Benefits of Multi-Stage Inventory Planning in Process Industries

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1. Inventory Management as a Driver for Supply Chain Performance

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** and impairing **profitability**. Furthermore, reported inventory figures become more and more important indicators for investors and other external stakeholders when assessing the efficiency and health of a company.

However, there is still an ongoing trend towards **increasing inventories in process industries** due to volatile markets, increasingly complex supply chains, and the fear of lost sales due to stock-outs. Therefore, it is widely recognized that the improvement of inventory management and planning offers a large potential for supply chain cost reduction. While traditional inventory planning approaches have focused on optimizing inventories locally at each single site, significant additional benefits can be realized by jointly optimizing the inventories across the entire supply chain. According to Ellis et al. (2009), the use of so called **multi-stage inventory planning** approaches can typically generate a **15-25% inventory reduction** while simultaneously preserving or even increasing service levels.

However, determining the optimal inventory allocation in a supply chain is a challenging problem that requires appropriate decision support and planning systems. Modern multi-stage inventory planning approaches have to be capable of optimizing large and global supply chains as well as meeting the specific characteristics of process industries. Using such an advanced inventory planning approach allows to simplify planning processes considerably and to realize the **hitherto unexploited potentials** in cost reduction and service improvement.

1.1. Inventory Management in Process Industries

For virtually all companies in process industries such as chemicals and pharmaceuticals, inventory management is a field of highest importance for successful operations and supply chain management. Especially the rightsizing of safety stocks across the supply chain remains an unresolved challenge for many companies. In many cases, **safety stocks** are a **significant driver** of total **inventory costs** as they account for up to 50% of all stocks held in a supply chain (Nyhuis und Wiendahl 2003, p. 285).

However, inventories, in particular safety stocks, are crucial for ensuring high **service levels** in a supply chain as they buffer against variability in supply and demand. Processes like chemical reactions usually need a fixed amount of time (i.e. acceleration is not possible), have long lead times, and are difficult to stop and restart (Shah 2005). Thus, process output cannot be easily adjusted while the options for process redesign are limited. Consequently, inventories are essential to cope with demand fluctuations. Furthermore, process behavior is frequently non-deterministic regarding processing time and / or process output, thus requires safety stocks on the supply side as well. Companies aiming on the optimization of inventories have to ensure that their inventory planning approach is capable of addressing the different sources of variability in order to attain the targeted end-customer service levels. Failing to provide the promised customer service will typically result in declining revenues due to strong competition in process industries. Especially for companies in the pharmaceutical industry, **on-shelf availability** of drugs, virtually everywhere on the planet, is an integral part of the business model due to legal requirements and ethical obligations (Shah 2004).

In addition to such service considerations, the structure of supply chains in process industries calls for powerful inventory planning approaches and systems as well. The process industries typically feature divergent process structures in which few inputs (e.g. raw materials like crude oil) are transformed into a large variety of different outputs, thus leading to a **high number of SKUs** downstream in the supply chain. Especially in the chemical and petrochemical industry also co- and by-products are common, which often lead to a complex and sometimes cyclic flow of materials (Shah 2005). While in process manufacturing supply chains the inputs are in most cases bulk goods or liquids, they are frequently transformed into a discrete product output (e.g. tubes of toothpaste, cans of motor oil, soft-drink bottles). These outputs can be consumer goods or serve as inputs for other process manufacturing or discrete manufacturing supply chains. Manufacturing facilities in process industry supply chains are typically located around the entire globe with multiple warehouses in the different regions in order to guarantee high responsiveness. As a consequence, **inventory management in process industries** must optimize stock levels at a large number of sites and has to deal with long-lead times due to globally dispersed operations and long manufacturing cycles.

When right-sizing inventory targets in order to reduce costs and attain the targeted service levels, the key question for a supply chain planner in such complex networks is typically whether the required **inventories** should be held **more upstream** or **more downstream**, closer to the end-customers.

1.2. The Impact of Lean Supply Chain Management on Inventory Planning

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 (King 2009). However, traditional lean manufacturing is mainly focusing on material flows within plants, while the planning and synchronization of operations as well as the optimal management of information flows (e.g. propagation of demand signals) across the entire supply chain are not adequately addressed. In addition, 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 in process industries have coined the vision of **lean supply chain management** for the efficient planning and execution of material and information flows in an end-to-end way (Packowski et al. 2010).

