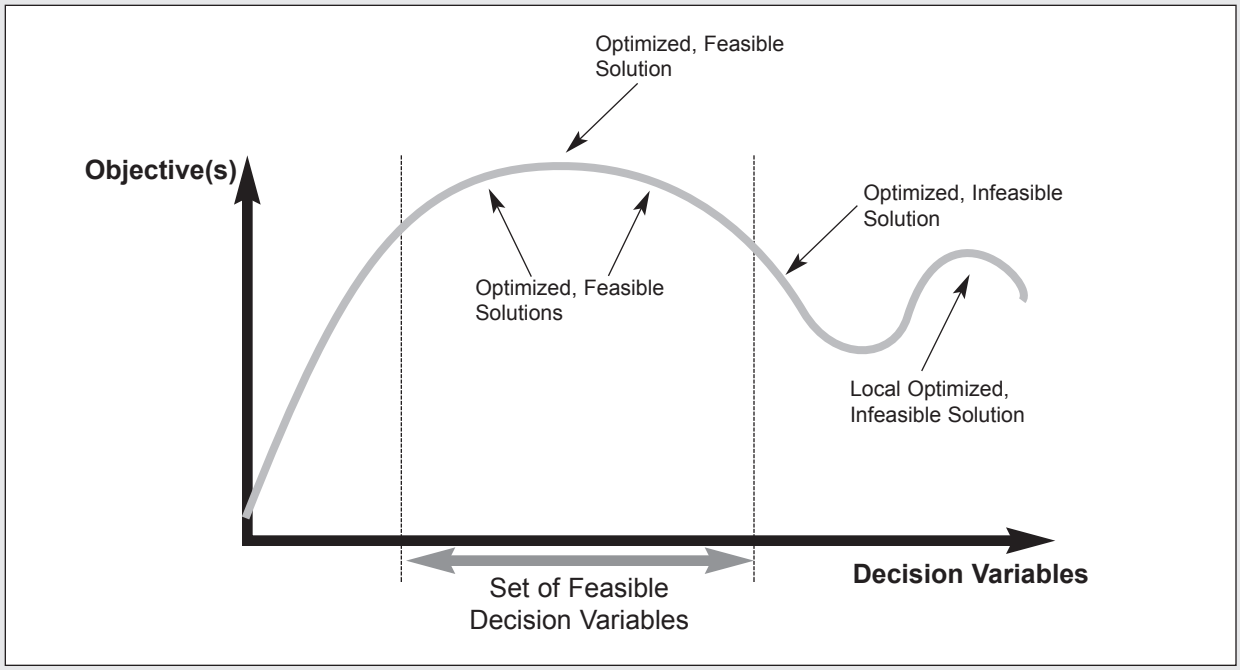

Figure 1: Graphical Representation of Optimization Solutions

Source: AMR, 1998

SUPPLY CHAIN PLANNING OPTIMIZATION FRAMEWORK

A network model graphically visualizes a supply chain and is used to depict the parts of a supply chain being considered in the planning process.

A supply chain planning environment can be described in terms of the supply chain's structure and the level of planning being supported. In general, the following holds true:

- A supply chain's structure is described using a *network model*.
- The planning processes are divided into three hierarchical-based levels: *strategic*, *tactical*, and *operational*.

Supply Chain Viewed as a Network Model

As part of the planning process, the structure of the supply chain needs to be represented. This is typically done using a network model. A network model graphically visualizes a supply chain and is used to depict the parts of a supply chain being considered in the planning process. Figure 2 represents a manufacturer's supply chain. Usually referred to as a *network* representation, the *nodes* represent facilities that add value to the supply chain. Nodes occur from the sources of raw materials and intermediate products to the consumers of the finished products. The *arcs* or *links* connecting the *nodes* represent transportation lanes for materials, semi-finished, and finished products.

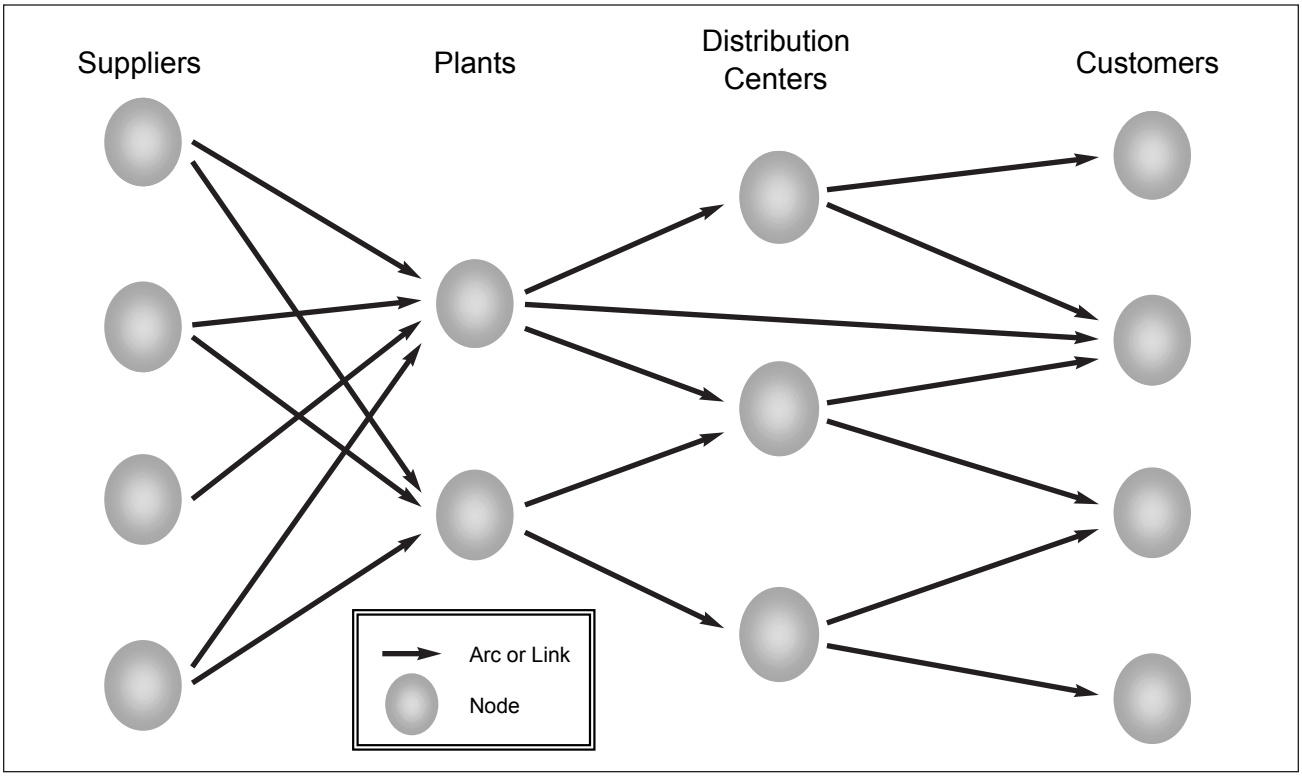

Figure 2: Network Representation of a Supply Chain
Source: AMR, 1998

Planning Processes Have Three Hierarchical-Based Levels

Planning processes are typically subdivided into multiple hierarchical-based planning levels. Each level has a planning cycle that its processes follow. Currently, supply chain planning is usually done using three hierarchical planning levels:

- Strategic or high-level planning is typically done yearly or on an ad hoc basis.
- Tactical or mid-level planning is typically done quarterly or monthly.
- Operational or low-level planning—largely involving scheduling, rescheduling, and execution—is typically done weekly, daily, or by shift.

