SmartOps™

What is Missing to Enable Optimization of Inventory Deployment and Supply Planning?

A Best Practices Solution that Bridges Top Academic Research and the Commercial Marketplace

April 2002 White Paper

Brief abstract:

Despite investments in their current systems and personnel, companies still seek a solution that allows them to improve their inventory deployment and supply replenishment planning over time. The most fundamental questions are still the hardest to answer: "What is the correct amount of inventory of this product that I should keep at this location to meet demand over time?" and "What should my reorder quantities be over time to accomplish a lowest net landed cost decision?" The inherent and growing complexities of today's supply chains require a new optimization approach that combines appropriate intellectual property in operations research with integration-friendly software design to enable advanced and rapid planning decision support at an enterprise level. Over the past decade, Dr. Sridhar Tayur and his peers have proven there is a optimization approach, now found in the SmartOps software suite, that bridges academic advancements and real-world business issues to drive significant profitability for today's multistage supply chains.

SmartOps™

What is Missing to Enable Optimization of Inventory Deployment and Supply Planning?

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Abstract: Although sizable investments have been made in supply chain applications, collaboration projects, planning process improvements, consulting, and personnel, companies still seek a solution that allows them to improve their inventory and supply replenishment planning. It seems the most basic questions are still the hardest to answer: "Given all the variables and complexities of my supply chain, what is the appropriate amount of inventory of this product that I should keep at this location to meet customer service levels over time? What should my reorder quantities be over time to accomplish a lowest total cost decision? How often should I recalculate my planning decisions and is there a rapid way to do that?" As a result, inventory turns and supply chain efficiencies have not significantly increased over the past decade, and most companies are spending about 10% of their sales revenue on supply chain costs (compared to 4% spent by top performers in each industry).

The inherent and growing complexity of today's supply chains requires a new optimization approach that combines appropriate intellectual property in operations research with integration-friendly software design to enable advanced planning decision support. However, an appropriate solution has eluded the marketplace because of several major challenges: different optimization techniques must be evaluated; supply chains are becoming more complex; supply and demand uncertainties continue to increase; uncoordinated "silo-based" decision making drives inefficiencies further; and there is a lack of consistency in planning approaches and no way to leverage existing investments to solve strategic and tactical planning problems. Additionally, sales incentives -- such as vendor deals and other discounts, financing, announced price increases, and bundling deals -- create cross-company inefficiencies.

Over the past decade, Dr. Sridhar Tayur, tenured professor in operations research and management at Carnegie Mellon University, was called upon by several visionary Fortune 500 companies to see if academic approaches and optimization techniques could solve industrial-size supply chain problems. After successfully implementing profitable solutions for companies like Caterpillar, Intel, and IBM, he established SmartOps to model those successes through a suite of software solutions. These solutions support inventory and supply planning at many levels (strategic, tactical, operational), and greatly enhance the performance and usefulness of existing ERP, APS, and home-grown execution systems to support operational activities. Today, case studies demonstrate the value that solutions like SmartOps can bring to driving supply chain profitability.

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Introduction

To improve their supply chains, companies have been making sizable investments in a range of solutions and expertise, yet significant profitability improvements have remained elusive. Largely unaddressed has been the opportunity to use enterprise and supply chain data to support the key planning decisions (determining inventory targets and order quantities) that fuel execution systems and activities -- something beyond a mere spreadsheet or desktop solution. That opportunity has been recognized by industry visionaries as being critical to enabling supply chain optimization.

Over the last decade, several Fortune 500 manufacturers from different industries called upon Dr. Sridhar Tayur, a tenured professor of operations management at Carnegie Mellon University (CMU), asking him to assess their supply chains and develop solutions that use the most appropriate and effective advances in operations research to solve persistent supply and inventory planning challenges. These were companies that had invested millions of dollars in ERP, Advanced Planning and Scheduling systems, supply chain planning and forecasting software, warehouse management and transportation systems, in-house personnel, and specialized consulting services, but they still sought a solution that effectively enabled an optimal supply and distribution network and significant reductions in overall inventory investments without impacting service levels to customers.

> 33% of companies are spending more than $10 million per year on supply chain initiatives, according to AMR Research's January 2002 Report on Supply Chain Management, yet Bain & Company reveals that inventory turns are only slightly better now than they were a decade ago.

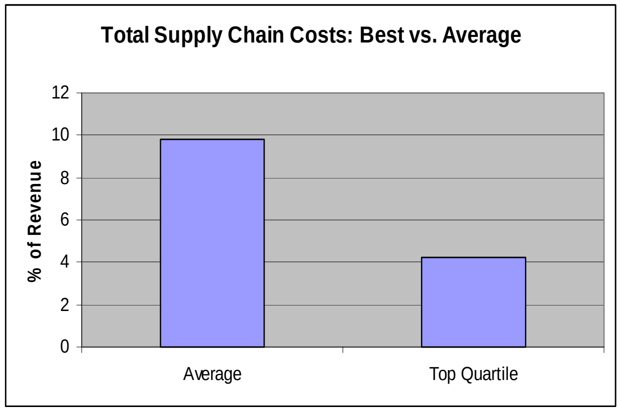
Today, even the seemingly most basic questions remain extremely difficult (or impossible) to answer accurately:

- Given all the variables and complexities of my supply chain and product mixes, what is the appropriate amount of inventory of this product that I should keep at this location to meet product availability targets and customer service levels?
- What should my optimal reorder quantities and frequencies be over time?
- How often and quickly can I perform rapid re-planning based on changing supply chain factors?

Knowing "how much" inventory is not enough to ensure optimization and superior planning support. A solution must also reveal and coordinate:	
WHAT	Form of inventory at different stages of the supply chain
WHERE	Location of inventory
WHO	Multi-agent view ("Who owns the inventory?")
WHEN	Timing matters
WHY	Know the purpose of carrying inventory

While those questions continue to linger, most companies are sinking more than twice the revenue into running their supply chains as the leading performers in their industry. A survey published in *Supply Chain Management Review* in late 2001 by Bain & Company found that average performers are spending nearly 10% of revenue on supply chain costs compared to the 4.2% spent by top-quartile players. Further, the same survey found that despite the solution investments companies have made, inventory turns today are only slightly better than they were 10 years ago.

While the top performers in each industry spend only slightly more than 4% of revenue on supply chain expenses, the majority of companies spend more than double – nearly 10% of their revenue. (Source: Supply Chain Management Review, November/December 2001.)



Add to those surveys the current reports of $1.1 trillion of inventory being held in the U.S., and it becomes clear that there is a substantial opportunity to increase corporate profitability and drive an economic turnaround.

Something has been missing in the marketplace to produce the growing supply chain performance gap seen today across industries. But why would companies contact members of academia?

Existing offerings are not designed to adequately address persistent inventory target and supply replenishment planning challenges and in fact, require that the hardest decisions are supported by "inputs" from planners, who generally do not have the appropriate optimization algorithms for supply chains. As a result, the most well-known offerings are not tackling the central issues that cause inefficiencies and continue to leave planners to their own "intuition" and locally optimal devices. A more impactful solution is needed, one that utilizes the best practices available to perform less local optimization and that can complement and refine planning intuition to yield a tangible, high return on investment.

Among the top researchers in the field of supply chain modeling and optimization algorithmic development, Dr. Tayur at CMU and his peers were asked by these leading multi-billion-dollar businesses to put academic advancements to practice in the real world to see if an alternative approach could provide a viable solution. What resulted were software development projects that leveraged optimization models and decades of advanced operations research compiled into an appropriate, practical solution.

Caterpillar was among the companies that called upon Dr. Tayur and his team, in this case to develop a rapid-response supply distribution network for their new line of compact construction vehicles and equipment. With results that included tens of millions of dollars in supply network investment savings and the ability to deliver high product service levels to customers, the project demonstrated that the academic research and algorithmic approaches implemented by Dr. Tayur's group could make a significant impact in Fortune 500 profitability. The Caterpillar project was featured in *FORTUNE* magazine in an article titled, "New Victories in the Supply Chain Revolution" (October 10, 2000).