In traditional planning processes, as proposed by the concepts of Material Requirements Planning (MRP I) and Manufacturing Resource Planning (MRP II), production and replenishment decisions are directly based on demand forecasts. In such a planning scenario, adjusting production is the default means of reacting to demand fluctuations. If the forecast- and planning-period is too long, accuracy of the forecast is usually low, resulting either in oversized inventory targets or in stock-outs due to insufficient inventory buffers. On the other hand, short forecast periods lead to frequent adjustments of the production schedule as short-term demand can be subject to significant fluctuation. Consequently, short forecast periods may lead to high setup costs and low capacity utilization.

To address these types of **waste**, lean supply chain planning is based on the principles of **'flow'** and **'pull'**. In contrast to the traditional planning approaches where material is pushed through the supply chain, in a pull system the material flow at each stage is triggered by a demand signal from the succeeding stages. A well-known realization of this concept is Kanban, which can be used to coordinate the material flow within a production facility (see Ohno 1988, pp. 25-28). In a Kanban system the production is controlled by a limited number of 'production cards'. As the amount of work in progress (WIP) is limited in such a pull system, overproduction is effectively avoided. It was shown that by limiting the amount of WIP, robustness and efficiency of a system can be significantly increased (Hopp and Spearman 2004). In general, the target of pull and flow is to "produce at a rhythm in synchronization with customer demand" (King 2009, p. 9). However, in most cases it would be highly inefficient to link the material flow to the fluctuating short-term demand. Regarding the linkage between customer demand and material flow, the pull concept must therefore be considered from a strategic point of view. This is where the second lean principle of 'flow' comes in.

To realize a **continuous flow** along the value stream, a technique called **'production leveling'** is used. The objective of production leveling is to smooth-out demand variations by defining a constant production rate based on the average demand over a reasonable period of time. Inventory is used to buffer operations from short-term fluctuation. To accommodate long-term variability and keep production in line with demand, the production rate is recalculated periodically or when the inventory level is running out of the defined upper or lower bound.

Compared to traditional planning approaches, lean supply chain planning uses inventories as the primary buffer against demand and supply variability, requiring well planned safety stocks. Consequently, inventory management is a key priority for lean supply chain management and planning. Moreover, to follow the guiding lean principle of avoiding waste, excessive stock must be eliminated wherever it occurs. In short, to realize the vision of lean supply chain management and planning, the **systematic optimization** of inventories must be actively addressed.

1.3. The Evolution of Inventory Management in Practice

Although many companies manage the inventory planning process **centrally** for all stages of the supply chain, the determination of inventory target levels (especially safety stock targets) for each stock point is usually done **in isolation**. Depending on the applied planning approach, six different **maturity levels** can be distinguished (Fig. 1). The figure 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 previous approximate planning policies with more systematic approaches.

In the most basic case, the same **parameter** is used to calculate the inventory target levels for all products, e.g. a fixed number of coverage days. On the second level of the maturity model individual stock parameters are applied, based on the planners' experience. On the third level a structured **segmentation** approach is used and individual planning parameters are defined for each segment. For example, products are segmented according to their sales volume or their demand characteristics. However, the definition of the planning parameters for each segment is still based on experience or rules of thumb. In contrast, optimization approaches (maturity level 4 – 6) explicitly take into account the **economic reasons** for holding inventories. Identifying and analyzing the different stock components facilitates the application of appropriate optimization approaches for each type of stock, e.g. cycle stocks can be optimized in the course of lot-size determination. A significant inventory reduction potential is given by the right-sizing of safety stocks. Maturity level five is therefore characterized by the additional use of **analytical optimization models** for the determination of safety stock levels based on the observed demand and supply variability and the desired service level.

