CHAPTER TWO

INVENTORY FUNDAMENTALS

I rarely encounter obstacles to good inventory performance that cannot be overcome with sound fundamentals. These building blocks and intrinsic trade-offs seem to elude all but the world-class few who have recognized that *breakthroughs are in the basics*.

A few months ago I facilitated an inventory strategy workshop with a manufacturer of high-tech components. During the workshop they proudly presented their supply chain and inventory performance and practices. They had even set their sales and operations planning (S&OP) process to music. However, despite their advances, something was missing.

I asked if they knew their inventory data accuracies. They did not. I asked if they knew what their safety stock, lot size, and pipeline inventory levels should be. They did not. I asked if their inventory planners were certified in inventory planning. They were not. Finally, their chief supply chain officer interrupted and said, "Dr. Frazelle, are you suggesting that we need to go back to basics?" I said, "Yes, that's exactly what I'm suggesting. No strategy is sophisticated enough to survive a faulty foundation. In fact, the most successful strategies focus on fundamentals."

Our sometimes tedious journey through inventory fundamentals will take us through nine aspects of inventory fundamentals: (1) Inventory integrity, (2) inventory philosophies, (3) inventory types, (4) out of stock conditions, (5) planning parameters, (6) financial terms, (7) demand terms, (8) decision variables, and (9) inventory interdependencies. We begin with integrity, the foundation of the fundamentals.

2.1 INVENTORY INTEGRITY

In a recent project with one of the world's largest and most critical health-care providers I was stunned to learn that they *did not even measure inventory accuracy*, let alone understand what it was or have ongoing efforts to improve it. On a project with a prestigious industrial conglomerate I helped them uncover the fact that *over 50%* of their MRP and BOM data was just plain wrong. In a project with a global aerospace company we discovered that over 500 people, some with minimal credentials, could make multi-million-dollar changes to high-level production schedules with little to no oversight. In a project with a major high-tech equipment company we found that unqualified inventory "analysts" were "tweaking" major inventory set points and true demand in the company's service parts inventory system. The premeditated tweaks were unvetted and unsupervised and were made to guarantee that reported turns coincided with these analysts' personal turn targets. In a recent project, one of the world's largest commodities companies balked at my suggestion that they even consider using the word *integrity* in reference to inventory because that word sounded moral.

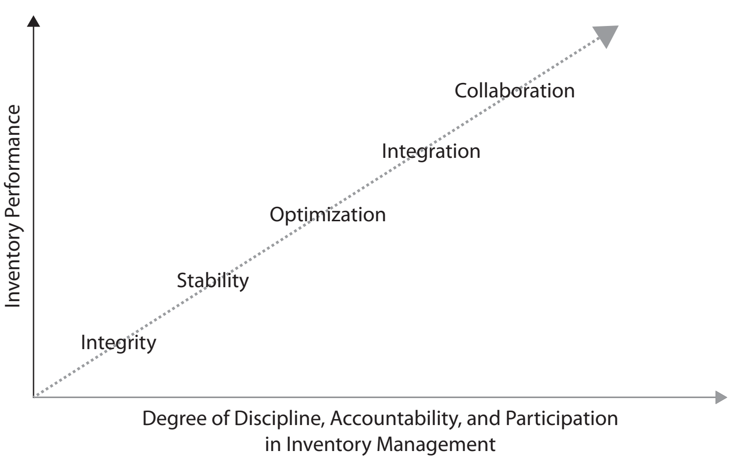
In all these cases, the companies yearned for and nearly demanded the most sophisticated practices in inventory management while struggling with, ignoring, flying in the face of, and/or naively overlooking the basis for all inventory improvements: integrity.

Integrity is the foundation for everything related to trust. Trust is the fertile cultural and technical soil required for true inventory optimization. Without it, each element of the supply chain hunkers down into its own inventory protection mode; this is commonly known as hoarding.

High levels of inventory integrity develop from high levels of inventory accuracy; reliable base data, including lead times, MRP records, and BOM records; measured and persistently improved forecast accuracy; and consistent disciplined participation, follow-through, and accountability by key players in inventory decision-making meetings and processes.

Once a high level of *inventory integrity* is established, the next phases of inventory management maturity are attainable (Figure 2.1). Level 2 is *inventory stability*, in which predictable cause-and-effect outcomes are the rule, not the exception in inventory behavior. Level 3 is *inventory optimization*, in which the SKU portfolio, forecast, lead times, lot sizes, deployment,

Figure 2.1 Inventory Management Maturity Phases



visibility, inventory carrying rate, inventory turn rate, and fill rate that meet required service levels and maximize financial performance are determined and implemented. Level 4 is *inventory integration*, in which inventory optimization incorporates cross-functional participation in and accountability for inventory decision making. Level 5 is *inventory collaboration,* in which sharing inventory levels, forecasts, and planning with key suppliers and customers is commonplace.

2.2 INVENTORY PHILOSOPHIES

There are two basic inventory management philosophies: push and pull. The push inventory model is so called because the emphasis is on pushing speculative inventory, or inventory that is made to stock (MTS) in response to forecast demand, out the door to customers. The push model financially outperforms the pull model when manufacturing utilization is critical and the cost of production is high relative to inventory carrying cost and the risk of obsolescence. We recently helped convert a variety of clients in the consumer packaged goods (CPG), food, beverage, and confectionery industries to push models, resulting in much higher profits, increased return on invested capital, larger market share, and improved customer satisfaction.

The pull inventory model is so called because true demand is said to pull made-to-order (MTO) inventory to customers on a just-in-time basis. The pull model financially outperforms the push model when inventory carrying cost and the risk of obsolescence are high relative to production and postponement costs. High-end, highly configurable electronics and pharmaceuticals are examples of products that work best financially and operationally in pull-based systems.

Many proponents of pull-based inventory and supply chain management have published and soapboxed to the point where any other approach to inventory or supply chain management is considered second-class, immature, or old-fashioned. However, in many respects pull-based programs—lean,

Figure 2.2 Push-Pull Decision Factors

Item Characteristics	Push/MTS	Pull/MTO
Shelf Life	High	Low
Setup or PO Cost	High	Low
Demand Variability	Low	High
Risk of Obsolescence	Low	High
Inventory Carrying Rate	Low	High
Item Value	Low	High

JIT, the Toyota Production System (TPS)—are philosophies founded in the highly unique logistics, business, geographic, historical, and cultural setting that is Japan. We work with clients around the world in diverse economic, competitive, geographic, and cultural settings. We compute return on invested capital, profitability, and customer satisfaction for each of their SKUs and unique nodes and links in their supply chains. We find that an *optimal mix of push and pull* that depends on product characteristics, business conditions, and transition points within the supply chain yields dramatically superior financial and service performance compared with strictly pull-based programs.

That optimal mix of push and pull is another facet of our RightStock inventory model. That optimal mix is based on a wide variety of item characteristics, including demand variability, item value, shelf life, and risk of obsolescence, along with logistics characteristics, including setup/purchase order (PO) costs and inventory carrying rates. A qualitative analysis of those factors and their impact on push-pull models is shown in Figure 2.2.

2.3 INVENTORY TYPES

Not all inventory is created equal, but in addressing inventory concerns, most companies lump all inventory into one bucket as if it were all there for the same reason. In reality, there are different types of inventory that fulfill different roles in supply chains and businesses. In this section we define those unique roles and the types of inventory that accompany them. We begin with buckets of inventory.

2.3.1 BUCKETS OF INVENTORY

A few years ago I received a phone call from one of the world's largest CPG firms operating one of the most advanced supply chains. They requested our assistance with inventory strategy. I was quite surprised to receive the call because the firm is widely known for its excellence in inventory management. I expressed my surprise and curiosity and asked why they had reached out to us. They said that in their research of inventory models they discovered that the RightStock model was one of the very few that incorporated *buckets of inventory* (BOI) the way their model did. They wanted to benchmark and utilize our model.

I asked what they meant by buckets of inventory. They explained that they allocate inventory into three buckets: safety stock inventory (SSI), lot size inventory (LSI), and pipeline inventory (PI). They wanted to see if our RightStock model recommended the same inventory allocations. I was encouraged by the call because the large majority of organizations lump all inventory into one bucket even though *all inventory is not the same*; it does not all serve the same purpose.

Safety stock inventory is required because demand is not perfectly predictable and supplier performance is not perfectly reliable. Lot size inventory is necessary because there are manufacturing economies of scale related to production run lengths and procurement economies of scale related to purchase quantities. Pipeline inventory refers to inventory that is fiscally on the books but is not physically available to sell.

To the extent that we can allocate inventory into those buckets we can develop cause-and-effect models for each type of inventory. (To the extent that we can't, inventory management becomes a trial-and-error guessing game.) For example, we can optimize safety stock inventory by trading off the cost of improving forecast accuracy and supplier reliability with the costs of implementing the processes and the systems required to do so. A safety stock optimization for a large aerospace company is shown in Figure 2.3. Note that safety stock levels are consistently too high for nearly all the SKUs, in this case reflecting a strong upward bias in the forecasting process (Figure 2.4). By correcting the forecasting bias and optimizing the safety stock inventory, we were able to reduce the inventory investment by 30%, over $4 million, and improve service levels at the same time.

Lot size inventories can be optimized by trading off reductions in manufacturing setup times and ordering costs with the investments required to do so. An example of lot size optimization for a large bottler is shown in Figure 2.5. Note that the lot sizes are consistently too small. The small lot sizes reflect the company's overly aggressive move into lean manufacturing and SKU proliferation, which cut sharply into manufacturing capacity. Contracting the SKU base and increasing lot sizes yielded a 15% reduction in total supply chain cost, adding over $29 million per year to the bottom line.

The RightStock model also distinguishes between value-added inventory (VAI) and excess, non-value-added inventory (NVAI). Value-added inventory is the sum of safety stock, lot size, and pipeline inventory. Those three types of inventory theoretically add value by mitigating risk in demand and supply variability, producing economies of scale in production and/or procurement, and floating fiscally and/or physically for an optimal period before becoming on-hand inventory:

$$\text{VAI} = \text{SSI} + \text{LSI} + \text{PI}$$

Inventory that is not adding value in those three buckets is non-value-added inventory. The difference between the *total inventory level* (TIL) and the value-added inventory is expressed as follows:

$$\text{NVAI} = \text{TIL} - \text{VAI}$$

Another key deliverable in the RightStock diagnostic is a comparative illustration of the way a client's inventory should be allocated to RightStock

Figure 2.3 Safety Stock Optimization for a Large Aerospace Company (RS = RightStock, SSI = safety stock inventory)

