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# Strategic Multi-Stage Inventory Allocation in the Process Industry

Focus Topic Paper

▶ Supply Chain Management



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**Authors**

Michail Heinmann · Visionary Officer  
Marco Klein · SCM Consultant

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## Preface

The challenge of managing a multi-stage supply chain will be familiar to many process industry companies. Implementers of MRP II in the 1980s and early 1990s found that the proposed approaches, whilst possibly sufficient for handling simple supply chains involving a single plant / single market or single plant / few markets were inadequate for the “real world” of process industry. They found that the multi-stages of their supply chains, from raw materials and intermediates to the final stages of manufacture and assembly, were poorly served. The consequences of trying to handle the necessary complexities of such supply chains were queues and instability in production plans that led to excessive inventories. Even the introduction of lean manufacturing failed to address the challenge of inventory management in an extended supply chain. Local improvements still failed to achieve optimum allocation of inventory.

A more strategic approach is required to handle multi-stage supply chains. Lean supply chain management provides a means of providing end-to-end synchronization of the supply chain to improve flow and inventory. However, there is still the need to understand how to set safety stock policies within this lean supply chain environment. This paper provides fresh and original insight into how these policies should be set to optimize performance whilst addressing risk, variability and customer service. It demonstrates how a full understanding of the end-to-end chain allows the optimization of the chain rather than point solutions. It shows how in some cases the necessary solution is counter-intuitive, meaning that effective end-to-end co-ordination and management is required in order to achieve the highest benefit.



**J. C. Amey**

Principal Fellow Warwick University

Former Vice President Supply Chain for AstraZeneca

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## Executive Summary

As innovation leader for supply chain management in process industries, we continuously focus on the analysis of industry trends and the adaptation of innovative cutting-edge methods to provide companies with pragmatic, industry-specific approaches to dealing with present challenges. This focus topic paper provides insights into the current state of inventory management methodology and illustrates how strategic-end-to-end inventory optimization can be used to achieve better service at lower costs.

**There are three reasons to have inventory management on the agenda:**

- **Good inventory management means more customer satisfaction:** reliable inventory management with right sized and allocated stock enables shorter lead times to customers and subsequently generates more added value for them.
- **Good inventory management means more growth:** sustained profitability and growth requires investments. Effective inventory management makes working capital available for this strategic purpose.
- **Good inventory management means supply chain continuity:** our business world is a world of continuous change. Having the right amount of inventory at the right places as a buffer against variability is more important than ever.

**This paper provides you with:**

- An overview of the current challenges in the area of inventory management
- Essentials of different inventory optimization methods
- Insights into the cutting-edge multi-stage inventory optimization approach

**You should read this paper...**

- ... if you are at the beginning of the inventory optimization journey, to get a structured road map and ideas to set up a well-structured project or program
- ... if you have already implemented particular aspects of inventory management, to get an idea about additional activities and enrichment of your approach
- ... if you have achieved a certain level of inventory management efficiency, to get inspiration for a further 15% inventory reduction potential on top

# 1 Inventory Management as a Key Driver for Supply Chain Performance

## 1.1 A Growing Complexity in Supply Chains Calls for New Approaches

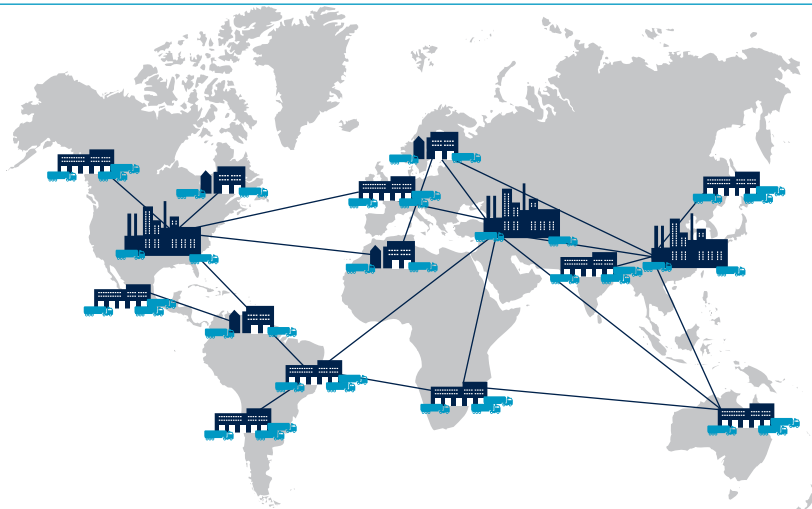
Inventory optimization remains one of the key challenges in supply chain management. Typically, large amounts of working capital are tied up in today's supply chains, restricting the opportunities for growth that are essential for a company's success in competitive markets such as the process industry sectors. Furthermore, reported inventory figures become an increasingly important indicator for investors and other external stakeholders when assessing the efficiency and health of the whole company.

Nevertheless, there is still an ongoing trend towards increasing inventories in process industries. Major reasons for this development are:

- Volatile markets
- Increased complexity of the product portfolio
- Fear of lost sales due to stock-outs
- Increased variability of the supply base
- Global supply chains and long lead times

However, market research and project experience have shown that inventories are **unnecessarily high** in most supply chains and there is a significant potential to reduce them.

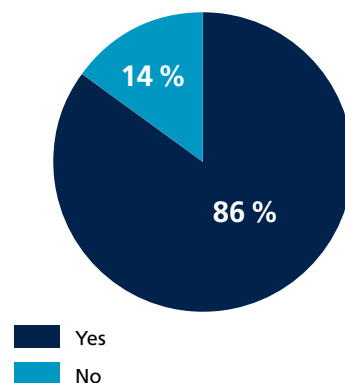
**Figure 1:** Supply chains are becoming increasingly complex and globally dispersed



New planning approaches are required to handle the complexity of today's supply chains and to improve customer service and cost efficiency.

Although large differences in inventory efficiency can be observed (e.g. measured in inventory turns), most companies identified the need to improve their inventory management (fig. 2).