After several projects concluded with other large companies and produced sizable benefits, it became clear that the inherent and growing complexity of supply chains required a new optimization approach not yet found in commercial software or consulting services. Ideally, a software product or suite of products to fill this large market need would combine the appropriate intellectual property in operations research with integration-friendly design that offered highly functional decision support matched to real-world business process workflows.

This paper outlines the major challenges to achieving effective optimization around inventory and inbound supply planning, describes the requirements for addressing those challenges, and how Dr. Tayur's solutions – now found in the SmartOps software suite – bridge academic advancements and real-world business issues.

> "There is no doubt of the importance of quantitative models and computer-based tools in decision making in today's business environment. This is especially true in the rapidly growing area of supply chain management… Every field has a 'Golden Age' – a period of exciting developments, providing both a highly intellectual environment as well as making a strong impact on industrial practice; the field of Operations Management appears to be enjoying one right now."
> – Dr. Sridhar Tayur, Ram Ganeshan, and Michael Magazine, *Quantitative Models for Supply Chain Management*, Kluwer Academic Publishers, 1999.

Inventory Optimization is a Hard Problem

Understanding Optimization

Inventory and inbound supply optimization has been over-promised, non-prioritized, and misunderstood, primarily due to the tremendous complexity involved in solving the problem and the difficulty in defining it.

First, it must be understood that supply chain optimization is *not* the following:

- Visibility of transaction data -- While visibility is beneficial, it does not involve the act of generating optimized planning recommendations and relies on another solution to do that.
- Forecast accuracy improvement -- Efforts to improve demand and promotions forecasting provide better data in the form of "inputs" to enable optimized inventory and supply planning.
- Ad hoc (and rule-based) myopic local improvements (both in time and space) -- Examples include packing a truck to its brim, optimizing a particular purchase order, or running large batch sizes. Those arguably have a negative impact on supply chain profitability and efficiency until the fundamental issues of optimizing inventory and supply plans are addressed.

Secondly, it must be recognized that there is a difference between "academic" optimization approaches and the practical optimization solution needed to enable real-world value for today's supply chains:

> *Academic definition* -- an act, process, or methodology of making something (as a design, system, or decision) as fully perfect, functional, or effective as possible; *specifically* the mathematical procedures (as finding the maximum of a function) involved in this, assuming perfect data is available.
>
> *Practical definition* – the methodology behind rapidly computing a robust, near-optimal solution that is pragmatic, appropriate, flexible, and significantly better than the current one, since '*academic'* optimization is neither practical nor likely to be achieved due to lack of perfect data and the extreme length of time and complexity involved in calculations, even if good data was available.

Purely academic optimization cannot be applied to businesses without modification, for several reasons: data is not available at high levels of accuracy, all factors germane to the decision cannot be accounted for in solvable mathematical form, the solution obtained is not implemented easily, and the world changes in fundamentally random, unpredictable ways. It is, however, a very good place to start from an intellectual property point of view.

Finally, there are different types of optimization in regard to the algorithms needed. Existing software offerings take a *deterministic* optimization approach, which assumes that supply and demand variables (lead times, capacities, demand forecasts, product margins, etc.) are certain. But since that approach does not reflect the "real world," these offerings are not able to model and mitigate the inefficiencies that exist in the majority of supply chains.

There is another, more advanced and appropriate approach to optimization, one that has its roots in more than 40 years of academic research and advancement. *Stochastic* (meaning "involving chance or probability through random variable(s)") optimization is a field of study that incorporates inherent variability and uncertainty. Its algorithms realize several different choices can provide a feasible solution, a small set of which are better than the rest, and then quickly find one in that small set that can be identified as nearly optimal.

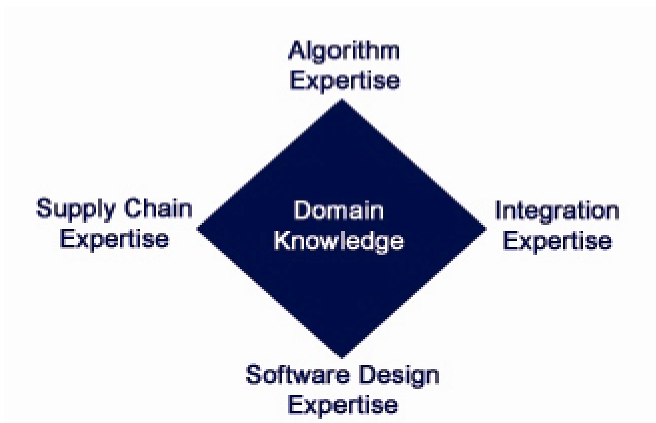
The Mix of Decision Approaches Needed for Supply Chain Planning and Optimization	
Combinatorial Planning Different combinations to achieve the same results -- which combination is the best?	**Risk Management** Measure the trade offs between decisions that lead to different result in the presence of uncertainty.
Economies of Scale Example: Buy more products at less per unit price? Less product at higher per unit price? Ship truck load or less than truck load?	**Managing Variety** Joint replenishment planning; mass customization; postponement; delayed differentiation; and make-to-stock, make-to-order, finish-to-order, and assemble-to-order inventories.
Deterministic Optimization Assumes supply and demand variables are known.	**Stochastic Optimization** Accommodates supply and demand variability and uncertainty, and accounts for a variety of customer classes with different service level expectations.

Appropriate decision support involves a blend of approaches, enabled by technology, integration expertise, and supply chain experience.

Stochastic optimization work as related to supply chains began in the 1950s when academic researchers at CMU, Stanford, Cornell, MIT, and other universities created early inventory models and identified fundamental issues around optimization. By the 1970s, academics began to search for simpler ways of computing optimal inventory policies to solve basic supply chain planning problems. In the 1980s, improved computational methods, driven by technology, allowed these approaches to be tested to find how long it would take to generate optimal results for larger and larger problems.

Then in the 1990s, Dr. Tayur and his peers began to find ways to manage the application of stochastic optimization to solve real supply chain challenges, including additional complexities and problems that result when multi-agent views of inventory (suppliers, distributors, dealers, etc.) unintentionally create competing incentives that increase inefficiency. These approaches were successfully implemented in projects where supply and demand uncertainties were accounted for, allowing businesses to make better, more profitable planning decisions on a daily basis. Those are the types of issues Dr. Tayur addressed when bringing the academic viewpoint of optimization to the Fortune 500 supply chain environment and later when establishing SmartOps.

Practical supply chain optimization requires an appropriate solution that combines supply chain expertise, algorithmic expertise, and the right suite of tools that can accommodate, measure, and mitigate the persistent forces behind supply chain inefficiency.



The components needed for an appropriate optimization solution for today's complex supply chains.

Inventory Optimization is a Hard Problem: Key Drivers of Supply Chain Inefficiency

Today's supply chains are subjected to several forces that, if not measured and managed properly, can drive inefficiencies not just within each stage but across the extended supply chain. The key drivers include:

1. **Multistage complexity** – Multiple stocking locations exist in a supply chain, carrying different forms of inventory, from raw materials, in-process inventory, and postponement goods, to distribution goods and dealer/retail inventory. Managing, planning, and optimizing the inventory "mix" at each location becomes more complex as the number of SKUs continues to increase and product life cycles decrease. True optimization must account for the interdependencies between "echelons" or stages/nodes in the supply chain, and it must allow planners to see and react to the impacts that local planning decisions have on the entire supply network.

2. **Inherent supply and demand uncertainty and variability** – A range of downstream (demand-driven) and upstream (supply-driven) uncertainties affect supply and inventory planning. Demand-related uncertainties may include time-based forecasts and forecast errors, seasonality, customer patience levels/wait times, and product margins. Supply- related uncertainties may include manufacturing and transportation lead time variances, capacity constraints in production, transportation, and warehousing, and inventory holding costs and budget constraints. The algorithms used to determine inventory targets, service levels, and order quantities must acknowledge and actively manage those uncertainties and variables to produce an optimized plan across the supply chain.

