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Inventory sizing for supply risk hedging: the Hilti case

Author:
Carlo PIAZZA 875188

Supervisor:
Professor Paolo TRUCCO

Co-supervisor:
Brian SIEBEN

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Declaration of Authorship

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Carlo Piazza

"How did you go bankrupt?" Bill asked. "Two ways," Mike said. "Gradually and then suddenly."

Ernest Hemingway, The Sun Also Rises (1926)

POLITECNICO DI MILANO

Abstract

Mechanical Engineering
Department of Mechanical Engineering

Master of Science in Mechanical Engineering

Inventory sizing for supply risk hedging: the Hilti case

by Carlo PIAZZA 875188

Hilti attualmente mitiga i rischi di supply disruption dimensionando le scorte di sicurezza basandosi sulla domanda media dell'anno precedente. In caso di un picco nella domanda durante un'interruzione della fornitura, il livello di copertura reale può risultare drasticamente inferiore a quello previsto. Questa tesi propone un approccio statistico finalizzato all'ottimizzazione dell'inventario dal punto di vista del rischio. Viene effettuata una previsione della domanda dell'anno successivo, decomposta in tre componenti: tendenza, stagionalità e variabilità casuale. Per quanto riguarda la tendenza e la stagionalità, è possibile reagire regolando i ritmi produttivi o attraverso l'utilizzo del cycle stock. Le scorte di sicurezza connesse al rischio vengono influenzate solamente dalla componente non prevedibile di disturbo. Ai manager vengono proposti nuovi punti di vista a supporto della riduzione dei livelli di inventario e del rischio di stockout.

Hilti currently mitigates supply disruption risks by sizing safety stocks based on previous year's average demand. Hence, in case of a peak in the demand during a supplier outage, the real coverage level can be drastically lower than the expected one. This thesis proposes a statistical-based approach to optimize the inventory on a risk perspective. The demand for the next year is forecasted and decomposed into three components: trend, seasonality and random variability. For the first two elements it is possible to react by adjusting the production or by using a cycle stock. The risk-based safety stock will be depending only on the non-forecastable noise. Managers are provided with insights to support reduction of inventory levels and of stockouts.

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List of Abbreviations

APO	Advanced Planner and Optimizer
BA	Business Area
BCP	Business Continuity Plan
BI	Business Interruption
BI12	12-Months Bunsiness Interruption risk
BIeff	Effective Bunsiness Interruption risk
BIRS Tool	Business Interruption Risk Tool
BOM	Bill of Materials
BU	Business Unit
CW	Central Warehouse
DOH	Days on Hand
EB	Executive Board
EMT	Extended Management Team
ERP	Enterprise Resource Planning
HC	Hilti Center
HK	Herstellkosten - Manufacturing cost
HQ	Headquarters
MTO	Make to Order
MTS	Make to Stock
MTTR	Mean Time to Repair
PVO	Purchase Volume
RM	Risk Management
RMO	Risk Management Organization
RO	Risk Owner
SC	Supply Chain
SCM	Supply Chain Management
SCR	Supply Chain Riks
SCRM	Supply Chain Risk Management

Dedicato a mia mamma e mio papà...

Chapter 1

Introduction

1.1 Supply Chain Complexity

1.1.1 Fragmentation of supply chains increases risk exposure

Recent events have convincingly proved that a disruption affecting an entity at any point in a supply chain can have direct consequences on a corporation's ability to maintain operations, get finished products to markets or provide critical services to customers. This effect is amplified in supply chains running thousands of companies over several tiers (Jüttner, Peck, and Christopher, 2003).

Fragmentation in supply chains is due to the presence of various suppliers and component manufacturers in the creation of a finished product. Companies, located in different geographical areas, produce parts while assembly stages are performed elsewhere. Thanks to fragmentation it is possible to be effective on costs and gain competitive advantages in a global market. However, fragmentation has its drawbacks. For example, the two main critical factors affecting the performance of a fragmented supply chain are uncertainty of lead times and supplier reliability. An event affecting a supply chain entity or process might interrupt the operations of other supply chain members.

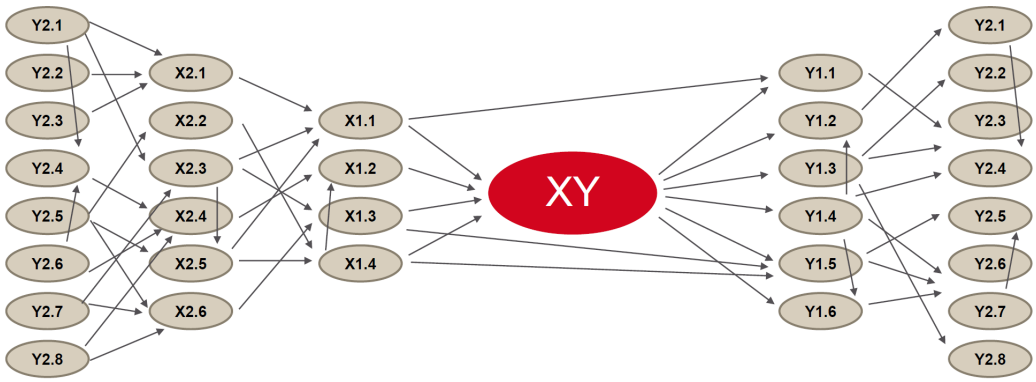

FIGURE 1.1: In a fragmented supply chain network multiple-tier suppliers connected with a manufacturer XY increase complexity

Figure 1.1 illustrates a typical supply chain from the perspective of a manufacturer XY, including three-tier levels of suppliers/sub-supplier, where materials flow into and through XY, and two levels of distribution, where materials flow away from XY toward the end customer. The first digit indicates the level and is decreasing the closer it gets to the manufacturer, while the second one only differentiates the nodes. The arcs are depicted as arrows indicating materials' flow.

Modern supply chain trends such as globalization, decentralization, outsourcing and Just-In-Time are introduced to try and make supply chains efficient. However, this has led to an increase in the number of exposure points (Stecke and Kumar, 2009). Complexity within the supply chain system can be defined as a condition occurring due to the association of numerous inter-related and inter-dependent entities in the supply system using several process inter-connections (Ghadge, Dani, and Kalawsky, 2013).

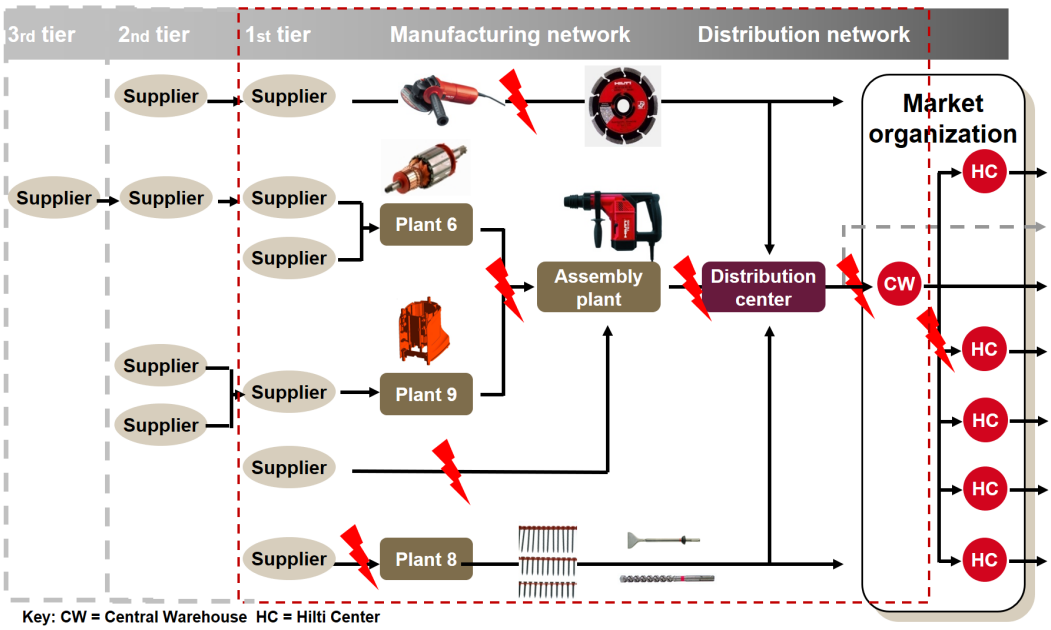

FIGURE 1.2: An example of vulnerability nodes within the Hilti supply chain

The complexity of the supply chain is not only due to the ramification of its flows but also to the nature of the nodes. Being organic entities, they can dynamically make decisions and take actions based on their current needs and convenience. For example, the decision of replacing a certain low performance supplier with another one could have an impact on the whole network, leading to a completely redefined arcs' system. This is increasingly leading firms to consider risk management topics in their normal business, due to the awareness that they need to rely on effective Supply Chain (SC) to be able to compete in a global environment. Supply chain management (SCM) is the management of material, information and financial flows through a network of organizations for the purpose of producing and delivering products or services.

The overall aim of a supply chain is the profit maximization by researching the best balance between productivity (efficiency) and profitability (effectiveness) (Manuj and Mentzer, 2008). It implies the coordination and collaboration among functions such as production, sales, marketing, research and development, procurement, logistics and finance within a network of sub-tier suppliers, logistics providers, manufacturers, distributors, and retailers (Tang, 2006). The different entities of the network are connected by the physical flow of materials, which reach the final customers in some desired form and quantity.

1.1.2 Globalization exasperates logistic complexity

When discussing SC fragmentation, it is automatically linked to globalization. Companies look for cost-effective suppliers or new technologies that are often located abroad. Therefore, companies have a global view of their supply chain, reaching across all countries, when talking about the selection and implementation of risk management strategies.

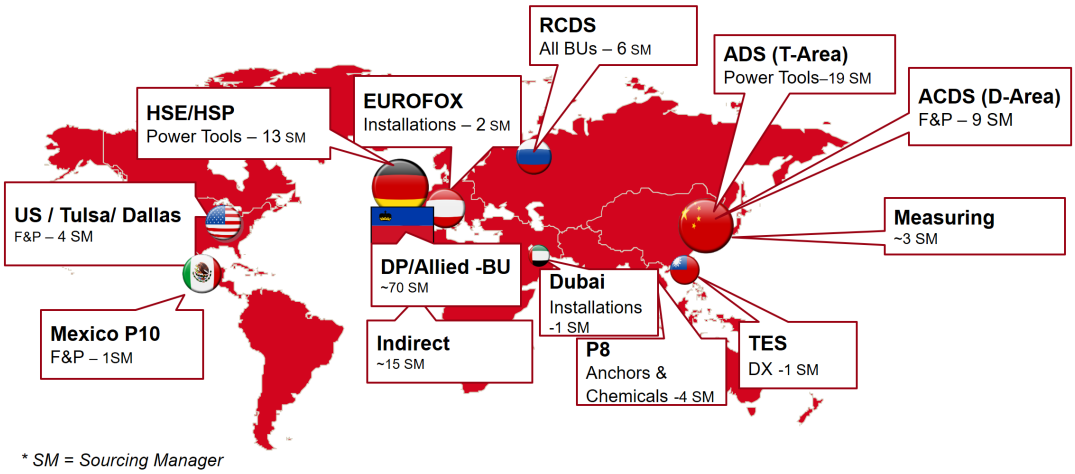

FIGURE 1.3: Hilti has a rather international sourcing set up

International supply chains involve more risk than domestic supply chains. Inventory management, border-crossing procedures, and transportation delays in case of international logistics involve more challenges, potentially impacting product availability, than domestic logistics.

Longer pipelines imply longer lead-time that require higher inventory. More inventory could be not profitable especially for product types experiencing rapid obsolescence. Longer shipping routes, transportation, and lead time affect product availability risk (Canbolat et al., 2008). Canbolat (2008) studied the effect of globalization on the SC. A global supply chain deals with additional risks due to cultural, political, legal, and technological differences as well as the distance between the outsourcing company and the supplier. A global supply chain, must face a lot of potential delay points and uncertainties between all its stages, thus requiring an incredible effort in coordination, communication and monitoring.

The risk can become huge when compared to the outsourced part price. For example, the monthly need of the component "Carbon Ribbon 83mm" is 31'500 meters, corresponding to an overall monthly invoice value of 800 Swiss Francs (CHF). Such component enters in different finished items' bills of material, and is mostly used for the production of consumables such as injectable mortars in the chemical anchors portfolio (Figure 1.4).

FIGURE 1.4: If one of the components in the bill of material is not available, it is not possible to produce the finished item

However, if production of such items stops due to a shortage of this particular carbon ribbon, the company could incur a profit loss of 3 MCHF each month, coming from the injectable mortars' lost sales.

1.2 Supply Chain Vulnerability

1.2.1 Understanding key risk exposures to proactively react

Many organizations actively try to anticipate terrorism acts, product quality issues as well as health and safety incidents. These problems potentially impact any company and cannot always be predicted or prevented.