**Figure 2:** Currently looking for new ways to improve inventory management?



## HOW TO BECOME A SUPPLY CHAIN CHAMPION?

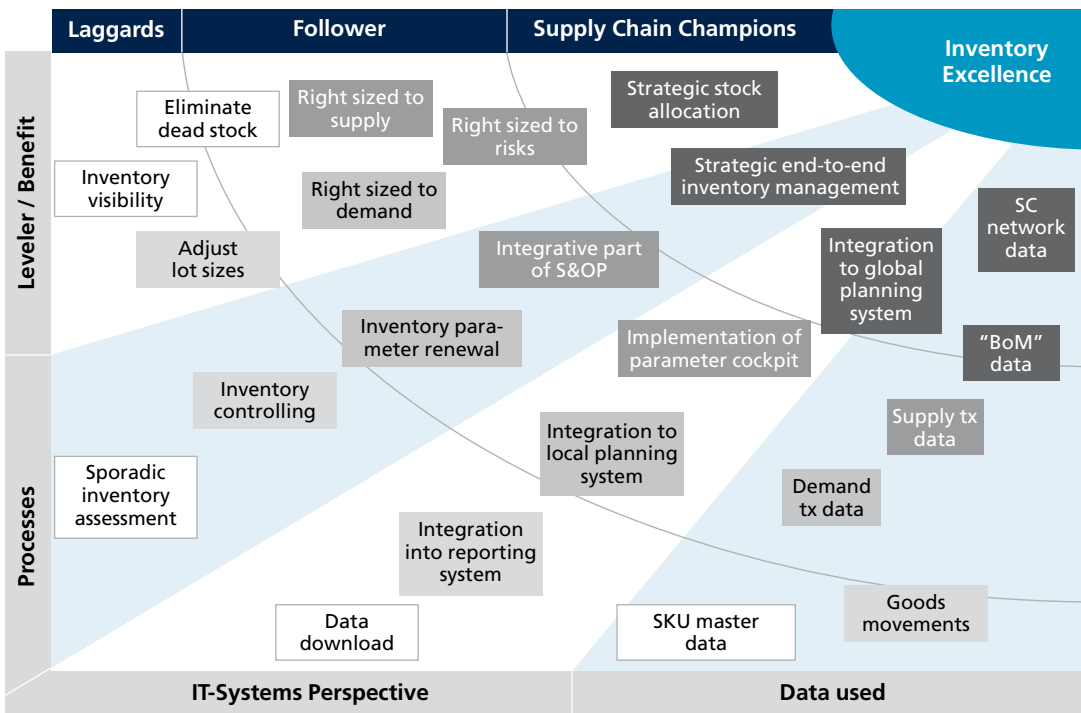


Figure 3: Challenges on the way to inventory excellence

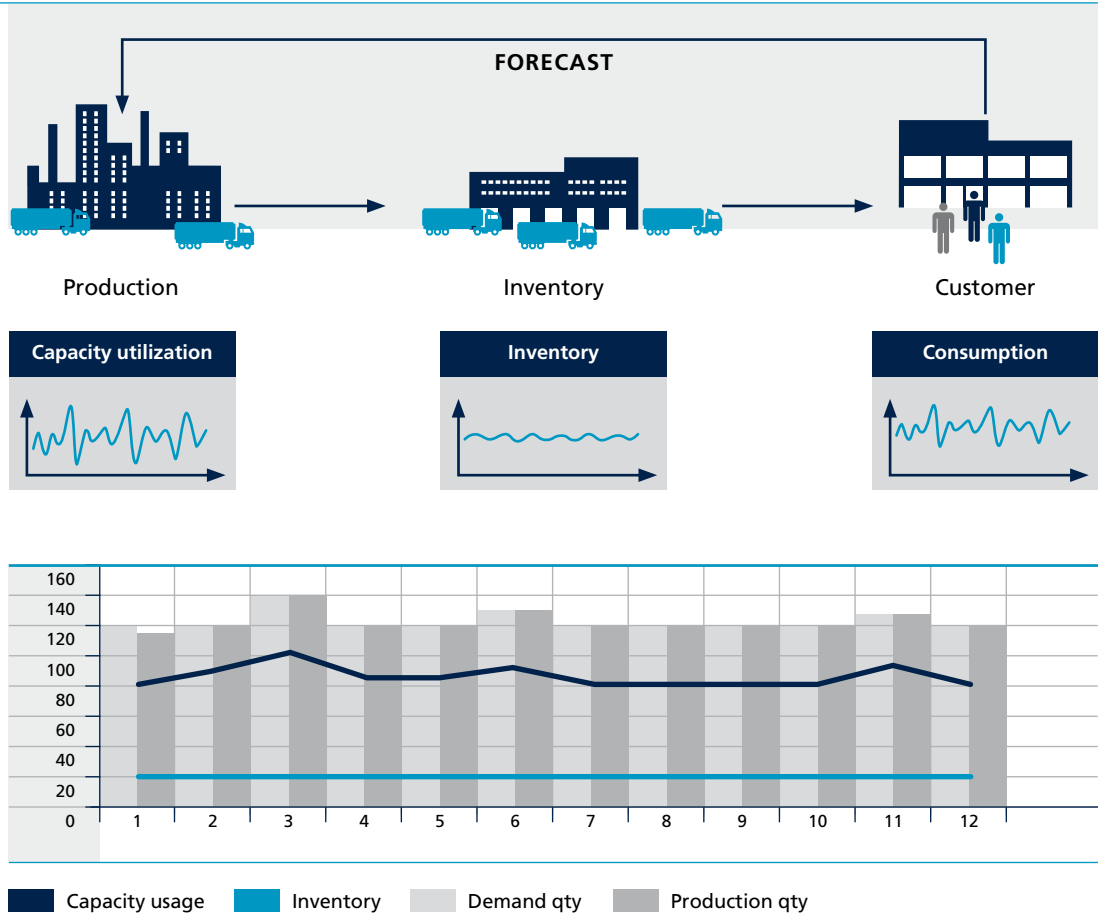
The first step to improving inventory efficiency is to set up a **regular inventory assessment process**. This requires collecting inventory data from all sites or nodes of the supply chain. The transparency achieved this way already helps to reveal inefficiencies like **dead stock**, which can be eliminated right away. Moreover, **inventory visibility** is a precondition for any further optimization.

As a second step, a common inventory controlling process should be established. The **integration** of inventory controlling into the existing reporting systems is important for uncovering the impact of the different supply chain decisions on inventory levels. For example, in many cases significant improvements can be achieved through the adjustment of production, purchasing and transportation lot sizes. A further reduction of inventories results from an individual optimization of the inventory control parameters at each stage. **Local inventory right-sizing** requires the determination of demand and supply characteristics, based on historical demand and replenishment data, and the identification of relevant risks. Different segments of the inventory can then be addressed quantitatively.

Finally, as the inventory-controlling processes are an integral part of the **global planning process**, additional cost reductions can be realized through the implementation of **strategic end-to-end inventory management**. Based on supply network data, end-to-end inventory optimization is able to improve both inventory cost-efficiency and customer service by simultaneously optimizing inventory levels across the supply chain and taking into account the dependencies between the various stages.

## 1.2 The Role of Inventory in Modern Supply Chain Planning

**Figure 4:**  
Traditional  
planning approach

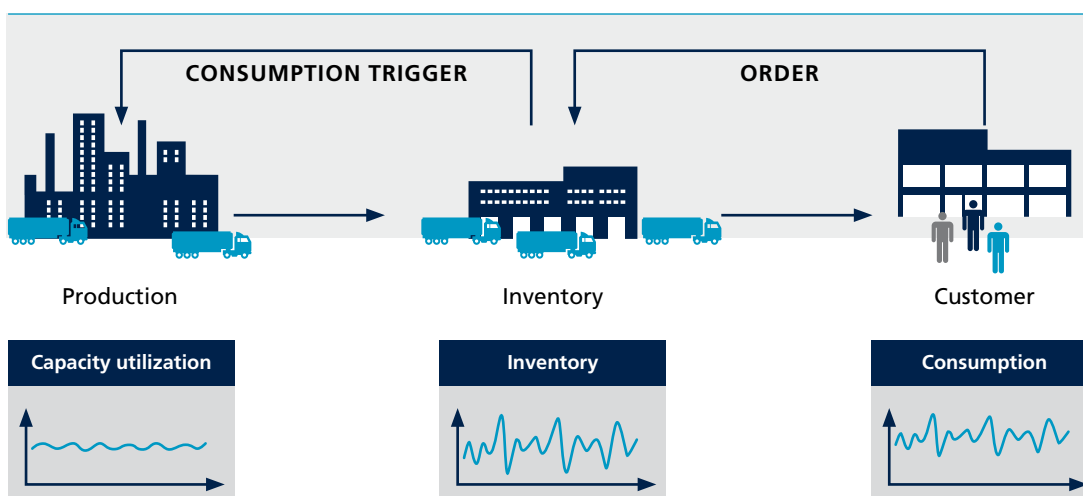


The implementation of **Lean Manufacturing** principles has led to substantial cost savings, lead time reductions and quality improvements in many industries. Originating in the automotive industry, these principles are increasingly applied in other industries, including process manufacturing. However, value generation is not limited to manufacturing alone: a substantial share of the total value added is contributed by supply and distribution processes. Consequently, many companies have coined the vision of **Lean Supply Chain Management** for the efficient planning and execution of all logistic processes.