3. **Uncoordinated decision making** – While improvements have been made within individual planning groups (purchasing, transportation/logistics, warehousing, etc.), a "less local" and more global optimization solution will drive true efficiency. Consider a very simple example, what may be an optimized planning decision for one group, such as buying larger quantities at a cheaper per unit cost, may not be globally optimal as costs increase in inventory storage and obsolescence and may ultimately outweigh purchasing savings. This problem becomes increasingly complex when those planning groups must simultaneously consider supplier pricing events, uncertain lead times, transportation alternatives, uncertain demand forecasts, seasonality, and promotions. This will, in many cases, involve not just a new tool but also a shift in thinking about the impact that individual decisions have on "total cost of supply." For certain manufacturing, distribution, and retail environments where product margins are especially thin, addressing this challenge provides a significant boost to profitability.

4. **Underutilization or lack of planning 'best practices'** – Although data is generally more available today, complexity and uncertainty in supply chains continue to increase. Planners do not have the optimization systems necessary to make better strategic, tactical, and operational decisions. Data provided by existing systems, which were not designed to enable true supply chain optimization, does not help planners determine what their inventory levels *should be* today or tomorrow. Further, different planners manage each product group differently, leading to inconsistent results. Some use spreadsheets, home-grown systems, or rules-of-thumb approaches where a more advanced mathematical solution is required to enhance the ERP and supply chain systems already in place. Finally, the practices and tools used by a single planner often vary. The solution should provide a more standardized, effective way to support inventory and inbound supply planning.

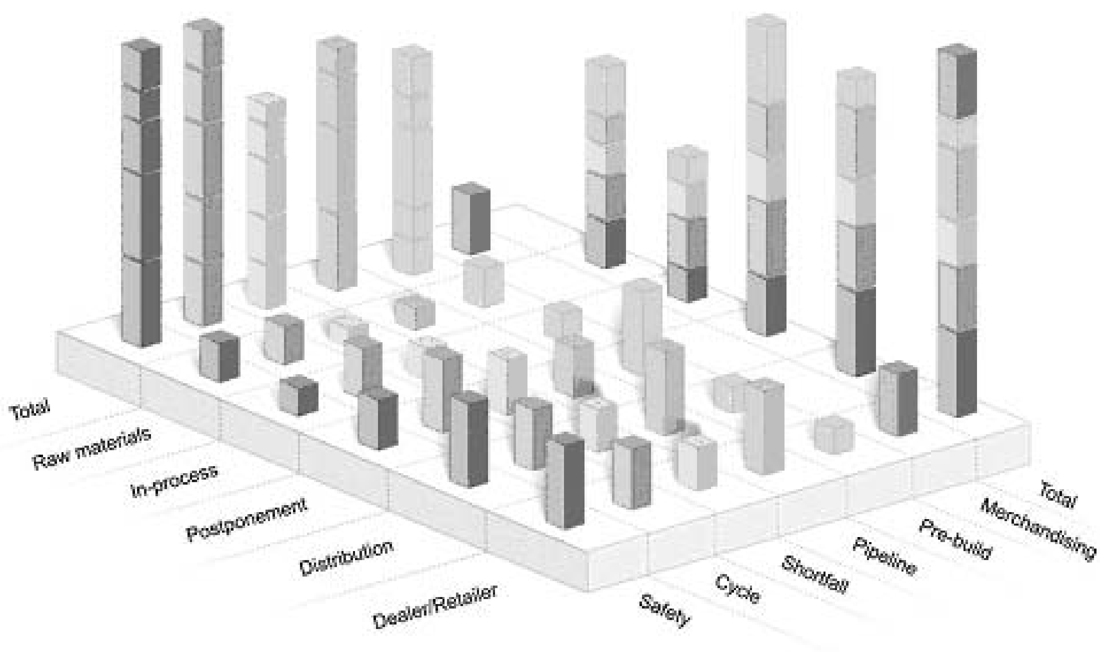
Inventory Optimization is a Hard Problem: Back to Basics
Why is Inventory Held in the Supply Chain?

> Inventory is the blessing and the curse of the supply chain. The overall deployment of optimal inventory and safety stock is the blessing that many supply chain managers desire. The deployment of too much or the wrong mix of inventory is the curse that can derail any company.
>
> – AMR Research, April 30, 2001, "Have You Considered Inventory Optimization?"

It is not enough to simply know what inventory levels are currently. Another key challenge to enable effective supply chain optimization is to understand and plan for the different reasons a company must carry inventory in the supply chain. This is a crucial, more granular planning detail that is missing from existing solutions and services in the marketplace, but it is essential to reduce overall inventory costs. While typically considered "waste" in lean manufacturing environments, there are fundamental and economic reasons for carrying inventory in the supply chain.

There are at least six (6) purposes inventory serves, which must be measured and managed:

1. **Safety stock –** Safety stock is a buffer added to inventory to hedge against stock outs when demand and lead times are uncertain.
2. **Shortfall stock** – This inventory accounts for upstream capacity constraints and variations.



The challenge is to determine the optimal mix between the different reasons (safety stock, cycle stock, etc.) for carrying inventories at each stage of the supply chain over time -- from raw materials through distribution and retail inventory.

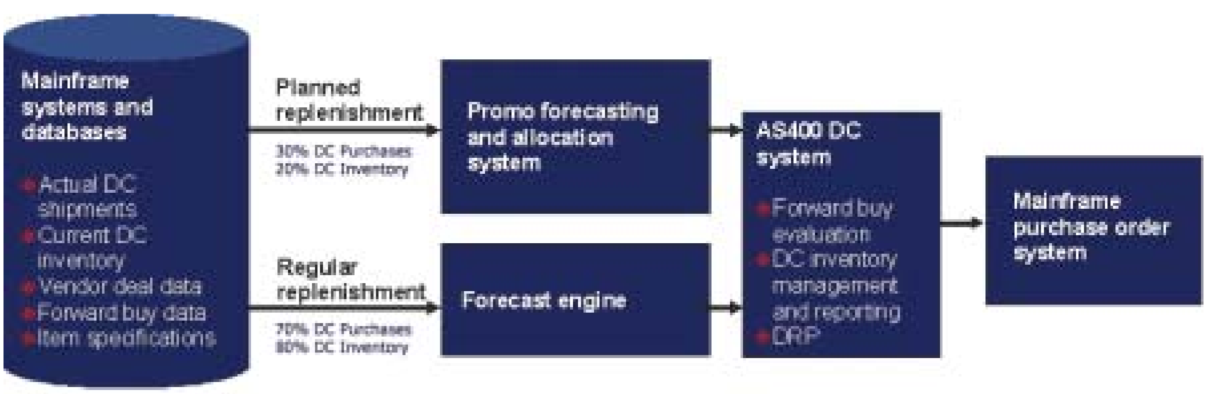
3. **Cycle stock** – Cycle stock accounts for economies of order, production, and transportation. Longer cycles account for greater cycle stock in the supply chain. Optimal cycle stock is the quantity of product ordered to replenish the target inventory position at that location, and it is determined by considering all relevant costs.
4. **Pipeline stock** – Pipeline stock is the on-order inventory not yet received as on-hand inventory. This is primarily due to time spent in moving and producing inventory.
5. **Pre-build stock** – Pre-build stock is required when capacity in a given period is less than the expected demand.
6. **Merchandising stock** – Merchandising inventory is required for display purposes and is a particularly important portion to measure when dealing with high-cost items or high volumes of display products.

Other reasons to hold stock involve opportunistic purchases made during vendor deals and announced price increases, speculative purchases made in anticipation of possible price increases, or to take advantage of market-based price fluctuations.

Inventory Optimization is a Hard Problem: The Need for Integration-Friendly Solutions

Because significant investments have been made in business systems and processes, a major challenge is to find an inventory and inbound supply optimization solution that will complement and enhance those investments.

The following diagram is a major retailer's distribution center replenishment workflow process, which illustrates that the investments in place – while important in delivering the functions they are designed to provide – *do not* offer a solution to optimize inventories and order quantities while accounting for inherent uncertainties and variables (in this case, seasonality and promotions are the most critical).



An overview of a major food & drug retailer's existing distribution center replenishment system. Despite these investments, this company is not able to set optimal inventory levels based on a total cost of supply perspective or manage its seasonal and promotional items for supply and inventory planning. However, they want to leverage, not replace, these systems where possible. (Source: February 2002 SmartOps interviews with the customer's management team.)