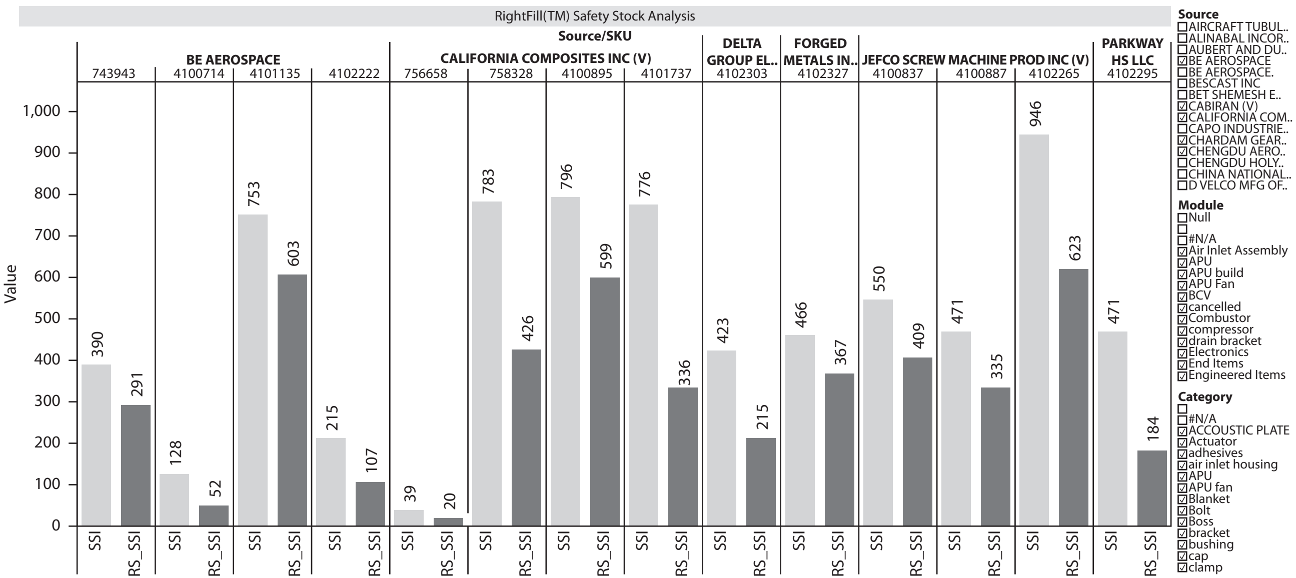
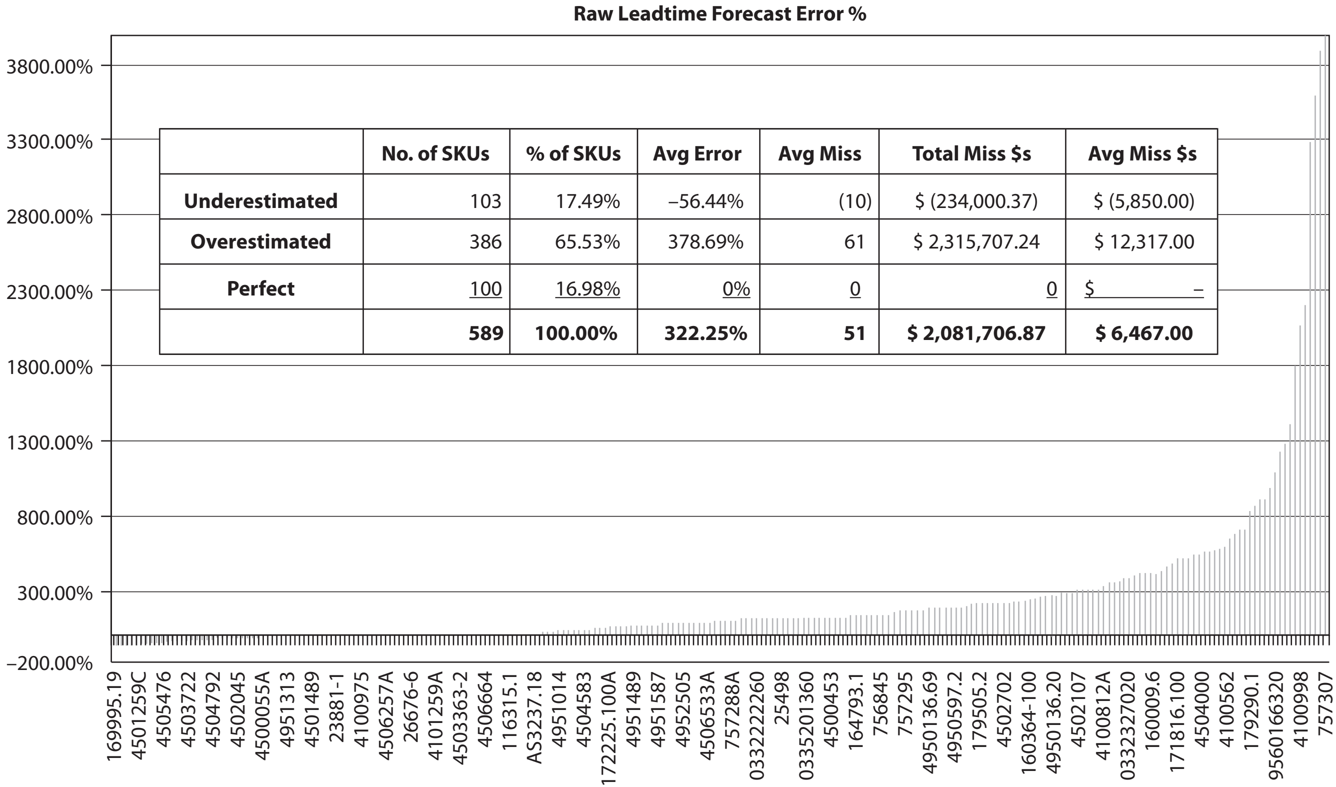


Figure 2.4 RightCast™ Forecast Bias Analysis

The majority (65%) of SKUs are overestimated by a large percentage (379%).



	No. of SKUs	% of SKUs	Avg Error	Avg Miss	Total Miss $s	Avg Miss $s
Underestimated	103	17.49%	–56.44%	(10)	$ (234,000.37)	$ (5,850.00)
Overestimated	386	65.53%	378.69%	61	$ 2,315,707.24	$ 12,317.00
Perfect	100	16.98%	0%	0	0	$ –
	589	**100.00%**	**322.25%**	**51**	**$ 2,081,706.87**	**$ 6,467.00**

Figure 2.5 RightLots™ Lot Size Optimization Analysis for a Large Bottler

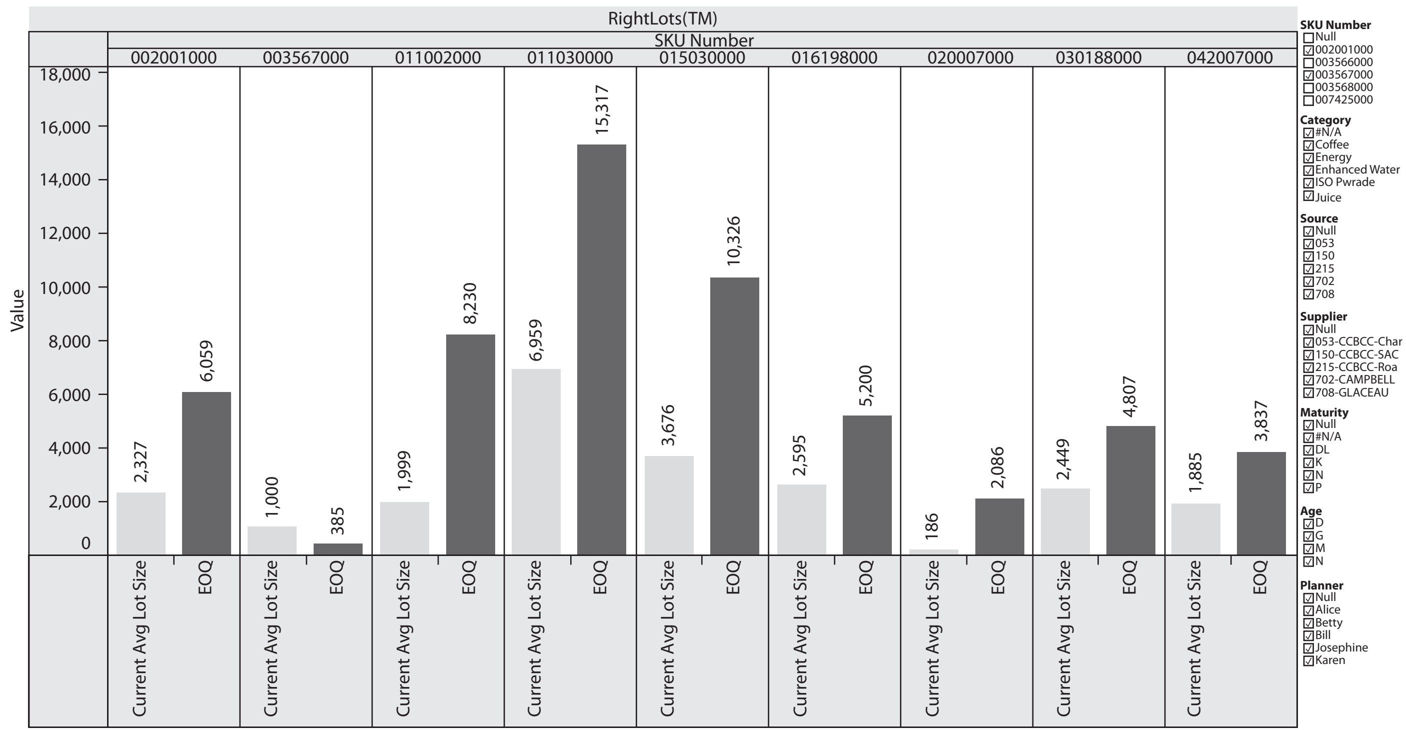


Figure 2.6 RightStock Buckets of Inventory Analysis for an HVAC SKU

Buckets	Units	$s	Days
Safety Stock Inventory	483	$ 2,897.28	32.20
Lot Size Inventory	677	$ 4,060.98	45.13
Pipeline Inventory	249	$ 1,493.63	16.60
Value Added Inventory	1,409	$ 8,451.89	93.93
Excess Inventory	*393*	*$ 2,357.41*	*26.20*
TOTAL INVENTORY	1,802	$ 10,809.30	120.13
On Order	400	$ 2,399.40	26.67

buckets of inventory and the excess that remains. A non-value-added inventory diagnostic for a single SKU from a heavy industry client is shown in Figure 2.6. The analysis reveals non-value-added inventory in units, dollars, and days. In this particular case there are 393 units, $2,357.41, and 26.20 days of excess inventory. Twenty-two percent of the inventory investment is excessive. This is not an atypical finding in RightStock assessments. Particularly disturbing is the $2,399.40 on order for an SKU that already has 22% too much inventory.

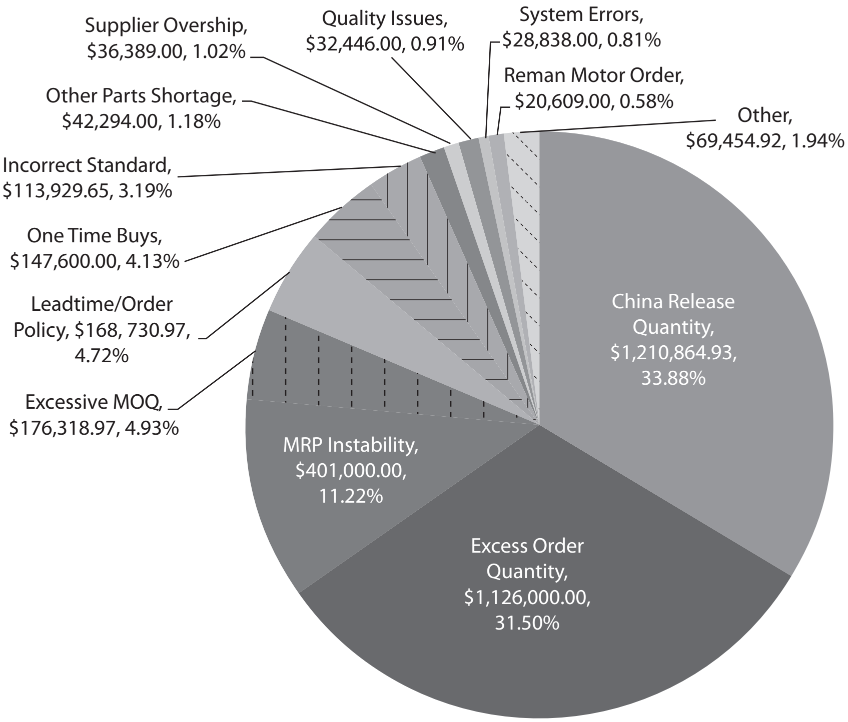
For this client we found that the large majority of SKUs were in a similarly overinvested state. They had large on-order quantities for even the most overinvested SKUs. Simply stopping and/or slowing down inbound orders for overinvested SKUs saved the company more than $14 million.

A similar analysis is shown in Figure 2.7, which is from a recent client in the aerospace industry and shows for each supplier the number of part numbers and the specific part numbers with excess inventory along with the amount of the excess. We use this profile to work collaboratively and consistently with suppliers to identify root causes for the excess and eliminate or minimize those excesses. In this case, we eliminated more than $12 million of excess inventory and maintained or improved service levels across the SKU and customer base.