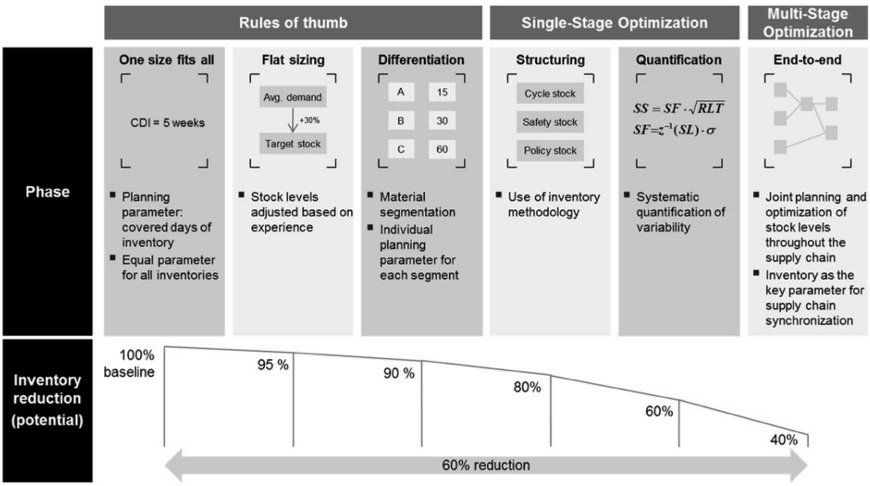

Figure 1: Maturity model of inventory management (source: Heinmann and Klein, 2011)

Finally, maturity level six refers to the use of **multi-stage** approaches for the joint planning and optimization of inventory levels throughout the supply chain. Using such a multi-stage inventory planning approach is essential to fully **exploit potentials** in cost reduction and service level improvement across the **entire** supply chain.

2. Effective Inventory Management through Multi-Stage Planning

This section aims on providing an overview of the **key principles** and **benefits** of a **multi-stage inventory planning approach**. It starts with a brief illustration and comparison of the basic concepts of single- and multi-stage optimization. The second part of this section explains from a managerial point of view the underlying **drivers** of the **inventory allocation** within a supply chain which are considered in a multi-stage inventory optimization. Finally, it is shown how to tackle the problem of inventory allocation in complex global supply chains through the use of cutting-edge multi-stage optimization tools.

2.1. The Difference between Single-Stage and Multi-Stage Inventory Planning

One of the key challenges in inventory management is the **determination of safety stocks within the supply chain**. On the one hand, safety stock is crucial to mitigate the effect of demand and supply variability and to maintain the desired level of customer service. On the other hand, in many supply chains safety stocks are unnecessarily high and offer one of the largest untapped potentials for cost reductions. By using multi-stage inventory models, the amount and cost of inventory required to attain the targeted service level can be substantially decreased (or vice versa, for the same inventory cost a higher customer service can be realized). To understand why multi-stage optimization leads to better results, it is useful to recognize the difference between single- and multi-stage inventory optimization.

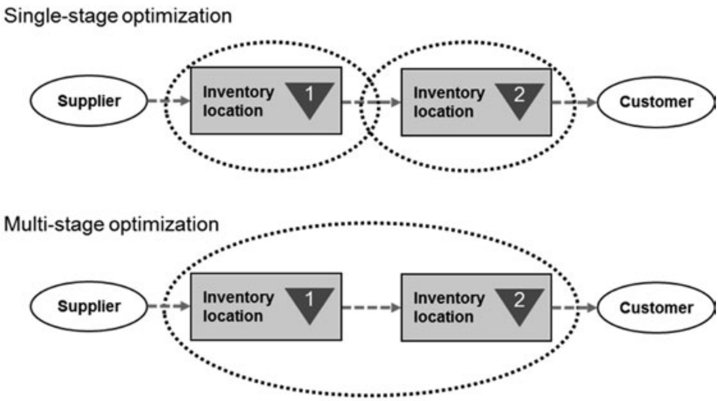

Figure 2: Single- vs. multi-stage inventory optimization (source: Heinmann and Klein, 2011)

The key difference between single- and multi-stage inventory optimization is illustrated in Fig. 2. Traditional **single-stage inventory planning** optimizes safety stocks **locally** at each stage or location of the supply chain and the required amount of inventory is determined by applying appropriate inventory models which typically depend on local replenishment times, local demand and supply characteristics, as well as locally defined service requirements (detailed overviews on single-stage approaches are provided in Silver et al. 1998 and Thonemann 2010). As a consequence, each stage of the supply chain holds safety stocks to buffer against variability.

Unfortunately, single-stage optimization models do not take into account the **dependencies between the stages** of the supply chain. Considering a basic two-stage supply chain, it is clearly visible that the replenishment time of the downstream stage depends on the stock equipment of the supplying upstream stage. However, the expected replenishment time is a key parameter for determining the appropriate inventory target level. While single-stage optimization models are very useful for **inventory right-sizing**, they are unable to give advice on the **placement of buffering stocks** within the supply chain. In fact, it is the **consolidation** of buffering stocks that often leads to significantly lower overall costs. When using single-stage inventory optimization, either buffering stock is held at all stages or these 'decoupling points' have to be determined manually, prior to the inventory right-sizing. With regard to the size of supply chains in industry, however, such a manual determination is a needle in a haystack**.** In contrast, **multi-stage optimization approaches simultaneously optimize the placement and sizing of inventories** within the entire supply chain, while considering all dependencies of the material flow between the stages (Klosterhalfen 2010).