Unexpected events can trigger new laws and regulations, which demands to actively react and adapt. Supply chain is a crucial part of organization growth and needs to be protected as much as physical assets and employees. Supply chains are dynamic and continuously expanding in dimension and growing in complexity. In this context they are always vulnerable to more risks. Many threats can be identified and fairly easily managed, but many others are difficult to be spotted.

For a company, having a full visibility of its own SC is a critical mission as, it is important to maintain a resilient SC to keep performances at high levels.

The Supply Chain Resilience Report 2018, issued by the Business Continuity Institute (BCI SCR), states that over the previous 12 months, based on a sample of 589 firms in 76 countries:

- 56% of organizations suffered at least one instance of supply chain disruption
- 52% of those disruptions occur at tier 1 suppliers, 23% at tier 2 suppliers
- 30% of firms do not analyze the full SC to identify sources of their disruption

Although organizations continue to look for trade maximization through modernization of their SC infrastructures and processes, they also need to focus on the increasing potential hazards, caused by fragmentation. According to the BCI SCR 2018, companies suffer disruptions mostly from a financial point of view. However, many professionals also record logistics and reputation impacts as long term repercussions of an incident. Short term consequences of disruption are, among others, loss of productivity, increase cost of working, and customer complaints.

Suppliers in developing countries can be more vulnerable to financial crises due to economic instabilities. Each kind of unpredictability has an impact on technology limitations, inventory management, quality and transportation delays across borders. For example, due to complexity and vulnerability of international logistics, companies increase their inventory levels to mitigate product delay risk. However, higher inventory implies higher stock holding cost and risk of product obsolescence and lower flexibility to react to changing markets (Canbolat et al., 2008). In a global environment the most common challenges supply chains deal with must consider differences in economies (transfer prices, tax rates, duties, exchange rates and inflation), cultures, politics (stability of government, law, etc.), infrastructure (banks, warehouses, transport agencies, etc.) and the overall competitive environment. The competitive environment together with the high resource requirements may be a source of big challenges in terms of customer service levels, anticipated costs and desired profitability (Manuj and Mentzer, 2008).

The performances of a supply chain can be affected by various vulnerabilities, ranging from unpredictable natural threats to economical issues or customers' trends. Supply chain vulnerability can be defined as "the propensity of risk sources and risk drivers to outweigh risk mitigating strategies, thus causing adverse supply chain consequences" (Jüttner, Peck, and Christopher, 2003). Supply chain risk management aims to address and avoid such vulnerabilities in complex and dynamic supply and demand networks, proactively by supporting robustness and reactively by supporting agility (Wieland and Marcus Wallenburg, 2012).

1.3 Supply chain risk management practices

1.3.1 Adoption of SCRM practices is increasing trough the years

In a volatile environment of increasing complexity and vulnerability, organizations acknowledge the importance of reporting disruptions. Firms have to take risk to make profit and high profit involve bigger risk. However, it is needed to differentiate between risk taken as a consequence of accurate judgment and risk taken unintentionally. It is clear that supply chain risk management is a broad field where interrelations among different factors lead to the need of a systematic approach. Strict collaboration across supply chain partners is compulsory to ensure the continuity of the business.

In the BCI SCR reports, it is possible to observe an upward trend in terms of emergency readiness as always more professionals address insuring financial losses. Furthermore, there are business continuity arrangements in place for many firms. This positively impacts areas such as SC visibility and top management commitment.

One of the highest operational risks faced by firms is the breakdown of suppliers' production plants or at own factory premises, with the consequences of not being able to supply their own demand. SCRM practices provide, in this context, guidelines on how to identify, assess, and manage potential risks that are threatening the supply chain. Reputations issues, loss of market share and many other threats continuously push organizations towards the implementation of a set of performance measurement standards capable to master a complex set of relationships. Companies are always more into SCRM practices in order to reduce their risk impact to a defined acceptable level.

1.3.2 There are still opportunities for refinement

Even if the attention towards supply chain resilience topics is continuously increasing, there are still opportunities for improvement. For example, according to the BCI SCR, strong top management commitment, one of the most important factors to ensure resilience, has declined from last year by 7%, even though it stays within the average value for the last 5 years (33%). Further, many companies admitted that they do not evaluate the full extent of their supply chain in case of disruption (30%). Different strategies are adopted by firms to foresee potential issues and prepare to both those risks and unforeseeable supply chain disruptions quickly and efficiently. The goal of the implementation of supply chain risk management practices is straightforward: Reducing the overall supply risk exposure to ensure business continuity under consideration of loss expectancy and costs for risk mitigation measures.

Chapter 2

Hilti

2.1 The Hilti Group

2.1.1 Who is Hilti

Hilti makes construction site work simpler, faster and safer. The company develops and manufactures products, systems, software and services that provide the construction and energy sectors with clear added value. Hilti stands for quality, innovation and direct customer relationships.

The company was founded in 1941, and evolved from a small family company to a world market leader in fastening and demolition technology for construction professionals. The groups' headquarters are in Schaan in the Principality of Liechtenstein, where Martin Hilti established the company 75 years ago and it counts roughly 28,000 employees in more than 120 countries. All company shares are in the possession of the Martin Hilti Family Trust, which ensures the long-term continuity of the company.

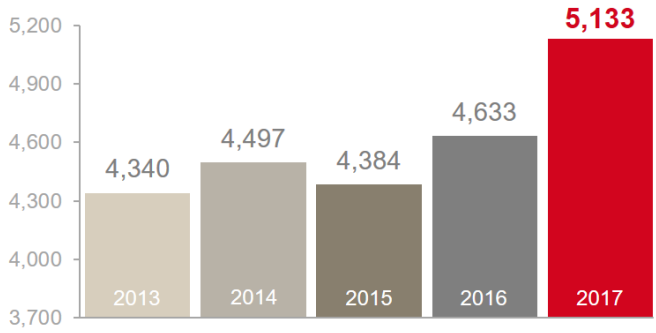

FIGURE 2.1: Hilti's Net sales in CHF million

Hilti is a direct sales approach company with over two-thirds of team members working directly with the customers every single day. The group has roughly 250'000 individual interactions each day, meaning that many innovative ideas are developed directly on construction sites.

	2017* in CHF million	2016** in CHF million	Change in CHF (%)	Change in local currencies (%)
Europe	2,469	2,222	11.1	9.7
North America	1,218	1,120	8.7	8.5
Latin America	128	117	9.4	9.7
Asia/Pacific	700	662	5.7	5.3
Eastern Europe / Middle East / Africa	618	512	20.7	17.4
Hilti Group	**5,133**	**4,633**	**10.8**	**9.6**

* incl. acquisition of Oglaend System Group (0.8 percentage points / CHF 38 million)
** incl. disposal of Unirac (CHF 17 million)

FIGURE 2.2: Net sales per region

If there is a challenge on the construction site for which there is no Hilti solution, one will be developed. This is why the company invests approximately 6 percent of sales each year in research and development.

Products	**Services**
Measuring systems	Engineering
Drilling and demolition	Fleet management
Diamond coring and cutting	Hilti Tool Service
Cutting and sanding	Repair service
Screw fastening systems	Delivery service
Cordless technology	Training and consulting
Direct fastening	
Anchoring systems	
Fire stop systems	
Foam systems	
Installation systems	
Software	

TABLE 2.1: Hilti products and services

2.1.2 Hilti business model

FIGURE 2.3: Hilti business model

Direct customer service

"We believe strongly in close and trusted relationships with our customers. We run a direct sales model, with around 15,000 of our Hilti team members working directly with our customers, worldwide. We work closely with our customers online, on the phone and onsite. We also run our own string of Hilti Stores where the construction industry can buy Hilti products directly from our own stores. Our sales reps and field engineers go out onsite, helping to find solutions – whether it's choosing the right kind of nail or designing a rebar system for a major metro system. This all gets fed back to our design labs, so we know what's needed to create even better and more daring projects."

We develop and make our own products

"At Hilti we know construction is dangerous and full of challenges. So we're constantly working to find solutions to make working on site faster, easier and safer. We run our own research and design labs, with specialist scientists and engineers inhouse. We also work with top technical universities worldwide to share research and push our boundaries even further. We make our own Hilti products and run our own factories in Europe, Mexico, the USA, India and China. We also work with external specialist suppliers, making sure that everything we make conforms to the same very high quality standards, both inhouse and externally."

Our people make us different

"Our people are Hilti. Our team members guide our everyday work and make our everyday decisions. We're passionate about our work and many of us have worked at Hilti for 10, 15, 20 years. We are strongly guided by our four Hilti values – integrity, courage, teamwork and commitment – which are lived every day, by every team member, in every location where we work."

Corporate Strategy Champion 2020

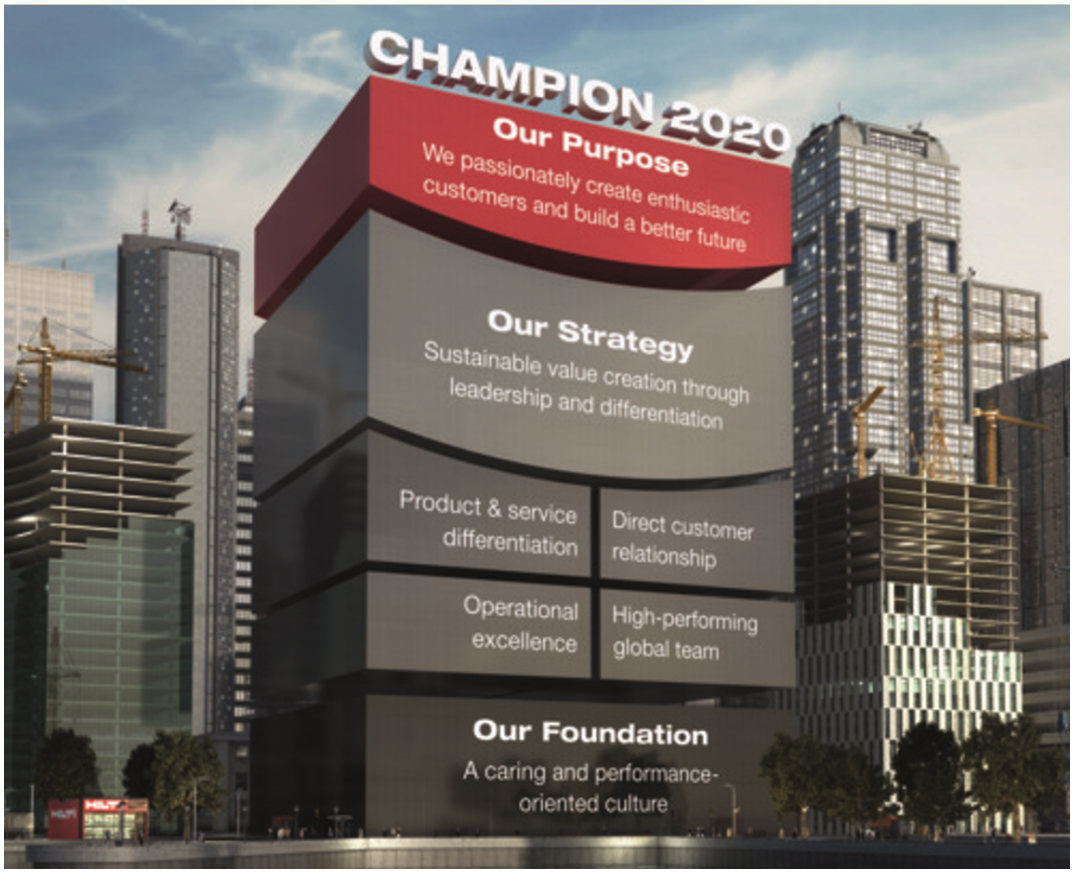

FIGURE 2.4: Hilti corporate strategy

Champion 2020 corporate strategy goals:

- Hilti aims to achieve sustainable value creation through leadership and differentiation. Market leadership through added value for Hilti customers by offering products, services and software that provide superior productivity and safety to Hilti customers and differentiate from the offering of competitors.
- With this Hilti brings the core purpose statement to life: "We passionately create enthusiastic customers and build a better future".

In order to implement the Champion 2020 corporate strategy, the focus relies on four areas that constitute Hilti's core competencies:

- Continuous innovation in products, services and software.
- Direct and partnership-based cooperation with Hilti professional customers.
- Operational excellence for efficiency and to live up to the brand promise.
- A high performing global team.

2.1.3 The Sourcing Excellence Team

Each of Hilti's eight Business Units has its own independent Supply Team. This allows Supply Managers to dedicate themselves entirely to the BU's success.