Figure 3 depicts the scope of APS processes in relation to these planning levels. A description of each supply chain planning level and how optimization is used within it follows.

Planning processes are typically subdivided into multiple hierarchical-based planning levels, each of which has a planning cycle that its processes follow.

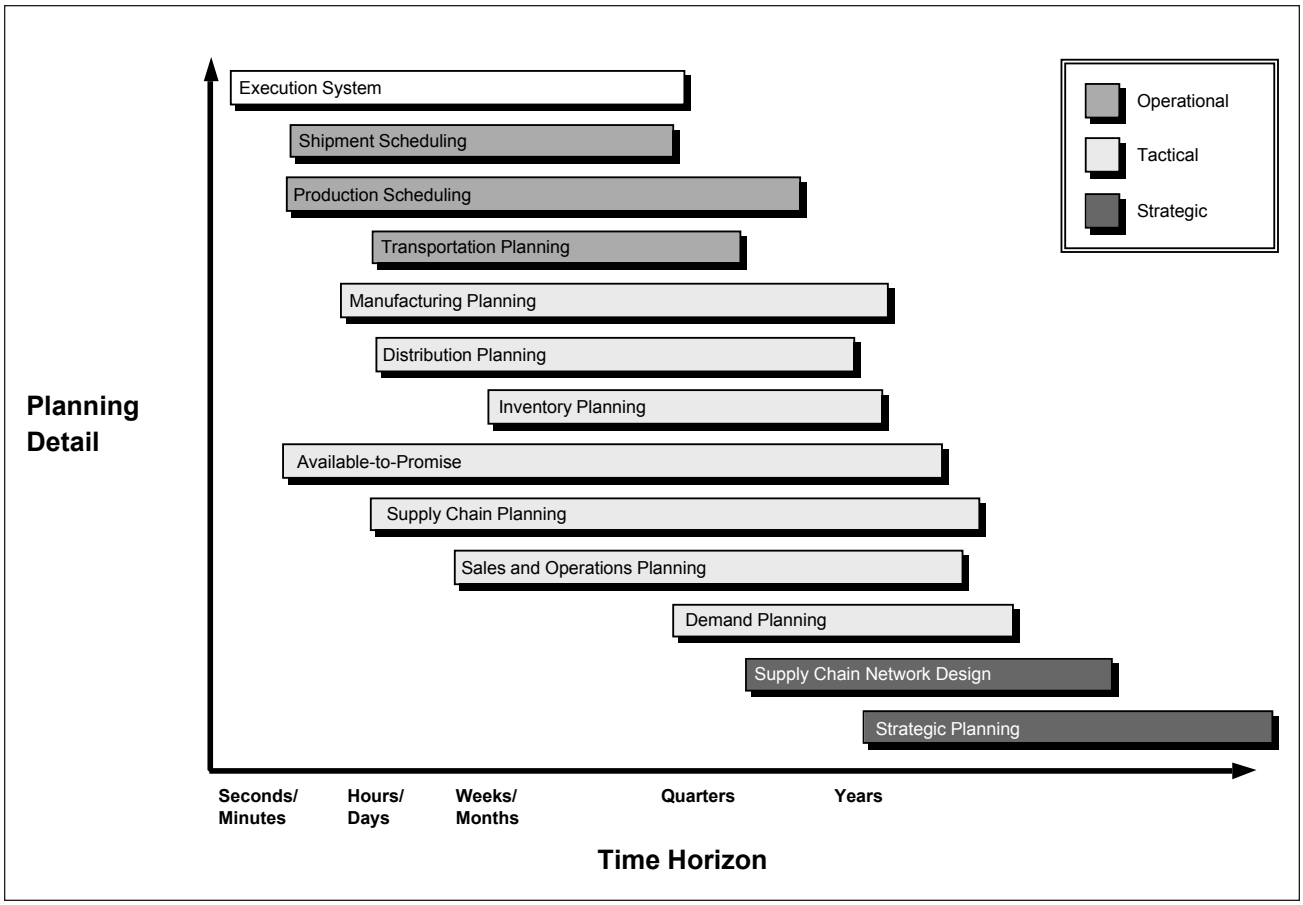

Figure 3: Scope of Advanced Planning and Scheduling and Planning Levels
Source: AMR, 1998

Strategic Level Planning—Supply Chain Network Design

Conceptually, supply chain network design can be thought of as determining the nodes and arcs within a supply chain network.

To support supply chain design, optimization determines the location, size, and the number of plants, distribution centers, and suppliers. This level of planning includes sourcing and deployment plans for each plant, each distribution center, and each customer. It also considers the flow of goods through the supply chain network. Generally, supply chain network design is done infrequently (i.e., every few years) as companies do not need to add new plants or distribution centers on a routine basis.

Conceptually, supply chain network design can be thought of as determining the *nodes* and *arcs* within a supply chain network. Multistage production processes are usually handled by creating nodes for each major step in the process (to handle cases such as feeder plants). The concept of time is usually not a consideration in supply chain network design. Month-to-month or week-to-week changes—for example in demand—are typically inconsequential to supply chain network design decisions.

Supply chain network design products include the following:

- *Supply Chain Strategist* from InterTrans/i2 Technologies
- *Supply Chain Designer* from **CAPS Logistics** (Atlanta, GA)
- *SAILS* and the *Global Supply Chain Model* from Insight
- *Network Designer* from SynQuest

Tactical Level Planning—Supply Planning

Supply chain planning at a tactical level is called supply planning and involves optimizing the flow of goods throughout a given supply chain configuration over a time horizon.

Supply chain planning at a tactical level is called *supply planning* and involves optimizing the flow of goods throughout a given supply chain configuration over a time horizon. Similar to supply chain design, supply planning develops sourcing, production, deployment, and distribution plans. But there are some major differences:

- The supply chain network configuration is already in place with supply entities such as suppliers, plants, distribution centers, and transportation lanes.
- Supply plans are time-dependent—using a "time buckets" concept. (Generally, supply planning is done monthly or weekly.)
- Supply plans may consider aggregate views of multistage production processes by incorporating partial levels of a plant's routings and a product's bill-of-materials.
- Setup and changeover times may also be considered, but not the sequencing of orders through a manufacturing facility.

Some manufacturers and software vendors subdivide the supply planning process into two or more planning processes and hierarchies. For example, a first level of planning might involve the development of

material and product flows within the supply chain network. This establishes optimized sourcing plans, which determine the suppliers for each plant and the plants/distribution centers that will replenish the distribution centers and customer stocking locations. This planning is typically done using aggregated product groups over longer periods of time (quarters or months). The second, lower level tactical planning might involve more detailed, optimized manufacturing master plans and distribution center inventory replenishment plans for individual SKUs over shorter periods of time (months or weeks).

Some of the software vendors that provide optimization-based supply planning solutions are listed in Table 1.