Root Cause Analysis We frequently find it helpful to identify and rank order root and systemic causes of excess inventory. An analysis completed for a large HVAC client is shown in Figure 2.8. In this case the root causes in rank order are as follows:

- Large order releases required by Chinese suppliers (33.9% = $1,210,864)
- Missized purchased orders with other suppliers (31.5% = $1,126,000)
- MRP data errors (11.2% = $401,000)
- Poorly negotiated minimum order quantities (4.93% = $176,319)

Figure 2.8 Excess Inventory Causes and Pareto for an HVAC Company



The RightStock root cause analysis gave birth to an extensive project plan aimed at eliminating non-value-added inventory (see Figure 2.9). Not every plan works, but this one led to the plant being named one of America's 10 Best Plants by *Industry Week*. The plan moves through four major phases: stabilization, optimization, automation, and collaboration. The entire plan yielded an inventory reduction in excess of $7 million, a reduction in days on hand from 35 to 21, and an increase in on-time delivery performance from 93.5% to 97.5%.

2.3.2 STAGE TYPES

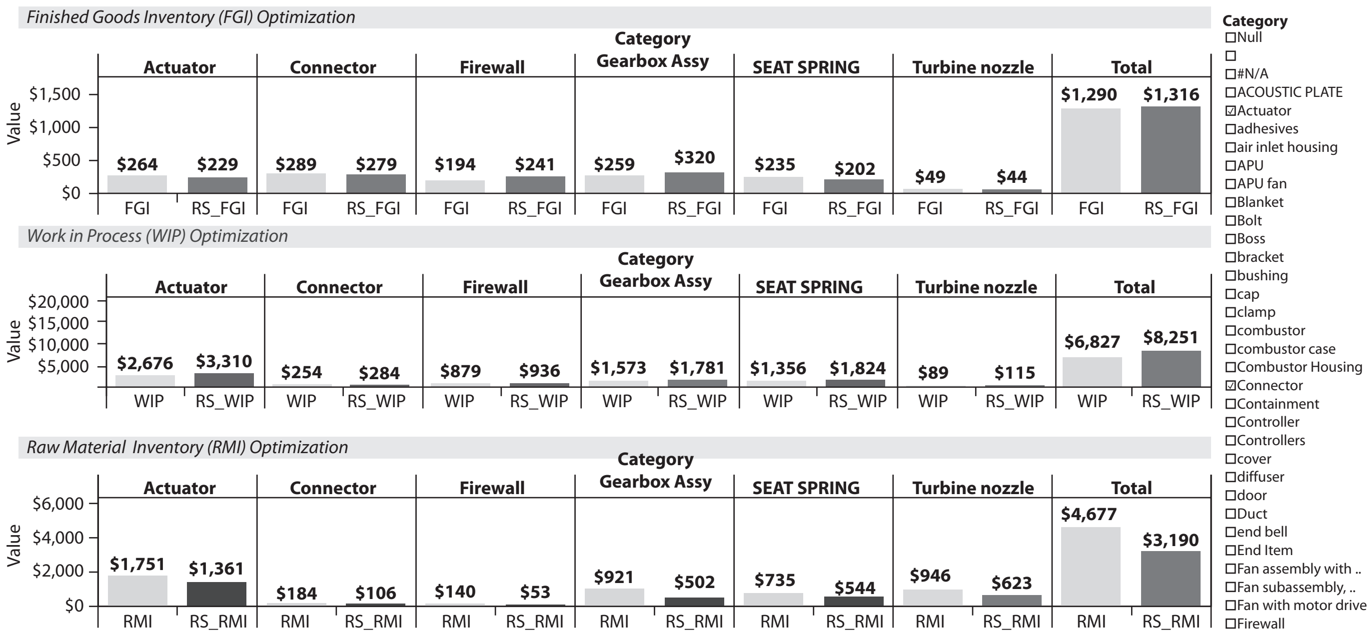
Inventory should also be classified by its stage in the value stream. *Raw material inventory* (RMI) has no value added. *Work in process* (WIP) has some value added but is not finished. *Finished goods inventory* (FGI) has all the value that is going to be added. Just as the allocation of inventory should be optimized across buckets of safety stock, lot size, and pipeline inventory, the allocation of inventory to raw material, work in process, and finished goods inventory should be optimized. To reduce inventory carrying costs, the allocation of total inventory value typically leans toward raw material inventory. However, supplier, production, and customer response lead times and variabilities may dictate that a higher percentage of the inventory be allocated to work in process and finished goods inventory. Tax structures and transition differentials may dictate a different allocation of inventory value across the stages.

An inventory stage optimization for a large high-tech manufacturing client is shown in Figure 2.10. Note that in this example raw material inventory is consistently too high (32% higher than optimal for the highlighted commodities), work in process is consistently too low (17% lower than optimal for the highlighted commodities), and finished goods inventory is consistently optimal. In this case the firm had placed great emphasis on optimizing finished goods inventory but needed to shift its investment in raw materials to WIP to optimize financial and service performance. Doing so yielded a 12% increase in Inventory Value Added and a 5% increase in on-time delivery.

Figure 2.9 RightStock Project Plan for a Large HVAC Company

Initiative	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9	Month 10	Month 11	Month 12	*PROJECTED SAVINGS ($000s)*	Phase Savings ($000s)
Order Stop on High DOH		$ 250	$ 200	$ 150									***$ 600***	
MRP Checks & Balances		$ 250	$ 200	$ 150	$ 100								***$ 700***	
China Buy Quantities		$ 150	$ 200	$ 150	$ 100	$ 50							***$ 650***	
Renegotiate MOQs		$ 40	$ 50	$ 50	$ 10	$ 6							***$ 156***	
Short Firm Fence		$ 10	$ 10	$ 10	$ 10								***$ 40***	***$2,146***
Leadtime/Pipeline Optimization				$ 75	$ 100	$ 150	$ 100	$ 50	$ 50				***$ 525***	
Lot Size Optimization					$ 200	$ 250	$ 200	$ 150					***$ 800***	
Forecast Optimization					$ 100	$ 125	$ 100	$ 75					***$ 400***	
Safety Stock Optimization					$ 150	$ 200	$ 250	$ 200	$ 150				***$ 950***	***$2,675***
Develop & Implement MPS						$ 100	$ 100	$ 100	$ 100	$ 50			***$ 450***	
Implement Real-Time Inventory							$ 100	$ 150	$ 100	$ 50	$ 50		***$ 450***	***$ 900***
Customer & Supplier Collaboration							$ 50	$ 100	$ 150	$ 100	$ 50		***$ 450***	***$ 450***
PROJECTED SAVINGS	***$ -***	***$ 700***	***$ 660***	***$ 585***	***$ 770***	***$ 881***	***$ 900***	***$ 825***	***$ 550***	***$ 200***	***$ 100***	***$ -***	***$ 6,171***	***$ 6,171***
CUMULATIVE SAVINGS	**$ -**	**$ 700**	**$ 1,360**	**$ 1,945**	**$ 2,715**	**$ 3,596**	**$ 4,496**	**$ 5,321**	**$ 5,871**	**$ 6,071**	**$ 6,171**	**$ 6,171**		
Projected Ending Inventory	**$14,200**	**$13,500**	**$12,840**	**$12,255**	**$11,485**	**$ 10,604**	**$ 9,704**	**$ 8,879**	**$ 8,329**	**$ 8,129**	**$ 8,029**	**$ 8,029**		
Projected DOH	**35.50**	**33.75**	**32.10**	**30.64**	**28.71**	**26.51**	**24.26**	**22.20**	**20.82**	**20.32**	**20.07**	**20.07**		
Projected TURN	**8.45**	**8.89**	**9.35**	**9.79**	**10.45**	**11.32**	**12.37**	**13.52**	**14.41**	**14.76**	**14.95**	**14.95**		
Inventory Accuracy	**37.5%**	**37.5%**	**42.0%**	**44.0%**	**48.0%**	**52.0%**	**55.0%**	**65.0%**	**75.0%**	**85.0%**	**90.0%**	**95.0%**		
On-Time Delivery	**93.5%**	**93.5%**	**93.5%**	**93.5%**	**94.0%**	**94.5%**	**95.0%**	**95.5%**	**96.0%**	**96.5%**	**97.0%**	**97.5%**		

Figure 2.10 Inventory Stage Optimization for an Engine Manufacturer (RMI = raw material inventory, WIP = work in process, FGI = finished goods inventory, RS = RightStock)



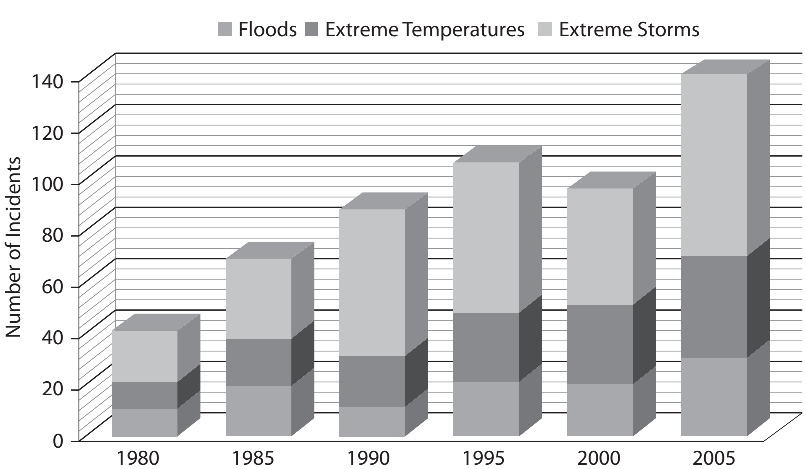
2.3.3 EXCEPTIONAL TYPES

The RightStock model acknowledges seven special types of inventory: (1) contingency and disaster inventory (CDI), (2) hedge inventory (HI), (3) seasonality and build inventory (SBI), (4) efficient procurement inventory (EPI), (5) consignment inventory (CSI), (6) active and dead stock, and (7) life cycle inventory (LCI).

Contingency and Disaster Inventory Contingency and disaster inventory ensures against unexpected situations outside the realm of those covered by traditional safety stock inventory. Those situations include natural disasters, labor strikes, and other abnormal supply chain disruptions. For example, in our work with telecommunications and utilities clients we often plan for contingency and disaster inventory to maintain service in the event of hurricanes, floods, and snowstorms.

The frequency and severity of highly unusual supply chain disruptions are increasing (Figure 2.11). In fact, according to the United Nations Office for Disaster Risk Reduction (UNISDR), 2011 was the most catastrophic year

Figure 2.11 Rate of Increase in Catastrophic Incidents
Source: CRED.



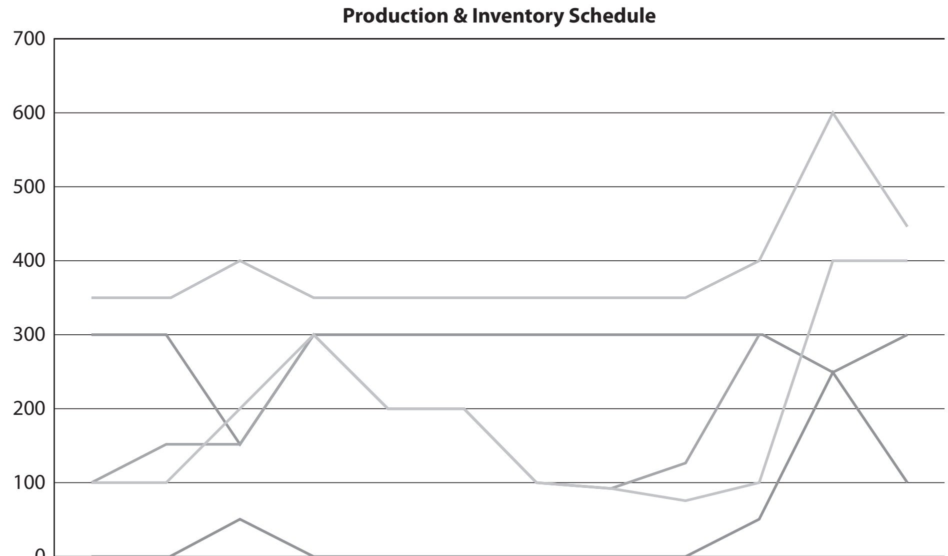
on record, with 27,782 people killed in 302 incidents that inflicted damage in excess of $366 billion. The most dramatic of those incidents was the simultaneous earthquake and tsunami that struck Japan, a place and people near and dear to my heart. Our small office in downtown Tokyo was damaged by the earthquake, and one of our RightChain™ team members lost a relative in the tsunami. It is ironic that an incident exposing many of the risks in lean thinking would strike Japan, the birthplace of lean. That incident has become the catalyst for rethinking inventory levels and supply chains that are designed with dangerously naive assumptions of supply chain certainties.