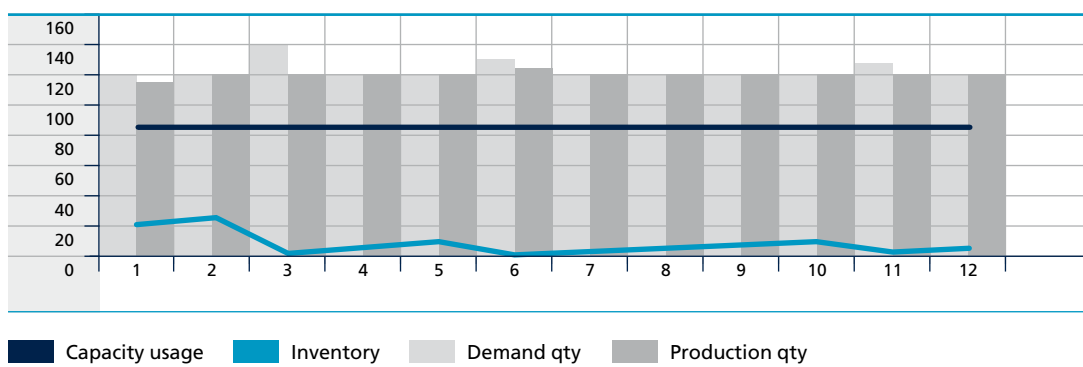
Traditional approaches for production planning which are still common in many industries are directly based on demand forecasts (fig. 4). Adjusting production is the default means of reacting to demand fluctuations and subsequently leads to frequently changing capacity utilization, while inventory levels basically remain constant due to the design of the applied planning methods, such as MRP. Furthermore, forecast inaccuracy results either in oversized inventory targets or in stock-outs due to insufficient inventory buffers

**Inventory planning** is a key priority for Lean Supply Chain Management. Inventories are specifically used to synchronize product flows and to mitigate the effect of demand and supply variability (fig. 5). This approach increases added value contributed by operations and results in more stable capacity utilization as well as in reduced average levels of inventory across the supply chain.

However, to follow the guiding Lean principle of avoiding waste, excessive stock must be eliminated wherever it occurs. Thus, to realize the vision of Lean Supply Chain Management, the systematic optimization of inventories must be actively addressed.



**Figure 5:**  
Innovative planning approach

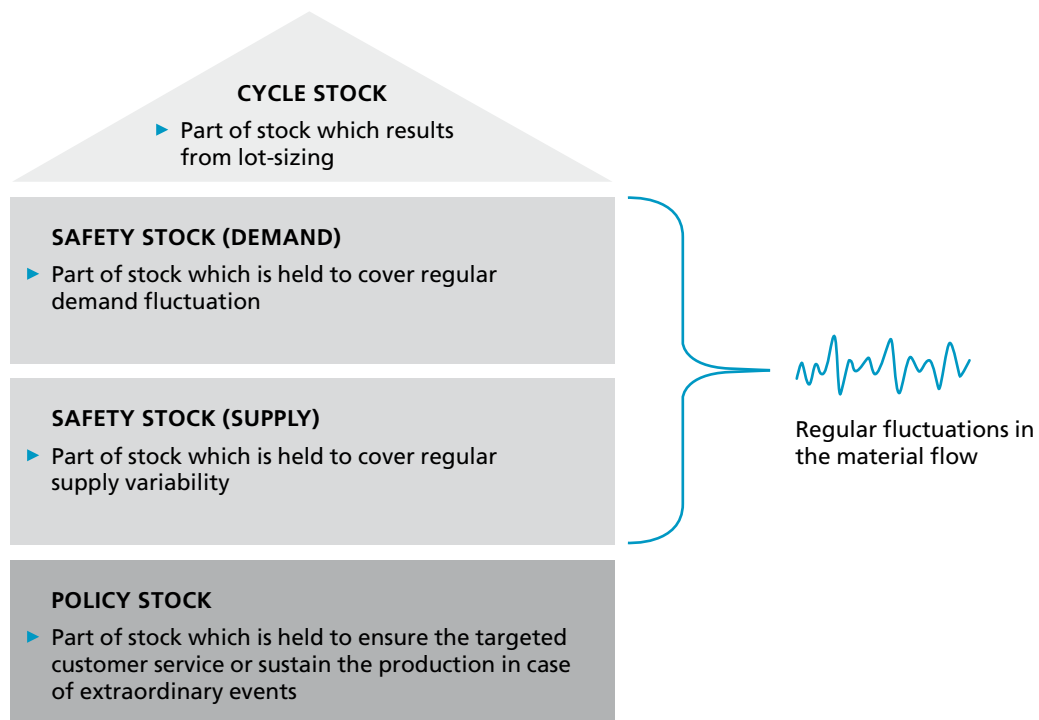


## 2 Effective Inventory Management through Multi-Stage Optimization

### 2.1 Principles of Inventory Management

Inventories can be found across the entire supply chain, e.g. in the form of raw materials, semi-manufactured products and finished goods. Considering all stages from purchasing raw materials to regional distribution of the finished goods, a substantial amount of capital is tied up in stock even in supply chains of moderate size. Balancing the stock levels at the various supply chain stages is one of the key objectives in supply chain management. The essential planning parameter is the amount of inventory which is deliberately held to cover variability in the supply chain. This **safety stock** is affected whenever replenishments arrive delayed, demand is higher than expected or insufficient quality results in scrap.

**Figure 6:**  
Classification of stock

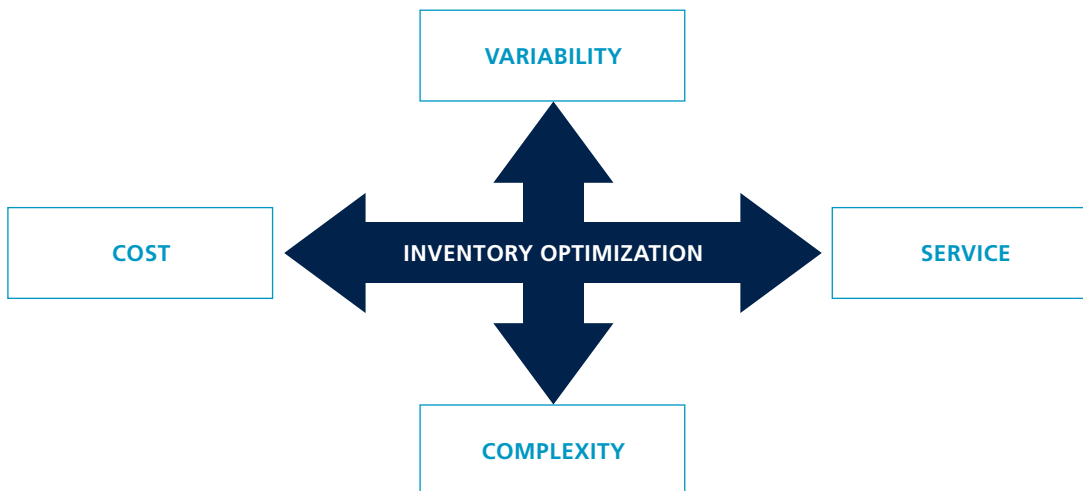


There are different stock components dedicated to the different roles of inventory within a supply chain: cycle stock covers the average expected demand over replenishment time, policy stock ensures continuity in case of strategic supply chain events such as force majeure, and safety stock addresses regular uncertainties within the supply chain. Due to the various sources of uncertainty, holding sufficient safety stock is crucial to achieve the required customer service level. Unfortunately, determining the appropriate amount of safety stock is a non-trivial issue.

Typically, safety stocks exhibit a great opportunity for inventory optimization, as it is not unusual to see that, for certain products, they account for more than 50% of the entire stock. Despite this large impact on total inventory costs, safety stock has received low attention in the past. However, it can be observed that many companies have started to redirect their optimization efforts. Three main reasons can be identified for the increased focus on safety stock optimization:

- The recent economic crisis and the rapid subsequent recovery have demonstrated how volatile markets are. Inventories are essential to steer companies through changing economic times.
- According to Lean Planning approaches, material flows are increasingly controlled by pull instead of push principles. However, the use of a pull control system requires the efficient synchronization of safety stock levels throughout the supply chain.
- Finally, the increasing complexity of today's supply chains reinforces the amplification of demand variability towards upstream stages ("bullwhip effect"). Fortunately, the negative effects of uncoordinated replenishment orders can be avoided by multi-stage inventory planning and optimization approaches.

In general, four determining factors must be considered in the context of inventory optimization (fig. 7).



**Figure 7:**  
Determining factors for inventory optimization

The two key targets for inventory optimization are **costs** and **service**. Generally, a certain customer service level has to be satisfied at the lowest possible costs. **Variability** and **complexity** are the two major challenges in the context of inventory management. For successful inventory management, all sources of variability must be considered. In addition to demand fluctuations and supply uncertainty, variability can also be induced by natural variations within the manufacturing processes such as varying process output in chemical manufacturing. Finally, the complex structure of global supply chains must be taken into account.