Vendor	Tactical Planning—Supply Planning Module
Adapta	*SKEP Optimizer*
Baan	*Baan Synch Planner* (June release)
CAPS Logistics	*Supply Chain Coordinator*
Chesapeake	*MIMI Planning*
Fygir	*FIT*
i2 Technologies	*Rhythm Supply Chain Planner* and *Factory Planner*
Logility	*Supply Planning* (under development)
Manugistics	*Supply Chain Navigator* and *Supply Planning*
Numetrix	*Numetrix/3 Enterprise Planner* and *Dynamic Distribution and Deployment Scheduling*
Paragon Management Systems	*Global Strategic Planner* (*GSP*) and *Supply Chain Planner* (*SCP*)
PeopleSoft	*Enterprise Planning*
Synquest	*Supply Chain Planner*

Table 1: Vendors With Optimization-Based Supply Planning Modules
Source: AMR, 1998

Operational Level Planning—Production Scheduling

At an operational level, supply chain planning can be viewed as supply scheduling. For a manufacturer, supply scheduling is essentially production scheduling done on a plant-by-plant basis. Production scheduling develops a minute-to-minute or hour-to-hour schedule for all of a plant's resource needs, including labor, equipment, and materials. Production scheduling optimally sequences orders into the manufacturing process. Generally, production scheduling is done frequently, potentially several times a day to account for changes to orders, machine failures, material shortages, and other plant disruptions. The process usually considers the lowest level of detail on plant routings, product bills-of-material, and changeover and setup times.

Production scheduling develops a minute-to-minute or hour-to-hour schedule for all of a plant's resource needs, including labor, equipment, and materials.

The following vendors provide some level of production scheduling optimization:

- Baan/Berclain
- Chesapeake
- **Fygir** (Burlington, MA)
- i2 Technologies
- Logility
- Manugistics/**ProMira** (Ottawa, Canada)
- Numetrix
- **Ortems** (Lisle, IL)
- **Paragon Management Systems** (Los Angeles, CA)
- PeopleSoft
- **STG** (Dallas, TX)
- SynQuest
- **Taylor** (Atlanta, GA)
- **Thru-Put Technologies** (San Jose, CA)

MODELS, DATA, AND SOLVERS ARE KEY ELEMENTS OF OPTIMIZATION

If a planning process is based on a model that inadequately represents reality or if the data used in a model is wrong, the solutions developed by the optimization will not be meaningful or executable.

Models and data are two very important elements of supply chain optimization. A plan's usefulness greatly depends on the quality of both. If a planning process is based on a model that inadequately represents reality or if the data used in a model is wrong, the solutions developed by the optimization will not be meaningful or executable. The two elements go hand-in-hand for the following reasons:

- Data is always needed to populate a model.
- A model should not be built needing data that is not available.

Another important element of an optimization process is the solver, which solves for an optimized solution. The planning model determines the best solver. (See the sidebar "Optimization Solvers" on page 18 for a discussion of solvers). Together, data, models, and solvers represent key elements of optimization-based planning.

Good Quality Models Are Needed

A supply chain planning optimization process requires "good quality" models. For good optimization, the level of detail in the model must be appropriate for the planning level. For example, in deciding how much to make in a plant this month, the model does not have to consider the exact sequencing of orders (actual or forecast) placed on the plant. On the other hand, to decide on the plant schedule for a specific day, the model should consider the order sequence.

While models and data are extremely important to the usefulness of a plan developed using optimization, realistic, executable plans can sometimes be developed without detailed models and data. A common guideline in supply chain planning optimization is that detailed models are not needed for strategic planning but are needed for operational and tactical planning. For strategic and higher levels of tactical planning, a model could be based on aggregate data such as product groupings or regional demand. It is important for an operational model to be based on detailed data such as SKUs and customer orders.

While models and data are extremely important to the usefulness of a plan developed using optimization, realistic, executable plans can sometimes be developed without detailed models and data.

Solvers Depend on Models Used

In addition to models and data, solvers are important since they generate the optimized solutions. Yet one of the most confusing aspects of optimization technology is the various methods or mathematical algorithms deployed in these solvers. Many of these methods were developed to solve problems with a specific model or mathematical structure, while others were developed to improve the computational speed of the solver. This led to esoteric names for these solvers and added to their "rocket-science" positioning. In the area of supply chain optimization, most methods can be grouped as one of the following types:

- Mathematical programming (largely linear and mixed integer programming)
- Heuristics (including scheduling methods like the Theory of Constraints or Simulated Annealing)
- Genetic algorithms
- Exhaustive enumeration

Generally, mathematical programming methods are used in solvers for strategic and higher levels of tactical planning. These methods generally work only for solving linear- and some integer-based models, commonly used in strategic levels of planning. Tactical and operational models are usually not linear and are much too complex to solve using mathematical programming methods. For this reason, heuristic methods are generally used in tactical and operational planning level solvers.

Generally, mathematical programming methods are used in solvers for strategic and higher levels of tactical planning.

Genetic algorithms are used primarily in operational planning to consider a large number of possible solutions. The Theory of Constraints, a heuristic method based on work by Eli Goldratt, is another solver method commonly used in operational planning. Vendors that use solvers based on the Theory of Constraints include the following:

- i2 Technologies
- STG
- Thru-Put Technologies

While not a formal optimization technique, exhaustive enumeration is predicated on using the computer to find a solution by looking at all possible alternative plans. This method proves useful in simple supply chain situations. Otherwise, this method is computationally intensive and slow to generate a solution. **Distinction Software** (Atlanta, GA), uses this optimization method for its manufacturing planning solution. Since the company focuses on mid-tier and smaller manufacturers, the exhaustive enumeration approach is feasible.

OPTIMIZATION SOLVERS

Optimization solvers use and are named for the different methods or algorithms deployed to find solutions. These methods can be grouped into four categories:

- Mathematical programming
- Heuristics
- Genetic algorithms
- Exhaustive enumeration

Mathematical Programming Methods

Mathematical programming methods are used for problems that can be modeled with equations that describe the constraints and objectives.

Mathematical programming methods are used for problems that can be modeled with equations that describe the constraints and objectives. Mathematicians have proved that if a problem can be described using certain sets of equations, then an optimum solution can be computed following a prescribed algorithm or technique. This is in contrast to other methods that search for an optimum but offer no guarantee that it can be found. The most commonly used mathematical programming technique is linear programming (LP). This method works only if all the constraints and a single objective can be expressed as linear equations (i.e., a linear equation looks like this: $\sum X_{ijk} - D_j Z_{kj} = 0$). If this holds, the optimum solution that either maximizes or minimizes the single objective can be generated. LP assumes that the decision variables can be expressed as regular, continuous numbers. If some decisions can only be expressed as an integer or whole number, LP does not work. For example, if the decision is to incur a production changeover or setup, this can only be expressed as a "yes" or "no" or mathematically as a "0" or a "1."

To handle this, mixed integer programming (MIP) was developed. This method also only works if all the equations are linear. In contrast to LP, however, while an optimum solution can be generated, it may take too long. The good news is that MIP does have a way to tell how much better an optimum solution would be if it could be generated.

Other mathematical programming methods include dynamic programming and nonlinear programming. However, these methods are not often used in supply chain planning optimization.

Heuristics

Heuristic methods are predicated on trying to improve a known feasible solution following prescribed steps. Heuristics do not guarantee that an optimum solution can be found, nor do they determine how much better an optimum solution might be. As an illustration, a simple heuristic for maximizing an objective might follow a three-step approach:

Heuristics do not guarantee that an optimum solution can be found nor do they determine how much better an optimum solution might be.

1. Start all decision variables at 0 value.
2. Continue increasing decision variables one at a time as long as the objective continues to increase.
3. Stop when increasing all decision variables no longer increases the objective.