Hedge Inventory Hedge inventory mitigates the risks of potential sharp price increases, shortages in critical commodities, and extreme price and availability volatility for those items. Fuel is a classic example of a commodity whose inventory may include an HI component.

Seasonality and Build Inventory Seasonality and build inventory levels production, machine, line, and plant utilization. One of our clients is a large frozen food manufacturer that is one of the world's largest producers of frozen pies. The large majority of those pies are purchased by consumers between Thanksgiving and Christmas, a 30-day window. The demand rate then is so much greater than the demand rate during the remaining 335 days of the year that matching manufacturing capacity to demand during those days would render manufacturing virtually idle for 11 months of the year. Instead, the company produces pies at a fairly even rate during the year and stores the "build" inventory for the season in large third-party frozen food warehouses. An example build plan is shown in Figure 2.12.

Efficient Procurement Inventory Efficient procurement inventory is often required to realize steep discounts when a special opportunity to procure arises but requires a large purchase quantity to negotiate the deal. One of our clients is a large confectionery company. The main raw materials for its chocolate candy are sugar and cocoa. Using highly advanced weather

Figure 2.12 RightBuild™ Seasonal and Build Inventory Optimization Example for Frozen Food



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Units Produced	100	150	150	300	200	200	100	90	125	300	250	300
Starting Inventory	–	–	50	–	–	–	–	–	–	50	250	100
Units Demanded	100	100	200	300	200	200	100	90	75	100	400	400
Production Capacity	300	300	150	300	300	300	300	300	300	300	250	300
Total Inventory	350	350	400	350	350	350	350	350	350	400	600	450

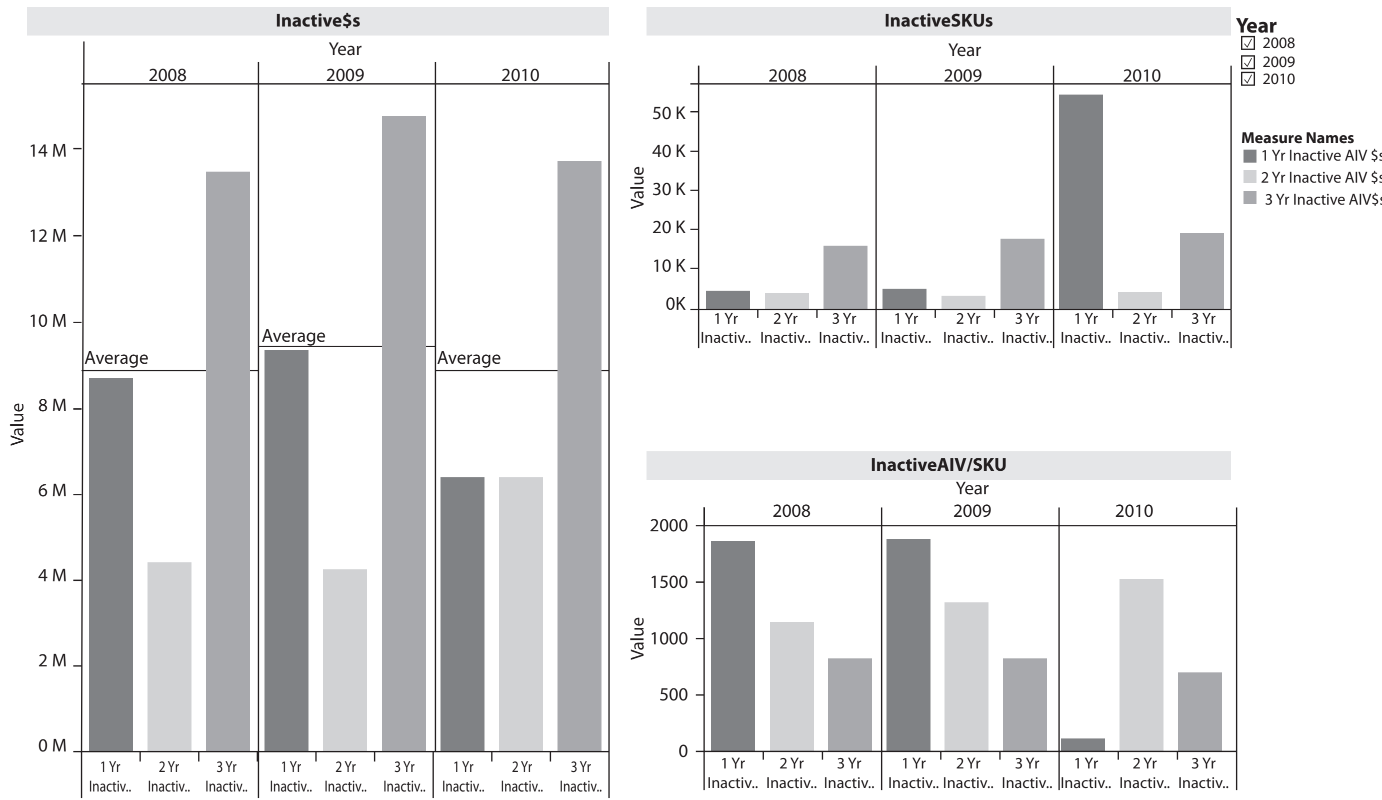
forecasting systems and highly technical analysis of sugar and cocoa futures prices, our client picks the optimal price point and time to buy megaquantities of both ingredients. Those purchases are housed in large storage facilities and consumed fairly quickly in production. Since the shelf life for chocolate candy is fairly long and the risk of obsolescence is fairly low, those large buys and conversions are the company's most profitable inventory and supply chain strategy.

Consignment Inventory Consignment inventory is physically on the premises but not fiscally on the books. It is still owned by and sometimes managed by the vendor. Hence, this inventory is sometimes referred to as *vendor-managed inventory* (VMI). One of our large computer clients has its entire supply base own and manage component inventory until it is picked from flow racks along the assembly line. When components are retrieved from the flow racks, they become this client's property. One of our mining clients houses large quantities of service parts maintenance inventory owned by the vendor until the point at which it is picked by our client and placed on a machine under repair.

Active and Dead Stock Active and dead stock inventories are references to inventory that is relatively fast-moving versus slow-moving or not moving. The definitions of *fast*, *slow,* and *not* are also relative. The most common definition of active inventory is *inventory on hand for SKUs incurring demand within the previous 12 months*. The percentage of total inventory investment in active SKUs is the *inventory quality ratio* (IQR). IQR is a revealing indicator of inventory performance, acting similarly to a bad debt ratio for banks.

An inactive inventory analysis for a mining client is shown in Figure 2.13. Note that the total inactive inventory investment has remained relatively constant over the last three years. However, the growth in the number of inactive SKUs and the growth in the investment in inventory that has been inactive for 48 months are alarming. Those profiles highlighted ineffective processes

Figure 2.13 Inactive Inventory Analysis for a Large Mining Company



that were (1) not purging inactive inventory on a regular basis, (2) allowing inactive SKUs to grow at a high rate, and (3) permitting inactivity to propagate. Once interventions were put in place, we were able to reduce investments in inactive inventory by more than $2.5 million.

Life Cycle Inventory Life cycle inventory models allocate inventory to categories on the basis of product maturities. Typical maturities include (1) conception, (2) infancy, (3) adolescence, (4) maturity, (5) aging, (6) decline, and (7) discontinue. An inventory maturity curve is shown in Figure 2.14. Just as inventory should be optimally allocated to buckets and status types, inventory should be optimally allocated by maturity.

A life cycle inventory optimization recently developed for a CPG client is shown in Figures 2.15 and 2.16. Figure 2.15 is a life cycle inventory profile that highlights the fact that the client has done an excellent job managing the number of SKUs in each phase of maturity. Figure 2.16 highlights the fact that the client is underinvested in the infancy, adolescent, and mature categories.