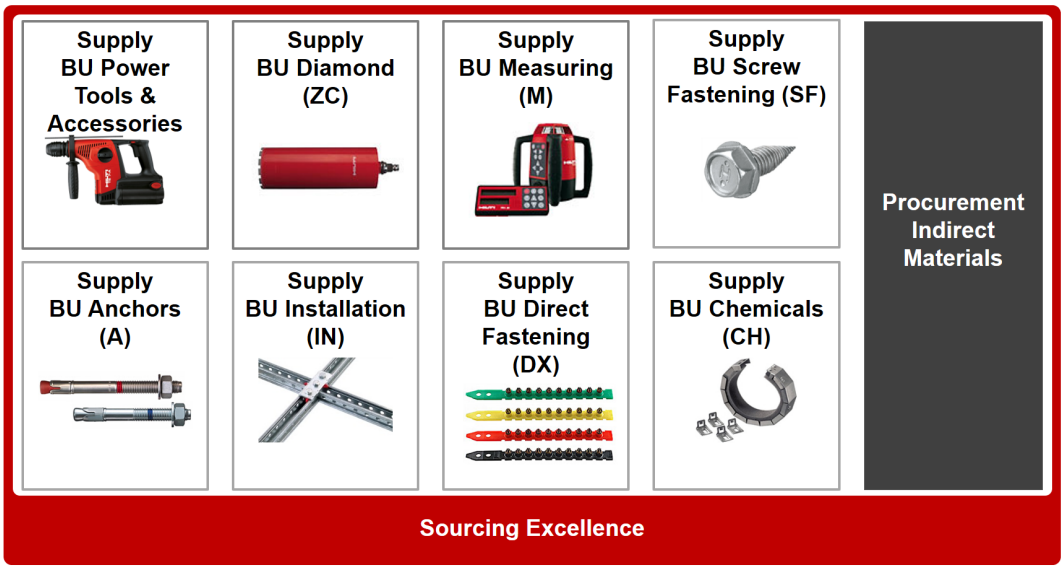

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FIGURE 2.5: Hilti has a decentralized sourcing function at BU level

However, many new sourcing methods and systems require more resources than would be available to one individual Supply Team. Without alignment between the BUs and joint efforts, Supply Teams could be missing out on new methods and tools that are indispensable to further improve Hilti's cost situation and overall supply efficiency.

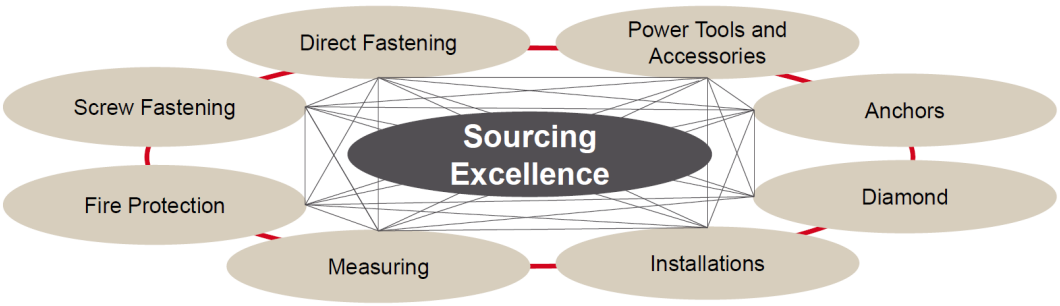

FIGURE 2.6: Initiatives and projects concerning all BUs constitute the need for an overarching corporate function: XLSE

For this reason the Sourcing Excellence Team (XLSE) was established. It helps to achieve operational sourcing excellence by optimizing processes and systems, implementing state-of-the-art methods and developing sourcing talents. It is the central hub for the Supply Teams within Hilti to call upon for hands-on support.

2.2 Risk management system at Hilti

2.2.1 Hilti's risk culture supports long-term success

Hilti counts on a well established risk management process within the company. A Risk Management Organization guarantees the existence of a responsible person who is ultimately accountable for ensuring risks are properly managed.

One of the main targets for the RM Organization is having full visibility of the whole potential threats for the company in order to avoid blind risk spots. This is obtained through a risk aware corporate culture aiming to the education of stakeholders on the value of risk ownership.

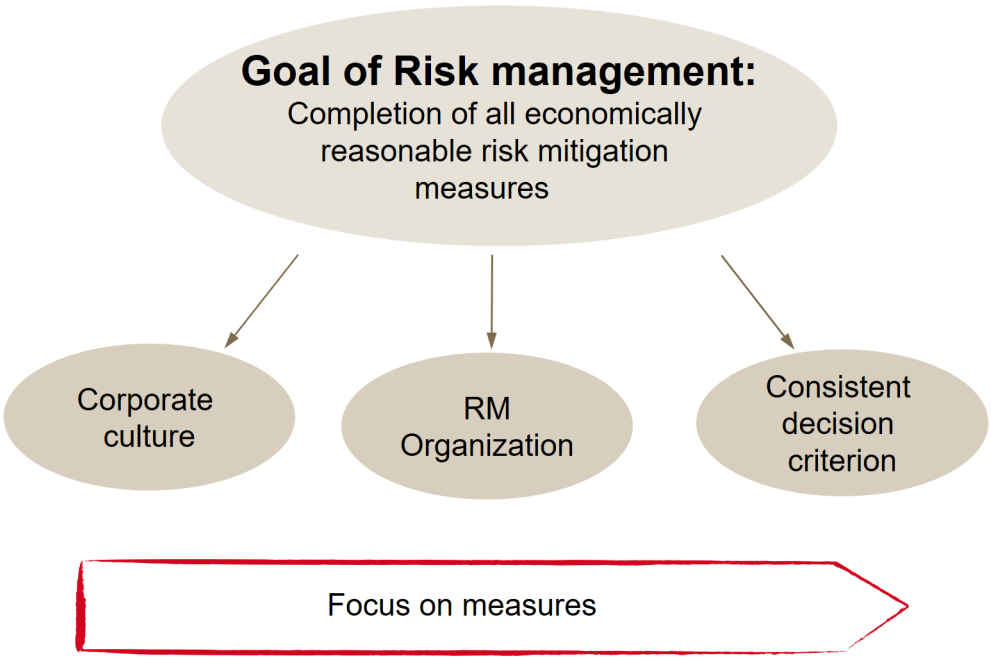

FIGURE 2.7: Risk management practices ensure profitability and continuity of the business

The focus of risk management is on the implementation of economically convenient mitigation measures in order to control the risks. The overall RM process within the company is based on a consistent decision criteria. This allows to have a method to reduce freedom of individuals, be prepared for all possible scenarios and proactively making decisions between acceptable risk levels and required investments to mitigate them.

2.2.2 Risk management system ensure protection to the company

The risk management system is the overall integrated process consisting of two components: Risk assessment and risk management. The first one refers to methods and tools used to identify and estimate risks and compare them with established evaluation criteria in order to determine their significance level and provide inputs to decision makers. The second components is related to the actions to implement in order to handle the assessed risks.

Processes to identify and manage potential events that can affect the overall business are applied across the company. Strategies are agreed to provide reasonable assurance regarding the accomplishment of set objectives.

Figure 2.8 illustrates the risk management system at Hilti with all its components.

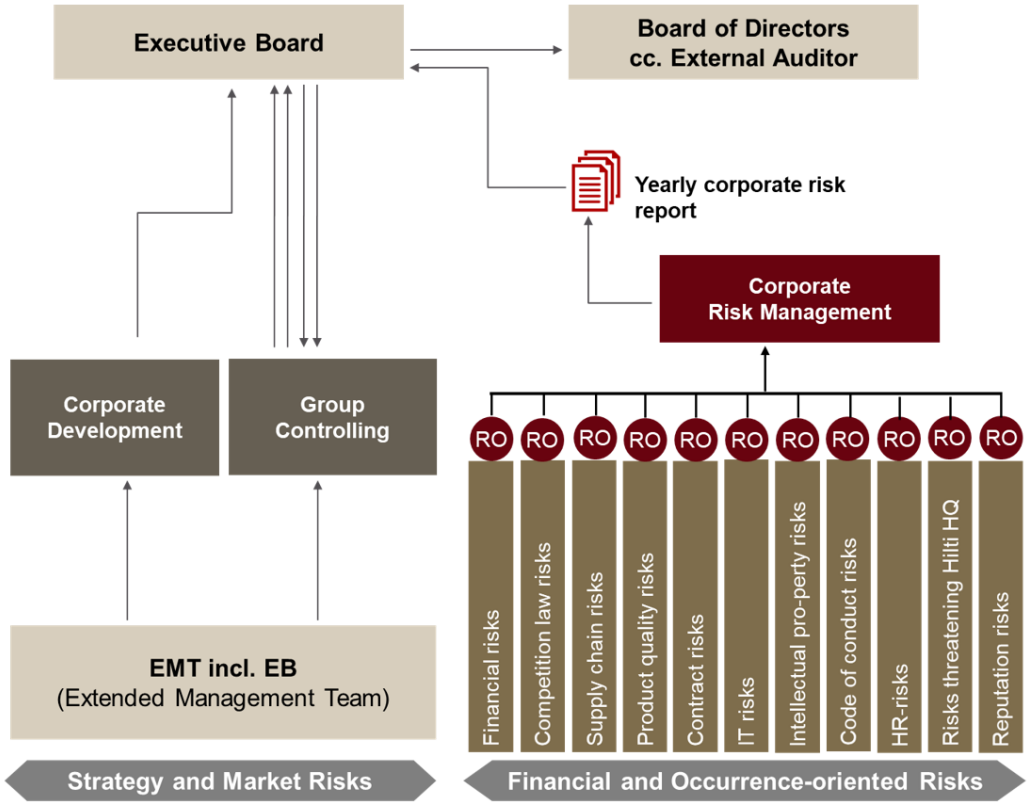

FIGURE 2.8: Risk management system at Hilti divides between strategy risks and occurrence oriented risks

Strategy risks and occurrence oriented risks cover all the existing risks

Many companies do not have a well defined differentiation between *strategy and market risks* and *financial and occurrence-oriented risks* and tend to combine these two macro categories. However, by associating dissimilar risk groups, companies will have inefficiencies due to complete different applicable methods and scenarios. This is the main reason behind the clear distinction that, Hilti's risk management organization has.

Strategy and market risks are related to any possible source of loss that could arise from an unsuccessful business plan. It includes the extended management team (EMT) and the executive board (EB) and considers strategical decisions as, for example, resource allocation or reactions to changes in the business environments. Each business unit (BU) defines its own strategy and makes its own assumptions. Corporate development is in charge for long-term and mid-term strategy development due to the direct sales approach of the company, while group controlling manages the business update information flow with the executive board.

Financial and occurrence-oriented risks contain all kinds of event-based risks and are related to: financial issues, competition law, supply chain management, product quality, contracts, IT, intellectual pro-perty, code of conduct, human resources, risks threatening Hilti HQ and reputation. A risk owner (RO) is defined for each risk. The different risk owners are responsible to implement mitigation measures and align among themselves on common topic. Furthermore, they are in charge to get the needed figures to produce a yearly corporate risk management report. This document contains descriptions of all types of risk and it is escalated at executive board level.

Part of the risk management process and parallel to the different components of the risk management organization is the internal audit. The aim of the internal audit is to check risk management processes. It includes independent checks on selected corporate risk topics and separate reporting to the board of directors.

2.3 Supply chain risk management in Hilti

All of Hilti's activities, every day, are aimed at enthusing customers. The strategic aim is sustainable value creation through market leadership and differentiation. For a direct sales organization such as Hilti, keeping promises to customers is a critical mission. For such reason, Hilti developed its own supply chain risk management (SCRM) process to protect itself from any supplier's disruption and assure its customers always an excellent service.

Hilti's SCRM process focuses on four main possible loss types. The first category includes all the elementary losses that could happen in the supply chain, for example, a fire at a supplier's production plant or warehouse and for which the standard approach requires periodical audits and insurance coverage. Second category is represented by financial issues of suppliers, for which generally Hilti monitors credit ratings or safeguards tooling of own property. The last two loss types included in the SCRM process are termination of contract and forced disruption. The first is related to suppliers who do not meet minimum contractual delivery duties and the second to all the remaining issues not yet included in the previous categories.

The common mitigation measures for all the four categories are increasing the safety stock and having an alternative source to switch in case of need. In figure 2.9 a summary of scenarios and related mitigation measures considered in the wide available risk management literature and applied by Hilti is presented.

Loss type	Description	Scenario to be considered ('realistic worst case')	Risk mitigation measures	
			specific	in general
Elementary loss	Destruction of production facility due to fire, flood, earthquake, storm	Total outage of one production facility	• BI-audits • Insurance	• Safety stock • 2nd source
Insolvency	Suppliers go bankrupt	In case of relevant tooling: Tooling belongings to Hilti remain available; tooling belonging to the supplier is not available.	• Monitor credit rating of supplier • Safeguard tooling which belong to Hilti	
Termination of contract	Unexpected termination of contract by the supplier	Immediate termination, i.e. supplier does not meet his contractual delivery duty.	• Relationship mgmt.. • Contractual duty of supplier	
Forced disruption	Closure due to CoC-issues, contagious disease, political instability, strike etc.	Closure of one production facility	• CoC (= Code of Conduct) audits	

FIGURE 2.9: Hilti has learned the merits of risk management

Hilti's SCRM approach focuses on the effect of the realization of the critical event and on the impact on that event on company performances. The main focus of the whole process is the lost profit associated with the incident. Such an event can affect the ability to match supply with demand and so having consequences on the whole business, due to potential extensive loss of image and reputation. Each disruption, then, can not only affect operations but generally results in financial damage well beyond the immediate operational impact.

