



## MULTISTAGE INVENTORY OPTIMIZATION IN AN ADVANCED PLANNING & SCHEDULING (APS) ENVIRONMENT

A question we are  
often asked is:

“What is missing  
from APS systems,  
and how does  
SmartOps fill the  
gap?”

### **Abstract:**

This paper describes how the SmartOps MIPO solution complements Advanced Planning & Scheduling (APS) systems by solving different yet critical planning challenges.

The SmartOps software solution, Multistage Inventory Planning & Optimization (MIPO), allows customers to optimize total chain inventory planning for all products and raw material components over multiple time periods, while ensuring customer service levels are met. MIPO is designed to address supply chain planning challenges that are nonlinear and stochastic (uncertain) in nature:

- multistage or “multi-echelon” inventory relationships
- time-varying capacity constraints
- total chain impacts of service levels and response times
- supply and demand uncertainties (such as lead time variability and forecast errors)

SmartOps MIPO takes a company’s existing supply and demand data and produces optimized planning targets at the individual item level for each time period. Those planning targets serve as significantly improved inputs into APS systems. For example, MIPO determines the safety stock requirements that would otherwise have to be manual rule-of-thumb inputs into APS.

In addition, SmartOps software offers:

- visibility into the drivers of inventory
- what-if scenario analysis
- support for S&OP and replenishment planning
- ability to achieve and maintain higher inventory turns
- the ability to extend the principles of lean manufacturing to total chain inventory deployment and postponement

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# MULTISTAGE INVENTORY OPTIMIZATION IN AN ADVANCED PLANNING & SCHEDULING (APS) ENVIRONMENT

## INTRODUCTION: WHAT APS ADDRESSES ... AND WHAT IT DOESN'T

SmartOps is a supply chain optimization software company that provides a solution for determining optimal total chain inventory deployment plans over time. The SmartOps product, Multistage Inventory Planning & Optimization (MIPO), accounts for inherent supply and demand uncertainty and variability across multiple forms and locations of inventory to generate target inventory positions. Those target inventory positions ensure that the company is keeping the right amount of stock for each product at each stage (raw materials through finished goods), at each location, for every planning period to reliably meet desired customer service levels at minimum total chain inventory.

How does SmartOps fit into the existing supply chain planning landscape? Companies frequently ask us: Do you compete with or intend to replace Advanced Planning & Scheduling (APS) offerings like those from i2 Technologies, Manugistics, SAP, Oracle, and others? Is SmartOps another type of APS solution? Phrased differently, *Why is yet another supply chain planning solution needed?*

SmartOps is designed to fill a critical gap in the area of supply chain planning: the ability to generate optimal planning parameters at the item/SKU level to support demand fulfillment, while taking into account the inherent nonlinear, uncertain nature of supply chains. Just as APS solutions brought substantive improvements to environments that had Materials Resource Planning (MRP) and Distribution Resource Planning (DRP) systems, SmartOps brings a complementary piece to today's companies that seek a way to drive total chain efficiency and economic savings.

To understand how this gap in planning still exists today, a quick look back at the roots of APS is useful. Advanced Planning & Scheduling systems emerged in the early 1990s as companies recognized that MRP and DRP systems did not adequately address capacity and material production planning. APS vendors offered a way to support factory and manufacturing planning and scheduling for large volumes of products in the supply chain, and they later extended their software suites to support activities in demand, distribution, and transportation planning.

APS software systems are designed to solve the complex linear, deterministic problems that make up factory scheduling and other activities. APS does that through the use of combinatorial planning that makes multiple passes through a variety of options (schedules, for example) for the best choice that respects factory capacity and material availability.

As a result, APS systems drove (and continue to drive) advances in productivity and greater accuracy in factory planning. Within a given plant, service levels and delivery times improved -- for some manufacturers, by leaps and bounds.

"Several companies were at the brink of disaster before implementing APS," AMR Research described in its 1998 report on APS. "Constant factory schedule changes that bloated work-in-process inventory, depressed customer service levels, and inflated costs were frequent problems... Fortunately, these manufacturers had planners and managers that realized that their poor planning methods, not a shortage of plants and equipment, were contributing to the capacity problems. As a result of implementing APS, many manufacturers found additional capacity in their plants."