Figure 2.14 Typical Part Life Cycle Transition Curve

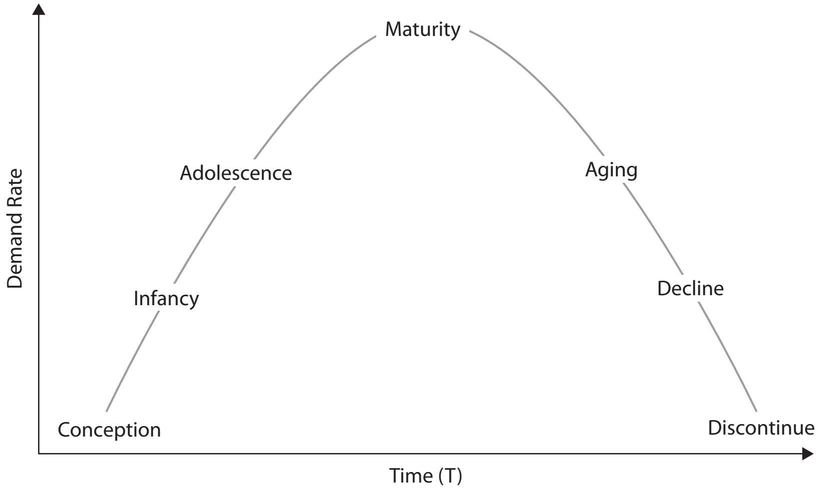


Figure 2.15 RightLife™ Inventory Profile for a Large CPG

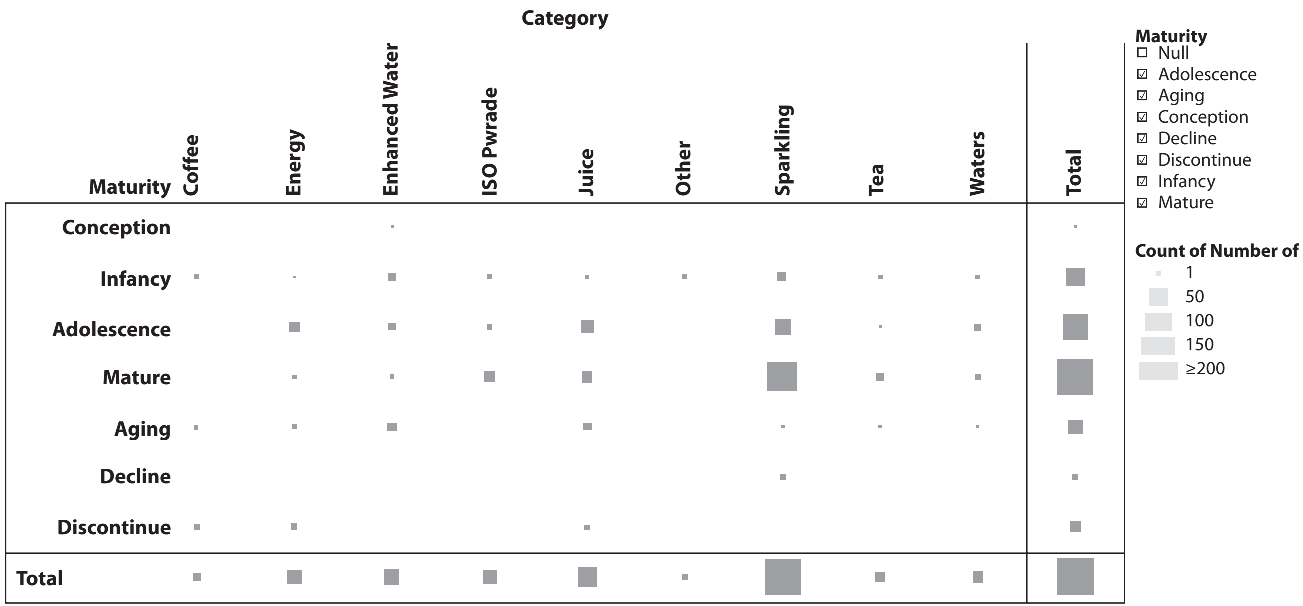
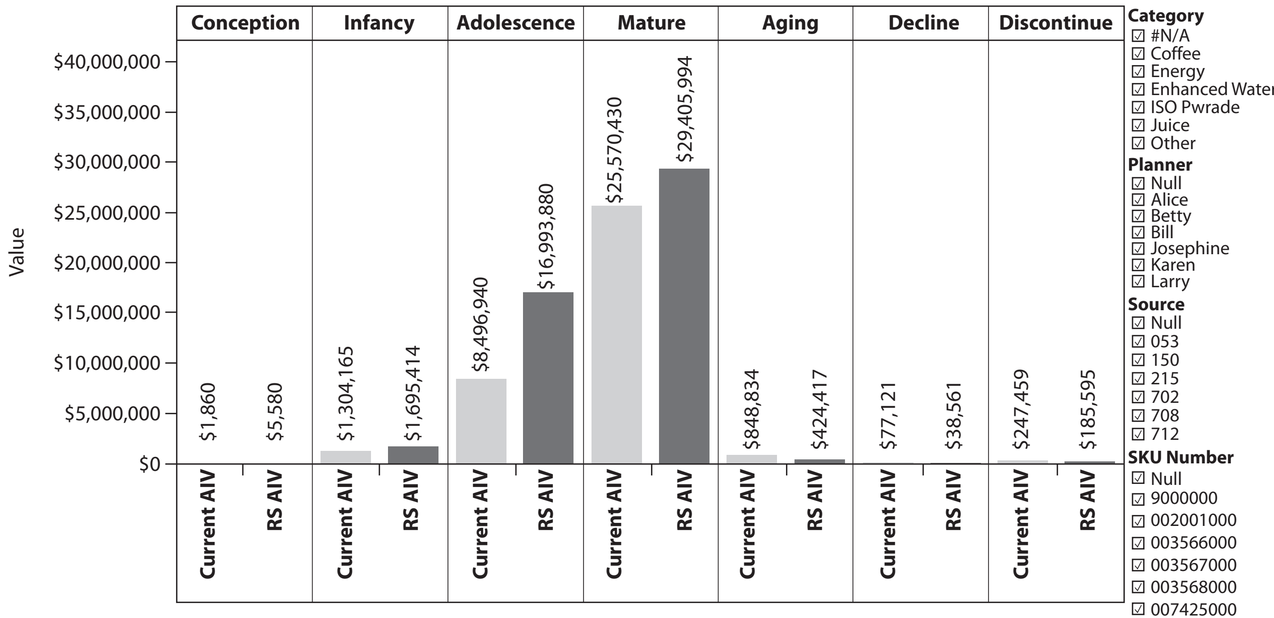


Figure 2.16 Inventory Maturity Optimization for a Large CPG ($000s) (AIV = average inventory value, RS = RightStock)



2.4 OUT OF STOCK CONDITIONS

Never being out of stock (OOS) is like having an insurance policy with no deductible. The inventory carrying cost for never being out of stock is literally infinite. As a result, not all demand can or should be satisfied directly from the shelf or sometimes at all. However, since stockouts are sometimes extremely costly in terms of lost sales, lost customer goodwill, and logistics, managing unsatisfied demand is a critical aspect of inventory management and an important competitive differentiator.

There are three alternative responses to unsatisfied demand: back ordering, substitutions, and lost sales. The appropriate response depends on the unique price, cost, margin, and logistics characteristics of each item, customer, and channel.

In *back ordering* the unfilled quantity requested by the customer is placed on a separate order called a back order. The special back order is filled as soon as product is available from internal and/or external sources. In some cases the back order is shipped directly from its original source to the customer. Back ordering is common when there is no other source for product (e.g., in captive markets).

Substitutions occur when a product acceptable to the customer is substituted for the product that is not available.

Lost sales occur when unsatisfied demand is lost. Lost sales are common in retail situations in which there are many alternative outlets for a product. Lost sales are critically expensive for A+ and A items. For those items, unsatisfied demand may result in negative publicity and/or the loss of customers' purchases of B or C items that depend on the availability of A items. Lost sales for B and C items, especially to B and C customers, are typically not as critical or costly.

The difference in penalties for shortages in A, B, and C items is reflected in the *shortage factor* (SF), which is an index applied to the selling price to reflect the magnitude of the damage or "cost" of a lost sale. We define it more specifically as *the percentage of the unit selling price lost when inventory is not available*. We typically set the default value for the shortage factor at the unit gross margin percent. However, shortages of highly critical, core, or heavily promoted items may generate such negative customer reaction that customers begin to complain publicly about shortages. In those cases shortage factors may be as high as 200 to 300%. When there are readily substitutable products and competition is weak, shortage factors may be minimal.

2.5 PLANNING PARAMETERS

The RightStock model employs six key planning parameters to define the unique inventory management characteristics for an item or enterprise:

- Unit selling price (USP)
- Unit inventory value (UIV)
- Unit gross margin (UGM)
- Inventory carrying rate (ICR)
- Purchase order cost (POC)
- Setup cost (SUC)

The *unit selling price* for an item is the price paid per unit by a customer for that item. The *unit inventory value* for a purchased item is the price paid to the supplier for that item, including inbound transportation cost. The *unit inventory value* for a manufactured item is the cost of manufacturing that item and is sometimes referred to as the standard cost. *Unit gross margin* is the difference between unit selling price and unit inventory value. The higher the unit gross margin, the higher the cost of lost sales associated with that item:

$$UGM = USP - UIV$$

For example, if an item sells for $25 per unit and its unit inventory value is $14 per unit, its unit gross margin is

$$\text{UGM} = \$25 - \$14 = \$11 \text{ per unit}$$

The *unit gross margin* percentage (UGM%) is the ratio of the unit gross margin to the unit selling price:

$$\text{UGM\%} = \text{UGM/USP}$$

In this case the unit gross margin percent would be

$$\text{UGM\%} = \text{UGM/USP} = \$11/\$25 = 44\%$$

The inventory carrying rate is the percentage of the unit inventory value used to compute inventory carrying cost (ICC). The inventory carrying rate includes the following:

- Opportunity cost of capital (the rate of return that could reasonably be achieved for each dollar not invested in inventory)
- Storage and material handling
- Loss from obsolescence, markdowns, damage, and/or pilferage
- Insurance and taxes

Inventory carrying rates vary widely across geographies and industries. In some Latin American countries, interest rates may be as high as 60% per year. As a result, inventory carrying rates may be as high as 70 or 80%. In Japan, where interest rates are low, inventory carrying rates are much lower. In Silicon Valley, where expectations for capital investments are upward of 20% per year, the inventory carrying rate is normally around 40%. In mature industries in the Midwest, inventory carrying rates are typically between 25 and 35%. For clients in the frozen food industry, inventory carrying rates are typically higher because of the high cost of frozen and refrigerated storage space.

As a result of the wide variety of interest rates and storage conditions, each company should determine, maintain, and publish its own ICR. The most advanced supply chain organizations compute and maintain inventory carrying rates uniquely for each SKU.

The *purchase order cost* is the cost of placing a purchase order with a vendor. A majority of those costs are related to sourcing, purchasing, and procurement salaries and benefits (in italics in the list that follows):

- *Purchase order planning*
- *Purchase order entry time*
- *Purchase order processing time*
- *Purchase order inspection time*
- *Purchase order follow-up time*
- *Purchasing management*
- *Authorization*
- *Tracking and expediting*
- *Inbound transportation, receiving, and inspection*
- Order forms
- Postage
- Telecommunications
- Office space
- Office supplies
- Purchase order entry systems

The cost of placing a purchase order typically ranges between $50 and $500. The most expensive activities are the *labor-related activities.* Hence, automating purchase order planning and processing typically yields significant labor cost reductions and productivity improvements. In addition, blanket purchase orders; vendor-managed inventories; joint, fixed cycle replenishments; supplier rationalization and integration; e-procurement;

and on-premise supplier programs should be evaluated to optimize purchase order costs and their related lot sizes.

Setup cost is the cost to set up (prepare or change over) a machine or production line to make a production run for a particular item or to change between items. It is sometimes referred to as *changeover cost* (COC). Setup or changeover costs include the following:

- Labor to prepare for and execute the changeover
- Training of typically highly skilled labor
- Lost production capacity during the changeover
- Material lost before, during, and just after the changeover
- Tools required for executing high-speed changeovers
- Computer hardware and software to plan and execute changeovers

Setup costs vary more widely than do purchase order costs. We have encountered setup costs with our clients ranging from $100 to $10,000 per setup. The most expensive component is normally the opportunity cost of lost production time. Parallel processing, early tool preparation, point-of-change tool placement, optimized changeover sequencing, comprehensive and repeated changeover practice sessions, dedicated lines, and focused factories techniques and investments should be evaluated to optimize setup and changeover costs and their related production lot sizes.

2.6 FINANCIAL TERMS

The RightStock inventory optimization methodology incorporates seven key financial terms:

- Average inventory value (AIV)
- Gross margin return on inventory (GMROI)

- Inventory turn rate (ITR)
- Inventory carrying cost (ICC)
- Lost sales cost (LSC)
- Inventory Policy Cost (IPC)
- Inventory Value Added (IVA)

Average Inventory Value Average inventory value is the average value of the total inventory investment over the course of a year. It should be computed as the average of several on-hand inventory values measured at random times during the year. An average inventory value calculation for a major textiles company is shown in Figure 2.17. The average is computed by taking the average of 13 end-of-period inventory values. Though better than quarterly figures, any end-of-period values may be somewhat misleading because inventory levels tend to be lowest at that time.

The natural assumption for average inventory value is that lower is better, especially if it is charted in isolation. However, AIV is properly presented relative to target values, within control limits, and/or with respect to service levels. Those presentations are required to demonstrate the critical relationship between inventory investment and the fill rate provided by that investment. Accordingly, inventory values are plotted relative to the target investments required to support target service levels in Figure 2.17. Figures 2.18 and 2.19 display expected average inventory values required to support target unit fill rates ranging from 50% to 99.95%. Note that as target fill rates increase, so does the expected inventory value required to support them. In Figure 2.18 the expected average inventory for a B SKU ranges from $42,463 to $51,480 to support target fill rates ranging from 50% to 99.97%. In Figure 2.19 the expected average inventory for a C SKU ranges from $77,847 to $221,445.

The figures are from our RightStock Inventory Optimization System, which is currently being used to guide inventory decision making in many

Figure 2.17 Average Inventory Value Computation for a Company

Entity	Period	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	FYTD	CYTD
Houston Factory	Actuals	⇨ $ 21.00	⇩ $20.00	⇩ $19.00	⇧ $34.00	⇧ $33.00	⇨ $21.00	⇧ $25.00	⇧ $26.00	⇧ $27.00	⇧ $28.00	⇨ $21.00	⇧ $36.00	⇧ $35.00	⇧ $32.00	⇧ $31.00
Target Threshold	Targets	$ 28.0	$ 28.0	$ 28.0	$ 28.0	$ 28.0	$ 28.0	$ 28.0	$ 28.0	$ 28.0	$ 28.0	$ 28.0	$ 28.0	$ 28.0	$ 28.0	$ 28.0
7.0%	Target Delta	-7.00	-8.00	-9.00	6.00	5.00	-7.00	-3.00	-2.00	-1.00	0.00	-7.00	8.00	7.00	4.00	3.00
	Target Delta %	-25.0%	-28.6%	-32.1%	21.4%	17.9%	-25.0%	-10.7%	-7.1%	-3.6%	0.0%	-25.0%	28.6%	25.0%	14.3%	10.7%
	Prior Year	$ 21.0	$ 21.0	$ 23.0	$ 24.0	$ 27.0	$ 28.0	$ 32.0	$ 26.0	$ 21.0	$ 22.0	$ 24.0	$ 32.0	$ 31.0	$ 30.0	$ 28.0
	Prior Year Delta	0.00	-1.00	-4.00	10.00	6.00	-7.00	-7.00	0.00	6.00	6.00	-3.00	4.00	4.00	2.00	3.00
RightStock™ Scoreboard	Prior Year Delta %	0.0%	-5.0%	-21.1%	29.4%	18.2%	-33.3%	-28.0%	0.0%	22.2%	21.4%	-14.3%	11.1%	11.4%	6.3%	9.7%

Definition
The Average Inventory Value (AIV) is the average over the specified time period of the value of inventories in the entity.