2.2. The Principles of Multi-Stage Inventory Planning

The objective of multi-stage inventory optimization is to determine the **allocation of safety stocks** within a supply chain that guarantees a high customer service level at the lowest cost possible. Safety stock costs result from the total amount of safety stock held in the supply chain as well as from the associated holding costs per unit of stock.

From a managerial point of view, it is very useful to understand the **drivers of inventory allocation** that determine whether the required inventories should be held rather upstream or downstream within the supply chain. In the following, the **key principles of multi-stage inventory optimization** and their impact on inventory allocation are illustrated. Generally, the cost-optimal allocation of safety stocks results from the **trade-off between four basic effects** (Fig. Figure ***3***).

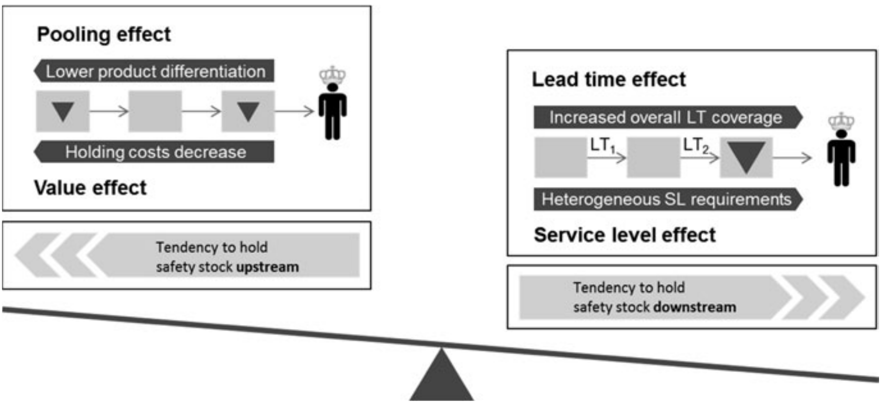

Figure 3: Safety stock allocation as a trade-off between four basic effects (source: Heinmann and Klein, 2011)

Value effect

As the total cost for buffering stock in the supply chain is linked directly to the average per-unit holding cost, there obviously is a tendency to **consolidate safety stocks at stages where holding costs are low**. Holding costs are mainly determined on the basis of the value of stock held, which generally increases through the stages of the value-added process. As shown in Fig. 4a, the value effect therefore suggests keeping buffering stocks at upstream stages, where capital costs are lower. In fact, a multi-stage inventory optimization typically leads to a result where safety stocks are partly consolidated prior to stages with a significant increase in product values.

Demand pooling effect

Process industry supply chains typically exhibit a sharp increase in the number of SKU-location combinations towards downstream stages due to global distribution structures and strong product differentiation. In supply chains with such diverging material flows the overall inventory level can be reduced by relocating safety stocks to upstream stages as depicted in Fig. 4b. As a part of short-term demand fluctuations from the different downstream stages is typically balanced out, less safety stock in total is required for the **joint buffering of variability** from different downstream SKUs (respectively from different customer demands), an effect which is known as **demand risk pooling**. The impact of the demand pooling effect depends on the number of downstream SKUs which can be jointly buffered, the level of demand variability at the downstream stages, and the correlation between these demands.

Lead time effect

The lead time effect describes what is also known as **'risk pooling over time'**. The purpose of safety stock is to cover fluctuations in supply as well as variability of demand during the expected replenishment time. Hence, the required amount of safety stock is directly linked to the time between the trigger of a replenishment order and the availability of the respective material. However, due to the fact that random, short-term demand and supply fluctuations are usually balanced out over time, the required amount of safety stock does not increase linearly with the replenishment time, i.e. when the time it takes to replenish an inventory is doubled, significantly less than twice the amount of safety stock is required to provide the