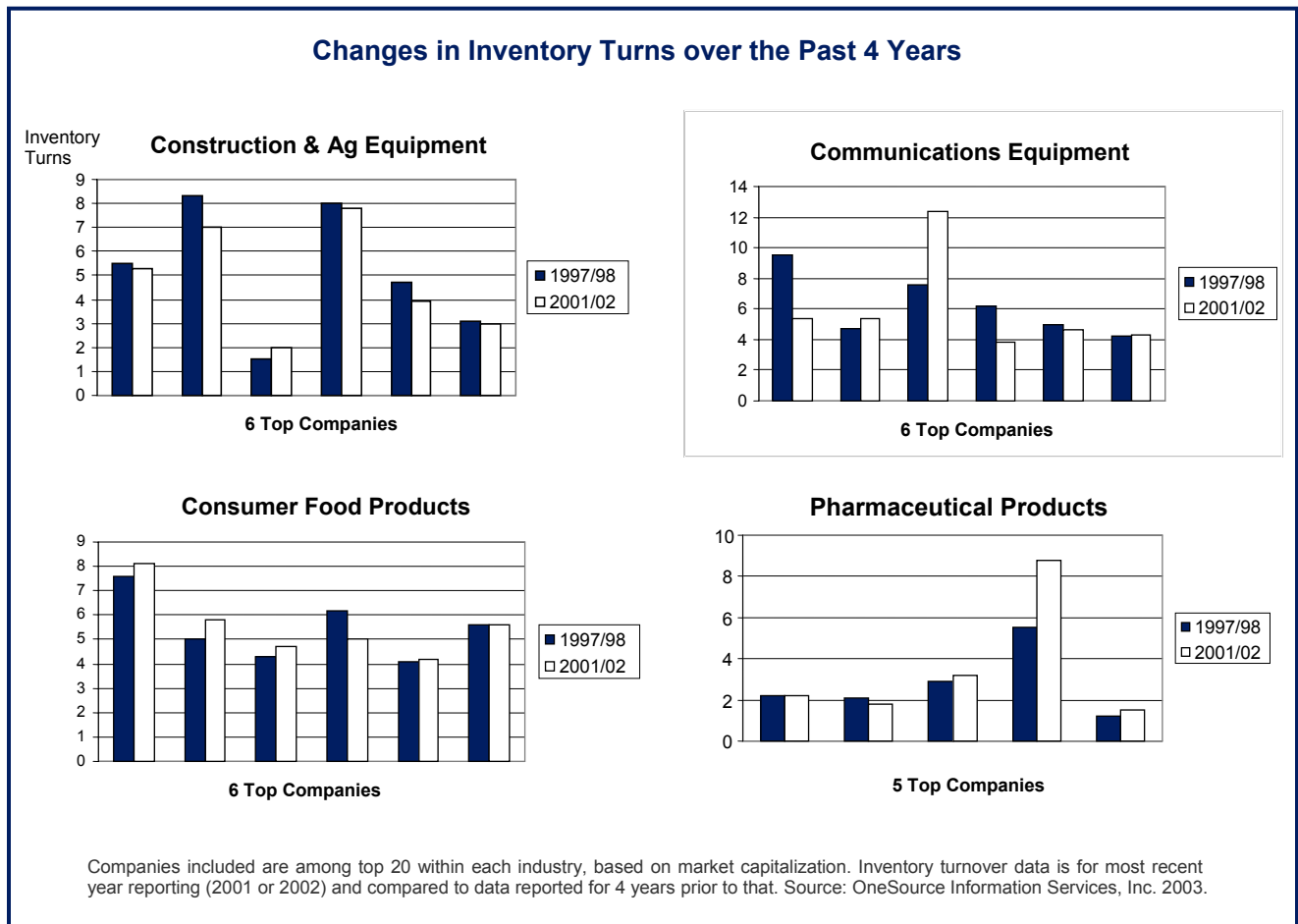
### Optimizing Safety Stocks and Other Key Inputs

SmartOps is designed to fill a critical gap in the area of supply chain planning: the ability to generate optimal planning parameters at the item/SKU level to support demand fulfillment, while taking into account the inherent nonlinear, uncertain nature of supply chains.