Algorithm
The Average Inventory Value (AIV) is computed by summing the inventory value in N periods and dividing by the number of periods N.

Data Sources
S1, S2

Reporting
Frequency: Monthly
Access: L1, L3, L4

Owner
S. Stensen

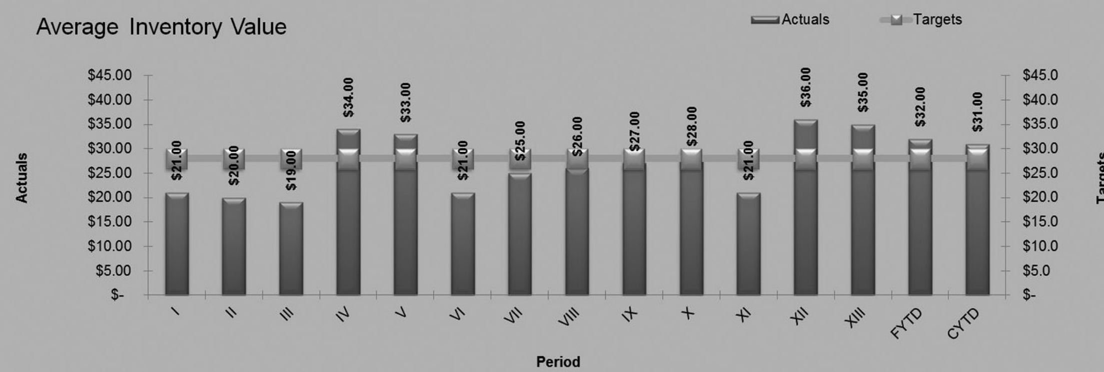


Figure 2.18 RightStock Inventory Optimization for a Food and Beverage Company: B SKU

LRI's SKUBoard™	Unit Fill Rate	Average Inventory Value (AIV)	Inventory Carrying Cost (ICC)	Lost Sales Cost (LSC)	Inventory Policy Cost (IPC)	Turns	Gross Margin (GM)	GMROI	Inventory Value Added (IVA)™
SKU or Category	50.00%	⇩ $ 42,463	⇩ $ 12,739	⇧$ 245,568	$ 258,307	15.0	$ 245,568	5.78	$ 232,829
002001000	60.00%	⇩ $ 43,128	⇩ $ 12,938	⇧$ 196,454	$ 209,393	14.7	$ 294,681	6.83	$ 281,743
400ML SPHR LS12 SW CLASSIC ORNAMENT	65.00%	⇩ $ 43,475	⇩ $ 13,043	⇧$ 171,897	$ 184,940	14.6	$ 319,238	7.34	$ 306,196
961 - CCE - JACKSONVILLE FLA	70.00%	⇩ $ 43,841	⇩ $ 13,152	⇧$ 147,341	$ 160,493	14.5	$ 343,795	7.84	$ 330,643
# of SKUs	75.00%	⇩ $ 44,235	⇩ $ 13,270	⇧$ 122,784	$ 136,054	14.4	$ 368,352	8.33	$ 355,081
1	80.00%	⇩ $ 44,674	⇩ $ 13,402	⇧$ 98,227	$ 111,629	14.2	$ 392,908	8.79	$ 379,506
Forecast Annual Demand (FAD)	85.00%	⇩ $ 45,186	⇩ $ 13,556	⇧$ 73,670	$ 87,226	14.1	$ 417,465	9.24	$ 403,909
106,634	90.00%	⇩ $ 45,830	⇩ $ 13,749	⇧$ 49,114	$ 62,863	13.9	$ 442,022	9.64	$ 428,273
Leadtime Forecast Error	92.50%	⇧ $ 46,245	⇧ $ 13,874	⇧$ 36,835	$ 50,709	13.8	$ 454,300	9.82	$ 440,427
⇧ **9%**	95.00%	⇧ $ 46,785	⇧ $ 14,035	⇧$ 24,557	$ 38,592	13.6	$ 466,579	9.97	$ 452,543
Unit Selling Price (USP, $/case)	97.00%	⇧ $ 47,405	⇧ $ 14,221	⇧$ 14,734	$ 28,955	13.4	$ 476,402	10.05	$ 462,180
⇧**$ 10.57**	98.00%	⇧ $ 47,859	⇧ $ 14,358	⇧$ 9,823	$ 24,180	13.3	$ 481,313	10.06	$ 466,955
Unit Inventory Value (UIV)	99.00%	⇧ $ 48,576	⇧ $ 14,573	⇧$ 4,911	$ 19,484	13.1	$ 486,224	10.01	$ 471,652
⇧**$ 5.96**	99.50%	⇧ $ 49,231	⇧ $ 14,769	⇧$ 2,456	$ 17,225	12.9	$ 488,680	9.93	$ 473,911
Shortage Factor (SF)	99.60%	⇧ $ 49,431	⇧ $ 14,829	⇧$ 1,965	$ 16,794	12.9	$ 489,171	9.90	$ 474,342
43.57%	99.70%	⇧ $ 49,683	⇧ $ 14,905	⇩$ 1,473	$ 16,378	12.8	$ 489,662	9.86	$ 474,757
Leadtime (L, Days)	99.80%	⇧ $ 50,026	⇧ $ 15,008	⇩$ 982	$ 15,990	12.7	$ 490,153	9.80	$ 475,146
⇧ **14.00**	99.90%	⇧ $ 50,583	⇧ $ 15,175	⇩$ 491	$ 15,666	12.6	$ 490,644	9.70	$ 475,470
Cost per Setup or PO	99.91%	⇧ $ 50,665	⇧ $ 15,199	⇩$ 442	$ 15,641	12.6	$ 490,694	9.69	$ 475,494
$ 308.00	99.93%	⇧ $ 50,857	⇧ $ 15,257	⇩$ 344	$ 15,601	12.5	$ 490,792	9.65	$ 475,535
Inventory Carrying Rate (ICR)	99.95%	⇧ $ 51,109	⇧ $ 15,333	⇩$ 246	$ 15,578	12.4	$ 490,890	9.60	$ 475,557
30%	99.97%	⇧ $ 51,480	⇧ $ 15,444	⇩$ 147	$ 15,591	12.4	$ 490,988	9.54	$ 475,544
FAD Rank Percentile	**Current**	**Current**	**Current**	**Current**	**Current**	**Current**	**Current**	**Current**	**Current**
⇧ **57%**	99.60%	$ 45,879	$ 13,764	$ 1,965	$ 15,728	13.9	$ 489,171	10.66	$ 475,407
Maturity	**UGM/Cube**	**UGM1%**	**UGM2%**	**UGM3%**	**UGM4%**	**UGM4/Cube**	**ROIC**	**GMROI/Cube**	**IVA/Cube**
P	$ 0.0697	43.6%	34.1%	32.9%	29.1%	$ 0.047	103.5%	0.161	$ 7,198.74
Rank %	**64.5%**	**61.5%**	**61.8%**	**63.1%**	**63.9%**	**68.2%**	**81.4%**	**82.5%**	**72.0%**

Figure 2.19 RightStock Inventory Optimization for a Food and Beverage Company: C SKU

LRI's SKUBoard™	Unit Fill Rate	Average Inventory Value (AIV)	Inventory Carrying Cost (ICC)	Lost Sales Cost (LSC)	Inventory Policy Cost (IPC)	Turns	Gross Margin (GM)	GMROI	Inventory Value Added (IVA)™
SKU or Category	50.00%	⇧ $ 77,847	⇧ $ 23,354	⇧$ 34,845	$ 58,199	7.1	$ 34,845	0.448	$ 11,491
348560000	60.00%	⇧ $ 88,449	⇧ $ 26,535	⇧$ 27,876	$ 54,410	6.3	$ 41,814	0.473	$ 15,279
16OZ CAN 4PK24 PB MONSTER ENERGY	65.00%	⇧ $ 93,971	⇧ $ 28,191	⇧$ 24,391	$ 52,583	5.9	$ 45,298	0.482	$ 17,107
712–HANSEN BEVERAGE COMPANY	70.00%	⇧ $ 99,971	⇧ $ 29,937	⇧$ 20,907	$ 50,844	5.6	$ 48,783	0.489	$ 18,845
# of SKUs	75.00%	⇧ $ 106,072	⇧ $ 31,821	⇧$ 17,422	$ 49,244	5.2	$ 52,267	0.493	$ 20,446
1	80.00%	⇧ $ 113,065	⇧ $ 33,920	⇧$ 13,938	$ 47,857	4.9	$ 55,752	0.493	$ 21,832
Forecast Annual Demand (FAD)	85.00%	⇧ $ 121,217	⇧ $ 36,365	⇧$ 10,453	$ 46,819	4.6	$ 59,236	0.489	$ 22,871
20,547	90.00%	⇧ $ 131,474	⇧ $ 39,442	⇧$ 6,969	$ 46,411	4.2	$ 62,721	0.477	$ 23,278
Leadtime Forecast Error	92.50%	⇧ $ 138,085	⇧ $ 41,426	⇧$ 5,227	$ 46,652	4.0	$ 66,463	0.467	$ 23,037
⇧ **55%**	95.00%	⇧ $ 146,677	⇧ $ 44,003	⇧$ 3,484	$ 47,488	3.8	$ 66,205	0.451	$ 22,202
Unit Selling Price (USP, $/case)	97.00%	⇧ $ 156,550	⇧ $ 46,965	⇧$ 2,091	$ 49,056	3.6	$ 67,599	0.432	$ 20,634
⇧**$ 30.46**	98.00%	⇧ $ 163,787	⇧ $ 49,136	⇧$ 1,394	$ 50,530	3.4	$ 68,296	0.417	$ 19,160
Unit Inventory Value (UIV)	99.00%	⇧ $ 175,194	⇧ $ 52,558	⇧$ 697	$ 53,255	3.2	$ 68,993	0.394	$ 16,434
⇧**$ 27.07**	99.50%	⇧ $ 185,634	⇧ $ 55,690	⇧$ 348	$ 56,039	3.0	$ 69,341	0.374	$ 13,651
Shortage Factor (SF)	99.60%	⇧ $ 188,824	⇧ $ 56,647	⇧$ 279	$ 56,926	2.9	$ 69,411	0.368	$ 12,764
11.13%	99.70%	⇧ $ 192,829	⇧ $ 57,849	⇩$ 209	$ 58,058	2.9	$ 69,481	0.360	$ 11,632
Leadtime (L, Days)	99.80%	⇧ $ 198,285	⇧ $ 59,486	⇩$ 139	$ 59,625	2.8	$ 69,550	0.351	$ 10,065
⇧ **40.00**	99.90%	⇧ $ 207,160	⇧ $ 62,148	⇩$ 70	$ 62,218	2.7	$ 69,620	0.336	$ 7,472
Cost per Setup or PO	99.91%	⇧ $ 208,463	⇧ $ 62,539	⇩$ 63	$ 62,602	2.7	$ 69,627	0.334	$ 7,088
$ 308.00	99.93%	⇧ $ 211,529	⇧ $ 63,459	⇩$ 49	$ 63,507	2.6	$ 69,641	0.329	$ 6,182
Inventory Carrying Rate (ICR)	99.95%	⇧ $ 215,541	⇧ $ 64,662	⇩$ 35	$ 64,697	2.6	$ 69,655	0.323	$ 4,993
30%	99.97%	⇧ $ 221,445	⇧ $ 66,433	⇩$ 21	$ 66,454	2.5	$ 69,669	0.315	$ 3,235
FAD Rank Percentile	**Current**	**Current**	**Current**	**Current**	**Current**	**Current**	**Current**	**Current**	**Current**
⇧ **26%**	99.60%	$ 35,190	$ 10,557	$ 279	$ 10,836	15.8	$ 69,411	1.97	$ 58,854
Maturity	**UGM/Cube**	**UGM1%**	**UGM2%**	**UGM3%**	**UGM4%**	**UGM4/Cube**	**ROIC**	**GMROI/Cube**	**IVA/Cube**
S	$ 0.0182	11.1%	7.9%	6.2%	4.9%	$ 0.008	10.3%	0.011	$ 315.49
Rank %	**41.6%**	**8.3%**	**9.4%**	**11.5%**	**12.9%**	**35.7%**	**20.6%**	**11.1%**	**21.2%**

of the world's largest and most successful supply chains. This example is from a large food and beverage company.