2.3.1 Manage supply chain risk at a glance

With the ever-expanding globalization and specialization of suppliers a process to effectively address business interruption risk is needed in order to keep the pace with the industry. The Hilti's supply chain risk management process addresses the most important steps (Figure 2.10) in analyzing and mitigating risks for suppliers, plants and warehouses.

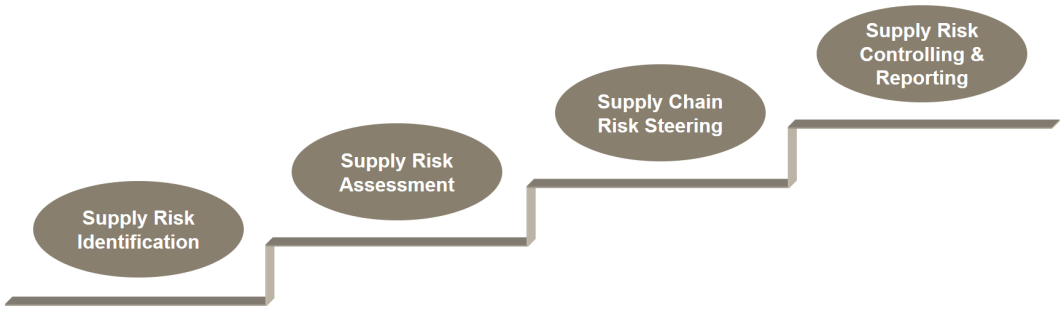

FIGURE 2.10: Hilti risk management process steps

To measure the business risks that evolve from supplier related events, the *business interruption* or *BI* risk indicator has been introduced. It is calculated for each supplier and it refers to the profit loss impacting the company as a consequence of lost sales due to the considered supplier's disruption.

The model based on the BI figure is widely explained in section 2.3.4. It is based on the *mean time to recover* or *MTTR*, defined as the time needed for the company to come back to the initial supply condition after a supplier's disruption occurs.

All critical suppliers are tracked on a specifically designed tool, namely BI-risk tool, to better target the risk assessment process and effectively assess risk mitigation measures in a straightforward accessible manner. The BI-risk tool allows supply managers to view the BI indexes for each of their suppliers, providing the mean time to recover figures in case of *elementary loss* - MTTRe - and *insolvency* - MTTRi - as well as other information.

This systematic approach for supply chain risk management allows the company to reduce the need to estimate the likelihood of low probability and high impact events, by evaluating the firm's vulnerability if a disruption occurs across its supply chain.

Process performance indicators

Process performance will be measured based on the following key data:

- Mean Time to Repair, or MTTR
- Business Interruption rate, or BI

In addition, the tactical supply manager is responsible for the quality of the risk mitigation measures.

2.3.2 Central steering of the safety stock redefine the SS in the plants based on the disruption risk

Safety stock (SS) settings are always made on the component level. The first safety stock calculation is done by the production plant where the availability of components is needed in order to keep production going. This calculation is done by using different methods depending on the specific case. Methods include demand variability, lead time variability and many other parameters but not supplier's disruption risk. Detailed safety stock calculation methods are explained in section 2.4.3.

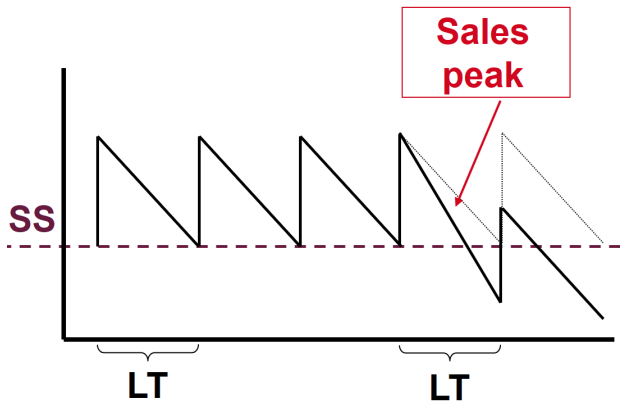

FIGURE 2.11: If an item has stable demand, replenishment occurs before SS is consumed. Due to a sales peak, SS is consumed

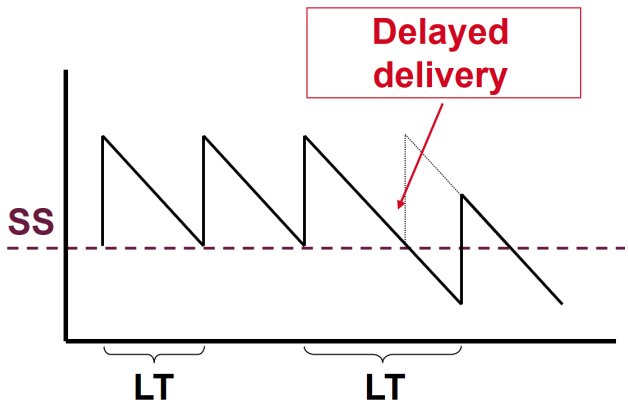

FIGURE 2.12: If an item has stable lead time, replenishment occurs before SS is consumed. Due to a delayed delivery, SS is consumed

In the central steering of the safety stock, the information on calculated SS in the plant is aggregated at supplier level and used as input for the BI risk process. Based on considerations on BI risk and MTTR, mitigation measures are defined. One of the most relevant risk mitigation measures applied to almost all suppliers is, as shown in figure 2.9, the safety stock.

For all the critical suppliers, the safety stock level defined in the production plant is redefined to take into account the disruption risk. A new safety stock coverage is determined at supplier level, dis-aggregated at component level and communicated back to the production plant. Materials managers in the production plant manually update the SS information and implement the new required safety stock, that at this point considers also the disruption risk at suppliers.

The central steering of the safety stock is an effective method to define mitigation measures at strategic level but presents some weak points. When a new safety stock level is defined to mitigate the risk, the process considers annual average demand and excludes fluctuating demand patterns. This way the SS centrally steered is defined based on constant turnover.

In the following sections the already established process is explained in detail and in section 2.5 the issue investigated on the thesis is presented.

2.3.3 Selection of the critical suppliers depends on business interruption index

Focusing only on the purchase volume to list the main risky suppliers, as in various classical selection methods available in the literature, would lead to material exposures hidden among the other suppliers. As result, the company would not be able to reliably identify where the exposures are and which will be their impact. Moreover, as also confirmed from a wide literature review, supply managers seem having a natural tendency to underestimate the likelihood of low-probability, high-impact events. These phenomena combined with the difficulty to access detailed data from sub suppliers led Hilti to the development of a vulnerability-based analysis into his supply chain risk management process. In this analysis the company focuses on understanding the quantitative impact, in monetary terms, of a disruption.

In the Hilti's supply chain risk management process, suppliers are listed based on a specifically defined index, namely business interruption index (BI) and described in Section 2.3.4, regardless of the disruption source or the purchasing volume figures.

The BI index is defined considering that the impact of a disruption often does not depend so much on the disruption cause but more on its duration. Moreover, the mitigation measures that the company would employ in case of realization of the disruption event are also potentially not related to the specific disruption causes.

2.3.4 The business interruption model

Inventory stockout cost is important for understanding the role safety stock plays in assuring business continuity to the company. Stockouts result in direct loss of revenues and profit and finally of customers and market share, as not meeting the demand could result in unsatisfied customers who will find someone else able to do so.

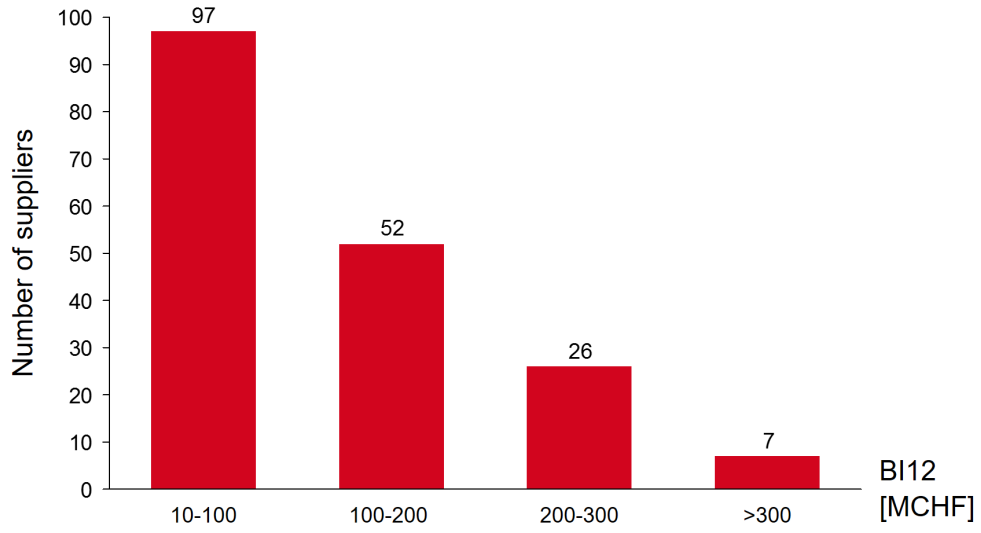

FIGURE 2.13: 182 critical suppliers from the BU Power Tools and Accessories have an overall BI12 impact of 2.1 BCHF

The approach adopted by Hilti requires the calculation of the Business interruption BI impact on the firm's performance assuming the firm responds optimally to the disruption scenarios.

The model considers the lost sales depending on the realization of the disruption and measures the exposure of the company by calculating the subsequent profit loss. The resulting impact is, in this way, the effect of the realized disruption scenario on the firm's profit, during the time period needed to recover to full performance.

The business interruption index has strategic relevance on components and suppliers risk exposure identification. It allows the supply teams to prioritize resource allocation by listing components and suppliers following a risk impact classification, from higher BI values to lower ones. Moreover, by combining the suppliers risk exposure with other information, such as the purchase volume (PVo), it is possible to gain insights about possible mitigation strategies that can be adopted.

2.3.5 Basis of BI12 index calculation

In case of a business interruption the insurer will pay the *FIXED cost* and the *lost profit*, which is in the following called "amount of coverage" or DB (Deckungsbeitrag).

Assuming the following variables are being defined:

- BIx = Business impact for a generic MTTR
- MTTR = Mean time to recover
- NSP = Net sales price
- MAT = Material cost
- HK = Production cost (Herstellkosten)
- Comp.Factor = Compensation factor

Step 1 in calculation, DB1

- Split sales in fixed and variable cost
- Elements considered as variable cost:
  - Material Cost
  - 6% of net sales which are considered as other variable cost, derived from finance department
- Formula to calculate "DB1"

$$DB1 = 0,94 * NSP - MAT \tag{2.1}$$

Step 2 in calculation, DB2

- Consider Compensation Factor for workers outside the manufacturing plants. In case of business interruption we assume that production employees cannot resume their work. Employees in markets will be able to partly compensate the interruption by selling / processing other items which are still available.
- Compensation factor is estimated by finance at 17%
- Formula to calculate "DB2"

$$DB2 = (DB1 - HK) * 0,17 \tag{2.2}$$

Step 3 in calculation, BI12

$$BI12 = DB1 - DB2 * 0,17 \tag{2.3}$$

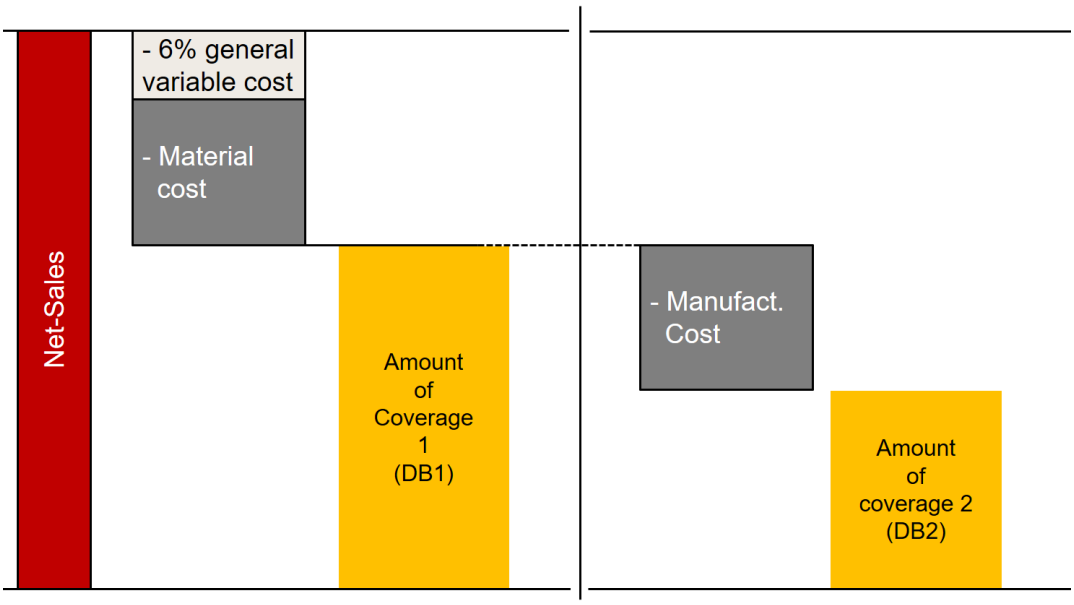

FIGURE 2.14: Basis of BI12 calculation

NOTE: DB2 refers to non plant employees. Business interruption can be partly compensated by processing / selling available materials. 17% of this amount can be compensated and must be deducted from DB1.