Today, more than 10 years after APS solutions were introduced to the market, most supply chains operate more efficiently within a given location or plant, benefits that are further bolstered at companies applying Lean Manufacturing and Six Sigma practices.

But despite those investments and management principles, U.S. inventory levels, currently at \$1.1 trillion, have seen little change over the past several years -- even with many companies attempting to “deplete inventories” in an economy of sluggish demand. Companies still struggle with *total chain* inventory planning and optimization, an area that generally has seen minimal to no improvement and continues to bog down the supply chain’s ability to be more efficient, responsive, and profitable.

While each industry certainly has its high performer, when you look at total chain inventory turns, the majority of companies (including market share leaders) have not been able to sustain or increase inventory performance in the presence of supply and demand uncertainties.



In late 2001, the management consulting firm Bain & Company conducted a research project with 300 supply chain executives in top manufacturing and retail companies. The report found that, “although nearly 70% of the poll respondents rate supply chain improvement as a top priority, it is clear that being aware of the challenges doesn’t always mean overcoming them.” (Source: “Lessons from the Leaders,” *Supply Chain Management Review*, November-December 2001.)

Starting in the early 1990s, several Fortune 500 companies began to pursue the discovery of new, innovative ways to improve their supply chain performance. Dr. Sridhar Tayur, tenured professor of

operations management at Carnegie Mellon University (and founder and CEO of SmartOps), was invited by many of those companies to see if applying the past 40 years of academic operations research could impact real-world supply chain profitability and product delivery.

What became clear during those consulting assignments -- which included Caterpillar, General Electric, IBM, Intel, and others -- was that APS systems were not designed to address the multistage/multi-echelon, uncertain nature of supply chains.

The identified gaps left by APS include the following:

1. Better planning inputs are needed -- APS systems require a large volume of data from legacy, ERP, and custom data sources, but critical to that process is the input of inventory planning parameters for each product. Optimal planning parameters would detail how much to carry in safety stock, cycle stock, pipeline stock, pre-build stock, merchandising stock, etc. Those planning inputs are nonlinear and stochastic ("uncertain and variable"), but APS is built to address planning challenges that are linear and deterministic (based on data that is "certain" or "known").
2. The drivers of inventory are not apparent -- Companies today have a better awareness of how much inventory they are currently carrying, but they have no understanding of *why* inventory is at certain levels or which drivers increase or decrease inventory and to what extent.
3. There is no "total chain view" of inventory -- Inventory optimization for today's supply chains means that inventory targets at multiple stages and multiple locations must be coordinated simultaneously, not sequentially (one location first, then the next, etc.) and not sub-optimally within just one location. Lean manufacturing, which for many has significantly reduced waste and improved inventory turns *inside* the plant, can be a philosophy that inventory plan optimization extends to the total supply chain to improve efficiency at *all stages*, while maintaining and improving service levels.

Example Customers using SmartOps:	Planning areas supported by SmartOps:	ERP & APS systems already in use:
John Deere	Setting weekly multi-echelon inventory targets; Sales, Inventory & Operations Planning	SAP and Manugistics
Caterpillar	Inventory deployment analysis to support improved order fulfillment strategies	SAP and i2 Technologies
GlaxoSmithKline	Annual inventory budgeting for their global pharmaceutical supply chains	SAP and Manugistics

The following sections will provide a closer look at those APS gaps that SmartOps addresses through multistage inventory optimization.

## GAP #1: OPTIMIZING PLANNING INPUTS

*From the SmartOps customer field:*

A director of logistics recognized: “For SAP and Manugistics, we need to input our safety stock requirements. In addition, those systems don’t tell us where in the supply chain is optimal to keep the inventory to meet customer demand at lowest financial risk to our business.”

Time-phased planning inputs should result from looking at supply, demand, product, and stocking location data (lead times, capacity, forecasts, service level requirements, seasonality, periods between reviews, product margins, etc.) to determine how much inventory of each product should be carried at a given location and at a given time. Optimization occurs when such analysis is conducted in a comprehensive way and at the item/location/planning period level of granularity.