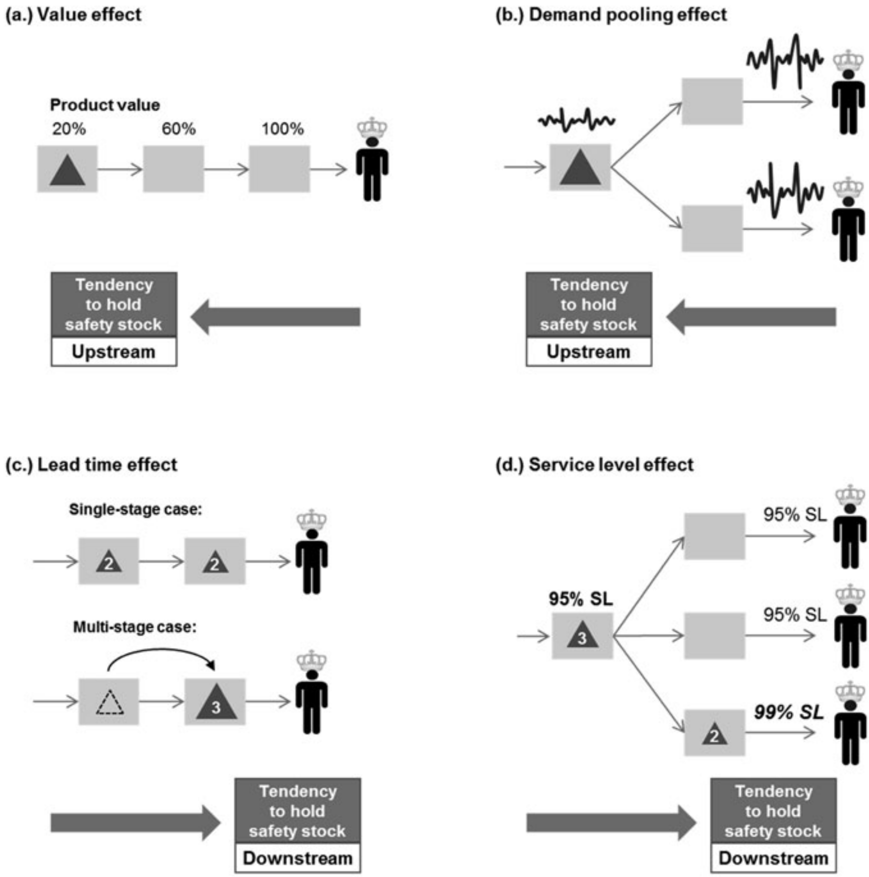

Figure 4: Multi-stage effects (source: Heinmann and Klein, 2011)

same level of customer service. Consequently, comparatively less safety stock is required if stock buffers are consolidated at downstream locations in a multi-stage supply chain as illustrated in Fig. 4c.

Service level effect

In analytical inventory optimization models, the size of the required safety stock buffers is determined by the observed variability and targeted service level. However, the targeted customer service levels may not be the same for all end-customers at downstream stages. For example, the various distribution channels in the pharmaceutical industry typically have different service requirements. If **heterogeneous service levels** have to be taken into account, centralizing safety stock can be unfavorable, as it would raise the problem of dealing with demands from the different downstream stages in the case of a material shortage at the centralized inventory. From a practical point of view, it is therefore beneficial to buffer high service requirements locally as shown in Fig. 4d, thereby avoiding the need for complex inventory control and allocation policies.

2.3. How to optimize Inventory Allocation in Global Supply Chains

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** (see e.g. Lee and Billington 1993, Graves and Willems 2000 and 2003, and Klosterhalfen 2010 for a comprehensive overview) 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 function of a **built-in multi-stage optimization**, most of the **available multi-stage tools** can be **integrated** into existing ERP and APS systems (Ellis et al. 2009, Schröder and Francas 2010).

A suitable multi-stage inventory optimization approach has to simultaneously consider the four drivers of inventory allocation, described in the previous section, as well as to efficiently master the complexity of the whole planning problem when jointly optimizing size and location of safety stocks. An example can help to illustrate the complexity of multi-stage inventory optimization and demonstrate why **efficient optimization systems** and engines are needed.