2.3.6 Definition and calculation of Business Impact

It is possible to extend the equation 2.3. By substituting the terms *DB1* and *DB2* it assumes the following form:

$$BI12 = (0,94 * NSP - MAT) - (Comp.Factor * (0,94 * NSP - HK)) * SalesQty \tag{2.4}$$

The BI12 allows the selection of the most critical suppliers by listing their potential impact on the same time horizon. Generally a supplier is considered critical when has a BI12>10MCHF.

The BI12 is the profit loss calculated on a time horizon of 12 months and it is based on past 12 months yearly sales (Figure 2.15).

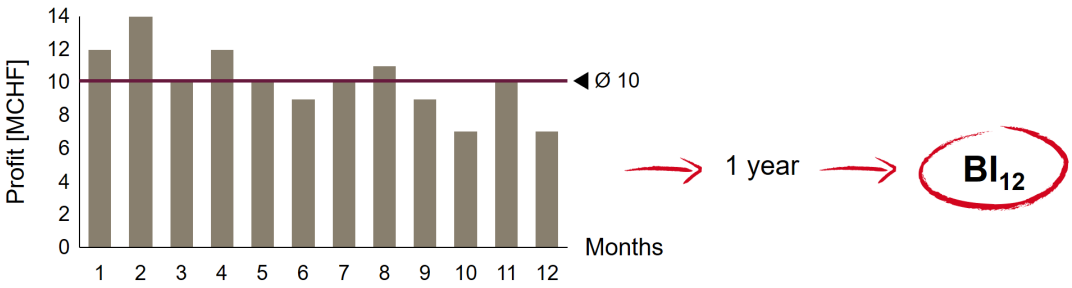

FIGURE 2.15: BI12 allows comparison across suppliers helping resources' allocation

It represents the potential annual profit loss in case of a supplier's disruption. It is calculated for each finished item, drilled down on item level (Figure 2.16) and then aggregate at supplier level.

SUPPLIER	Supplier Name	Component	Component name	Sold item Number	Sold item name	12m Sales Quantity	Unit of measure sold QTY	NS	HK	MAT	BI12 CHF
4401	HILTI MA	236604	Component 1	236604	Item 1	49	PC	6,463	1,642	1,642	3,679
4401	HILTI MA	236605	Component 2	236605	Item 2	603	PC	95,679	31,320	31,320	48,653
4401	HILTI MA	360637	Component 3	360637	Item 3	94	PC	11,345	3,130	3,130	6,254
4401	HILTI MA	360638	Component 4	360638	Item 4	39	PC	5,706	1,299	1,299	3,374
4401	HILTI MA	360639	Component 5	360639	Item 5	595	PC	64,260	22,991	22,991	31,053

FIGURE 2.16: Example of output formats for BI12 calculation, drill-down on item level

Note on product cost HK

Product cost "Herstellkosten" assumes different values depending on the supplier type.

1. In case of allied supplier

$$HK = MAT \tag{2.5}$$

2. In case of non-allied supplier

$$HK = MAT + ProductionCost \tag{2.6}$$

The product cost is in the first case calculated by only considering the material costs, as for an allied supplier there is no impact on fix assets plants. In the second case, instead, the product cost needs to take into account also the production cost, as for non-allied suppliers there is impact on fix assets plants.

The BI index can be referred to any other horizon simply by linearly scaling it to the time period of interest. In the following formula the Mean Time to Recover frame is considered. A detailed explanation on the MTTR figure is provided in section 2.3.8.

$$BIx = BI12 * \frac{MTTR[months]}{12[months]} \tag{2.7}$$

In the graph represented in Figure 2.17 the red curve characterizes the behavior of product group sales. It is possible to notice a decreasing trend after the realization of the disruptive event (date of loss) with consequent reduction of net sales period (lost turnover). After the MTTR the normal supply conditions are restored and the curve has a ramp up. In the long term it is possible that the customers find an alternative supplier with direct effect on market share.

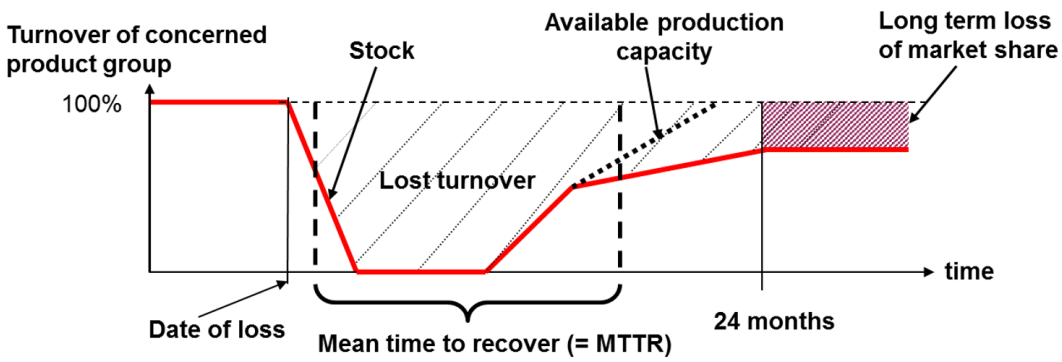

FIGURE 2.17: A systematic approach for managing Business Interruption (BI) risk has been implemented

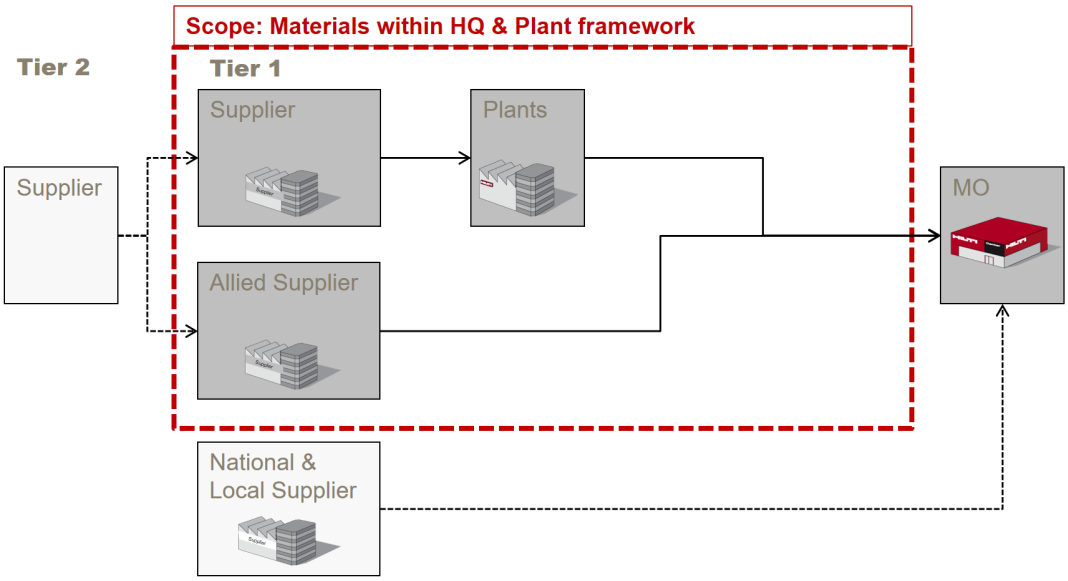

FIGURE 2.18: All materials with a Product Cost calculation in HQ and Plants are in Scope for BI12 calculation

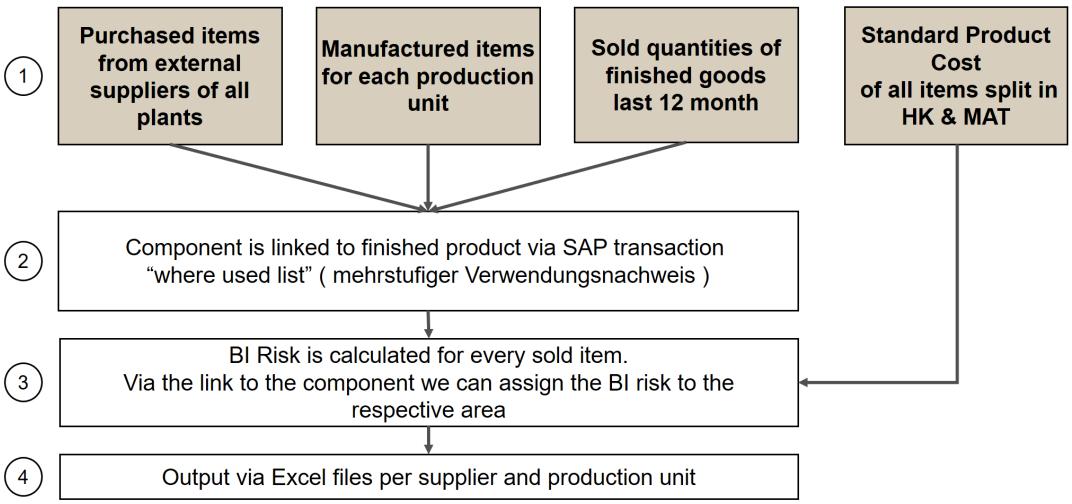

FIGURE 2.19: General data sources used for the preparation of business interruption risk reports

Purchased items from external suppliers of all plants consider all materials per suppliers with actual 12-months purchase volume. Manufactured items for each production unit are obtained from the Material Master query "MD_01" in SAP, where all items are assigned to a certain production area within a plant. Sold quantities of finished goods in last 12 months include sales on material level on last 12 months, sold quantity & units.

The risk management process requires that, according to the assigned responsibilities within the organization, in each project key activities are performed. In tables 2.2, 2.3, 2.4, it is provided a detail of the key activities with respect to suppliers, plants, and warehouses.

Activities for Suppliers	
Supply Risk Identification	Conduct BI Risk audit
	Evaluate Supplier with Cost Competence Matrix and/or Follow up Rating
Supply Risk Assessment	Calculate and generate list of actual BI12 values
	Mark all critical suppliers in SAP for export to BIRS
Supply Risk Steering	Assess the risk probability for all risk categories for the suppliers in the BIRS Tool
	Elaborate for all suppliers a detailed BCP
	Identify possible risk mitigation measures for all suppliers
	Discuss and approve/ deny new suggested measures from BI Risk POV
	Implement approved measures
Supply Risk Controlling and Reporting	Finalize the Summary to BA-Heads for the Corp. Risk Report

TABLE 2.2: Key activities for suppliers

Activities for Plants	
Supply Risk Identification	Identify the BI-Risks Elementary Loss and Forced Disruption
	Identify and rate the impact regarding: -back up capacity -safety stock -replacement time -emergency measures/prevention -probability of occurrence
Supply Risk Assessment	Annually preparation of supply risk assessment for units (plants): -Generation of "where used list" -Generation of HK, MAT, NSP tables
Supply Risk Steering	Complete reasonable FM-Global recommendation
	Create a detailed BCP
Launch preparation phase	Document supply risk status in Corp. Risk Report (yearly)

TABLE 2.3: Key activities for plants

Activities for Warehouses	
Supply Risk Identification	Identify the BI-Risks Elementary Loss and Forced Disruption
Supply Risk Assessment	Assessment and implementation of all economically reasonable risk mitigation measures (FM Global Audit)
Supply Risk Steering	Corporate Risk Management defines the warehouses with extraordinary risk exposure
Launch preparation phase	Yearly Documentation of supply risk status in Corporate Risk Report

TABLE 2.4: Key activities for warehouses

2.3.7 Business impact and purchase volume are compared to get interesting insights on suppliers' categorization

Simchi-Levi et al. (2015) performed a graphical analysis based on the relationship between total spend at supplier site and performance impact in terms of lost profit (monetary unit) for the company. Such analysis finds various similarities with the Hilti's way of assigning and managing mitigation measures for critical suppliers and for this reason included in this work.