After APS implementations were completed, some early customers began to realize that better planning inputs were needed to drive improvements in total chain performance and asset utilization. By the mid-1990s, experienced APS customers began to work towards improving inventory planning targets that serve as inputs into the APS process.

Traditionally, planning inputs are user created and derived, produced by rules of thumb, spreadsheet work, historical data reliance, and other such workarounds that have become the status quo. However, those practices offer strict limitations in the frequency and scope in which planning can be done, leaving little room to look at more than just small subsets of product groupings for a single stage, based on uncapacitated data, at any given time. Otherwise, the calculations become too time-consuming and complex to support with available resources, expertise, and tools.

Recognizing the limits of current practices, consultants and in-house planners were called upon to explore better ways of calculating planning inputs based on larger sets of data and within shorter timeframes. There, initial work was done mainly through the better use of spreadsheets, but there was still no feasible way to handle multistage nonlinear relationships, time-varying capacity constraints, and stochastic variables for hundreds or thousands of items -- let alone at a frequency that could produce decisions for real-world, real-time business support.

Inventory Planning Parameters Optimized by SmartOps MIPO	Input Parameters Analyzed through SmartOps Scenario Planning
<p>SmartOps generates outputs for each item, at each location, for each planning period:</p> <p>On-hand inventory</p> <ul style="list-style-type: none"> <li>• Safety stock</li> <li>• Cycle stock</li> <li>• Pre-Build stock</li> <li>• Merchandising stock</li> </ul> <p>On-order inventory</p> <ul style="list-style-type: none"> <li>• Physical pipeline stock</li> <li>• Total pipeline stock (including 'non-physical' order processing times and wait times)</li> </ul>	<p>Different values of supply chain factors can be evaluated, prioritized, and optimized for each item, at each location, for each planning period:</p> <ul style="list-style-type: none"> <li>• Lead time average and standard deviation</li> <li>• Forecasts</li> <li>• Forecast errors</li> <li>• Service levels</li> <li>• Service times</li> <li>• Capacity constraints</li> <li>• Minimum production quantities</li> <li>• Periods between reviews</li> <li>• Batch sizes</li> <li>• Supply reliability and yield</li> </ul>

Academic research in the areas of nonlinear programming and stochastic optimization began in the 1950s, but until recently had no meaningful application in the supply chain marketplace. That changed, however,

when operations research academics such as Dr. Tayur of CMU and his peers at other universities were asked to analyze the challenges associated with optimizing inventory planning targets. Those academics found that by taking larger sets of supply chain data and applying stochastic optimization algorithms and nonlinear modeling techniques, they could accommodate uncertainties and variability in the system to generate optimized planning parameters.

The results of these projects clearly demonstrated that supply chain profitability and customer service could be impacted in ways previously not possible. Further, they presented an opportunity for Dr. Tayur to offer a solution to the marketplace, and SmartOps was established in 2000.

## GAP #2: MANAGING THE DRIVERS OF INVENTORY

### *From the SmartOps customer field:*

A common experience shared by many companies we speak with: “We have several continuous improvement projects in place or under consideration, but we have no way of quantifying and therefore prioritizing them.”

Separately, the President of John Deere’s Commercial and Consumer Equipment division, John Jenkins, told us: “SmartOps allows us to understand the sensitivity of each of the factors that drive the need for inventory, so that we can identify which to work on first.”

Another key piece of functionality that SmartOps offers to an APS planning environment is the ability to gain visibility into and manage the fundamental drivers of inventory. While companies today are more aware of how much inventory they are currently carrying, they lack a clear, simple method for understanding why inventory is or should be at a certain level and the factors that affect those inventory levels.

SmartOps allows companies to pinpoint the main drivers of inventory in their current plans or in different planning scenarios. Planners use the SmartOps MIPO software to identify and understand the outcomes when changes are made to a supply chain’s supply and demand variables and constraints, many of which are stochastic and nonlinear in nature.