## 2.2 Evolution of Inventory Planning Approaches

**Figure 8:**  
Camelot Maturity Model

Although many companies manage the inventory planning process centrally for all stages of the supply chain, the determination of inventory target levels at each stockpoint is usually done in **isolation**. Depending on the applied planning approach, six different maturity levels can be distinguished (fig. 8).

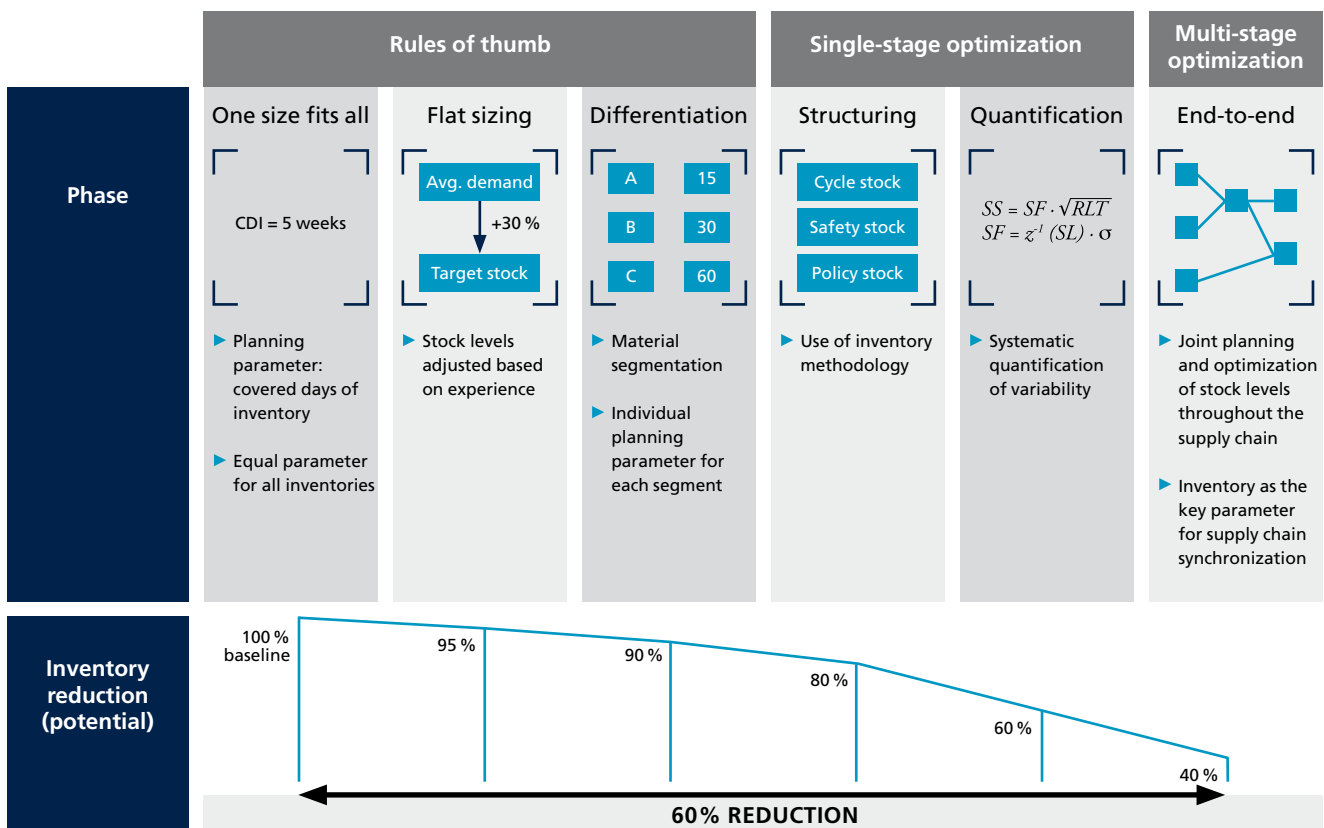
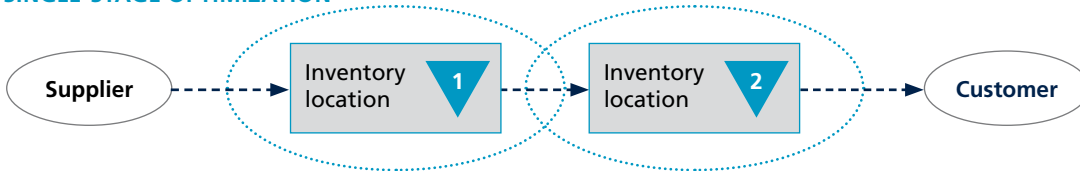


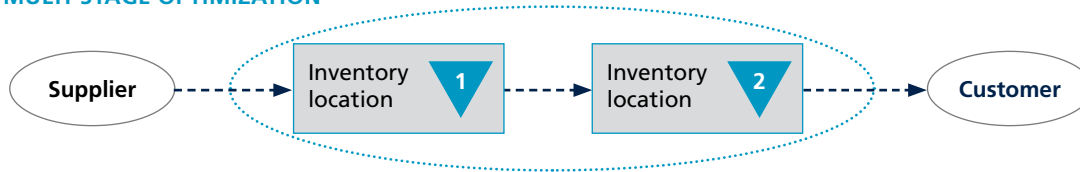
Figure 8 also illustrates the typical impact of different inventory planning approaches on overall inventory levels. Due to the significant inventory reduction potential, many companies have started to replace their previously approximate planning policies with more systematic approaches. In contrast to such elementary rules of thumb, these advanced approaches explicitly take into account the economic reasons for holding inventories. For example, the required amount of safety stock is based on observed variability and the desired service level.

However, only the simultaneous optimization of all inventories takes into account the dependencies between the stages (fig. 9) and leads to real inventory management excellence. Ignoring these dependencies can lead to **sub-optimal inventory allocation**.

**SINGLE-STAGE OPTIMIZATION**



**MULTI-STAGE OPTIMIZATION**

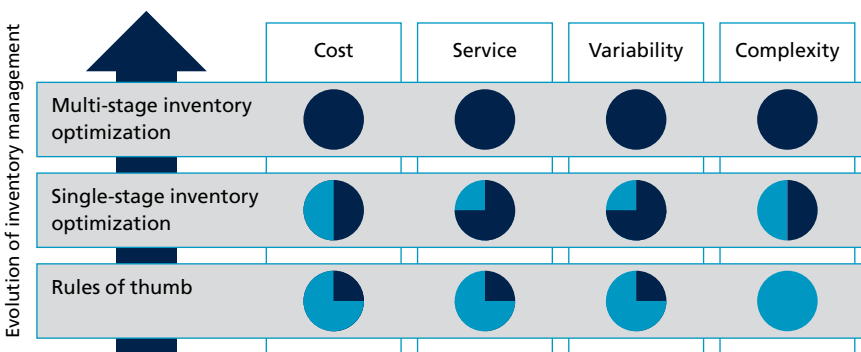


**Figure 9:** Single- vs. multi-stage optimization

A multi-stage optimization approach provides answers to the following questions:

- Is it cheaper to place safety stock at the upstream or at the downstream part of the supply chain, near to the final customer?
- How does the inventory policy at one stage impact the material flow at succeeding stages?
- Are the service level targets at the various stages appropriate to achieve the desired end customer service level?