In the following section the same analysis is carried out referring to Hilti's data, considering as vertical axis the PVO and as horizontal axis the BI12 value. The idea consists of segmenting suppliers into different categories depending on the BI12 and PVO combinations.

The power of such classification, as the reader could see in Figure 2.21, relies on the agility of finding basic rules on which supply managers can refer to afterwards develop strategies, simply considering the position of the suppliers in the scatter plot.

As a first consideration it is possible to notice that some of the largest lost profit exposures are not correlated with the amount the company spends at the supplier. In these cases, traditional risk mitigation strategies, for example focusing on purchase volume to list the critical suppliers, may lead to not optimal resource allocation.

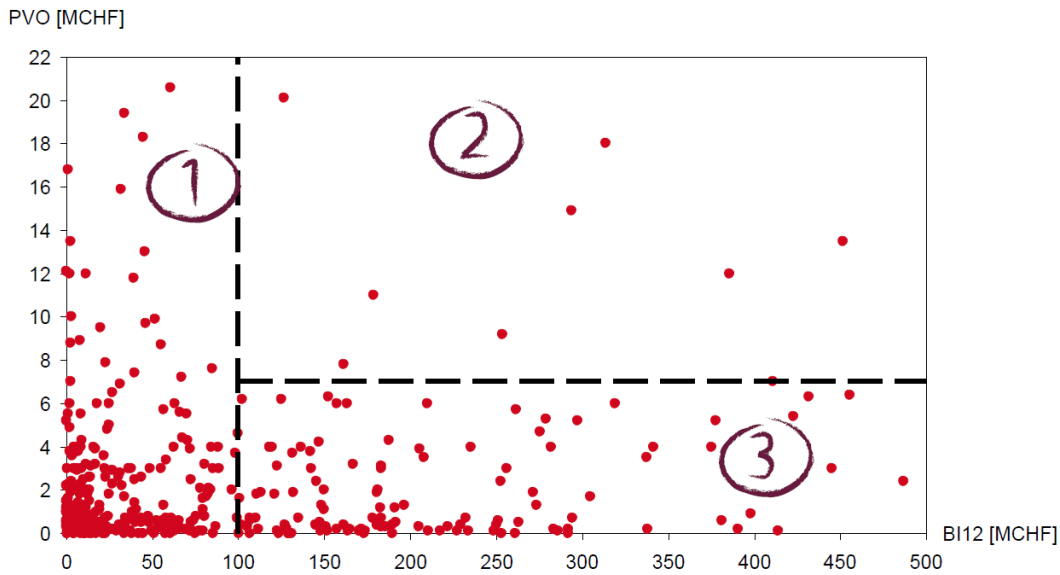

FIGURE 2.20: Around 500 critical suppliers monitored in the Hilti BIRS tool where purchase volume and BI12 are compared

As effect of applying such traditional strategies we could see high and not necessary resource allocation at low exposure suppliers and not enough protection at high exposure ones.

Suppliers are segmented into three categories. Each segment leads to a different set of challenges with different mitigation strategies that the company should pursue. Referring to the numeration indicated in Figure 2.21 we can distinguish the following areas:

1. Suppliers in this section are characterized by low BI risk values. The strategy of the company when dealing with this supply group should involve signing long-term supply contracts and tracking inventory.

2. Suppliers in this area are characterized by high PVO and high BI risk. Simchi-Levi et al. (2015) refer to them as strategic suppliers as form many companies they represent the 20 percent of suppliers accounting for about 80 percent of total spent. An appropriate supply strategy for these suppliers is to focus on long-term partnership and implement effective supply contracts in which the company can share risks with suppliers and track performance. Because of the high total spent with these suppliers, the company could be able to force them to have backup sites in different regions in certain situations.

3. This area includes the most challenging suppliers, with low total spent and high BI risk value. In these cases, a company may invest in inventory, require the supplier to have multiple sites or apply a dual-sourcing strategy with the related issues. Investing in inventory may be in contrast with the company's lean strategy. Requiring the supplier to have dual site can be difficult due to the not optimal position of the firm in case of low total spend. Moreover, dual sourcing strategy can be really challenging since these are often the cases of suppliers associated with high volume, low cost, and low margin components. In this scenario generally, few manufacturers dominate the market because of their lower costs and higher quality.

2.3.8 The mean time to repair model

The $MTTR_{gross}$ represents the time needed to recover after a disruption to full functionality

The $MTTR_{gross}$ figure indicates how much time in months is needed, with all efforts, to assure a material flow of the relevant items equivalent to the scenario before disruption.

Supply managers from the supply teams of the different business units are responsible to provide $MTTR_{gross}$ figures to the BIRS Tool. This evaluation has to consider the supplier outage types, as the time needed to find an effective alternative solution could vary depending on the disruption nature. The main worst case scenarios of unexpected outage of a source are:

- Elementary loss
- Insolvency
- Termination of contract
- Forced disruption

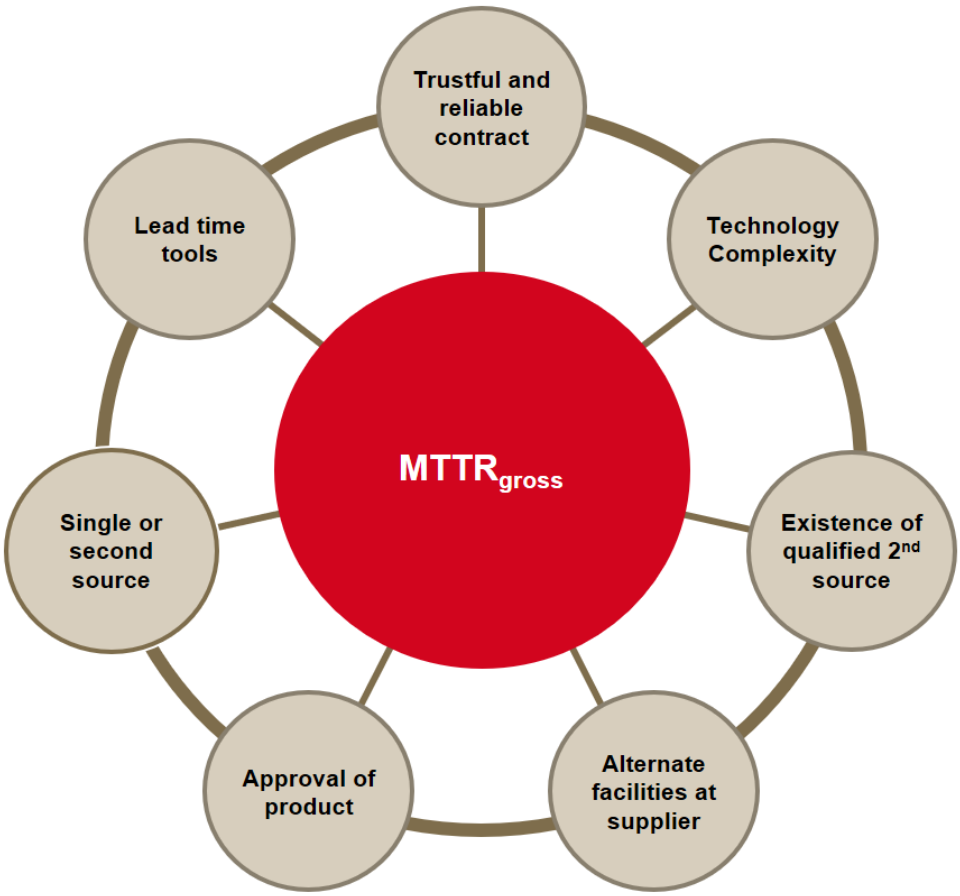

FIGURE 2.21: Influencing variables in the MTTR evaluation

For the sake of simplicity, the calculation is restricted to the risk categories "elementary loss" and "insolvency", since an impact due to the two other risk categories "termination of contract" and "forced disruption" is considered to have a lower impact, and is mainly relevant for Asian suppliers.

It is really important to notice that, in this gross time horizon, safety stocks measures at Hilti and at suppliers' side are not included, as they will be the main point in the NET MTTR definition (section 2.3.8).

The BI effective is business relevant and is driven by the $\mathbf{MTTR_{net}}$

Equation 2.7 shows that it is possible to scale the BI12 figure to a specific mean time to recover in order to get the business interruption impact related to the interruption time frame. The effective business interruption which the company is exposed to, is a function of the net MTTR (Equation 2.8). It is possible to combine the information of Equation 2.7 and 2.8 obtaining the Equation 2.9. Hence, the $BI_{effective}$ is obtained by scaling the BI12 to the net $MTTR_{net}$.

$$BI_{\text{effective}} = f(MTTR_{\text{net}}) \tag{2.8}$$

$$BI_{\text{effective}} = BI12 * \frac{MTTR_{\text{net}}[months]}{12[months]} \tag{2.9}$$

The $MTTR_{net}$ represent the effective time of exposure of the company to the risk, after mitigation measure such as safety stocks. As showed in Equation 2.10 and graphically in Figure 2.22, the net MTTR is calculated starting from the gross MTTR by deducting the different available safety stocks the company can count on in case of emergency.

The first safety stock to be deducted is the safety stock located at supplier's production plant or warehouse. This SS has to be periodically checked by supply managers and update in the BI risk tool, in order to be sure about its physical availability.

Another stock to be included in the process is the so called "Days on Hand stock" or DOH. It involves all the finished products available within the supply chain and located in trucks, market organizations and in all other physical entities.

Last SS to be deducted is finally the SS at Hilti. It is located directly in Hilti's production plants and it is easy to directly control, even if it could be source of high investments.

When all the mitigation measures have been considered, it is possible to define the net MTTR. This time horizon is the effective mean time to recover considered from the company to define the effective impact of a disruption. The BI effective is in this way calculated by scaling down the initial BI12 on the net MTTR months.

$$MTTR_{\text{net}} = MTTR_{\text{gross}} - SS_{@\text{supplier}} - DOH - SS_{@\text{Hilti}} \tag{2.10}$$

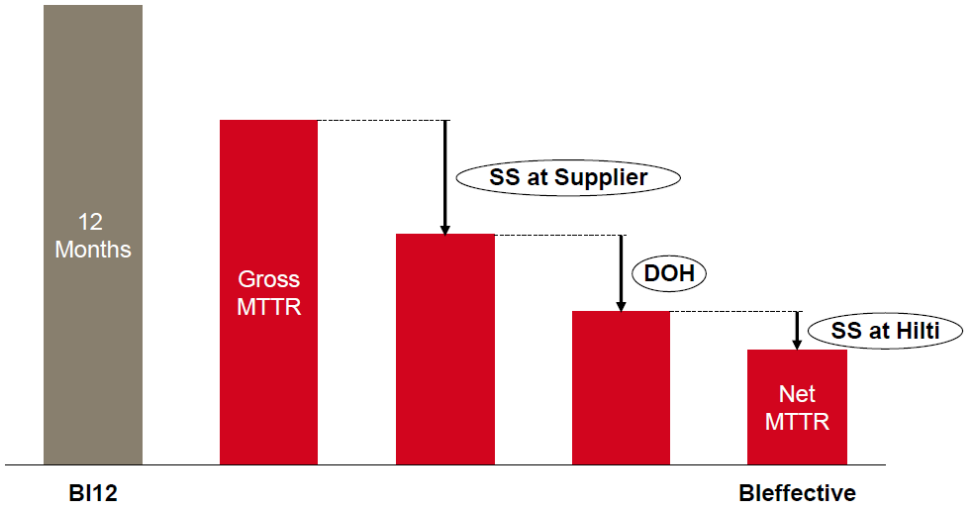

FIGURE 2.22: The difference between the gross and the net MTTR represents the actions

MTTR definition is critical for the whole process

Mean time to repair information is not known with accuracy in various practical situations mainly for two reasons:

- Uncertain information
- Supply managers' optimistic assessment

The time needed to find an alternative supply solution in case of a disruption is almost never a calculated field. In most of the cases $\text{MTTR}_{\text{gross}}$ is assessed as a rule of thumb by supply managers. The judgment is done based on their business experience and available alternatives in case of incident. The scenarios are many and each supplier is a different story. With these settings, finding a common rule, in order to evaluate reliability of mean time to recover approximations, is practically impossible. Furthermore, supply managers are generally optimistic. The effect could be underestimating the time required to repair and hence underestimating Hilti's risk exposure.

Assessing the mean time to recover is one of the most critical and weak point of the overall BI model. If the provided figure is not reliable, it will lead to a not reliable business interruption index calculation, which will in turn lead to a wrong definition of the safety stocks.