While this heuristic method might not lead to the optimum, solutions will usually get better or stay the same. Simply put, heuristics are based on the logic a reasonable person might follow in looking for an optimum.

Some scheduling optimization solutions use heuristic logic based on the Theory of Constraints (TOC) espoused by Eli Goldratt. These methods focus on critically constrained resources or "bottlenecks" to develop a schedule. The TOC approach revolves around a *drum*, *buffer*, and *rope* concept. First, TOC uses the critically constrained resources to develop a master plan or *drum* that the plant or system "beats to" or to which the pace is set. *Buffers*, such as work-in-process inventories and surplus time in the schedule, are put in place to ensure maximum utilization of the critically constrained resources that ensure they do not sit idle. Lastly, all non-critically constrained resources are "tied" together according to the drum, creating so-called *ropes* that pull work through the system.

In addition to TOC, there are many types of heuristic methods that are proprietary knowledgeware of the vendors. Some of these are based on known, published approaches such as Simulated Annealing and Repair-Based Scheduling methods.

The Theory of Constraints uses the critically constrained resources to develop a master plan or drum that the plant or system "beats to" or to which the pace is set.

Genetic Algorithms

Genetic algorithms are predicated on a biological selective breeding concept of survival of the fittest. The methods attempt to find an optimized solution from a large set of possible solutions by comparing them and selecting the best ones of the group. The ones that *survive* this test are

then *mutated* or *crossbred* to establish another set of solutions. This search method continues testing from *generation-to-generation* for some duration of time, thereby developing a reasonably optimized solution. These methods work well when a baseline schedule or plan exists. For example, sequencing a number of orders through a single assembly-line operation to maximize on-time delivery or to minimize changeover is an optimization task where genetic algorithms could be used.

Not always considered a formal optimization technique, the exhaustive enumeration method evaluates all possible combinations of decisions to find the best combination.

Exhaustive Enumeration

Not always considered a formal optimization technique, the exhaustive enumeration method evaluates all possible combinations of decisions to find the best combination. This method is used when there are relatively few decision-variable combinations to consider. For example, a job shop with 1 machine and 10 orders to sequence would generate 3.6 million potential combinations for evaluation. While this is a lot for a human to handle, it is an easy task for a computer.

VENDORS ARE MOVING TOWARD MORE HOLISTIC OPTIMIZATION

Generally, optimizing each piece of a plan in isolation from other plans does not guarantee that optimization is achieved for the total planning process. For example, developing an optimal production plan in isolation from distribution does not guarantee that the total production/distribution plan is optimal. Vendors are addressing this concern in the following ways:

- Moving toward *synchronized concurrent* planning from *synchronized sequential* planning
- Providing functionality that helps to synchronize planning levels
- Moving toward real-time planning and execution

Generally, optimizing each piece of a plan in isolation from other plans does not guarantee that optimization is achieved for the total planning process.

Each of these vendor trends attempts to provide users with a more holistic approach toward optimization. They each address planning processes that may be somewhat subdivided but that support optimized plans across the entire supply chain. Each trend is discussed below.

A Move Toward Synchronized Concurrent Planning

Figure 4 is a graphical representation of a synchronized sequential supply chain planning process. In this process, demand planning is done first. The resulting forecasts are used as input to the distribution planning process (including planning for inventory, transportation, and warehousing). The distribution plans developed by this process are

then used as input to the manufacturing planning process. Lastly, the output of this process is used as input for the procurement planning process. The planning process is synchronized, since any change in "downstream" plans is automatically reflected in the "upstream" planning processes. From a product perspective, Manugistics' supply chain planning suite was the first major solution providing this type of synchronized sequential planning approach.

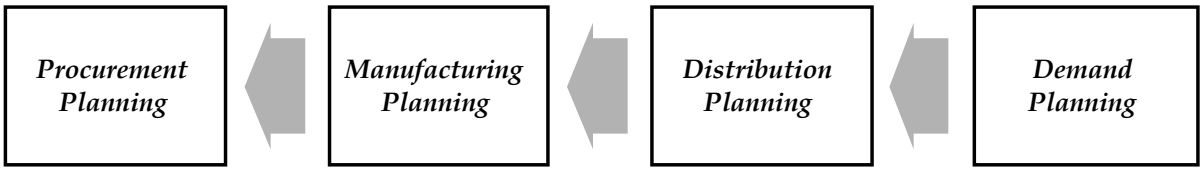

Figure 4: Synchronized Sequential Planning
Source: AMR, 1998

The synchronized sequential approach works well in integrating supply chain planning and in moving it to a consumer demand "pull" environment. It has, however, two problems from an optimization perspective:

- Each planning component's resource constraints are typically not considered, nor is there any attempt to optimize an objective.
- Separate optimization of each planning process rarely produces an optimized plan in the context of the whole supply chain.

In synchronized concurrent planning, the demand, distribution, manufacturing, and procurement plans are jointly or simultaneously developed.

Some optimization processes solve these two problems through "synchronized concurrent" planning (See Figure 5). In synchronized concurrent planning, the demand, distribution, manufacturing, and procurement plans are jointly or simultaneously developed. All constraints along the supply chain and optimizing objectives, such as cost or profitability, are considered within the planning process. Many vendor applications have moved or are moving toward this planning approach. For example, Manugistics' *Supply Chain Navigator* provides synchronized concurrent planning.

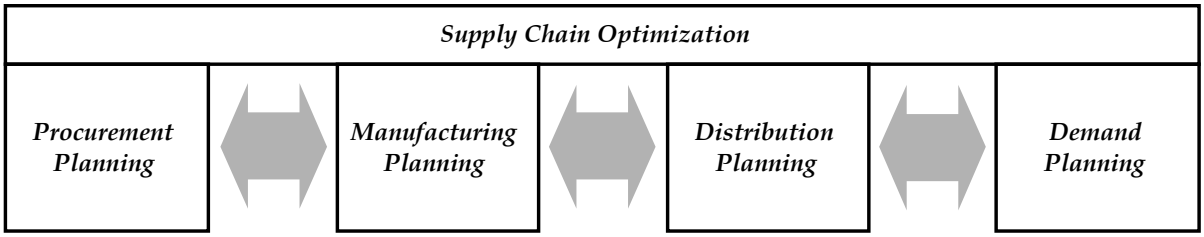

Figure 5: Synchronized Concurrent Planning
Source: AMR, 1998

Planning Levels Are Being Synchronized To Ensure Optimality

In most optimization frameworks, optimal solutions generated at higher levels in a planning hierarchy are used as starting points or constraints on the optimization taking place at lower levels.

In most optimization frameworks, optimal solutions generated at higher levels in a planning hierarchy are used as starting points or constraints on the optimization taking place at lower levels. In a planning environment where optimization is a goal, plans at different levels may need to be synchronized to ensure that the supply chain is continually operating in an optimized fashion.

Figure 6 depicts the difference between architectures that do and those that do not have synchronization functionality. Disjointed plans and data levels do not ensure that optimization is achieved. To ensure synchronization and consistent optimization across hierarchical planning levels, vendors use several approaches:

- The use of *telescoping* planning horizons
- The use of a *common data structure* for all planning levels
- The monitoring and control of the degree of synchronization

In a *telescoping* planning horizon, "time buckets" vary over time (typically increasing):

- The first few weeks may be planned in *continuous* time, like minutes or hours.
- The next few months might be planned in weeks.
- The last periods of the planning horizon might be represented in months or quarters.