Gross Margin Return on Inventory Gross margin return on inventory is the ratio of gross margin (GM) to average inventory value. It is similar to a return on investment analysis for inventory. The metric is increasingly popular in retailing; however, it is still underutilized in that industry as well as in most other industries.

$$\text{GMROI} = \text{GM/AIV}$$

GMROIs associated with fill rates ranging from 50% to 99.95% for a medium-moving beverage SKU were illustrated in Figure 2.18. The example is taken from a recent inventory optimization engagement with one of the nation's largest bottling groups. The maximum GMROI is 10.06 achieved at a fill rate of 98.00% and a turn rate of 13.3. The analysis helped the client realize that in its case inventory was relatively inexpensive compared with lost sales cost and lost gross margin and led to substantial, profitable increases in inventory investments. The GMROI optimization for a slower-moving, less profitable, and less forecastable SKU is shown in Figure 2.19. The maximum GMROI for that SKU is 0.493, achieved at a target fill rate of 75% and a target turn rate of 5.2.

In addition to GMROI, we often recommend the use of GMROI per unit cube as a guiding metric when shelf space is limited. We used the metric to great effect in three recent engagements: stocking beverages in retail grocery and convenience store aisles, stocking jewelry and cosmetics in high-end retailing, and stocking frozen food items on home delivery trucks. GMROI per unit cube for an SKU is shown in Figure 2.18, computed as 0.161.

Inventory Turn Rate The inventory turn rate is most commonly expressed as the ratio of the cost of goods sold (COGS) to the average inventory value:

$$\text{ITR} = \text{COGS/AIV}$$

For example, if a company experiences cost of goods sold of $412,000,000/year and maintains an average inventory value of $83,000,000, its inventory turn rate is

ITR = $412,000,000/$83,000,000 = 4.97 turns per year

To differentiate it from retail and unit turns, we sometimes refer to the inventory turn rate as turns at cost (TAC). Turns at retail (TAR) is the ratio of annual sales to average inventory value:

TAR = sales/AIV

In this example, if the company had annual sales of $1,114,000,000, its turns at retail would be

TAR = $1,114,000,000/$83,000,000 = 13.42 retail turns per year

Those first two ratios are fiscal inventory turn rates. Turns can also be measured physically. We refer to the physical inventory turn rate as the unit turn rate (UTR). It is the ratio of annual units shipped (AUS) to the average inventory level (AIL) in units:

UTR = AUS/AIL

For example, if a company ships 350,000 cases per year and has an average inventory level of 73,000 cases, its unit turn rate is

UTR = 350,000/73,000 = 4.79 unit turns per year

Considered in isolation, higher inventory turn rates are preferred to lower inventory turn rates. However, the inventory turn rate is a critical factor in a wide range of supply chain decisions and should be set to optimize the performance of the business and supply chain as a whole. As a result, inventory turn rates should be evaluated within control limits or relative to targets set in conjunction with fill rates and other fiscal measures of inventory performance.

Inventory Carrying Cost The Inventory Carrying Cost annualizes the cost of carrying (or holding) the average inventory value. The annualization is important because it allows inventory carrying cost to be placed alongside and optimized with lost sales cost, transportation cost, and warehousing cost in the computation of total supply chain costs.

Inventory carrying cost is computed by multiplying the average inventory value by the inventory carrying rate:

$$ICC = AIV \times ICR$$

For example, if the average inventory value in a warehouse is $10 million and the inventory carrying rate is 30% per year, the inventory carrying cost in the warehouse is

$$ICC = \$10{,}000{,}000 \times 30\%/\text{year} = \$3{,}000{,}000 \text{ per year}$$

Expected inventory carrying costs associated with target unit fill rates ranging from 50% to 99.95% for a medium-moving SKU in a large food and beverage company were shown in Figure 2.18. Note that inventory carrying costs grow from a low of $12,739 per year at a target fill rate of 50% to a high of $15,444 per year at a target unit fill rate of 99.97%.

Lost Sales Cost Lost sales cost is the cost of the sales lost when a company is not able to satisfy customer demand. The lost sales cost for an item is computed by multiplying its annual sales potential (i.e., sales that would have occurred if all demand were satisfied = AD × USP) by the portion of sales that the company was not able to satisfy (1 – UFR) by the shortage factor:

$$LSC = [AD \times USP] \times (1 - UFR) \times SF$$

For example, if an item has an annual demand of 2,000 units per year, a unit selling price of $2,400 per unit, a unit fill rate of 90%, and a shortage factor of 40%, the lost sales cost is

$$\text{LSC} = [2{,}000 \times \$2{,}400] \times (1 - .9) \times (.4) = [\$4{,}800{,}000] \times .1 \times .4$$
$$= \$192{,}000 \text{ per year}$$

In Figure 2.18 the expected lost sales costs associated with a medium-moving SKU were plotted versus the target unit fill rates and inventory investments required to achieve them. Note that expected lost sales cost declines from $245,568 per year at a target unit fill rate of 50% to $147 per year at a target unit fill rate of 99.95%.

Inventory Policy Cost The Inventory Policy Cost for an item is the sum of the inventory carrying cost and lost sales cost for the item. It strikes a balance between the financial costs and the benefits of inventory availability:

$$\text{IPC} = \text{ICC} + \text{LSC}$$

One way to play the inventory game is to set unit fill rate and inventory turn rate targets to minimize Inventory Policy Cost. Inventory Policy Costs for target fill rates ranging from 50% to 99.95% for two food and beverage SKUs were shown in Figures 2.18 and 2.19. The SKU in Figure 2.18 is a medium-moving SKU with a low forecast error and a short lead time. The minimum Inventory Policy Cost is $15,578 at a target unit fill rate of 99.95% and a target turn rate of 12.4 with an associated target inventory investment of $51,109. The same computations for a slow-moving SKU with a higher forecast error, longer lead time, and smaller unit gross margin were shown in Figure 2.19. The minimum Inventory Policy Cost for that SKU is at a target unit fill rate of 90% with a target turn rate of 4.2.

Inventory Value Added Logistics Resources International developed Inventory Value Added (IVA) as an inventory financial performance measure several years ago. It is the difference between gross margin and inventory carrying cost. Like GMROI, it holds gross margin accountable for the inventory investment required to achieve it. It is the best indicator we have developed so far to predict the impact of various inventory strategies on shareholder value:

$$IVA = GM - ICC$$

In the example in Figure 2.18, the maximum IVA is $475,557, which is achieved at a target unit fill rate of 99.95% and a target inventory turn rate of 12.4. For the slower-moving SKU in Figure 2.19, the maximum IVA is $23,878, which is achieved at a target unit fill rate of 90.00% and a target inventory turn rate of 4.2.

Slow-Moving Consumer Products Figure 2.20 shows an inventory optimization for a large consumer products business unit. When I put the first screen shot up, the president called it an eye chart and begrudgingly got up out of his chair to read it. He asked me to help him interpret the chart and figure out the optimal target fill rate. I asked him what his main financial objective was for the coming year. He said they wanted to increase shareholder value. I shared with him that the metric most closely tied to shareholder value was Inventory Value Added. He pointed to that column, read down the list until he came to the highest value, took his finger across to the corresponding fill rate, and said, "You mean to tell me that our target fill rate for C SKUs should be 99%?" I said, "For those C SKUs, yes." He asked what the current target was. I said 92%. He asked me what would happen if they raised the fill rate target. I said, "Your profit, market share, customer satisfaction, shareholder value, and inventory levels will increase." He turned to the head of supply chain planning and told him to design a regional pilot to try the strategy. The pilot lasted three months, and the predictions came true. The company expanded the pilot nationwide and soon afterward won its industry's awards for customer satisfaction and operational excellence.

Figure 2.20 RightStock Inventory Optimization: Slow-Moving CPG SKUs

Category	Forecast Error	Setup Cost	Lead Time	ICR	SKUs	Shortage Factor
C's	52.0%	$ 2,000	19	45%	32	50%

Customer Service Level	Unit Fill Rate	Average Inventory Value	Inventory Carrying Cost	Lost Sales Cost	Inventory Policy Cost	Turns	Gross Margin	GMROI	Inventory Value Added (IVA)
50%	50.00%	$ 1,888,903	$ 850,006	$ 4,737,293	$ 5,587,300	5.02	$ 4,737,293	2.51	$ 3,887,287
60%	60.00%	$ 2,005,653	$ 902,544	$ 3,789,835	$ 4,692,379	4.72	$ 5,684,752	2.83	$ 4,782,208
65%	65.00%	$ 2,066,471	$ 929,912	$ 3,316,105	$ 4,246,017	4.58	$ 6,158,481	2.98	$ 5,228,570
70%	70.00%	$ 2,130,563	$ 958,753	$ 2,842,376	$ 3,801,130	4.45	$ 6,632,211	3.11	$ 5,673,457
75%	75.00%	$ 2,199,729	$ 989,878	$ 2,368,647	$ 3,358,525	4.31	$ 7,105,940	3.23	$ 6,116,062
80%	80.00%	$ 2,276,749	$ 1,024,537	$ 1,894,917	$ 2,919,454	4.16	$ 7,579,670	3.33	$ 6,555,133
85%	85.00%	$ 2,366,524	$ 1,064,936	$ 1,421,188	$ 2,486,124	4.00	$ 8,053,399	3.40	$ 6,988,463
90%	90.00%	$ 2,479,482	$ 1,115,767	$ 947,459	$ 2,063,226	3.82	$ 8,527,128	3.44	$ 7,411,361
92.5%	92.50%	$ 2,552,285	$ 1,148,528	$ 710,594	$ 1,859,122	3.71	$ 8,763,993	3.43	$ 7,615,465
95%	95.00%	$ 2,646,903	$ 1,191,107	$ 473,729	$ 1,664,836	3.58	$ 9,000,858	3.40	$ 7,809,751
97%	97.00%	$ 2,755,632	$ 1,240,034	$ 284,238	$ 1,524,272	3.44	$ 9,190,349	3.34	$ 7,950,315
98%	98.00%	$ 2,835,335	$ 1,275,901	$ 189,492	$ 1,465,393	3.34	$ 9,285,095	3.27	$ 8,009,194
99%	99.00%	$ 2,960,958	$ 1,332,431	$ 94,746	$ 1,427,177	3.20	$ 9,379,841	3.17	$ 8,047,410
99.5%	99.50%	$ 3,075,926	$ 1,384,167	$ 47,373	$ 1,431,540	3.08	$ 9,427,214	3.06	$ 8,043,047
99.7%	99.70%	$ 3,155,167	$ 1,419,825	$ 28,424	$ 1,448,249	3.00	$ 9,446,163	2.99	$ 8,026,338
99.95%	99.95%	$ 3,405,282	$ 1,532,377	$ 4,737	$ 1,537,114	2.78	$ 9,469,850	2.78	$ 7,937,473

2.7 DEMAND TERMS

Every item has a unique set of demand characteristics. Some of those characteristics can be represented mathematically, including the following:

- Annual demand (AD)
- Forecast annual demand (FAD)
- Lead time (L)
- Lead time demand (LD)
- Forecast lead time demand (FLD)
- Standard deviation of lead time demand (SDLD)
- Lead time forecast error percent (LFEP)