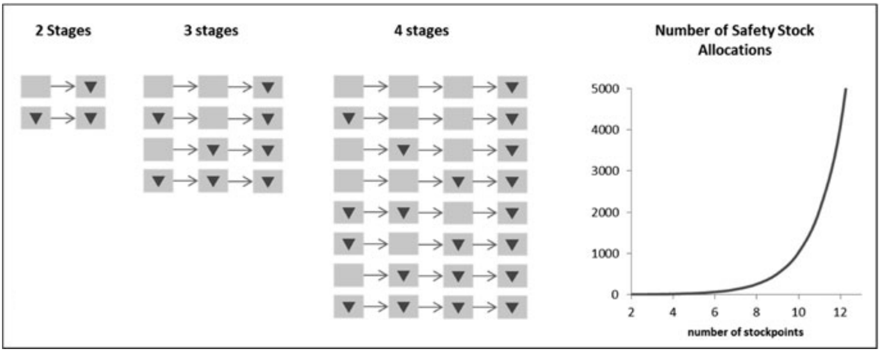

Figure 5: Complexity of multi-stage inventory planning in supply chains (source: Heinmann and Klein, 2011)

Even if the attention is restricted to 'all-or-nothing policies' in which a stage either holds no inventory or holds enough inventories to always satisfy demand from the shelf, the **number of possible configurations** for stock placement **grows rapidly** with the size of a supply chain as shown in Figure 5. In a rather simple serial three-stage supply chain, one has to consider four different options, while the number of options increases to eight in a four-stage supply chain, and to 16 in a five-stage supply chain. In detail, the number of potential stock allocations is given by 2^n, where n is the number of non-final stages (SKU-location combinations) in the supply chain. If we consider real-world supply chains, multiple production and distribution sites with hundreds or thousands of unique SKU-location combinations have to be considered. For each SKU, one has to determine the optimal inventory location and size, while simultaneously considering the interdependencies in the supply chain caused e.g. by bill of materials / recipe structures. Consequently, the **number of possible stock allocations grows to billions** in a supply chain of practical size.

Clearly, the **complexity** of multi-stage inventory planning cannot be mastered by using spread-sheet-based approaches. Instead, a multi-stage inventory planning tool is required that allows to optimize large supply chains in reasonable times. Based on advanced planning algorithms, leading multi-stage tools are able to provide solutions for large and complex supply chains within minutes or even seconds (Humair and Willems 2011).

From a data management perspective however, the difference between single-stage and multi-stage inventory optimization approaches is less pronounced. As shown in Table 1, the **data requirements** of both approaches are **very similar**. Additional data requirements for multi-stage inventory planning are especially bill of materials / recipe information and the value of holding costs across supply chain stages. Therefore, companies that use single-stage inventory optimization approaches already have virtually all data to **extend their inventory management to multi-stage capability**.

Required data	Single-stage	Multi-stage
Structure of the material flow / supply chain	(✓)	✓
Processed SKUs for each stage in the supply chain	✓	✓
Demand series for all end-item SKUs	✓	✓
Lead times for all stages in the supply chain	✓	✓
Service level requirements	✓	✓
Holding costs per stage	×	✓
Bill of material / recipes, i.e. input materials for all SKUs	×	✓

Table 1: Comparison of data requirements for single-stage and multi-stage inventory planning (source: Camelot Management Consultants)

3. Case: The Optimization of a Blockbuster Drug's Supply Chain

The following case illustrates the multi-stage inventory optimization of a pharmaceutical supply chain which has been conducted by **Camelot Management Consultants** as part of a comprehensive supply chain optimization project. The supply chain described in this chapter belongs to one of the world's top-selling branded pharmaceuticals, with multi-billion annual revenue figures.

Description of the Supply Chain

As typical for the pharmaceutical industry, the supply chain of the blockbuster drug is highly globalized. In brief, the production of the blockbuster drug comprises four major production steps (Fig. 6). At a production site in France the so called active pharmaceutical ingredient (API) of the blockbuster drug is synthesized from a chemical precursor. This precursor is produced by two different subcontractors, located in Japan and Italy. Though the same substance is produced by these two subcontractors, there is no sourcing decision at the API production site, as a fixed quota is determined for the two subcontractors based on contractual agreements. Raw materials required for the precursor production are obtained from external suppliers. At a drug formulation site in the US the API is brought into different pharmaceutical forms, e.g. into tablets of different dosages. These bulk drugs are then shipped to a number of packaging sites around the world, where they are bundled to sales units of different types and sizes and finally sold to pharmaceutical distributors, hospitals, and other external customers.