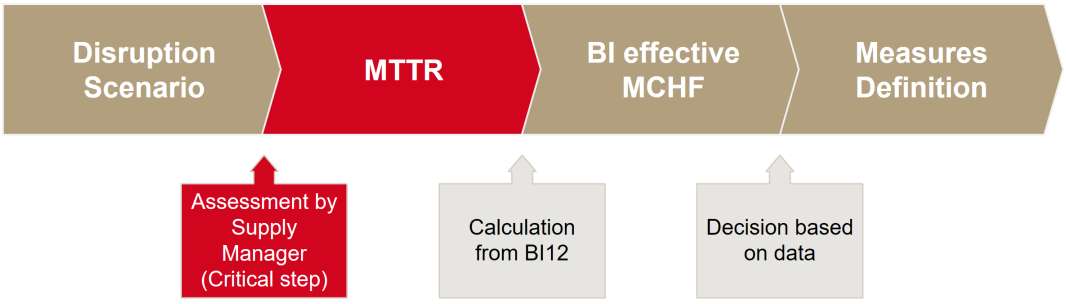

FIGURE 2.23: Risk mitigation measures reduce the profit loss in case of disruption

A statistical analysis on the MTTR figures has been conducted, considering a sample of 182 suppliers from the Business Unit Power Tools and Accessories, tracked in the Hilti's BIRS tool.

There are two objectives of this analysis. On one side, how optimistically supply managers judge the impact of disruption at the suppliers' side to detect possible discrepancies. On the other hand, this analysis can identify potential waste caused by excessive protection measures, for example excessive safety stock, and hence considering different cost saving strategies by resource allocation adjustments.

The MTTR is affected by uncertainty and one of the main challenges is identifying robust allocations of inventory and capacities under uncertainties in MTTR values.

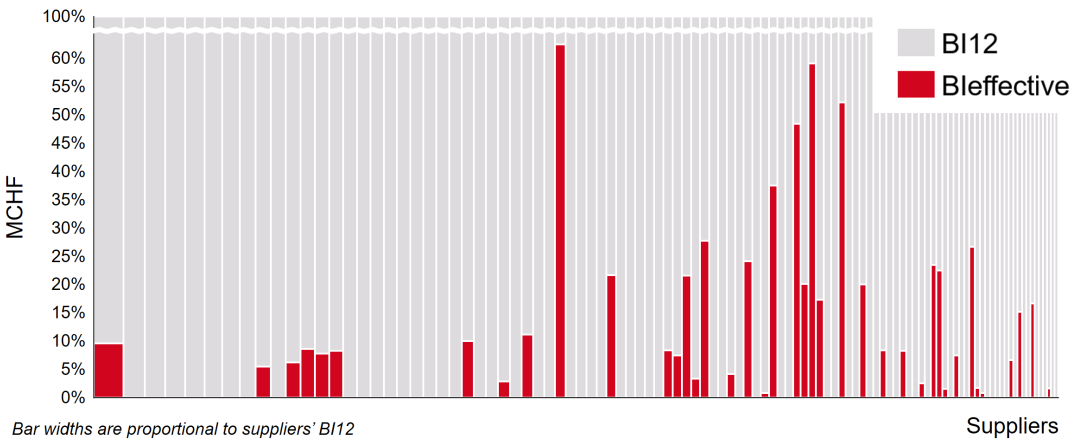

FIGURE 2.24: 101 suppliers in the tool have no effective impact because of low MTTR figures

Out of 182 analyzed suppliers, 101 have BI effective equal to zero, coming from $MTTR_{net}$ equal to zero (figure 2.25). This means that in case of disruption of such suppliers the company will have no monetary impact, as the mitigation measures in place are enough to cover all the $MTTR_{gross}$. However, this optimistic data could be depending on low $MTTR_{gross}$ figures provided as input from supply managers.

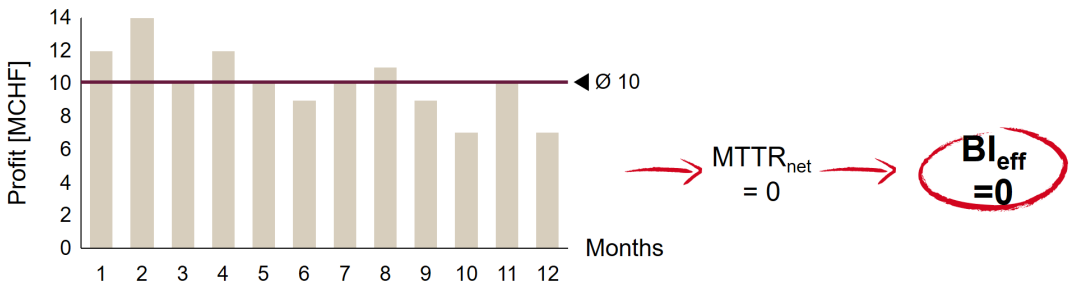

FIGURE 2.25: A null MTTR$_{net}$ leads to a null BI$_{effective}$

By investigating the source of this optimistic result, it turned out that for many suppliers the MTTR definition is actually quite low (figure 2.26).

In details, 45 suppliers have MTTR depending on elementary loss shorter than 3 months and 59 suppliers have MTTR due to insolvency shorter than 3 months. Such values need to be investigated deeply as they could hide some discrepancies. Indeed, it is practically hard to switch to a second source within 1 or 2 months. It could be the case if such suppliers have already a second source or a second production site. Another reason that could explain such a low MTTR could be related to suppliers providing standard parts.

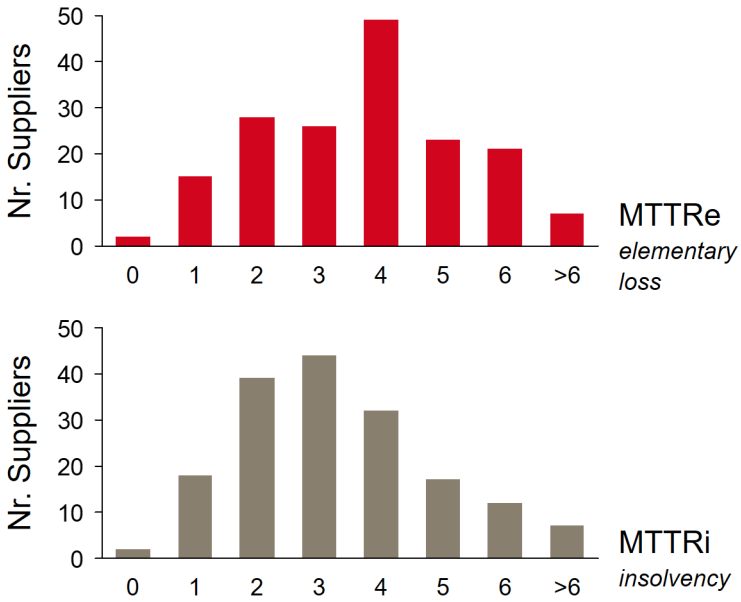

FIGURE 2.26: Do supply managers underestimate the MTTR?

2.3.9 Supplier rating and audits

Key roles not only of the business in general but also of the risk management process, are played by supplier rating and supplier audits that are done on a regular basis. Managing, rating, and auditing of suppliers secures quality standards and increases the business success of the company, all the while also leading to lower risk.

Continuous improvement	Discussion basis	Acting proactively	Secure supply
The supplier rating in the fulfilment process is also used as continuous improvement Process (CIP) steering and information instrument.	The result from the evaluation can serve as useful discussion basis in semi-annual or annual visits at the suppliers.	Acting proactively also helps to identify shortfalls, quality, delivery and cost problems.	A careful rating and auditing of the supplier means that already in the beginning of the value chain, an early security of quality is guaranteed.

FIGURE 2.27: Ratings contribute to the development of our suppliers

2.3.10 Code of conduct for suppliers is part of the BI process

Hilti builds a better future with sustainable and innovative solutions. The company accepts an equal amount of responsibility for society and for the environment so that it can actively pursue a better future also outside the core business area. In addition to the charitable Hilti Foundation, the company's values of integrity, courage, teamwork and commitment contribute to building a better future. These values are lived out every day by more than 28,000 employees in interactions with team members, partners and customers.

For the philosophy of Hilti, topics as corruption, social responsibility and environmental responsibility play a key role in supplier selection processes and in business interruption with non-compliant suppliers. These issues are systematically monitored in the BIR tool and are part of the regular audits.

The Hilti code of conduct for suppliers stipulates the minimum requirements that have to be fulfilled by the Hilti suppliers even if applicable national or international laws set lower standards. If national or international laws set higher standards the Hilti supplier has to comply with these of course.

With respect to anti-corruption, expectations and requirements for suppliers that Hilti does business with are the following: Zero tolerance towards corruption, correct behavior in competition and business behaviors, no involvement in bribes, not giving or receiving inappropriate benefits, and no money laundering.

Hilti includes an ethical framework in its operations covering the following points for its suppliers: Healthy and safe working conditions for the employees, product safety, minimum wages, no tolerance against child or forced labor, discrimination of any kind is not allowed, not exceed legal working hours excessively, and disciplinary action systematic harassment.

The suppliers Hilti buy from or collaborate with are selected and monitored also by considering environmental restrictions, for example: Minimize waste and emissions, recycling and reusing of materials, meet chemical requirements set by Hilti, complying with laws and regulations, and handling chemicals in a non-harming way, to mention a few.

Anti-corruption	Social Responsibility	Enviro. Responsibility
	Expectations of suppliers:	
• Zero tolerance towards corruptions • Correct behaviour in competition	• Healthy and safe working conditions • Product safety • Minimum wages	• Minimize waste and emissions • Recycling and re-usage • Meet chemical requirements of Hilti
	Restriction for suppliers:	
• Involvement in bribes • Giving or receiving inappropriate benefits • Money laundering	• Child or forced labor • Discrimination of any kind • Exceed legal working hours excessively • Disciplinary action & systematic harassment	• Disregard laws and regulations • Handle chemicals in a harming way

FIGURE 2.28: Main focus issues in the CoC for suppliers

2.4 Inventory management in the plant

To create enthusiastic customers and solidify loyalty, Hilti needs the right product, in the right place, at the right time.

In order to accomplish such a goal, inventory is needed. However, determining the right inventory level is one of the most challenging tasks that operation managers need to deal with on a daily basis. The overall scope is satisfying the demand and, at the same time, maintaining an efficient stock supply.

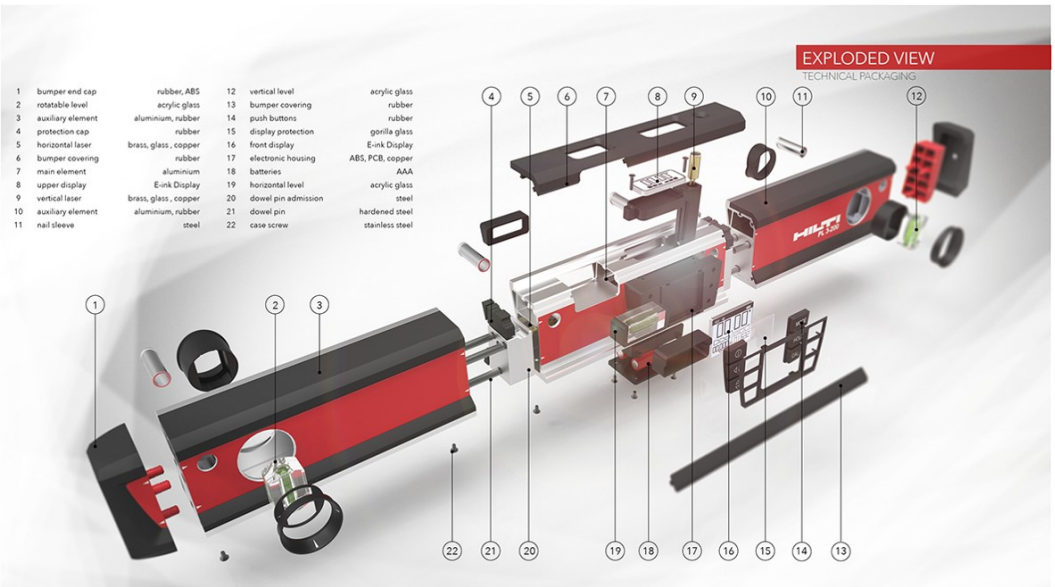

FIGURE 2.29: Ensure availability of all components is challenging for complex products

Holding inventory means carrying an asset with its related risk in terms of obsolescence, deterioration and quality faults. From a financial perspective inventory impacts the balance sheet, cash flow and profit as well as loss accounts. In operational terms inventory has an impact on production efficiency and on-time delivery. In a nutshell, good inventory management is essential to accomplishing business targets and building competitive advantage. The three basic reasons why there is inventory are (Relph, Brzeski, and Bradbear, 2002):

- **Time**
  There is a time lag from supplier to user at every stage. This requires that you maintain certain amounts of inventory to use during this "lead time."

- **Uncertainty**
  Buffers or “safety stock” are maintained to meet uncertainties in demand, supply and movements of goods.