Because the company faces the following shortcomings that are driving costly inefficiencies, it is seeking an optimal solution that will fit into its existing architecture:

- Distribution center inventory levels are not set by minimizing total cost of supply
- The forecasting, inventory management, and reporting systems (installed in the early 1990s) cannot handle seasonal or promotional demand forecasting
- For its seasonal/promotional items and its non-seasonal/non-promotional items (handled by a software vendor's forecast engine), the systems in place work sequentially and therefore do not optimize inventory planning
- Optimal order quantities are not calculated
- Vendor deals are not evaluated holistically

Companies seeking improved inventory and supply planning likely are not looking to "boil the ocean" by re-thinking their entire supply chains and system investments. From an integration standpoint, an ideal solution should be designed to work with existing data systems and execution systems and create minimal interference with the IT environment.

What is Missing?

ERP and supply chain planning platforms meet the need of enabling and improving execution-level decisions. However, the marketplace has been without a solution that comprehensively measures all the drivers of inventory to generate optimal planning parameters that support strategic, tactical, and operational decisions. This solution would allow companies to mitigate inefficiencies, increase inventory turns, deliver better service to customers, and manage to a lowest total cost perspective.

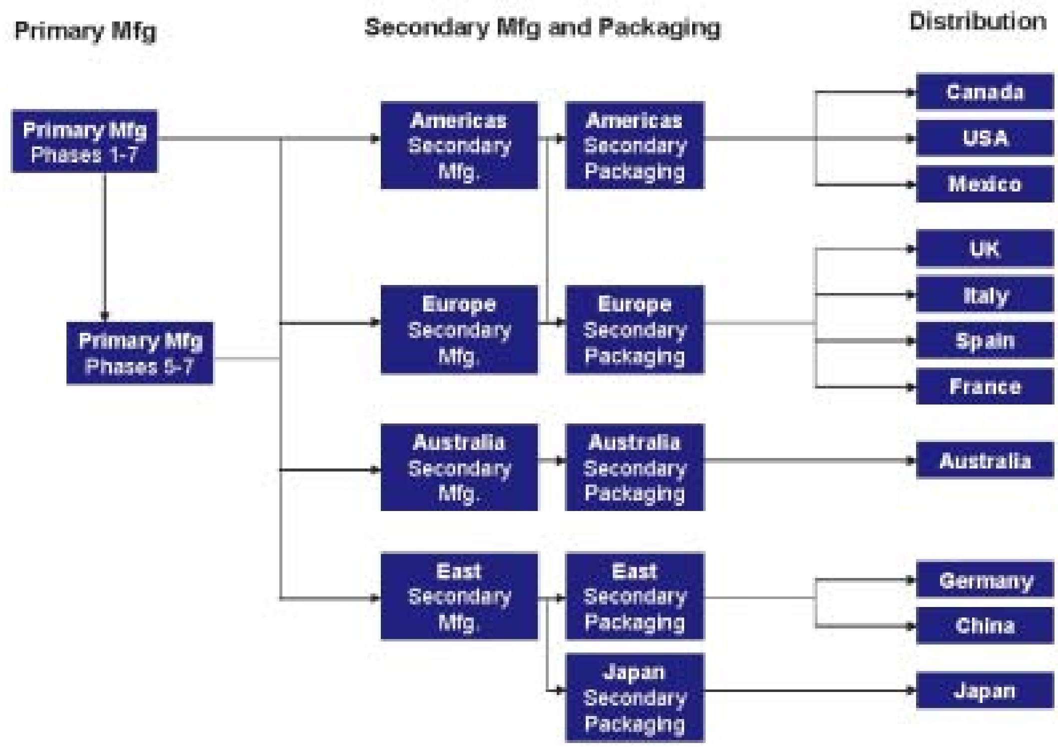
To adequately satisfy the market requirements of major supply chains, the solution at a minimum must address three of the key drivers of supply chain inefficiency outlined earlier in this paper: (1) multistage complexity; (2) the need to model the inherent, random presence of supply and demand uncertainties and variables; and (3) uncoordinated decision making.

What is Missing: Managing Multistage Complexity

Multistage complexity cannot be addressed effectively through single-location planning or through sequential planning, which looks first at one stage, and then the next without considering location relationships.

To enable multistage optimization, the approach should recognize that supply chain nodes or echelons are interdependent and must be calculated simultaneously, accommodating all forms of inventory (i.e., raw materials, in process, finished goods, etc., held at different echelons/stages) as well as the purposes of carrying inventory (safety, cycle, pipeline, pre-build, etc.).

The representative multistage supply chain shown on the following page is of a medical product company's manufacturing, packaging, and distribution network for one product line. As illustrated, many locations are dependent on other locations for their inventories. The optimization solution must account for those relationships and rapidly, simultaneously re-calculate planning targets for all locations affected by supply or demand changes.



An example multistage supply chain for one product line of a medical product manufacturer; note the relationships between many locations.

Take a few specific examples of some multistage interdependencies found in the manufacturing supply chain shown above:

- **Japan DC wants to increase service levels from 97% to 99%** to meet growing demand, but at the same time, the **East Secondary Manufacturing** location is experiencing longer lead times from its suppliers -- how will those factors impact inventory target re-planning at the East secondary manufacturing, East and Japan secondary packaging, and Japan, China, and Germany DC locations?
- **Primary Manufacturing Phases 5-7** are experiencing growing capacity constraints -- how should all stocking locations downstream adjust their inventory and supply replenishment planning so service levels are not affected?
- **Europe's Secondary Packaging** site is carrying too much inventory -- how can planners view different planning scenarios that look at **America and Europe Secondary Manufacturing** inputs and how those decisions may impact downstream **UK, Italy, Spain, and France DCs**?

For multistage supply chains, planning decisions must be coordinated and supported for all SKUs at all locations over time.

What is Missing: Accounting for Supply and Demand Uncertainties

> In the aftermath of the terrorist attack, the Semiconductor and extended High-Tech industry supply chains must rethink some of the assumptions of managing their supply chains. The economy's role in the further slowdown of the overall demand is obvious, but the industry is also going to have problems with the logistics slowdown caused by increased security measures. The measures, in turn, will increase cycle time and force companies to revisit their inventory strategies across their network.
>
> – AMR Research, September 24, 2001, Semiconductor Industry Outlook

There must be a way for companies to measure and manage the impacts of changing factors and uncertainties on planning decisions. Uncertainties affect supply chains to varying degrees, but without an approach that accommodates and calculates them, there is no true solution.

This is where stochastic optimization is needed as part of the total solution because, unlike deterministic algorithms, it is the algorithmic approach designed to account for demand and supply-related inventory drivers.

The table that follows shows a partial list of the many inventory and cost drivers -- most of which typically change over time (some very frequently and routinely) -- that planners struggle to manage and calculate when making planning decisions for inventory targets and supply replenishment for each SKU at each location.

DEMAND RELATED INVENTORY DRIVERS	SUPPLY RELATED INVENTORY DRIVERS
• Demand forecasts and forecast errors • Periods between demand • Intermittent demand • Seasonality • Product promotions • Service levels and product availability targets • Customer wait times (patience levels) • Showroom and merchandising inventory levels • Pricing and product margins • Amount of lost sales	• Manufacturing and transportation wait times, lead times, and lead time uncertainty • Vendor deals and forward buys • Variability of lead times • Capacity variability and constraints in production, transportation, and warehousing • Transportation alternatives • Expediting costs • Budget constraints on inventory dollars • Frequency of shipments from supplier to plants, plants to warehouses/pools, and pools to dealers • Inventory holding costs

Accounting for, gaining visibility into, and managing the growing number of uncertainties and variances in supply and demand is crucial to effective planning.

Stochastic optimization also delivers significant value to promotional and seasonal inventory planning. For retailers where promotions are a way of life, most approaches and solutions assume a consistent "lift" in demand from one promotion to the next. However, promotions-driven planning must also have a way to measure and manage variables and uncertainties over time and not assume predictable demand lifts.