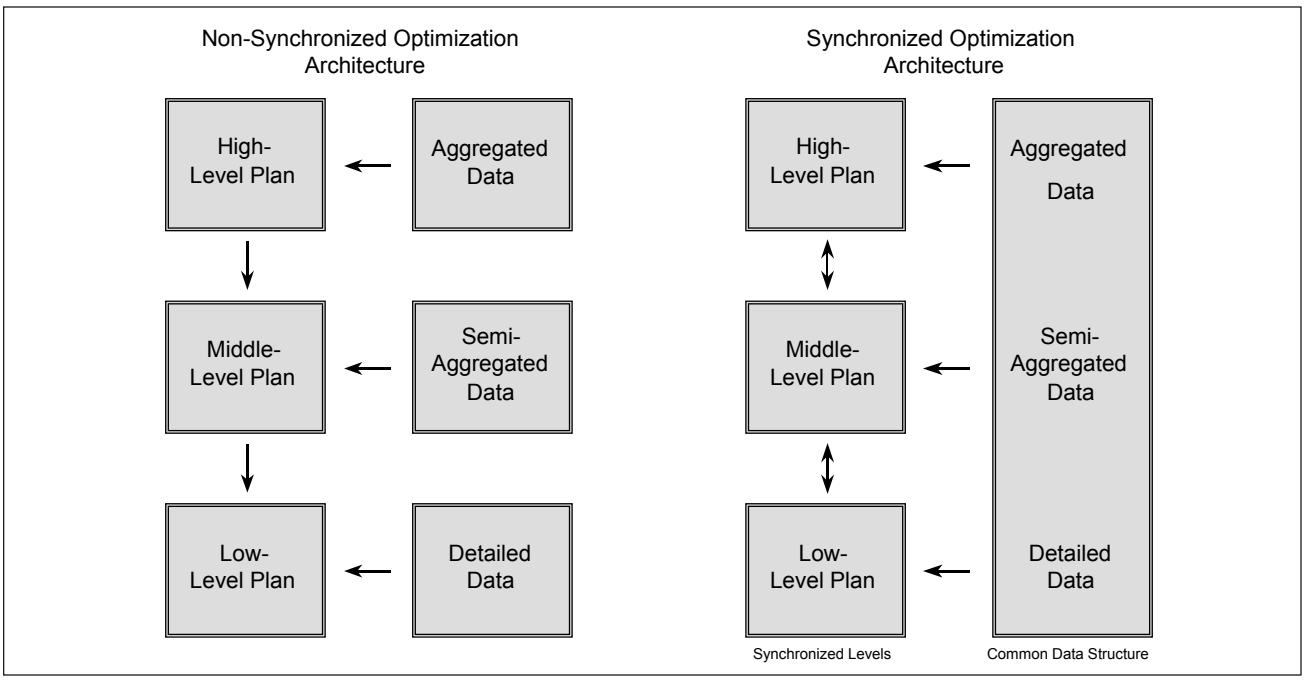

Figure 6: Non-Synchronized Versus Synchronized Optimization Architecture
Source: AMR, 1998

This approach helps ensure synchronization along the time dimension for the different planning levels. For example, Thru-Put Technologies' *Resonance* product allows the user to define a telescoping planning horizon for viewing results. Other vendors with telescoping planning horizons include Chesapeake and Numetrix.

Some vendors address the synchronization issue by incorporating functionality to monitor and control the degree of synchronization among planning levels.

Vendors also address the synchronization issue by using a *common data structure* for all planning levels. This common data structure ensures that aggregated data is always derived from and synchronized with detailed data—possibly down to the lowest level of base data (e.g., ERP transaction data). If needed, these solutions also allow a planner to build models using detailed data. For example, if a lower-level work task or portion of a plant's routing is always a major bottleneck, a user can include it in higher level plans to ensure that the solution is optimal and feasible. For example, Paragon Management Systems uses a common data structure approach within its applications; Ortems has a data structure with aggregated data derived from detailed data.

Some vendors address the synchronization issue by incorporating functionality to monitor and control the degree of synchronization among planning levels. As a planner works with the system, if a lower-level plan gets significantly out of synch with higher-level plans, the higher-level plans are regenerated. Paragon Management Systems has designed its APS product suite to ensure synchronization among planning levels in this way. Numetrix's *Collaborative Enterprise Network* product takes a slightly different approach. The application monitors the degree of synchronization among plans and sends a planner an alert message when they are out of synch.

Real-Time Planning and Execution Is a Goal

As computers get more powerful, companies are shrinking planning cycles and achieving real-time planning and execution.

As computers get more powerful, companies are shrinking planning cycles and achieving real-time planning and execution. In turn, this moves them toward achieving real-time optimization, as well as reducing the need for hierarchical planning processes with long cycle and lead times. A reduction in these planning cycles would lead to the following improvements:

- Reduced supply chain inventories
- More responsive supply chain operations with improved customer service

Up to now, reducing planning cycles with the use of applications has been limited by the speed at which an optimized plan can be generated. While some manufacturers have moved from planning in a batch mode, many have not. Applications are getting closer to generating optimized plans in real-time.

Memory-resident applications are faster as long as the planning problem can fit into memory, but they quickly degrade in performance on large problems that also require hard disk space.

To do this, some vendors, such as i2 Technologies and Ortems, use memory-resident planning applications loaded into and executed in main memory. This speeds up the application substantially. Other vendors, such as Manugistics, have designed applications to use both memory and hard disk space. Generally, both approaches achieve the goal of faster plan generation. Neither approach works better in all planning environments. For example, memory-resident applications are faster as long as the planning problem can fit into memory, but they quickly degrade in performance on large problems that also require hard disk space.

APPLICATION ARCHITECTURES DIFFER SUBSTANTIALLY

A variety of design issues must be considered to develop the architecture or framework of a supply chain planning optimization application:

- The balance between modeling flexibility and built-in functionality
- The ability for the user to maintain control of optimized solutions
- The use of third party optimization components
- Special functionality for handling multiple objectives
- Functionality for supporting special optimization problems

Vendors have addressed these issues in a variety of ways, many times depending on a specific vendor's history and market focus.

Applications Need To Balance Flexibility and Built-In Functionality

Optimization depends heavily on the ability of the application to model real world issues. This can be done with built-in modeling functionality, such as predefined models for setting safety stocks. Rather than built-in functionality, an application may provide flexibility with general-purpose modeling capability that allows users to create models—such as defining safety stocks models. Applications need to provide users with a balance between built-in capability and flexibility.

Some vendors provide general-purpose modeling applications that allow users the flexibility to optimize across a broad range of decisions.

Some vendors provide general-purpose modeling applications that allow users the flexibility to optimize across a broad range of decisions. These products allow users to tailor the optimization to their own environment, letting them optimize decisions uniquely important to them. Chesapeake Decision Sciences' *MIMI Planning and Scheduling* is a general-purpose modeling application. Other companies providing these types of applications include CAPS Logistics, i2 Technologies, and Numetrix.

To provide some level of built-in functionality, many of the general-purpose modeling application vendors are developing or offering templates.

These are semi-custom applications, created using their general-purpose modeling applications. Templates reduce implementation configuration efforts. For example, i2 Technologies is building templates that are specific to industries such as Semiconductor, High Tech, and Metals. In addition, CAPS Logistics now markets *Supply Chain Designer a*nd *Supply Chain Coordinator*, strategic and tactical supply chain planning applications built with its toolkit.