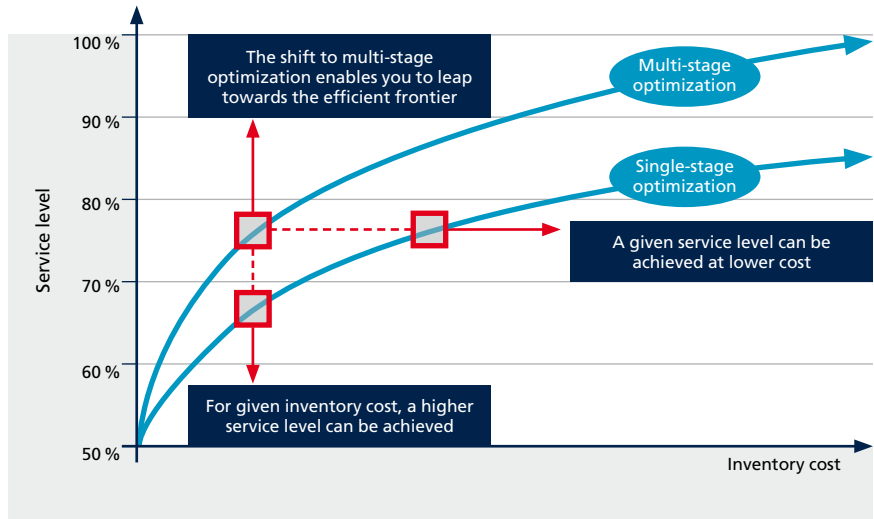
Obviously, answering these questions is essential for holistic planning and optimization of all sites and processes, which is the guiding principle of supply chain management.



**Figure 10:** Scope of the different inventory maturity levels

Fig. 10 summarizes the discussed inventory planning approaches with respect to the four determining factors of inventory optimization. Approximate planning approaches only take into account these determining factors in a rudimentary way. In contrast, systematic single-stage optimization approaches already start to exhibit significant improvements. Though single-stage approaches give advice on the rightsizing of inventories, only multi-stage optimization gives complete consideration to all the factors and leads to an optimal allocation of stock within the supply chain.

**Figure 11:**  
Trade-off between service level and inventory cost



The use of multi-stage inventory optimization approaches makes it possible to move the general trade-off between inventory cost and customer service to the next level of excellence (fig. 11). That is, for a given cost, the multi-stage optimization results in significantly higher service level, whereas substantially lower inventory holding costs can be expected for a given target service level.

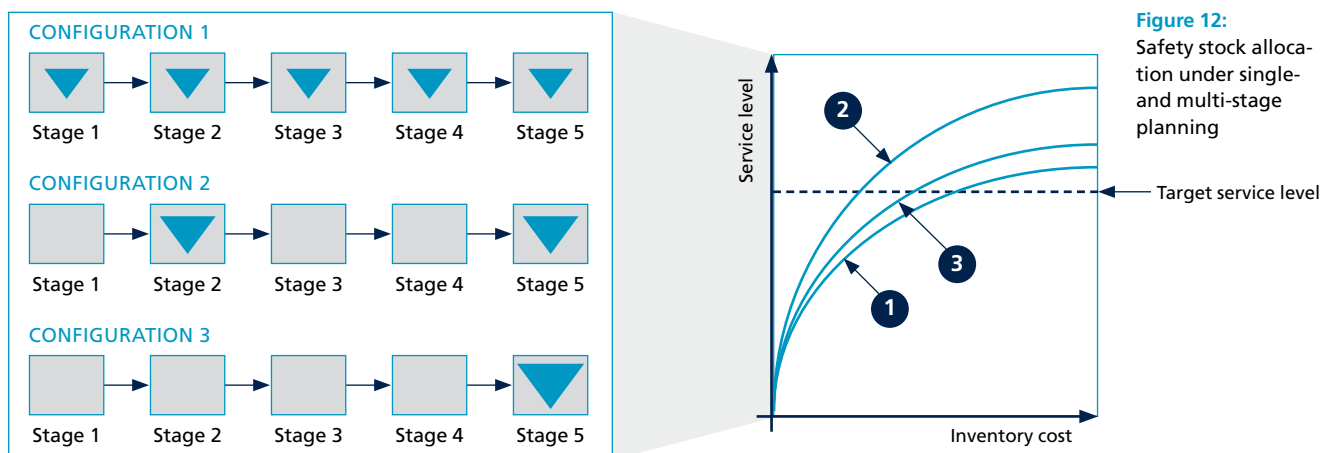
*Supply chain excellence involves having the right amount of inventory in the right place, which is achieved through the use of a multi-stage optimization approach.*

## 2.3 Principles of Multi-Stage Inventory Optimization

In recent years, the field of inventory optimization has undergone a major development. The availability of more powerful IT-systems and substantial progress in research has led to multi-stage optimization approaches which are capable of handling even complex global supply chains. Though common Enterprise Resource Planning- (ERP) and Advanced Planning and Scheduling (APS) systems still lack the functionality of a built-in multi-stage optimization, most of the available multi-stage tools can be integrated into existing ERP and APS systems.

To illustrate the concept of multi-stage optimization, we consider a basic supply chain with five stages (fig. 12). The question is where to allocate safety stock. Due to the added value, inventory-holding costs are higher at downstream stages. Fig. 12 displays the impact of the allocation decision:

- In **configuration 1**, safety stock is held at each stage, an allocation which is typically the result of single-stage planning approaches. While from a single-stage perspective the distribution of safety stock is reasonable to protect the service performance of the individual stages, the resulting total inventory level is usually higher than necessary.
- As the other extreme, in **configuration 3** the entire safety stock is consolidated at the final stage of the supply chain. While such a consolidation might lead to a lower total inventory level, the downside of this allocation is that holding costs (and often the number of SKUs) are highest at this stage.
- In contrast, advanced multi-stage optimization approaches will identify an allocation strategy which optimizes both inventory levels and service. Typically, this leads to a solution where safety stock is consolidated at few stages, as shown in **configuration 2**.

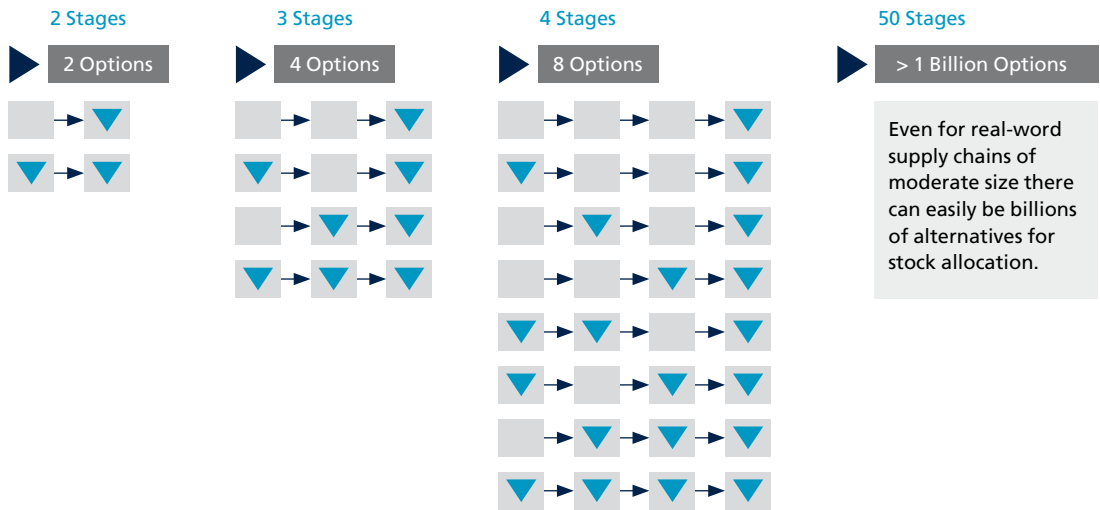


**Figure 12:** Safety stock allocation under single- and multi-stage planning

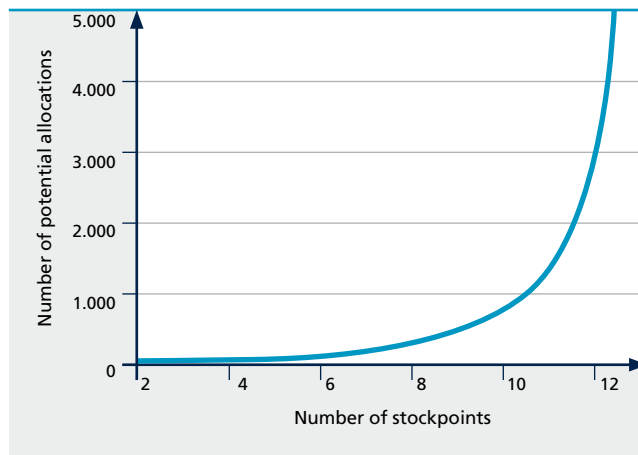
The example also illustrates the complexity of multi-stage inventory optimization. Even if the attention is restricted to “all-or-nothing” policies in which a stage either holds no inventory or holds enough inventory to always satisfy demand from the shelf, 32 configurations for stock placement are possible in this rather small five-stage supply chain.