What is Missing: Coordinating Silo-Based Decision Making to Drive Total Cost Optimization

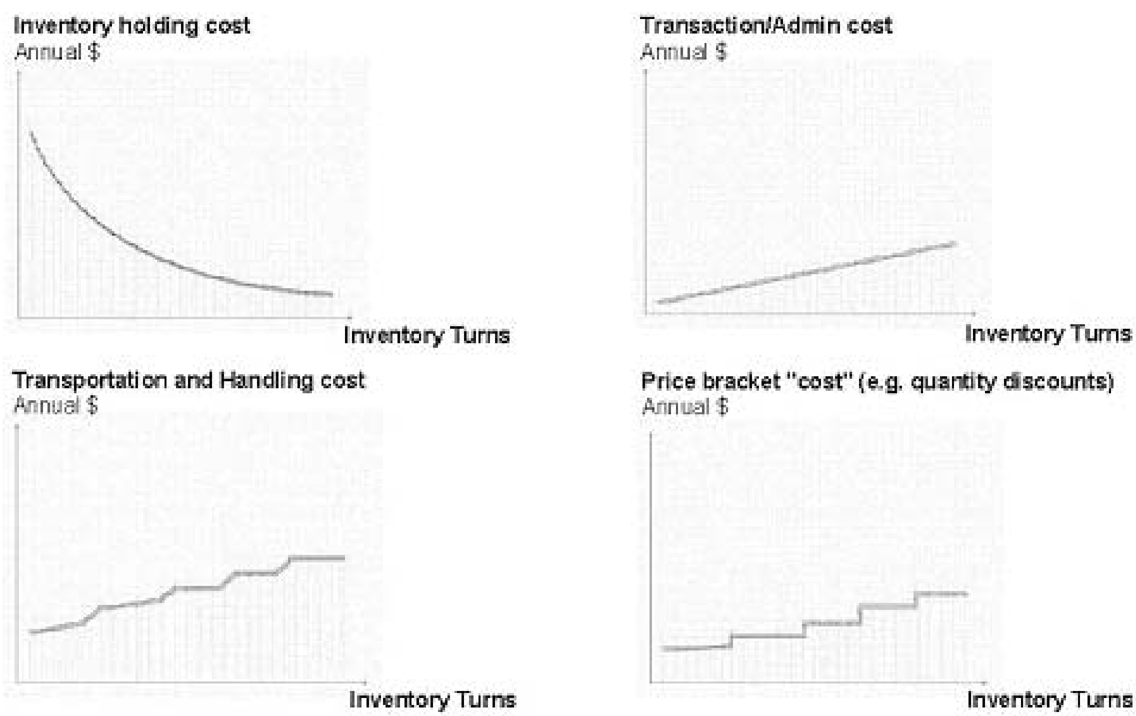
> By some estimates, the cost of excess inventory in stores, driven by "silo" planning and misaligned trade promotions, amounts to more than 25% of annual sales.
> – "Lessons from the Leaders," *Supply Chain Management Review*, November/December 2001

In the area of inbound supply planning, a solution is needed to improve the decisions made in planning reorder quantities, shipment frequencies, and deployment methods for each product at each stocking location. The most critical step in accomplishing that goal is to coordinate decisions across planning groups and weigh all cost drivers. The objective should be finding the optimal inventory level to meet desired service levels at the lowest total cost.

Determining the total landed cost of a SKU, raw material, or product depends on factoring ***at least*** the following four cost components:

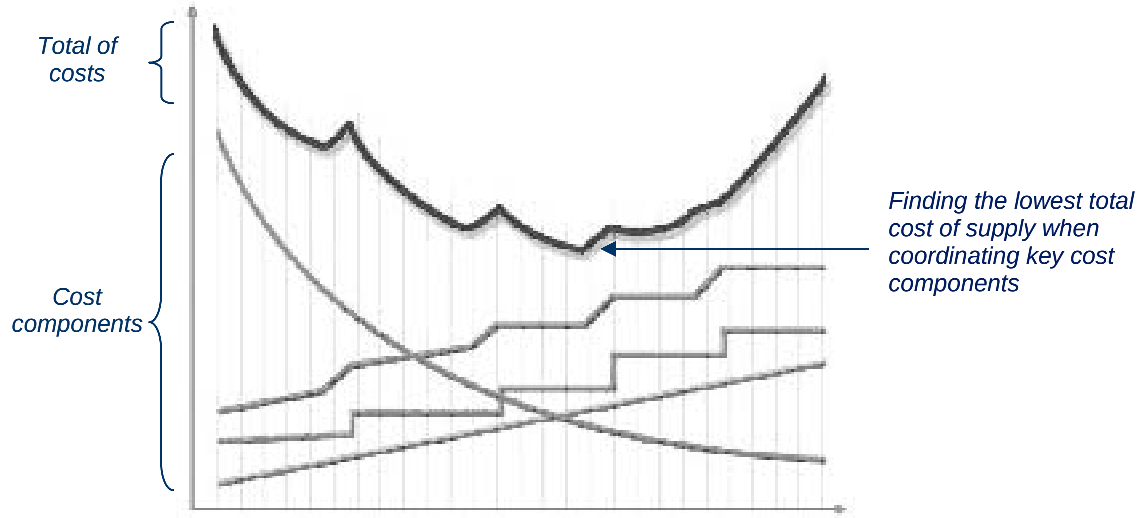
1. **Inventory holding costs** -- including cost of capital, scrap, obsolescence
2. **Transportation and receiving/storage costs** -- shipping truck load, full truck load; picked up or vendor delivered; warehouse costs dependent on utilization
3. **Administration costs** -- executing purchase orders; accounting
4. **Unit costs at the source** -- product price brackets

In many industries planning decisions tend to be driven by cost per unit decisions or to meet a goal of increased inventory turns. Ideally, the planning optimization solution should enable a total cost perspective by simultaneously accounting for all cost components, the drivers of those costs, and their tradeoffs. That would include accounting for supply and demand uncertainties and variables such as supplier pricing events, seasonality, uncertain lead times, transportation alternatives, uncertain demand forecasts, customer promotions, and many other inputs.



Key areas that affect inbound supply planning must be coordinated and evaluated against inventory turns, to determine the lowest cost of supply to meet service levels.

Further, the solution should provide a way to calculate the lowest total cost given a desired service or product availability level:



Because transportation and joint economies of scale are non-linear problems, academically speaking this becomes a very difficult challenge to solve. The appropriate algorithms to enable total cost optimization are not found in traditional solutions, which are based on linear programming models – they must be part of a solution that includes nonlinear and stochastic optimization analytics. Such a solution has been implemented by Dr. Tayur and can be found in the SmartOps product suite.

Inventory Planning and Optimization is Critical

With an effective supply and inventory optimization solution in place, critical business decisions at all planning levels can be supported and improved:

Strategic Planning

These decisions are generally done on an annual or one-time basis and include activities like inventory budgeting, designing rapid-response supply networks, new product introductions, postponement strategy ("delayed differentiation"), and strategic sourcing. The correct solution answers strategic questions such as:

- "What is a good (efficient and responsive) network?"
- "Where should we strategically place inventory based on target manufacturing lead times, target availabilities, and capacities? At what target inventory levels?"
- "Where should I deploy inventory given a corporate inventory budget constraint, and what does this mean for customer service and product availability?"
- "What is the cost/benefit of inflexible/flexible capacity?"
- "What product lines can benefit from postponement strategy and where in the supply chain should the 'differentiation' occur?"
- "What is the benefit or business case for attacking certain supply chain parameters, such as lead times, availabilities, or capacity flexibility?"

Tactical Planning

Tactical decisions are made on a quarterly, monthly, or sometimes even weekly basis, depending on the company's planning "velocity." Decisions supported at this level include Sales and Operations Planning (S&OP), inventory deployment, scenario and "what if" analysis, and the setting of optimized planning parameters for an execution system to use as an input. Examples of tactical planning questions that are answered:

- "What are optimal inventory levels by product, component, and location over time?"
- "What key factors shift the optimal inventory curve?"
- "What happens to the optimal inventory curve in different demand scenarios?"
- "What are the impacts if we improve lead times, forecasting, customer wait times, or service levels?"
- "How low can we reduce inventory before we begin to impact sales?"
- "How often should I order?"
- "What is my optimal multi-item order quantity?"
- "Should I consolidate shipments or ship to each location separately?"
- "From which vendor location should I order?"