While applications with built-in capabilities limit the ability to optimize unique decision environments, they minimize the implementation configuration efforts for specific supply chain problems.

Other vendors offer built-in capabilities rather than general-purpose modeling application functionality. While these applications limit the ability to optimize unique decision environments, they minimize the implementation configuration efforts for specific supply chain problems. For example, Manugistics has recently added optimization capability to its product suite tailored for consumer products and distribution-intensive companies. While this provides less flexibility to optimize, it reduces configuration efforts. Logility is developing similar optimization capability.

Users Need To Maintain Control of the Solutions

Generally, optimization solutions must be understood and controlled by a user. Optimized solutions are frequently not reasonable or executable and need to be adjusted by the planner. Remember, these are decision-support, not decision-making systems! In fact, one APS vendor claims that around 40% of software development efforts are spent solely on enabling user control functionality.

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The major purpose of user control is the inability to enter all details into the optimization model. For example, an optimized solution may suggest that a customer's due date be pushed out because it is critical in achieving a low-cost solution. The manufacturer, however, may have already pushed out the due date for the customer's last three orders. This would be an unacceptable solution!

To ensure that optimization applications provide reasonable, executable solutions, most vendors provide graphical user interfaces (GUIs) to facilitate manipulating data and modifying solutions. This functionality includes the following:

- Graphical drag-and-drop planning boards
- User-defined constraints and rules
- Control of the optimization procedure

Many graphical planning boards allow users to change a variable (e.g., a date or order) and immediately see the impact on the objectives and assess new constraint violations.

Some vendors allow users to control the progress and performance of the solver method—usually by allowing the planner to set a time limit on the solver and then pause.

Vendors also give users control over the solution by allowing them to incorporate unique constraints or rules into the model. For example, a planning application might allow a user to specify that customer due dates can be relaxed by one or two days, or the user may approve the maximum level of overtime. While this is useful functionality, some users are tempted to abuse it by changing the objective. This is conceptually an invalid approach to an optimization problem. Solutions that are not reasonable are best changed by altering the constraints.

Some vendors allow users to control the progress and performance of the solver method. This is usually done by allowing the planner to set a time limit on the solver and then pause. This lets the planner evaluate the solution so far. If it is good enough, the user can finalize the plan. If it is not, the user can have the solver search longer for a better plan.

Many Vendors Use a Mix of Third Party and Internally Developed Optimization Components

Embedded within vendor solvers are *components*, submodules that perform the underlying optimization logic. Some vendors use optimization components from third party vendors to shorten development time. This approach also allows the vendor to focus ongoing development resources on the planning application while the third party takes on the responsibility for improving the optimization component.

The leading optimization component vendor is ILOG. The company offers three optimization components including market-leading LP/MIP acquired from CPLEX. The CPLEX solution is embedded in many applications including those from the following vendors:

- Manugistics
- i2 Technologies
- CAPS Logistics
- SynQuest

Many application vendors exclusively offer optimization components that are internally developed, as they believe that they have a core competency in optimization, especially for planning environments in their target markets.

ILOG's other optimization components are general-purpose planning and scheduling components called *ILOG Planner* and *ILOG Scheduler*. Fygir has embedded the *ILOG Planner* within its *FIT* planning and *GRIP* scheduling products.

Sunset Software Technology (San Marino, CA) is another component vendor. **Adapta Solutions** (Hawthorne, NY), has embedded this company's LP/MIPS functionality into its planning suite.

Many application vendors exclusively offer optimization components that are internally developed, as they believe that they have a core competency in optimization, especially for planning environments in their

target markets. For example, Ortems uses proprietary heuristics based on "graph theory" in its *SRP* product, which focuses on production scheduling and the lower levels of tactical planning. Similar to Ortems, Thru-Put uses its own proprietary methods based on the Theory of Constraints. The company believes that these methods provide greater optimization benefit for the complex manufacturing environments it targets (such as Automotive and Industrial Product manufacturers).

Most application vendors use both internally developed and third party optimization components. These vendors usually have a broad suite of supply chain planning products.

Most application vendors use both internally developed and third party optimization components. These vendors usually have a broad suite of supply chain planning products. For example, i2 Technologies offers a full suite of optimization products that use internally developed components based on proprietary heuristics (including those based on Constraint Anchored Optimization and Simulated Annealing methods), genetic algorithms, and third-party LP/MIP components.

Some Vendors Provide Multi-Objective Functionality

Some vendors allow planners to define multiple objectives. For example, both customer service and costs can be optimized together—despite the fact that two or more objectives cannot be optimized at the same time. Maximizing customer service is not likely to minimize costs; quite the opposite usually holds true. To accommodate planners that want to strike a balance among competing objectives, some vendors provide solvers that find an optimized solution using the objectives in priority sequence. i2 Technologies offers this type of solver using a "hierarchical" LP/MIP algorithm.

Another way in which applications allow planners to use multiple objectives is through the use of weights. This is accomplished by creating a single objective that is a combination of the different objectives, weighted by a number. For example, a customer service objective might carry a weight of 90 (out of a possible 100), while a cost objective might carry a weight of 70. The solvers in these applications optimize a single, composite weighted objective. ProMira, recently acquired by Manugistics, provides this functionality, incorporating a graphical slidebar interface to make it easy for a planner to set the weights.

Some Applications Handle Special Optimization Problems

Some special planning environments involving trim and blending optimizations cannot be accommodated by many supply chain planning applications. Some vendors have incorporated such capability to be integrated into their supply chain planning suites.

Some special planning environments involving trim and blending optimizations cannot be accommodated by many supply chain planning applications.

For example, integration of trim optimization in the Paper industry can lead to substantial benefits by reducing waste paper from cutting opera-

Blending optimization is used in the Fruit Beverage and Oil industries, where raw materials are limited and prices are volatile.

tions. Chesapeake and IBM both have special trim optimization functionality to support Paper manufacturers as part of a total supply chain planning optimization application.

Blending optimization is used in the Fruit Beverage and Oil industries, where raw materials are limited and prices are volatile. Materials must be efficiently blended to create products that meet specifications. Fygir, Chesapeake, and STG have products that can incorporate blending optimization into the supply chain planning application.

OPTIMIZATION USAGE GUIDELINES

While the use of optimization in supply chain planning is extremely appealing, the technology may not be for everyone. Rather than by employee headcount reduction alone, these solutions are justified by such supply chain benefits as the following:

- Inventory reduction
- Improved customer service
- Increased asset utilization
- Improved corporate profitability

Though there are no hard-and-fast rules for manufacturers deciding whether to purchase optimization technology, AMR offers the following guidelines:

- Optimization is generally beneficial in complex manufacturing environments where many interrelated decisions need to be made. These include environments with many resource constraints and large numbers of products, plants, suppliers, and distribution centers. Planners in these environments need computer support to make optimized decisions. In contrast, planners may not need optimization support in simple, mature environments, where methods based on experience may already yield nearly optimal decisions.
- In strategic and higher-level tactical planning, the pursuit of optimized solutions is typically more important than it is for low-level tactical and operational planning. In the former, the feasible set for decisions is much larger, meaning there are more opportunities to make poor decisions. Also, these decisions have greater revenue and cost implications.
- The answer to "Where is the most pain in my supply chain?" will be important in deciding what portion to optimize. In supply-constrained industries that experience material shortages, optimizing the use of these materials in the manufacturing process is important. In make-to-order environments, especially in discrete manufacturing,

In supply-constrained industries that experience material shortages, optimizing the use of these materials in the manufacturing process is important.

optimized production schedules are crucial. For distribution-intensive environments, planning must focus on optimizing manufacturing and distribution operations simultaneously.