Typically, supply chains of practical size consist of several production and distribution sites with hundreds or thousands of unique SKU-location combinations. To identify the optimal stock allocation in such real-world systems, “smart” optimization approaches are mandatory (fig. 13).

**Figure 13:**  
Complexity of the multi-stage optimization problem



Even for real-world supply chains of moderate size there can easily be billions of alternatives for stock allocation.



**# of potential allocations = 2<sup>n</sup>**  
 where **n** is the number of non-final stages (SKU-location combinations) in the supply chain.  
 (assumption: final stages always carry inventory to ensure off-shelf availability)

For a cost-efficient placement of safety stock, four effects must be considered:

**1. Lead time effect**

As short-term fluctuations in the material flow are usually balanced out over time, comparatively less safety stock is required if stock buffers are consolidated at downstream locations.

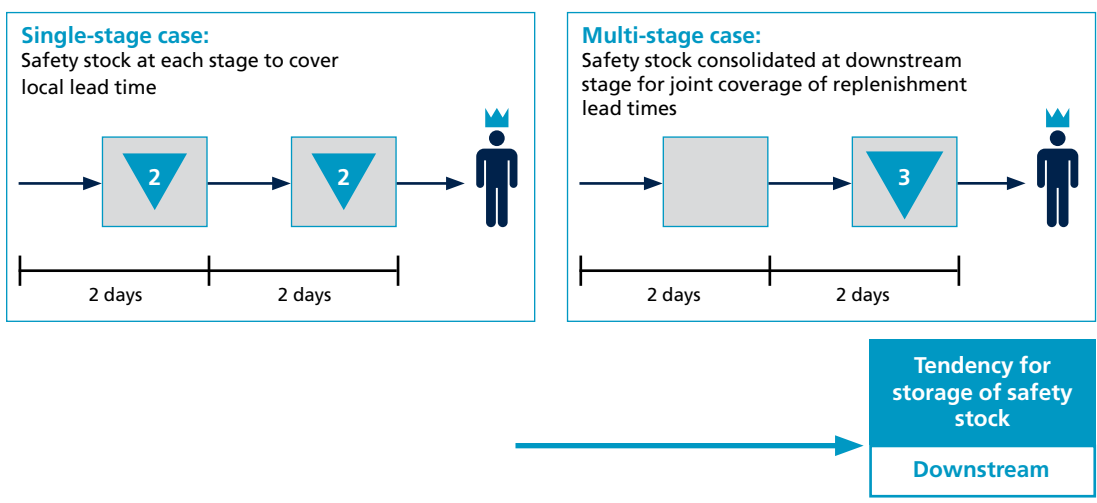


Figure 14: Lead time effect

**2. Pooling effect**

In supply chains where the number of SKUs increases at downstream stages – as typically observed in process industries – the overall inventory level can be reduced by relocating safety stocks to upstream stages with lower product differentiation due to demand risk-pooling.

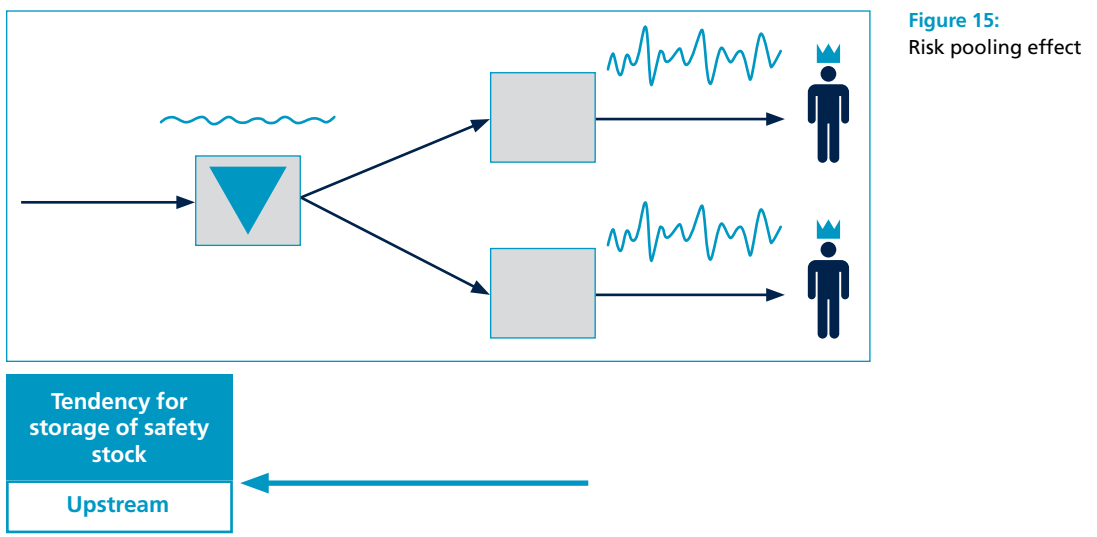
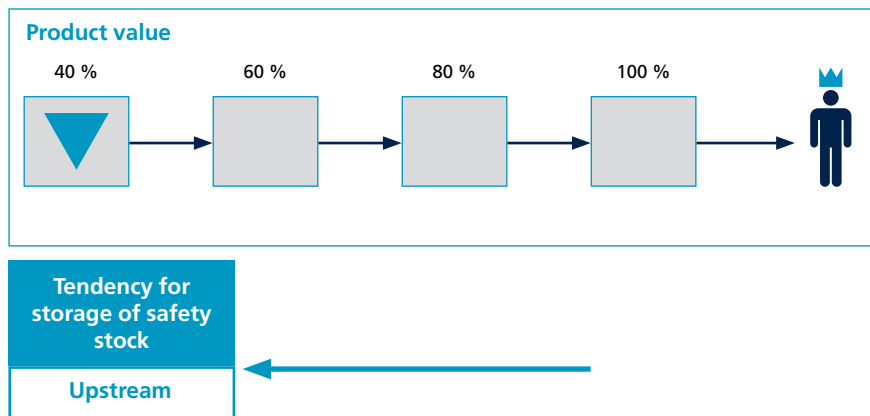


Figure 15: Risk pooling effect

### 3. Value effect

Inventory holding costs are directly linked with product value, which generally increases through the stages of the value-added process. Consequently, it is cheaper to hold inventories at upstream stages, where material values are lower.

**Figure 16:**  
Value effect



### 4. Service level effect

In a systematic inventory planning approach, the size of the required safety stock buffers is determined by observed variability and targeted service level. Clearly, end-customer service levels may not be the same for all downstream stages. If heterogeneous service levels have to be taken into account, the use of a centralized inventory leads to rather complex inventory control policies or unnecessarily high inventory levels. Therefore, it is usually beneficial to buffer high service requirements locally in the case of heterogeneous service levels.