Operational Planning

An effective supply chain optimization solution inevitably will, as a natural 'by-product', impact operational planning by generating better key operating targets for use in execution systems and allow closer synchronization of demand with supply chain constraints. This supports supply management, inventory management, and the dynamic updating of inventory targets:

- "Can I be alerted when current planning decisions require attention?"
- "How can I actively manage exceptions and rapidly re-plan?"
- "How can I generate reports on supply chain performance?"

Why Now?

Because the problem has been so overwhelming and hard to manage, most companies have not clearly defined and prioritized a project to tackle the optimization of inventory and supply planning. However, a number of convergent trends and developments are making this the right time for companies to re-evaluate the significance and feasibility of inventory optimization projects:

- **Data** – there is an increased availability of data and methods to improve the accuracy of data, providing a better foundation for optimization analytics.
- **Knowledge** – through advanced, focused educational programs and skills development, the transfer and creation of supply chain knowledge has dramatically increased in recent years.
- **Technology** – computing hardware, development platforms, and the Internet have seen massive improvements, enabling better optimization of industrial-sized problems.
- **Algorithms** – operations research in academic settings have yielded advances in algorithmic development to address mixes of deterministic, stochastic, and non-linear challenges, and to perform well even though data is not perfect.
- **Case examples** – successful solution implementations done by Dr. Tayur and others at Fortune 500 companies in the past decade have illustrated that there is a practical way to overcome persistent drivers of supply chain inefficiency.

A comprehensive approach is now available to the marketplace, one that takes advantage of the convergent trends. SmartOps was established to provide software solutions that bridge the academic work in operations research, best practices in supply chain planning, and real-world business and systems environments.

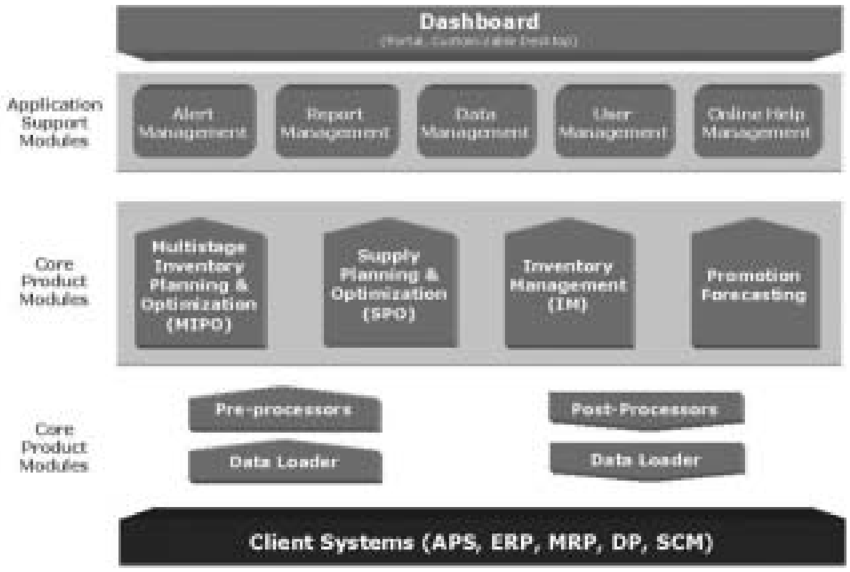
SmartOps offers a suite of solutions that, used separately or combined, optimize inventory and inbound supply planning for today's complex supply chains:

SmartOps™ Planning and Optimization Suite			
Multistage Inventory Planning and Optimization (MIPO)	**Supply Planning and Optimization (SPO)**	**Promotions Planning**	**Inventory Management**
Determines optimal inventory positions over time (daily, weekly, monthly, etc.) to meet desired service levels. Provides visibility into the drivers of inventory. Enables rapid scenario analysis.	Reduces net landed cost of supply by coordinating and optimizing inventory and inbound logistics decisions. Provides visibility into the drivers of inventory. Enables rapid scenario analysis.	Adjusts demand periods for promotional and seasonal items. Determines demand stream for new products and short lifecycle products. Provides trend profiling.	Generates recommended replenishment plans. Enables exception-based management by providing supply chain alerts. Offers reporting and exporting capabilities.
Daily, weekly, monthly, quarterly, annually	Daily, weekly, monthly, quarterly, annually	Daily	Daily
• Overall inventory and cost reduction • Improved inventory deployment plan • Improved service levels • Responsive supply chain	• Reduced net landed cost of supply • Improved product availability	• Improved promotional product availability • Reduced seasonal and promotional stock outs or buffering • Improved product margins	• Tight integration with operational and execution systems • Enables execution of optimal planning targets • Coordinates and standardizes replenishment decisions

In addition to its intellectual property offering, SmartOps has built its products and services to address current business concerns: establishment of strong, tangible ROI for project investments, and selection of software solutions that are both usable and supportive of existing IT environments.

Working with customers, SmartOps spends time up front with the client conducting a supply chain assessment to find the largest efficiency opportunity. For example, in retail environments where product promotions are a sizable part of business, the customer's data and supply chain information is often used to compare their actual planning data to results that the SmartOps Promotions Planning and SPO solution would generate. In other cases, several high-tech and semiconductor manufacturers are finding where they can optimize inventories across multiple stages using the MIPO product.

Usability and ease of integration are important decision factors for evaluating vendor software offerings, since most companies are looking to enhance, not replace, sizable investments in existing systems. The SmartOps suite of products is engineered to provide practical, appropriate solutions that can easily integrate into and scale within existing corporate environments and business workflow processes. In addition, because the products are developed for planners, ease of use and performance are key design characteristics that permeate the architecture.



The SmartOps products employ a multi-tier architecture in which core product modules share common functional services that interface with clients systems, such as data pre-processing and post-processing and data loading, as well as application support modules that interface with the user's view, including report management, user preference management, data and alert management, and online help.

Case Studies

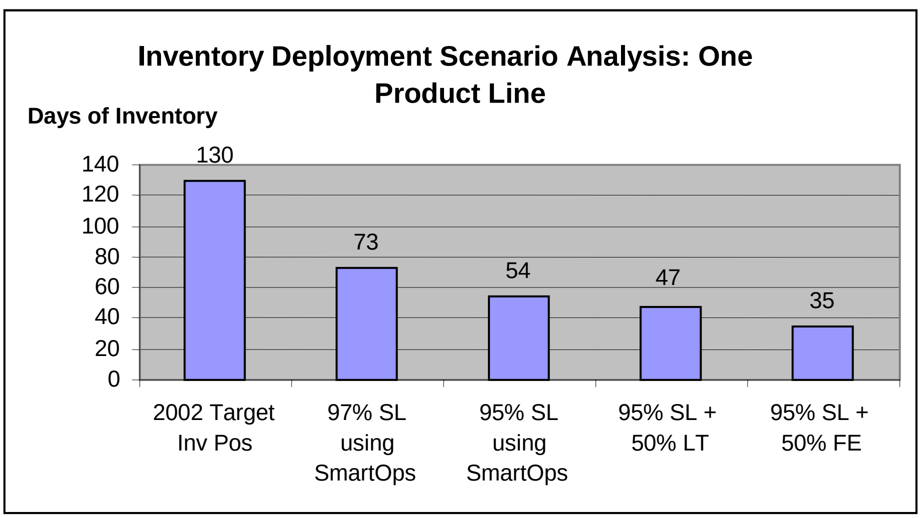
The following three case study overviews describe, in summary, how the SmartOps approach to multistage inventory optimization and total cost of supply optimization is driving significant efficiency improvements and profitability for three businesses today.

Case #1 -- Multistage Inventory Optimization for an Industrial Products Manufacturer: Distribution Centers to Dealers

SmartOps is implementing a multistage inventory optimization solution for a $4 billion division of this leading machinery manufacturer. The company chose SmartOps to implement a comprehensive methodology to decrease significant inventory inefficiency and increase inventory turns to improve its competitive position. The company held more than $1 billion in inventory and its annual turns were less than half that of the leader in its industry segment, which Dr. Tayur worked with several years earlier in an inventory optimization project. The industrial products manufacturer hoped to reduce inventory 50% by 2005 without losing any sales.