Supply-Related Inventory Drivers	Demand-Related Inventory Drivers
<ul style="list-style-type: none"> <li>• Manufacturing lead times</li> <li>• Transportation lead times</li> <li>• Total lead times</li> <li>• Wait times</li> <li>• Lead time variability</li> <li>• Plant capacity constraints</li> <li>• Capacity variability</li> <li>• Batch sizes</li> <li>• Expediting costs</li> <li>• Transportation alternatives</li> <li>• Periods between shipments</li> <li>• Supplier reliability</li> </ul>	<ul style="list-style-type: none"> <li>• Forecasts</li> <li>• Forecast errors</li> <li>• Service levels</li> <li>• Seasonality</li> <li>• Promotions</li> <li>• Events</li> <li>• Customer wait times and patience levels</li> <li>• Buying trends</li> <li>• Periods between reviews</li> <li>• Product substitutions</li> <li>• New product introductions</li> </ul>

In addition, this functionality creates an excellent competitive opportunity for dynamic, continuous improvement by enabling prioritization of supply chain areas that should be addressed.

### GAP #3: DELIVERING A TOTAL CHAIN VIEW OF INVENTORY

A third major benefit to current and prospective APS customers is the ability to gain a “total chain view” of inventories through a multistage planning solution like SmartOps. Rather than focusing just on the planning activities needed within a given location or stage in a supply chain, SmartOps recognizes and calculates the inter-relationships between inventories, service levels, capacity constraints, and costs across all stages.

Those stages include (where present) raw materials, component, sub-assembly, manufacturing and assembly, postponement, packaging, warehousing, and distribution to dealer, reseller and/or retail channels. The SmartOps MIPO calculations are done so that the planning targets generated reflect the interdependencies across the supply chain.

Further, the advanced ability to model multistage supply chains enhances a Lean Manufacturing environment that focuses on how to reduce waste and improve inventory turns inside a plant. Those principles are extended to the supply chain to improve efficiency at *all stages* of inventory and increase total chain inventory turns, while maintaining and improving customer service levels and response times.

### WHY IS SOFTWARE NEEDED?

“The hard lessons being learned in today's economy demand a tactical business planning process that can identify optimal inventory deployment. Based on conversations with end users, the market timing of SmartOps is impeccable.”

- AMR Research: “SmartOps is Addressing Supply Chain Tactical Planning,” Research Alert, June 4, 2001

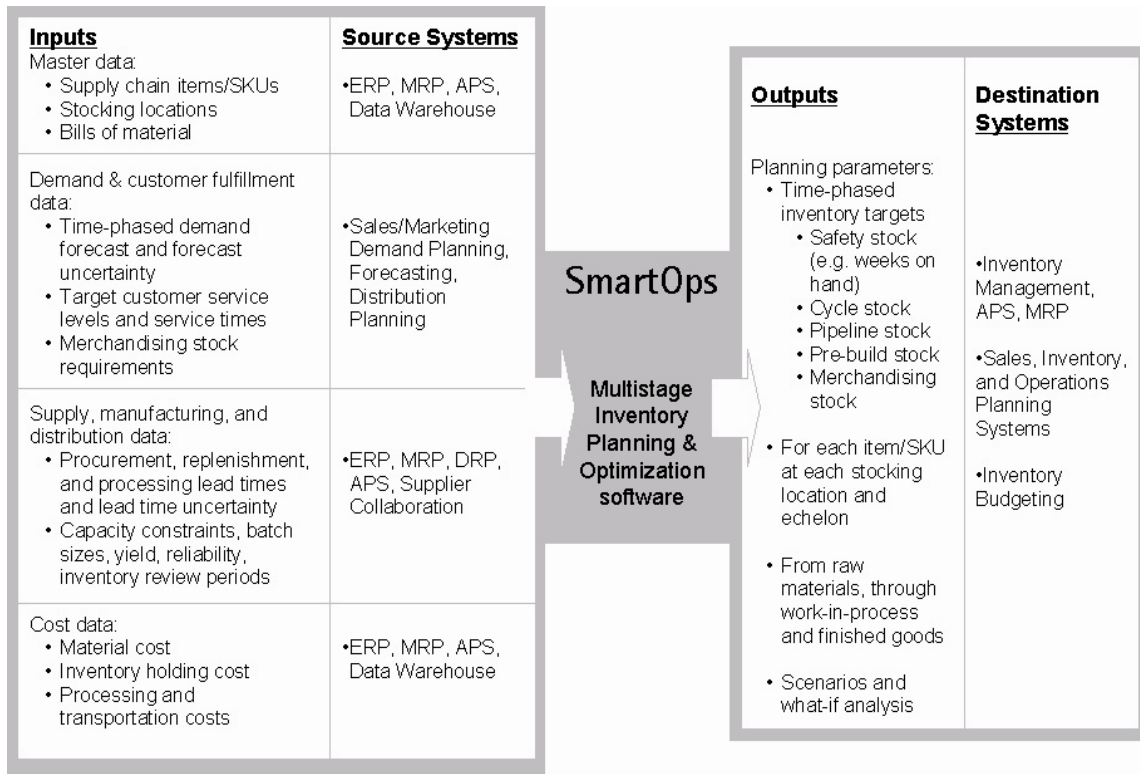
SmartOps has demonstrated that a software solution, as opposed to ongoing project-based consulting, is the appropriate approach to fill the gap left by APS, for several reasons:

- **Optimization must be maintained through frequent reviews and updates to the plans:**
  - Supply chain variables change weekly, even daily, which means companies need to calculate and continue to re-calculate planning parameters, the frequency of which depends on both the industry and what decisions are being supported, such as:
    - Annual budgeting -- requires inputs only once per year
    - S&OP -- monthly or quarterly inputs
    - Tactical inventory planning -- weekly or monthly
    - Replenishment planning -- daily or weekly
    - Unexpected events -- unpredictable, but requires planners to measure and manage the level of disruption to the supply chain
  - A software solution should be designed to easily recalculate planning parameters as needed, to support a variety of decision processes; this should not be a cumbersome or burdensome task.
  - One-time consulting and evaluation projects are able to improve targets (safety stock levels, for example) for a given planning period, but are not time-phased, dynamic solutions and must be revisited often when changes occur in the supply chain.
- **The appropriate optimization solution should be scalable:**
  - The ability to quickly scale calculations is needed due to the following characteristics found in most supply chains today:

- The addition of stocking locations and stages of inventory as the supply chain expands geographically
  - An increasing number of component parts and finished goods/SKUs, postponement and customization, new product introductions, and shorter product life cycles
  - The growing volume of data related to products, suppliers, and demand
  - An increasing number of variables that can contribute to driving inventory at any given time
- **A solution must be maintained, supported, and advanced:**
    - Custom applications and projects require consultants to be called back each time additional optimization or recalculations must occur
    - SmartOps offers continual advancement and improvement to its solutions based on feedback from customers, partners, analysts, academic advisors, and internal supply chain experts. This ensures that the most appropriate, tested approaches and field learnings are incorporated in the software to deliver a best-practice solution for optimizing planning targets.

## UNDERSTANDING HOW SMARTOPS MIPO INTEGRATES IN YOUR ENVIRONMENT

SmartOps MIPO software integrates into the customer environment by taking existing supply chain data and optimizing planning parameters for destination systems. As the following diagram illustrates, the inputs into the SmartOps system include stochastic data -- such as demand forecast uncertainty and supply lead time uncertainty, along with service targets, capacity, bills of material, related costs, and other critical information.



The outputs are optimal target inventory positions by SKU, by planning period, for each location, as well as the ability to conduct scenario and sensitivity analysis on the drivers of inventory.

*From the SmartOps customer field:*

“We selected SmartOps because we are confident that their solution will help us determine the optimal level of inventory for each product family, at each dealer, and at each warehouse -- every week throughout the year.”

- Loren Troyer, Director of Order Fulfillment, Deere’s C&CE Division

## DIFFERENCES BETWEEN SUPPLY CHAIN PLANNING SYSTEMS

In summary, there are distinct differences between ERP, SCP, APS, and supply chain optimization solutions, defined by why they exist, the planning areas they support, and fundamental technology design choices they offer. The following chart highlights the focus, users, time to implement, and payback periods between ERP, APS, and the SmartOps MIPO solutions.