**Figure 17:**  
Service level effect

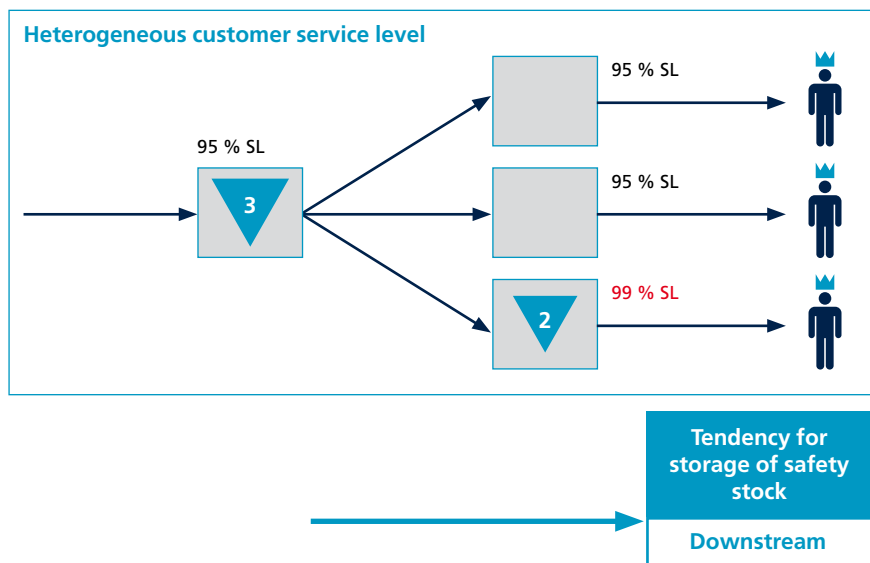
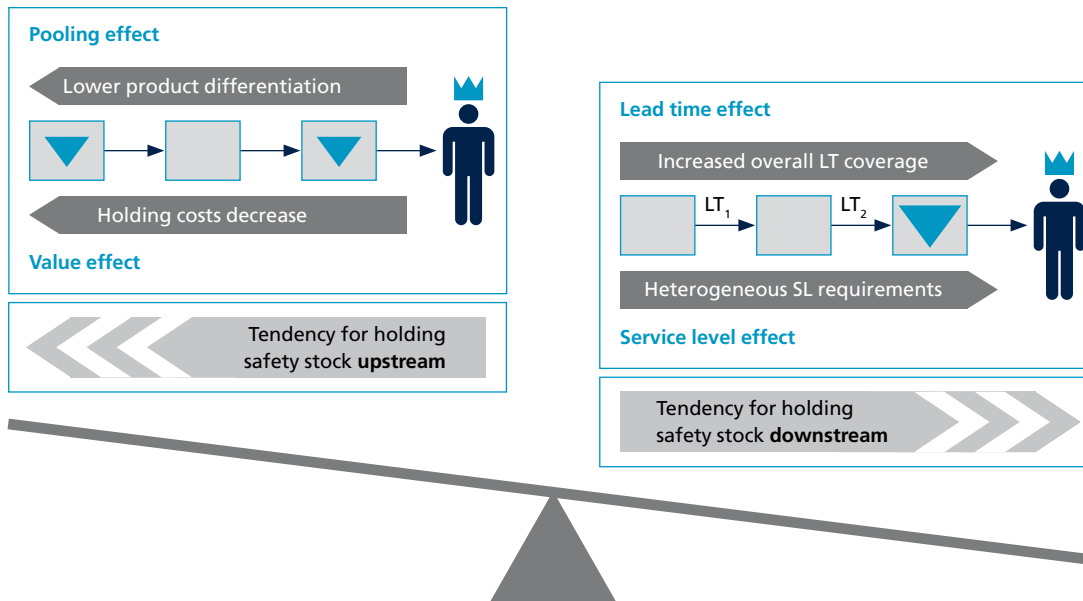


Fig. 18 illustrates the **trade-off** between the different effects. Advanced multi-stage optimization approaches are able to identify the **optimal configuration** by taking into account all four of these effects as well as **additional constraints** like storage capacities and maximum service times.



**Figure 18:** Safety stock allocation as a trade-off between four basic effects

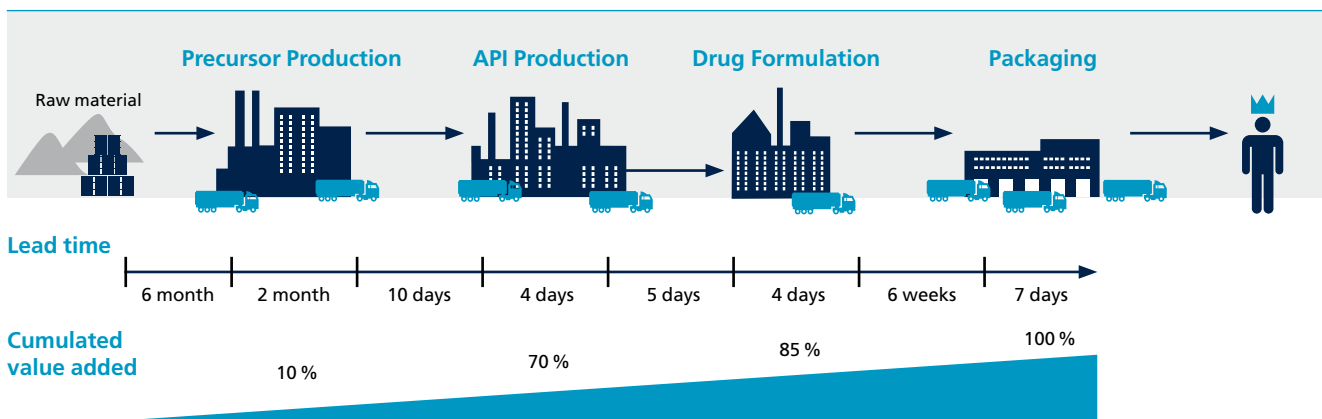
*Multi-stage inventory optimization reduces inventory cost by exploiting risk-pooling and value effects within the supply chain.*

### 3 Multi-Stage Inventory Optimization in the Pharmaceutical Industry – Case Study

#### 3.1 Challenge

The following case illustrates a multi-stage optimization of a pharmaceutical supply chain. The supply chain depicted in fig. 19 belongs to one of the world’s top-selling branded pharmaceuticals, with multi-billion annual revenue figures. As part of a comprehensive inventory optimization project conducted by Camelot Management Consultants, one objective was to identify the optimal allocation of safety stock.

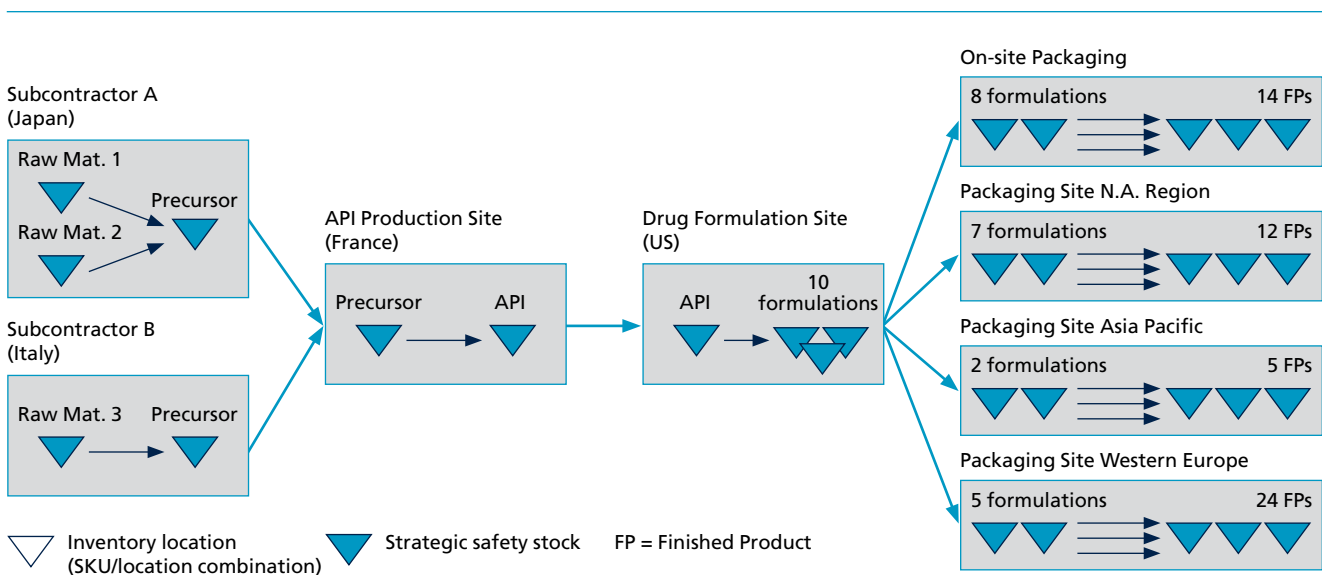
**Figure 19:** Supply chain characteristics



Typically for the pharmaceutical industry, operations are highly globalized, with a significant product fan-out at downstream stages (fig. 20). Due to production scheduling, time consuming clearance processes and the geographical separation of the production sites, lead times are rather long, amounting to over 10 months in total.