Fig. 6 also displays the lead times between the stages, the number of considered SKUs and the cumulated value added. Due to the geographical distance between the production sites and the rigid quality control processes which are mandatory for any pharmaceutical operation, lead times between the different stages are comparatively long. Within the supply chain most of the value is created during API production and drug formulation. In fact, the contained API commonly accounts for the major part of finished drug product's value, whereas other input materials like excipients and packaging materials have only a marginal value. As a consequence, the inventory optimization project focused on the material flow associated with the blockbuster drug's API. The number of SKUs in main focus is shown in Fig. 6. The **strong product fan-out** at the final stage of packaging can be traced back to the need for country-specific sales packages due to national requirements (language, legal regulations).

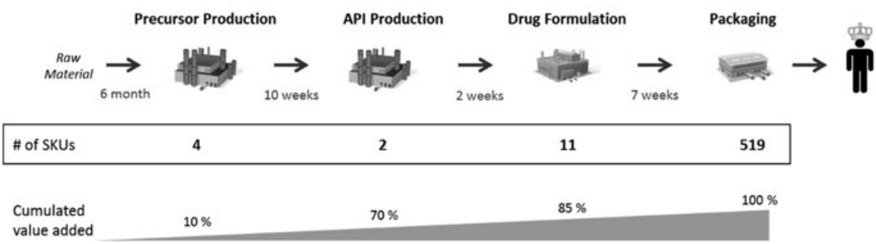

Figure 6: Supply chain characteristics (source: Camelot Management Consultants)

The Challenge

The situation initially found in the blockbuster drug supply chain was characterized by **ample stocks** at most stages and by the dominance of **local inventory and replenishment planning**. While overall inventory levels were fairly high, significant differences could be observed between the various production and distribution sites, with the individual inventory efficiency being largely dependent on the capabilities and experience of the responsible local planners. Due to these local responsibilities, **safety stocks** were virtually **spread over the entire supply chain**. Though the service level for the finished products was very high (around 99%), at upstream production sites the lack of a common global planning process frequently led to 'firefighting' actions like short-term re-scheduling and thus to a **volatile capacity utilization**.

The Inventory Optimization Project

The optimization project was divided into two parts, associated with corresponding project milestones. In the first phase of the project, the most important inventory locations were analyzed and optimized individually. By applying a **systematic single-stage approach**, inventories worth **several million dollars** could already be freed up within few weeks, without compromising on customer service. Based on these 'quick wins', the second and major phase of the project was about developing and establishing a new common process and platform for inventory and replenishment planning of all stages in the supply chain. This objective included organizational adjustments as well as the implementation of a new global planning system. Furthermore, a part of this project phase was to **optimize the safety stock allocation** within the supply chain, which was realized by the use of an advanced multi-stage optimization tool.

The structure of the supply chain and the number of SKUs at each inventory location are displayed in Fig. 7. Prior to the multi-stage optimization, safety stock was held at each of these locations.

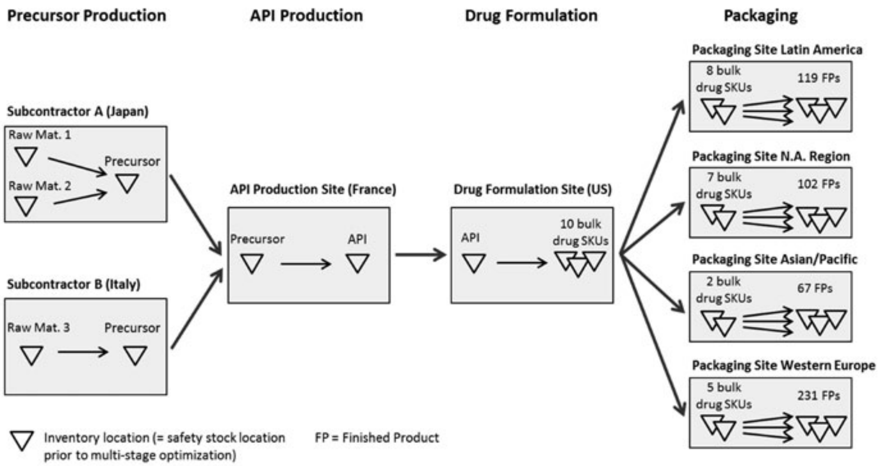

Figure 7: Supply chain structure (source: Camelot Management Consultants)

Multi-Stage Optimization Results

Fig. 8 represents the optimized safety stock allocation for the blockbuster drug supply chain. As a result of the multi-stage optimization, safety stock was **consolidated** at rather few stages in the supply chain. Stock buffers of finished products at the packaging sites are required to ensure on-shelf availability. In addition, safety stock was consolidated at the inbound sites of the API production and formulation, which now act as the 'decoupling points' within the supply chain.