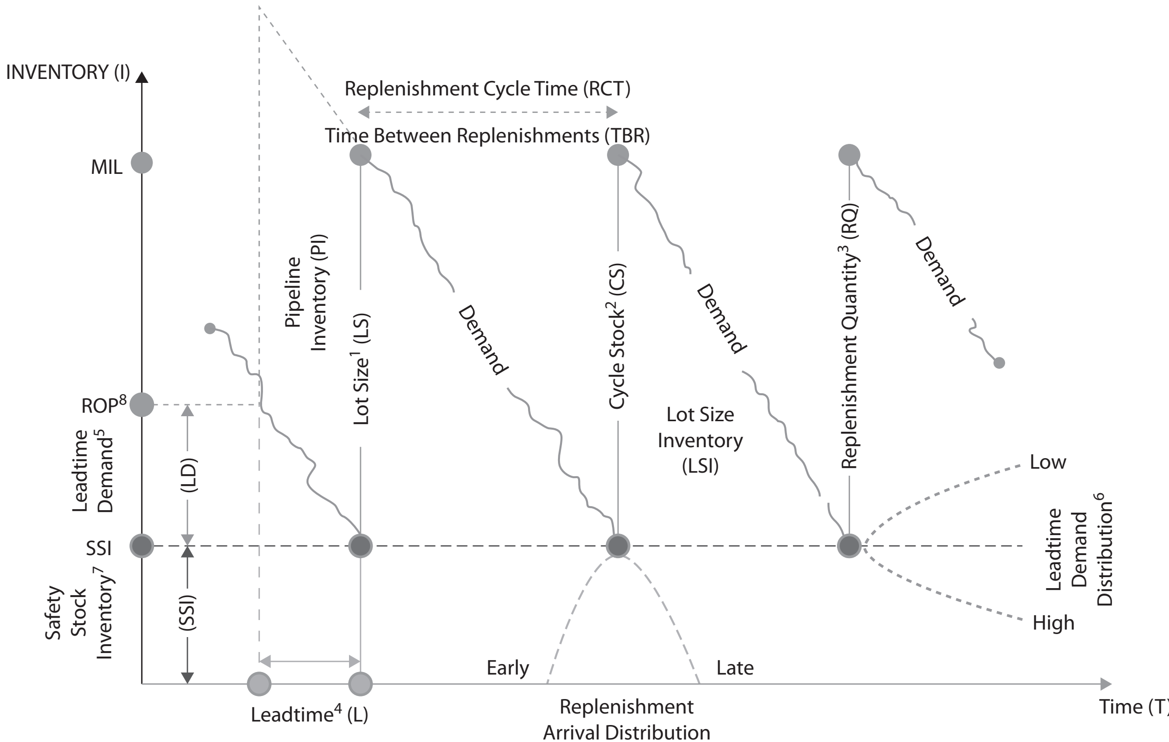
The *annual demand* for an item is the number of units requested for that item during a year. It looks backward over the prior year and is strictly historical. The *forecast annual demand* is the forecast (or expected) annual number of units requested by customers over the upcoming 12 months. The *lead time* for an item is the elapsed time from the placement of the replenishment order until the item is available to satisfy customer demand (point 4 in Figure 2.21). *Lead time demand* is the historic number of units requested by customers during a lead time (point 5 in Figure 2.21). The *forecast lead time demand* is the forecast (or expected) number of units that will be requested by customers during a future lead time. The expected value of the forecast lead time demand is the product of average lead time in days and average daily demand:

$$FLD = L \times (FAD/365)$$

For example, if an item has a lead time of 60 days and a forecast annual demand of 12,000 units, its forecast lead time demand is

$$\begin{aligned} FLD &= 60 \text{ days} \times (12{,}000 \text{ units}/365 \text{ days}) = 60 \text{ days} \times (33 \text{ units/day}) \\ &= 1{,}980 \text{ units} \end{aligned}$$

Figure 2.21 Inventory Management Dynamics



The *standard deviation of lead time demand* is a measure of the variability of the demand during a lead time (point 6 in Figure 2.21). The greater the variability in lead time demand, the greater the need for safety stock to protect against large spikes in demand during a lead time.

Lead time forecast error percent is the absolute value of the forecast error over a lead time. The greater the error, the greater the safety stock inventory required to support a particular fill rate. In addition, since the forecast is used in nearly every major supply chain decision, the greater the error, the greater the error in all supply chain decision making. I can say from experience that bias and a lack of individual accountability for forecast accuracy are the two principal causes of poor forecasting.

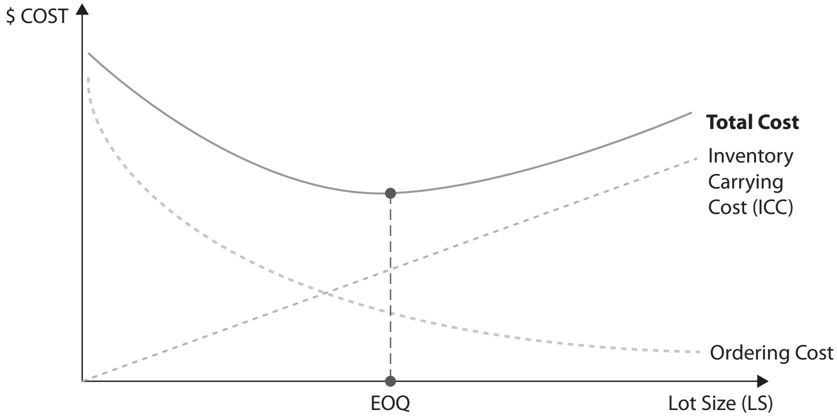
2.8 DECISION VARIABLES

The RightStock inventory model serves to make key decisions for the following variables, which work together to constitute an inventory strategy:

- Lot size (LS)
- Economic order quantity (EOQ)
- Unit fill rate (UFR)
- Safety stock inventory (SSI)
- Reorder point (ROP)
- Order up to level (OUL)
- Review time period (RTP)

Lot Size The *lot size*, also known as the replenishment quantity (RQ) or the cycle stock (CS), is the number of units that arrive in a replenishment lot or are produced in a manufacturing lot (points 1, 2, and 3 in Figure 2.21). The average replenishment quantity (ARQ) is the average size of lot size replenishments, derived by dividing the total replenishment quantity over a particular period by the number of replenishments received during that time.

Figure 2.22 Lot Size Optimization Curve



Economic Order Quantity The *economic order quantity* is the lot size that minimizes the sum of ordering cost and inventory carrying cost associated with the size of the order (Figure 2.22). The higher the order quantity, the greater the inventory level. However, the higher the order quantity, the fewer the number of orders and the lower the resulting ordering cost.

The economic run quantity (ERQ) is the production lot size (or run quantity) that minimizes the total of setup/changeover costs and the inventory carrying costs associated with the inventory produced by the run length. The trade-offs between manufacturing setup cost and inventory carrying costs for determining optimal production run sizes for a large textile client are illustrated in Figure 2.23. Note that in this example the optimal run length is three or four rolls per setup for that particular SKU. As is often the case with EOQ modeling, the total cost curve is fairly flat near the optimal solution. The key, as is also often the case, is to make decisions that are at least in the ballpark of optimal. Unfortunately, we often find that lot sizing is off by 200 or more.

The formula for computing the EOQ for a purchased item is

$$EOQ = [(2 \times FAD \times POC)(UIV \times ICR)]^{1/2}$$

For example, if an item has an annual demand of 3,000 units per year, a purchase order cost of $300 per purchase order, a purchase price of $2,100 per unit, and an inventory carrying rate of 30% per year, its EOQ is

$$\text{EOQ} = [(2 \times 3{,}000 \times \$300)/(\$2{,}100 \times 30\%)]^{1/2} = [(1{,}800{,}000)/(630)]^{1/2}$$
$$= [2{,}857]^{1/2} = 53 \text{ units}$$

The formula for computing the EOQ for a manufactured item, which is sometimes referred to as the economic run quantity, is as follows:

$$\text{ERQ} = [(2 \times \text{FAD} \times \text{SUC})(\text{UIV} \times \text{ICR})]^{1/2}$$

For example, if an item has an annual demand of 5,000 units per year, a setup cost of $3,200 per setup, a standard cost of $85.00 per unit, and an inventory carrying rate of 25% per year, its EOQ is

$$\text{ERQ} = [(2 \times 5{,}000 \times \$3{,}200)/(\$85 \times 25\%)]^{1/2}$$
$$= [(32{,}000{,}000)/(21.25)]^{1/2} = [1{,}505{,}882]^{1/2} = 1{,}227 \text{ units}$$

EOQ is considered passé, outdated, and nearly prehistoric in many inventory circles. However, in our work with the most advanced supply chain organizations around the world we are finding great profit, service, and operational improvements with EOQ.

Unit Fill Rate The *unit fill rate* for an item is the portion of the total number of units requested with inventory available to fill the request. It is distinct from and higher than the *line fill rate* (percentage of lines shipped complete) and the *order fill rate* (percentage of orders shipped complete). The target unit fill rate is a decision, not an outcome. It is perhaps the most important inventory planning decision of all.

As was discussed previously, the higher the unit fill rate, the lower the lost sales cost. However, the higher the unit fill rate, the greater the inventory required to provide it and the greater the resulting inventory carrying cost. There are many ways to determine optimal target unit fill rates. One method is to choose the unit fill rate that minimizes expected Inventory Policy Cost. Another method is to choose the unit fill rate that maximizes expected GMROI. Still another method is to choose the unit fill rate that maximizes IVA. What do we do? It depends on the financial, service, and operational goals. The ability to visualize and simulate those relationships, as was demonstrated in Figures 2.18 to 2.20, from the RightStock Inventory Optimization System is the key and often the missing piece in the inventory strategy puzzle.

Safety Stock Inventory The literal definition of *safety stock inventory* is the inventory on hand when a replenishment arrives (point 7 in Figure 2.21). The average safety stock is the average on-hand inventory at the end of several replenishment cycles. Safety stock is required to support promised levels of inventory availability when the demand during a lead time or the length of a lead time is variable. For example, if a replenishment is delayed or if the demand during a lead time is much greater than normal, safety stock is in place to fulfill demand until the replenishment arrives or to satisfy some portion of the excess demand. There would be no need for safety stock if we knew exactly what customers wanted, when they wanted it, and exactly when replenishments will arrive. To the extent that there is uncertainty in any of those three variables, safety stock is required to provide anything better than 50% inventory availability.

Reorder Point The *reorder point* is the inventory level at which a replenishment order is placed (point 8 in Figure 2.21). As a rule, the reorder point is set at the lead time demand plus safety stock:

$$\text{ROP} = \text{LD} + \text{SSI}$$

There are a variety of other inventory control policies and variables, including the use of *order up to levels*, the level of inventory a replenishment quantity should yield when it is placed; *review time periods*, the fixed times between inventory reviews; and a wide mix of programs for joint item replenishment.

2.9 INVENTORY INTERDEPENDENCIES

So far we have discussed the elements of inventory decision making to a large degree in isolation. The complex truth of inventory decision making is that many of the elements are interrelated. Those interrelationships create the conflict, difficulty, and challenges of inventory decision making.

A few years ago one of our clients in the health and beauty industry asked us to help it work through those difficulties with its executives. In response we developed an inventory simulation tool that our clients now use in real time to work through a wide range of inventory decisions. That tool, our RightStock Inventory Simulation System, is shown in Figure 2.24. It ties together item characteristics, planning parameters, financial terms, and decision variables in a single dynamic visual simulation of inventory decision making. Specifically, it computes key financial metrics (IVA, IPC, ICC, GM, LSC, LS, AIV, GMROI, turns) and inventory investments [safety stock inventory value (SSIV), lot size inventory value (LSIV), pipeline inventory value (PIV)] as a function of key planning parameters (ICR, SF, POC), item characteristics (USP, UIV, L, FAD, LFEP), and target fill rate.

A baseline scenario from a large toy company is shown in Figure 2.24. It presents the company's SUPER SKU, a term used to designate a client's fictitious median SKU that we sometimes employ for modeling purposes. We will use the model in Chapter 3 to teach a variety of inventory decision-making dynamics, including RightCast (forecast optimization), RightTimes™ (lead time optimization), RightLots (lot size optimization), RightRate™ (inventory carrying rate optimization), and RightStock (total inventory optimization).