- Optimization is more useful in mature, relatively non-volatile manufacturing industries where product demand and manufacturing processes are more predictable. In these planning environments, realistic models can be constructed to support all levels of planning. In volatile manufacturing environments, optimization will be less useful for strategic and tactical planning. In these environments, planning focuses on supply chain readiness and responsiveness rather than on operational efficiency. Optimization will be more useful for operational planning, when the level of uncertainty is substantially reduced (e.g., when many customer orders are already placed).

Optimization is more useful in mature, relatively non-volatile manufacturing industries where product demand and manufacturing processes are more predictable.

CONCLUSION

The guidelines above and in this AMR Report will hopefully reduce some of the mystery surrounding optimization, and they should help buyers during their technology selection and implementation processes. The research for this Report has led to the following conclusions:

- While the term *optimization* is confusing to buyers, the APS market is getting a lot of attention. This is primarily driven by the increasing complexity of manufacturers' supply chains. This complexity is caused both by the trend toward globalization and the myriad products, materials, facilities, trading partners, and trading relationships that need to be planned. In many companies, planners are becoming overwhelmed by the complexity, and they need better computer support in decision-making.
- The ability to model a manufacturer's environment adequately is a critical success factor in being able to use computer-generated optimized decisions. The availability of data to input into one's supply chain models is closely related to this factor. Thus, modeling capabilities and data requirements are the key factors to consider in implementing optimization solutions.
- One of the most confusing aspects of the optimization market is the variety of solver methods marketed with names like *mathematical programming*, *heuristics*, *Theory of Constraints*, *Simulated Annealing*, and *genetic algorithm*. Generally, vendors employ solvers depending upon the structure of the optimization model. By and large, vendors are diligent (some even fervent!) in using appropriate methods within their solvers—whether the methods are proprietary, purchased from another vendor, or based on known methods. This makes solver type a secondary consideration in choosing among different optimization-based applications.

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To summarize, optimization technology offers great promise for improving a manufacturer's supply chain performance. But understanding it will take a great deal of work and great effort on the part of users. AMR expects, however, that its use in supply chain planning will continue to grow, since the benefits should far outweigh the efforts.

Perspectives on Optimization

by Janet Suleski

A number of business groups are intimately involved in the creation and execution of supply chain optimization (SCO) technology. Each group, however, has a different perspective on the following issues:

- The definition of supply chain optimization
- The best methods to optimize a supply chain
- How clean the data must be
- The scope of the optimized supply chain

To get their perspectives on supply chain optimization, AMR interviewed two representatives from each of the following communities:

- **Software Vendors**: Sanjiv Sidhu, CEO, **i2 Technologies**, and Monte Zweben, founder of **Red Pepper**, formerly general manager of **PeopleSoft**'s manufacturing business unit
- **Manufacturers**: Greg Sampson, senior business analyst at Kodak, and an analyst from Coca-Cola
- **Academics**: Professors Hau Lee of Stanford University and Steve Graves from the Massachusetts Institute of Technology
- **Consultants**: Brad Scheller, supply chain planning practice manager from **Computer Sciences Corporation**, and Masud Arjmand, a partner with **Andersen Consulting**

AMR asked this prestigious group to respond to eight questions concerning supply chain optimization. Their responses are summarized below.

WHAT IS YOUR DEFINITION OF SUPPLY CHAIN OPTIMIZATION?

The consultants' definition of SCO focused on the following factors:

- Enumerating variables and constraints
- Quickly sorting possible ways to move materials through the supply chain
- Producing the best mix of choices

SNAPSHOT

Interestingly, both consultants felt the definition of best "mix" should be left to the manufacturers. One vendor's definition, however, stated that SCO is a tool meant to increase the client's return on assets, suggesting that the best solutions are those that maximize that particular metric. The professors agreed that SCO covers both operational and strategic decision-making. One professor proposed another category, one that cuts across the operational and strategic levels: decision-making about the location and quantity of inventories.

The manufacturers had opposing viewpoints on what constitutes the scope of SCO. One indicated that SCO is the application of formal optimization methods (meaning linear or integer programming, excluding heuristics) to a model, which covers a reasonably comprehensive scope of a company's internal and external supply chain. The other manufacturer stated that SCO is the ability to look across only the internal supply chain of a company and determine the optimal way to produce and distribute products to meet demand.

WHEN IS SUPPLY CHAIN OPTIMIZATION MOST USEFUL?

It was felt that SCO would not be as useful—it may even be unnecessary—in a make-to-order environment with few supply points and a simple supply chain.

There was a consensus from all parties, except the vendors, that SCO is most useful in situations where a company or a product has a complex supply base, a complex manufacturing process, a complex distribution system, and volatile demand. Essentially, whenever there is uncertainty in the behavior of supply chain operations or in market demand, SCO could benefit a company. It was felt that SCO would not be as useful—it may even be unnecessary—in a make-to-order environment with few supply points and a simple supply chain. The vendors, however, felt optimization was useful to all companies, regardless of the makeup of the supply chain.

One of the manufacturers described two conditions necessary for the implementation of useful SCO initiatives:

- A champion, preferably at the corporate level, who understands the modeling process itself, as well as the usefulness of the optimization effort.
- The right people to develop and contribute to the creation of the optimization model.

The manufacturer felt that if a company could not meet these two conditions, any effort at supply chain optimization would be unsuccessful.

FOR WHAT TYPES OF DECISIONS IS SUPPLY CHAIN OPTIMIZATION MOST HELPFUL?

One of the professors described SCO software as a tool to help people in various functional areas of a company broaden their focus to encompass

the entire supply chain, from raw materials to the final customer. With this "supply chain perspective," the functional teams would have a common language to make better decisions about optimizing the flow of products through the supply chain.

While the software could suggest improvements, decisions about changes should remain in the planners' hands.

In contrast, the consultants and manufacturers focused on the specific decisions for which they would use SCO:

- Sourcing
- Making versus buying
- Production allocation
- Supply chain design
- Sales and operations

The vendors emphasized that SCO could help to identify supply chain problems such as bottlenecks or unreliable suppliers. The SCO process directs planners to supply chain operation problem areas. While the software could suggest improvements, decisions about changes should remain in the planners' hands.

IN WHAT INDUSTRIES IS SUPPLY CHAIN OPTIMIZATION MOST USEFUL?

The participants put forth a number of possible answers to this question. One consultant and one vendor replied that there are three general types of industries where SCO is useful:

- Distribution-intensive (Food & Beverage, Consumer Packaged Goods)
- Asset- or capacity-intensive (Semiconductors, Steel)
- Material-intensive (Apparel, Electronics)

Each type of industry benefits from SCO, but each should optimize different things. For distribution-intensive industries, transportation optimization and inventory deployment were regarded as the two areas where SCO would be most effective. In the asset-intensive industries, optimizing throughput times, product mix, and setups were identified as important. In material-intensive industries, decisions about what to produce, where to produce it, and who to source materials from in order to generate high margins were noted.

For distribution-intensive industries, transportation optimization and inventory deployment were regarded as the two areas where SCO would be most effective.