The focus of the initial project involves four company plants that deliver a mix of 150 products to 21 independent dealers. The company's own plans to reduce inventory by $300 million consisted of arbitrarily cutting inventory levels by certain percentages across all dealer and plant locations -- a "top-down" approach not based on any facts about supply chain parameters. Because this approach was not analytical or looked at the impacts of those decisions, the SmartOps approach was selected to offer an advanced, yet practical way for planners and dealers to determine optimal inventory targets based on a desired service level of 95%.

The company knew that demand for most products was very seasonal in nature, but it did not have an effective way to forecast this information and manage inventory levels accordingly. By taking demand and supply inputs (drivers of inventory) from the dealers and the manufacturer, SmartOps found that the company could reduce inventory by $700 million without adversely affecting service levels from the plant to dealers and from the dealers to customers.



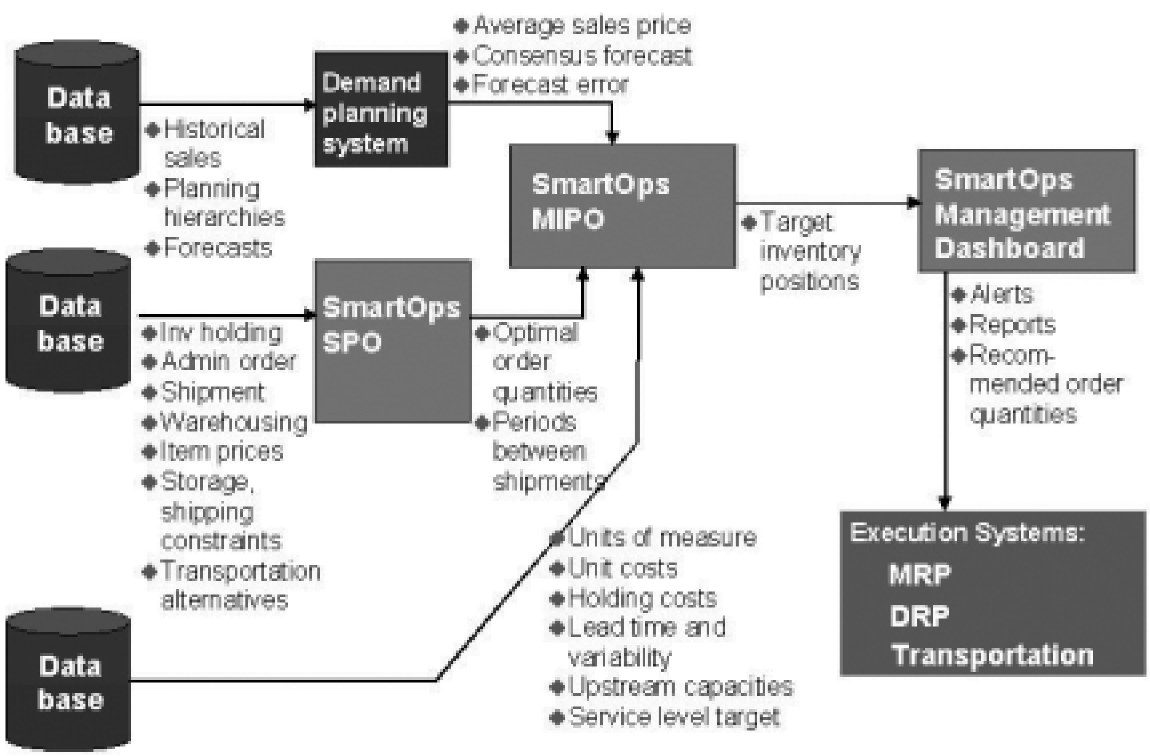
By providing tools for scenario analysis, SmartOps allows this industrial products manufacturer to compare inventory targets for each product based on different service levels, as well as see how different inputs impact planning decisions across the multistage supply chain. In this example, the planners compare 97% and 95% service levels, and based on a 95% service level, how lead time and forecast error reductions can further reduce inventory target levels.

By conducting analysis and generating key planning parameters at the SKU level, the solution is enabling the company to meet – and exceed -- its 2005 goals two years earlier and provided a way to model scenarios, such as forecast error reductions or lead time improvements, to further evaluate efficiency opportunities.

Case #2 -- Multistage Inventory Optimization for a Pharmaceutical Manufacturer: Optimizing the End-to-End Inventory Chain

For a leading $40 billion pharmaceutical company, SmartOps is supporting a global inventory strategy that will determine optimal stock target policies at high service levels, yet ensure lowest risk and minimal cost to the company. The company identified several reasons for its high inventory levels and low turns: an inability to quantify the impact of inventory levels, inconsistent planning when faced with supply and demand variability, "double buffering" because there was no holistic view of the supply network, and lack of scenario analysis to aide in planning decisions.

The SmartOps solution allows them to address those primary drivers of inventory, as well as other drivers the company may not have been aware of previously. The pharmaceutical manufacturer is using SmartOps products to set optimal order quantities and inventory levels at each node in the global supply chain, as well as provide a way for the company to perform scenario planning.



An overview of how SmartOps products fit into the data workflow of this major pharmaceutical company.

While the benefits are still being quantified, the pharmaceutical company reports it will gain clarity of stock levels and processes to setting those levels, fewer stock outs, increased service levels through product availability improvements, freed-up warehousing and storage space, and increased profitability through release of capital.

Case #3 -- Total Cost of Supply Optimization for a Retailer: Finding Lowest Cost of Supply Replenishment

This $5 billion retailer identified that significant inefficiencies existed in its supply chain ($10 million to $15 million estimated), which were being driven by "silo-based" departmentalized planning. In addition, the retailer needed to coordinate those decisions with promotions, short-term price discounts from vendors, capacity limitations, and seasonality, among other variables.

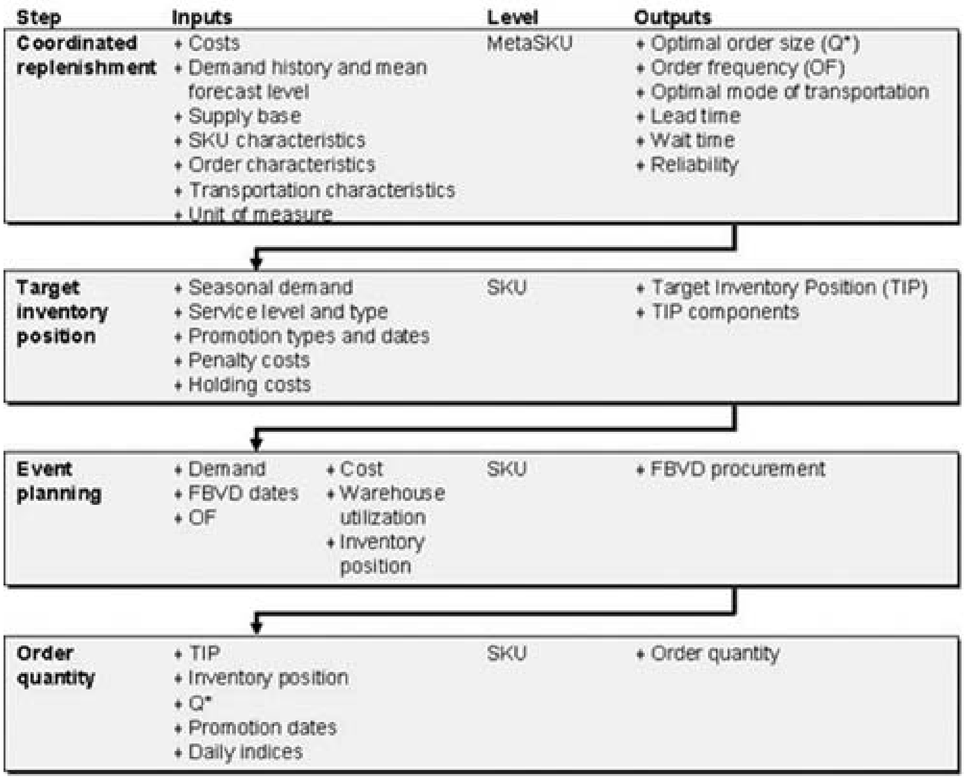
The company needed to find a solution that overcame several business challenges within one of its primary retail divisions:

- Optimize inbound supply decisions at distribution centers by coordinating logistics, purchasing, and warehouse management planning while simultaneously considering the necessary joint replenishment economies. A sub-optimal approach was in place because each department's incentives were different and in competition:
    - The *purchasing department* can receive better price discounts if it orders less frequently but in larger sizes.
    - *Warehouse management* needs to minimize inventory holding costs, so it prefers smaller orders to accomplish that goal.
    - *Logistics planners* want to minimize transportation costs by shipping full truckloads, but as the number of purchases increase and orders are smaller, trucks are underutilized and logistics costs increase.
    - Increased frequency of purchases also drives up *administrative costs*.
- Improve inventory and supply planning by accommodating inherent and growing supply and demand uncertainty and complexity, such as discounts on total order quantity, intermittent demand, multiple warehouses, vendor deals and forward buys, forecast variability and errors, and promotions.
- Improve profitability and customer service through better product availability at a lower cost.