**Figure 20:** Supply chain structure

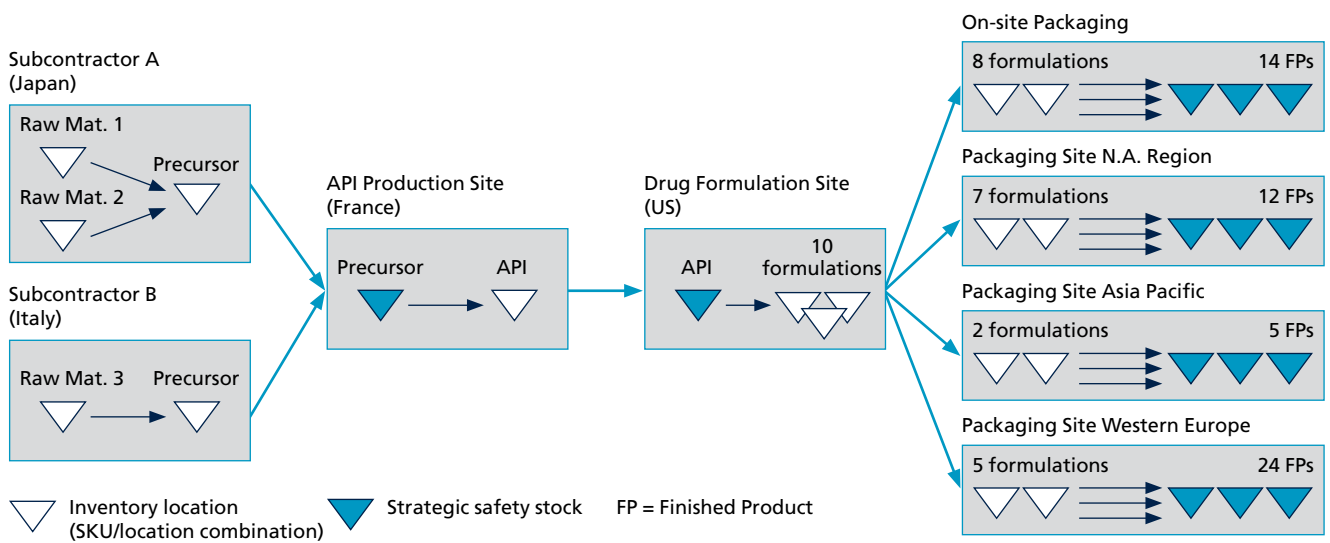
Fig. 20 displays the considered number of SKUs at each site. Overall, 95 unique SKUs at eight inventory locations were taken into account. Though an advanced inventory planning process was already in place, safety stock was spread over the entire supply chain due to the applied single-stage approach.



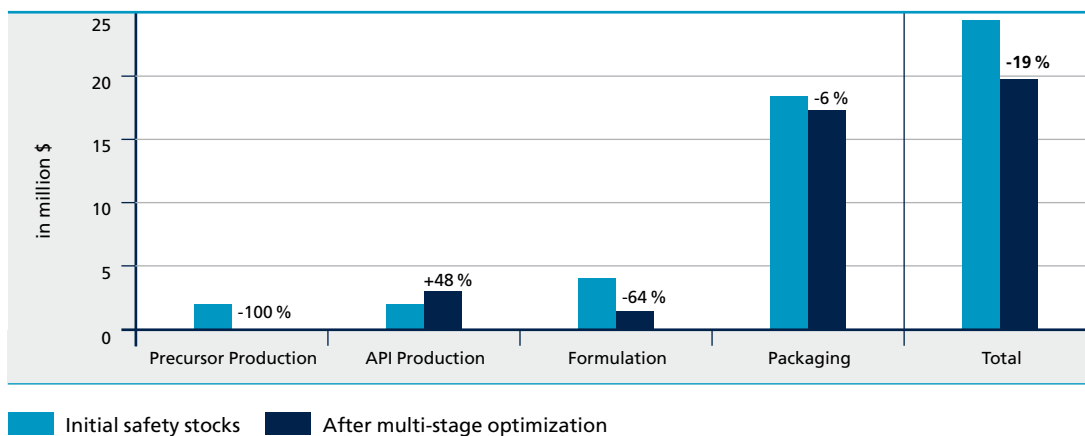
### 3.2 Results

As a result of the multi-stage optimization, safety stock was consolidated at a rather low number of stages in the supply chain (fig. 21). Stock buffers of finished products at the packaging sites are required to ensure off-shelf availability. In addition, safety stock is consolidated at the inbound sites of the API production and formulation.

**Figure 21:**  
Optimized safety stock allocation



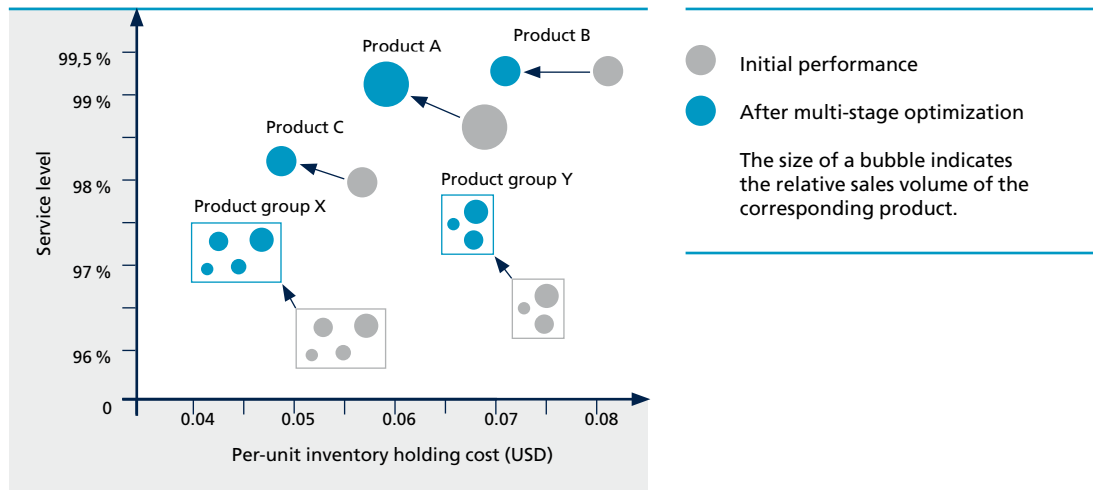
As service levels were already high, the primary focus of the project was on working capital reduction. The financial impact of the multi-stage optimization is displayed in fig. 22. By the time the inventory relocation and right-sizing had been largely completed, the total working capital tied up in safety stock had already been reduced by 19%.



**Figure 22:**  
Working capital reduction through multi-stage optimization

Though not the primary target, compared to the initial situation, a slight further improvement of the realized service levels was also noted for most of the product groups (fig. 23).

**Figure 23:**  
Multi-stage optimization result for major product groups



Besides the multi-stage optimization of the safety stock allocation, additional improvements were realized by refining inventory management processes and synchronizing replenishment policies. Together with a complementary lead time reduction, the capital tied up in inventories was finally decreased by 27.3%.

Of course, inventory optimization is not a one-time exercise. Product demands are changing according to the product life-cycle, existing products are introduced to new markets and alternative production facilities or suppliers may be used. Consequently, the re-evaluation of the optimal inventory allocation has been established as part of the tactical supply chain planning process.

*By streamlining the replenishment process and the implementation of an end-to-end inventory management inventories could be reduced by 27.3%.*

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**Your contact for further information:**

Camelot Management Consultants AG  
Michail Heinmann · Visionary Officer  
mhe@camelot-mc.com

**Camelot**  
**Management Consultants AG**  
Theodor-Heuss-Anlage 12  
68165 Mannheim  
Germany  
Phone +49 621 86298-0  
[www.camelot-mc.com](http://www.camelot-mc.com)

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