As the service level was already very high in the initial situation, the primary focus of the project was on **decreasing stock levels**. For the multi-stage optimization a target service level of 99% was defined. However, few months after the safety stock consolidation it was reported that the actual OTIF-fill-rate (customer orders delivered on-time-in-full) was even slightly higher than before the optimization.

The **financial impact** of the multi-stage optimization is displayed in Fig. 9 and is measured in terms of total safety stock value (i.e. working capital tied up in safety stock) before and after the multi-stage optimization and aggregated for each stage of the value chain. Compared to the situation after the single-stage optimization, the multi-stage optimization resulted in an additional reduction of total working capital tied up in safety stock by **19%**. Especially in the upstream

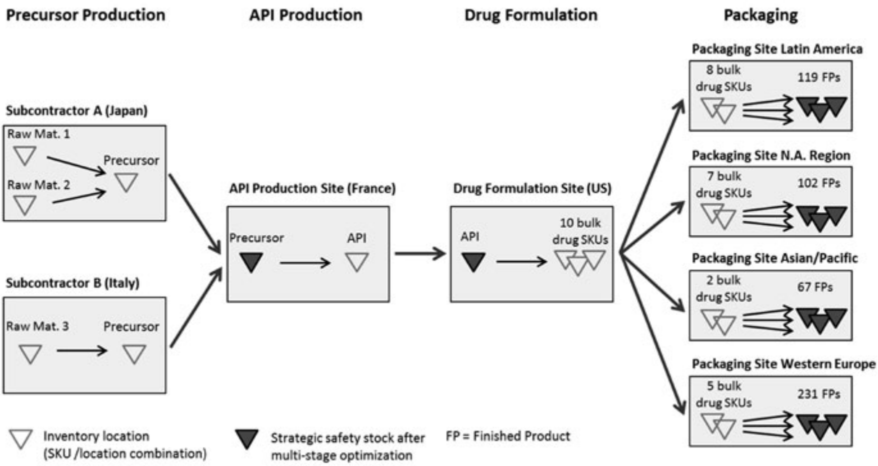

Figure 8: Optimized safety stock allocation
(source: Camelot Management Consultants)

part of the supply chain, i.e. from precursor production to formulation, the total amount of buffering stock could be significantly reduced through the inventory consolidation, which can be explained with the strong impact of the lead time risk pooling effect.

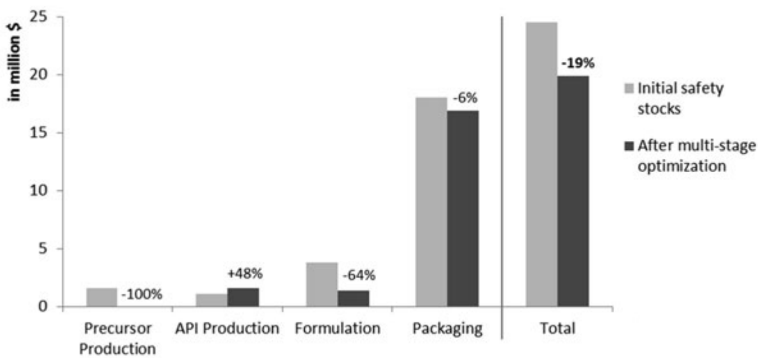

Figure 9: Working capital reduction through multi-stage optimization
(source: Camelot Management Consultants)

4. Summary and Conclusion

Successful inventory management has highest priority for supply chains in process industries. Inventories are a **major driver** of **working capital** and thus intensively monitored by shareholders and investors of companies. Furthermore, especially safety stocks are crucial to attain the promised customer service and to enable smooth operations and material flows in a firm as advocated by the principles **of lean supply chain management**.

Multi-stage inventory planning approaches provide an efficient measure to optimize especially safety stocks in a supply chain, which typically account for a major share of total stocks and are among the key drivers of high service levels to the customer. By **optimizing both location and size** of safety stocks, multi-stage inventory planning exploits previously **untapped improvement potentials** within a supply chain.

Empowered by latest state-of-the-art research, modern multi-stage inventory planning tools are capable of optimizing the **complex and global supply chains** in process industries and can be successfully **integrated** in existing planning processes and IT-landscapes. As industry cases show, the resulting **cost reductions** and **service improvements** through multi-stage inventory planning are substantial.

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