SmartOps was selected because it met two critical requirements for this retailer: First, it allows planners to evaluate cost alternatives, coordinate planning decisions, and gain visibility into the effect of local decisions on the entire supply network; and second it offers a way to effectively manage supply and demand uncertainty. The solution also coordinates the company's existing execution tools, including a logistics system, purchasing application, and warehouse management system by setting key operating targets.

This retailer used a combination of the SmartOps Supply Planning and Optimization (SPO), Multistage Inventory Planning and Optimization (MIPO), and Inventory Management solutions.

Starting with SPO, SmartOps performs the analysis at the aggregate or Meta-SKU level, which looks at a group of individual SKUs that have similar characteristics such as vendor, source, lead time, and order frequency to be combined for joint replenishment planning. Optimal order size, frequency, mode of transportation, lead times, wait times, and reliability are calculated in SPO. Next, MIPO generates optimal inventory targets for each SKU at each location, taking into account demand-side inputs like promotions and seasonality, stocking location inputs, and the outputs from SPO. Other events like forward buys and vendor deals are also considered, resulting in optimized order quantities that ensure lowest net landed cost to meet desired service and product availability levels.



Step	Inputs	Level	Outputs
Coordinated replenishment	• Costs • Demand history and mean forecast level • Supply base • SKU characteristics • Order characteristics • Transportation characteristics • Unit of measure	MetaSKU	• Optimal order size (Q*) • Order frequency (OF) • Optimal mode of transportation • Lead time • Wait time • Reliability
Target inventory position	• Seasonal demand • Service level and type • Promotion types and dates • Penalty costs • Holding costs	SKU	• Target Inventory Position (TIP) • TIP components
Event planning	• Demand • FBVD dates • OF • Cost • Warehouse utilization • Inventory position	SKU	• FBVD procurement
Order quantity	• TIP • Inventory position • Q* • Promotion dates • Daily indices	SKU	• Order quantity

Using SmartOps solutions, this diagram shows key points of a four-phased process to optimizing supply replenishment plans for a retailer that must constantly manage forward buy and vendor deal opportunities (FBVD), seasonal demand, and promotions. (Source: SmartOps Strategic Services group, March 2002.)

Within the first six weeks of implementation, the company began to see an overall reduction in on-hand inventories and net landed cost, while increasing service levels by roughly 1% (from 98% to 99%).

Over a longer period of time, SmartOps demonstrated to the retailer an opportunity to reduce annual costs by $2.4 million and improve store margins by $3.4 million within just one business division. If the solution is extended to all divisions, the possible savings for inventory optimization is projected at $18.1 million annually.

Additionally, on the business process side, the new visibility into the drivers of total cost of supply has led management to move away from departmentalized incentives, thus aligning the organization around a more "global" planning perspective.

Conclusion

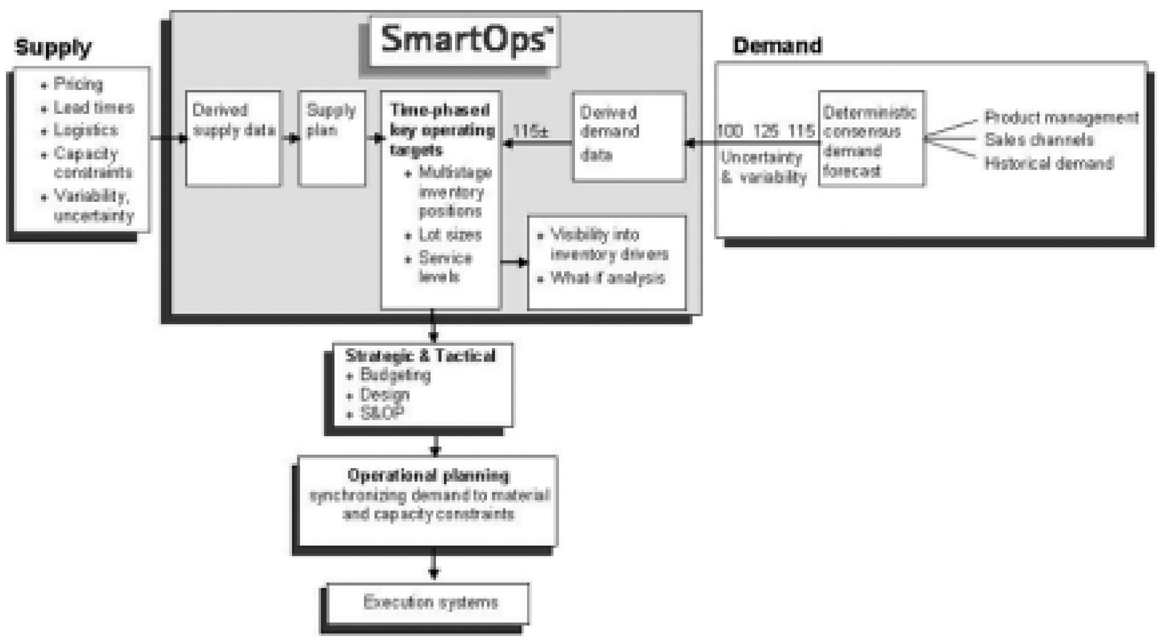
> Many companies struggle with deploying a responsive and meaningful business planning process that can identify supply chain inefficiency and impact bottom-line results. Activities can be marred by failed attempts at implementing an Advanced Planning System (APS), or by not actively managing the constant variability, complexity, and uncertainty inherent in planning the supply chain.
> - AMR Research Alert on Supply Chain Management, June 4, 2001

A customer of SmartOps recently said, "We needed to stop trying to fit reality into a sub-optimal model." The specific area of strategic and tactical supply chain decision support has been left without a comprehensive, effective solution. Existing offerings have not been designed to offer a way to manage and measure multistage, nonlinear, stochastic, uncoordinated supply and demand variables.

The SmartOps approach has been proven to deliver results for Fortune 500 clients, because it tackles and provides visibility into the key drivers of supply chain inefficiency. Its algorithms are based on stochastic optimization to recognize that supply and demand variables are uncertain and have a probability distribution.

SmartOps considers all the forms of inventory (raw materials, in process, postponement/semi-finished, distribution, and dealer/retail) as well as all the purposes of carrying inventory (safety, shortfall, cycle, pipeline, pre-build, and merchandising stocks).

Finally, the solutions account for multistage interdependencies and the complexities of collaborating across different planning groups, to arrive at a lowest total cost decision that meets desired service levels.



An example of the inputs and outputs of the SmartOps Multistage Inventory Planning and Optimization (MIPO) product. Existing supply and demand data is leveraged to determine time-phased inventory positions for all purposes of carrying inventory, based on lot size and service level trade-offs, and also provides scenario analysis and visibility into the recommendations being made. Those outputs support strategic, tactical, and operational planning processes and systems.

Based on supply and demand data inputs, SmartOps software generates optimized planning parameters – including target inventory positions, service levels, and order quantities for each SKU at each stocking location over time – to drive and raise the performance of operations planning and execution systems.

The marketplace requirements of today's supply chains are being met through solutions like SmartOps. Companies should evaluate inventory deployment and inbound supply optimization offerings against the criteria outlined in this paper, due to the track record of demonstrated efficiency and profitability gains for customers that implemented approaches like those found in SmartOps.

Further reading:

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