In general, one consultant felt that process industries would find SCO more useful than discrete industries. In contrast, a vendor pointed out that this is a myth, born out of the early adoption of SCO by process manufacturers. The vendor also pointed out that techniques for tackling some of the more complex, discrete industry optimization problems have only recently become available. Both process and discrete manufacturers will find SCO useful.

Turning the question around, the other vendor felt that some companies would not benefit from SCO. These companies include those with level demand, predictable supply, and predictable competitive environments. The vendor also noted, however, that he didn't believe that such stable environments exist in any industry today.

WHAT SOLUTION METHODS ARE MOST USEFUL?

The perspectives on solution methods can be summed up with a quote from one of the vendors: "Different problems require different solutions." There are some general categories, however, where certain solution methods are predominant. The categories fell along the lines of the decision-making hierarchy:

- Strategic
- Tactical
- Operational

The consensus among the participants was that at the strategic level, optimization most frequently employs mathematical programming, especially linear and integer programming.

The consensus among the participants was that at the strategic level, optimization most frequently employs mathematical programming, especially linear and integer programming. At the tactical level, combinations of linear programming, heuristics, simulation, genetic algorithms, and other methods are most frequently used. At the operational level, heuristics is most common.

The participants, however, also agreed that the method employed to solve any particular problem was much less important than understanding and properly framing the business problem. When the problem is understood, the granularity of data needed to solve it and the ease of acquiring and using this data play a role in determining which method will be the most useful.

HOW GOOD OR CLEAN MUST THE DATA BE TO PRODUCE USEFUL RESULTS?

This question provoked a range of answers from "very clean" to "use whatever data you have." In part, the answers varied because participants had various views on what constitutes a useful result. At one extreme, a consultant stated that data must be very clean because many optimization projects fail because of bad data. In failed projects, implementation could be successful, but the results coming out of the system are not useful. One professor's view was that the data that the industry deems most important must be very clean. Data relating to less critical parts of the business must be good, but less precision is required.

In contrast, the vendors felt that companies should not "exhaustively comb through data files to get 98% purity." By using whatever data is available, the company may be able to make better, if not completely optimal decisions. In addition, the process of optimization helps companies pinpoint what data needs to be improved first. The vendors felt that planners would detect and correct a faulty plan quicker and easier using optimization software. The gist of the vendor perspective is worry about your data, but don't make that an excuse for not optimizing. They also felt that "data gets better the more you exercise it."

The gist of the vendor perspective is worry about your data, but don't make that an excuse for not optimizing.

The manufacturers we interviewed felt that the data put into an optimization system does not need to be "squeaky-clean." It should be 90% clean and perhaps, more importantly, representative of the problem the user is trying to solve. One manufacturer stated that problems are generally not caused by dirty data. They are more often caused by "data that measures something slightly different from what you really need in your model." For example, plugging the cost of port-to-port transportation into a model requiring the cost of transporting a good from the plant's dock to the retailer's door will result in poorly optimized transportation costs.

AMR's research has shown the accuracy and timeliness of data is important to both conventional materials requirements planning (MRP) and SCO. Many manufacturers reported struggling to cleanse data in preparation for SCO.

WHEN CAN ONE USE AGGREGATED DATA AND WHEN IS DETAILED DATA IMPORTANT?

Most survey participants believe that aggregated data is appropriate for optimizing at the strategic level and detailed data is appropriate for the operational (day-to-day, assembly-line) level. The vendors, however, emphasized that it depends on the planning problem. The manufacturers believe that there is an art to finding the right level of aggregation. One consultant felt that detailed data is important for key business drivers (e.g., transportation data in a distribution-intensive industry), but that other data could be aggregated. A vendor expressed the feeling, based on his experiences, that neophytes in the optimization business often use detailed information where aggregated data is appropriate. He also believes that companies should spend more time both before and during implementation to determine the right level of aggregation. Companies should also be prepared to revise levels of aggregation as the supply chain modeling process advances.

Most survey participants believe that aggregated data is appropriate for optimizing at the strategic level and detailed data is appropriate for the operational (day-to-day, assembly-line) level.

Consultants recognize that a company is only one piece of a larger supply chain and that individual companies need to align with others in their supply chain.

WHAT TRENDS DO YOU SEE IN THE USE OF SUPPLY CHAIN OPTIMIZATION?

The different communities see a variety of trends shaping the use of SCO over the next few years. The consultants reported the following trends:

- Broader adoption of supply chain optimization
- Recognition that a company is only one piece of a larger supply chain and that individual companies need to align with others in their supply chain

The professors reported the following trends:

- Wider acceptance of sophisticated optimization methods to do supply chain design
- Increasing interest within companies about the use of SCO to leverage the large amounts of high-quality data ERP systems collect

Vendors see the following trends:

- CEOs becoming sensitive to the need to optimize their supply chains
- Reduced cycle times that will make decision windows shorter and detailed planning more critical than ever before
- Collaboration among companies expanding across many levels of the supply chain, including suppliers and customers

Manufacturers see the following trends:

- Increasing availability and deployment of easy-to-use optimization software (However, one manufacturer warned that, "They've made coming up with a linear programming model about as difficult as calling someone on the phone, and so there'll be an awful lot of crank calls.")
- Improved physical and electronic systems to support SCO

THE FUTURE OF OPTIMIZATION

Companies dealing with complex supply bases, complex manufacturing processes, complex distribution systems and/or volatile demand patterns can benefit from the use of SCO.

Regarding the creation and execution of SCO technology, several consistent themes emerged from our conversations with the different constituencies:

- Companies dealing with complex supply bases, complex manufacturing processes, complex distribution systems, and/or volatile demand patterns can benefit from the use of SCO.
- The availability of powerful, relatively easy-to-use optimization software is encouraging companies to expand their efforts to integrate and optimize the flow of materials through the supply chain.

Collaboration among companies within industry supply chains will continue to accelerate in the foreseeable future.

- Industry drivers dictate what data must be clean and detailed, but companies should not aim for perfect data before they implement an optimization package.
- Companies must work closely with software vendors and consultants to ensure that the appropriate solution methods and levels of data aggregation are being used in the supply chain model.

While the participants in our survey had varying opinions on the aspects of supply chain optimization, one thing is clear: As a business practice, supply chain optimization is here to stay.

Industry drivers dictate what data must be clean and detailed, but companies should not aim for perfect data before they implement an optimization package.

Notes

Notes

Founded in 1986, Boston-based Advanced Manufacturing Research (AMR) is the preeminent industry and market analysis firm specializing in enterprise applications and related trends and technologies. Tracking more than 400 leading software and service providers, AMR helps Global 1000 companies evaluate, select, and manage new systems for every part of the enterprise, including logistics and supply-chain management, Enterprise Resource Planning (ERP), Manufacturing Execution Systems (MES), and electronic/Internet commerce.

Your comments are welcome. Reprints are available. Send any comments or questions to:

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Reader's Acronym List

ACRONYM	DEFINITION
3PL	Third Party Logistics
AI	Artificial Intelligence
APS	Advanced Planning System
CPG	Consumer Packaged Goods
CRP	Capacity Requirements Planning
ERP	Enterprise Resource Planning
GUI	Graphical User Interface
LP	Linear Programming
MIP	Mixed Integer Programming
MRP	Materials Requirements Planning
SCO	Supply Chain Optimization
SKU	Stock-Keeping Unit
TOC	Theory of Constraints
VMI	Vendor Managed Inventory