	ERP	SCP and APS	Multistage Inventory Optimization
<b>Focus</b>	Transaction processing	Decision making and support	Decision support and continuous improvement
<b>User group</b>	People running daily operations	Decision makers and planners	Planners and supply chain analysts
<b># Users</b>	50-500	10-100	5-50
<b>Implementation time</b>	18-48 months	6-12 months	3-5 months
<b>Payback period</b>	24-60 months	6-18 months	2-12 months
<b>Areas improved</b>	Operational efficiency, control and visibility of business transactions (customer order fulfillment, financial, etc.)	Demand planning, manufacturing planning, warehouse management, transportation management	Inventory deployment, service levels, inventory turns, inventory-related costs, order fulfillment, capacity planning
<b>Implementation technology</b>	Relational data storage and rule-based transaction processing	Linear and integer programming and deterministic algorithms	Nonlinear optimization and stochastic algorithms

As mentioned, most SmartOps customers have already invested in ERP and APS systems. John Deere, Caterpillar, and GlaxoSmithKline are among them, using the MIPO software for planning functions such as global inventory budgeting, setting multistage weekly inventory targets, and analyzing inventory deployment to improve order fulfillment strategies.

The benefits consistently demonstrated as a result of optimizing inventory planning targets include:

- Increased total chain inventory turns
- Reduced overall inventory costs
- Improved product availability and customer service levels
- Enhanced APS performance
- Ability to continuously improve supply chains by monitoring the drivers of inventory

## SMARTOPS MIPO BEFORE APS?

So, what about the company that does not yet have an APS system or is in the process of evaluating APS solutions?

In some cases, it may make sense to leverage the intelligence of the SmartOps solution to conduct an analysis of supply chain data. This analysis, typically done as a 'Proof of Concept' project, allows a company to identify and quantify the biggest drivers of inventory and inefficiency. This helps to develop greater certainty in prioritizing the strategic initiatives, supply chain projects, and evaluations/purchases of APS modules or technology.

Some companies have also seen the value in improving planning inputs first, so that they will have better performance from the APS systems once implemented.

Since each situation is unique, we recommend a discussion with SmartOps supply chain consultants, who have extensive experience in working with and evaluating APS and other solutions for manufacturers, distributors, and retailers.

To set up a worksheet discussion on inventory optimization, please contact the business development group for Dr. Tayur at SmartOps at (412) 231-0115 or sales@smartops.com

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## WORKSHEET FOR A SMARTOPS DISCUSSION:

Companies with make-to-stock, assemble-to-order, finish-to-order or similar supply chains that require inventory at some stage(s) may be candidates for evaluating their inventory planning practices and gaps in their systems.

This worksheet provides an excellent starting point for an initial 20-minute discussion with SmartOps.

- What are your primary supply chains/how many are there? (Examples: By product/brand, by business unit, by market, etc.)
  
- How many production and distribution echelons/stages are in your supply chain? What are they?
  - Raw materials
  - Manufacturing stages
  - Assembly
  - Postponement
  - Finishing
  - Packaging
  - Warehousing
  - Distribution
  - Retail/Dealer/Reseller
  - Other
  
- What systems are you using to conduct and support inventory planning and order fulfillment?
  - Materials Resource Planning
  - Distribution Resource Planning
  - Warehouse Management
  - Enterprise Resource Planning
  - Advanced Planning & Scheduling
  - Forecasting & Demand Planning
  - Spreadsheets
  - Other
  
- What supply chain planning processes and initiatives are current priorities at your company?
  - Sales & Operations Planning
  - Lean Manufacturing
  - Six Sigma
  - Vendor Managed Inventory
  - Collaborative Planning and Forecast Replenishment
  - Efficient Consumer Response
  - Net Landed Cost Optimization
  - Postponement
  - Strategic Supply Chain Planning/Budgeting
  - Other
  
- Safety stock and target inventory positions:
  - How are you setting those stock levels for your products?
  - Are you setting targets at the item/SKU level? By location?
  - How often are those targets updated?

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