- **Economies of scale**
  Minimum order quantities are maintained, to lower production and transportation cost. This order quantities can be higher than the immediate demand, which results in inventory.

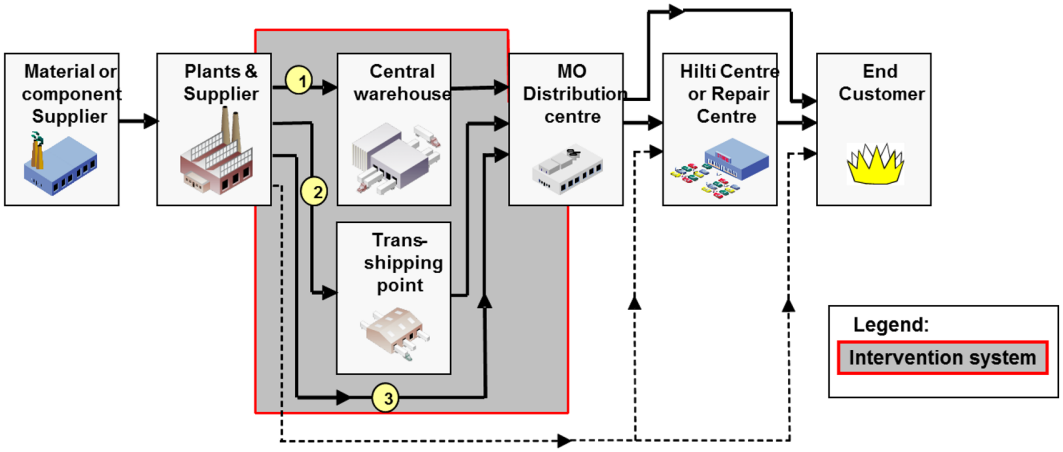

FIGURE 2.30: Understand the supply chain and intervene if necessary

Component delay or unavailability involves delays of varying duration that may interrupt the regular sales. In this case, the cost represents a lost opportunity cost reflecting the profit margin of the considered finished product, multiplied by the daily sales rate and multiplied again by the duration of the delay. The cost of a sales interruption delay is linked to the company's inventory policy, as this cost is moderated by the inventory available to compensate for the short-term delay (Canbolat et al., 2008). Different inventory classifications are available in literature. Three main types of inventory considered in the present work (Figure 2.32), as well as in the materials requirement planning by the production plants at Hilti, can be listed as:

- **Over Stock**
  The result of our order behavior, poor management of phase in/phase out, poor event management and low forecast accuracy. The aim of operations managers is generally to avoid it.

- **Cycle Stock**
  The result of producing or ordering goods in certain batches. Sometimes it is called also Batch Stock. The average cycle stock is one half the batch size or economical order quantity.

- **Safety Stock**
  Stock that might be needed if demand is higher than forecast or average history or if replenishment processes are uncertain. Various researches address it as Buffer Stock.

Cycle stock is the stock ordered on a regular basis to chase demand. It permits to not produce all products simultaneously giving more flexibility to operations managers. It is generally represented by saw-tooth patterns (see figure 2.32) even if it looks much more irregular in the reality. Cycle stock approximation shows a linear decreasing behavior while meeting demand and a sharp rising when the goods arrive to replenish the warehouse.

The focus of this research relies especially on the *Safety Stock*, as its definition is the most critical when it comes to mitigate disruption risk and it is strictly related to customer service levels. Its role is not only mitigating uncertainties in volume and timing of supply and demand, but also safeguarding against future shortages.

OVER STOCK	Price paid for poor planning
CYCLE STOCK	Price paid for the inflexibility of the processes
SAFETY STOCK	Price paid for uncertainty and instability

FIGURE 2.31: Different inventory types as prices paid to reduce fluctuations

Strategic targets for safety stock are:

- High availability for the items ordered most frequently
- High availability for the items contributing the most to the bottom line
- Low investment on items ordered infrequently and which contribute little to the bottom line

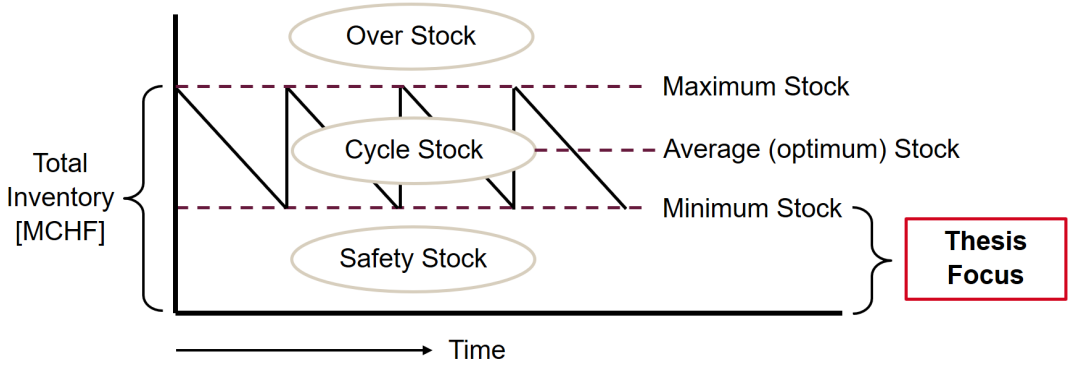

FIGURE 2.32: A simple inventory view

2.4.1 Safety stock covers uncertainty in demand and supply

In a nutshell, safety stock is extra inventory beyond expected demand to prevent stockouts. Statistical safety stock methods are used by operations managers at Hilti to be prepared against changes in demand, incorrect forecasts, and raw materials or components lead times variability. On one side, safety stock avoids stockout costs related to sales losses, however, on the other hand, it has negative impacts on the efficiency of storage spaces as well as in holding and capital costs. For these reasons the calculation of the safety stock is complex and requires multiple formulas to be adapted to each of those situations. Calculation methods are built by considering volatility in supply, volatility in demand and a desired service level, among the others. For example, variables taken into account for the safety stock calculation include:

- Lead time and standard deviation of the lead time in the last 6 months.
- Average daily demand of last 6 months and standard deviation of this demand.
- Service level: probability that a chosen level of safety stock will satisfy customer demand during the lead time. It can be seen as the probability that a stockout will not occur.

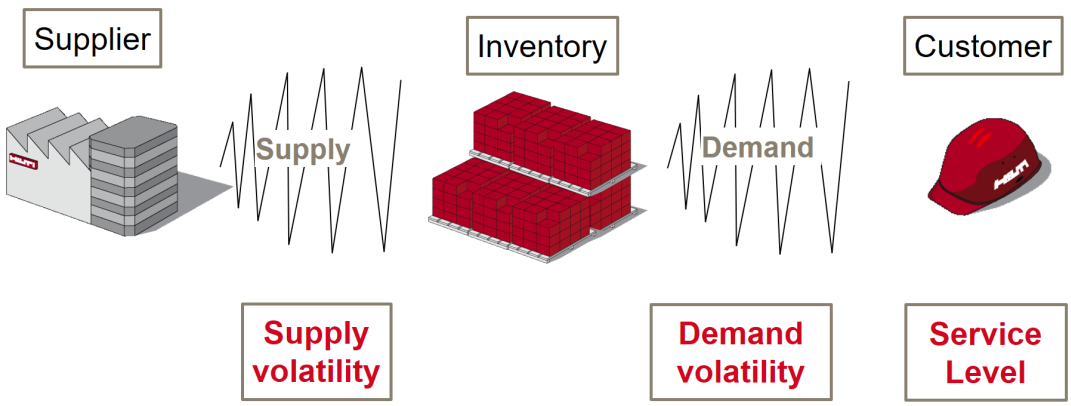

FIGURE 2.33: Volatilities in the supply chain and service level

2.4.2 Safety stock APO transaction in SAP

All the data used for the scope of this research are derived by using SAP. SAP is among the biggest vendors of enterprise resource planning (namely ERP) software and connected applications for enterprises.

The safety stock transaction is included in SAP APO (figure 2.34), where APO stands for Advanced Planner and Optimizer. SAP APO is a supply chain planning tool including powerful instruments to support companies in areas such as:

- Demand and supply network planning
- Production planning and detailed scheduling
- Transport management

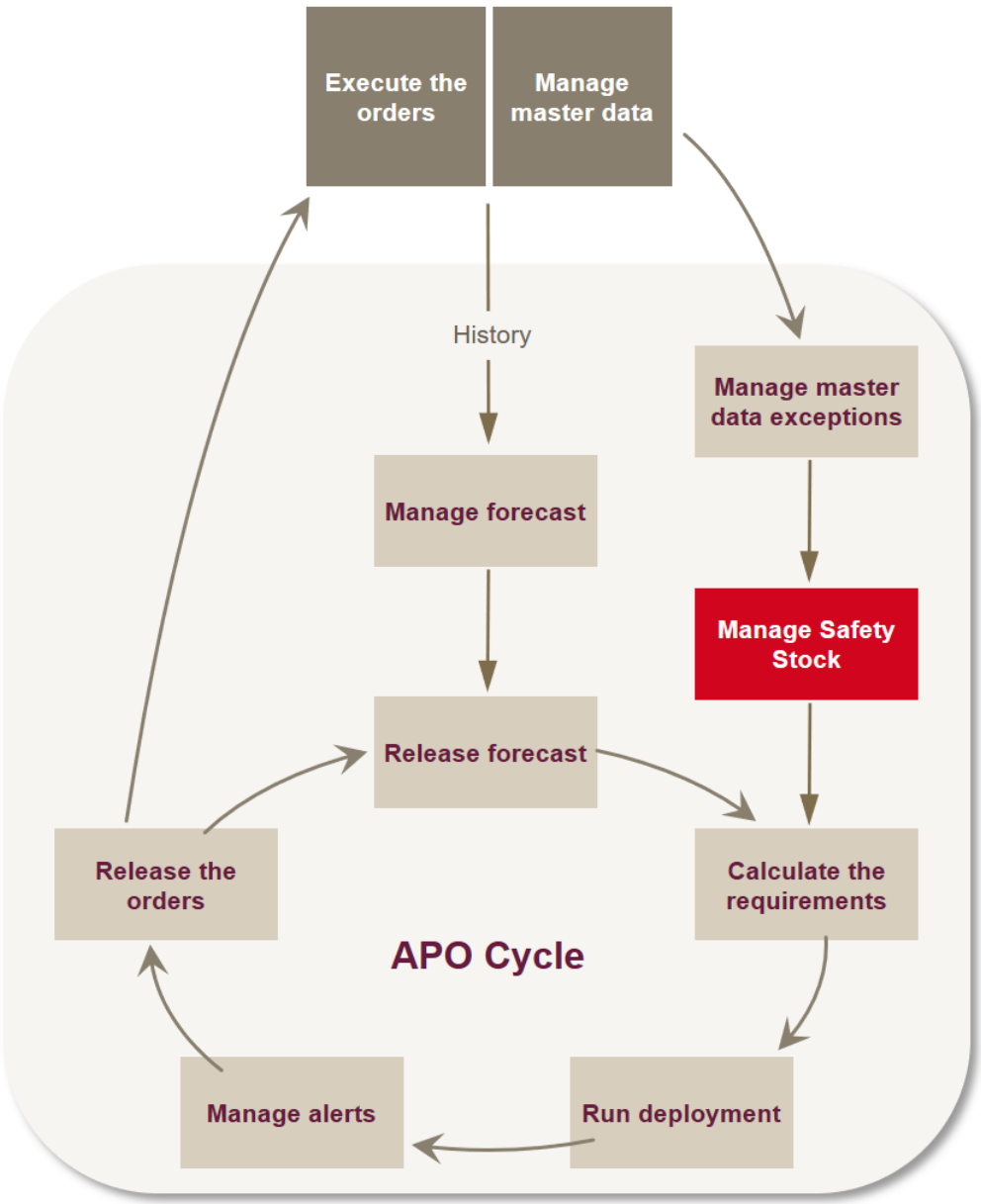

FIGURE 2.34: Safety Stock is an element of the APO processing cycle

2.4.3 Safety stock calculation methods used in the production plant

Safety stock and ROP methods used by operations managers in the production plant uses:

- Statistical data
- Forecast data
- Order History data

The following table (table 2.5) summarizes the ten available methods used most commonly by materials managers in the production plant to calculate the safety stock.

The first three are *Reorder-Point methods*, calculating ROP and Safety Stock. The following six (SB1, SB5, SB8, SB9, SBA and SBB) are *Safety Stock methods* calculating Safety Stock and the last one, SRS, is a method to display *Special Reserved Stock*, which is out of the scope of this thesis.

SS method	**Description**
RP1	Reorder-Point with cons. based SS. (SB9)
RP2	Reorder-Point based on avg. sales order
RP3	The higher value between RP1 and RP2
SB1	Constant days of coverage
SB5	CDO + SST (hist2)
SB8	Cons. based + MAD fcst
SB9	Cons. based
SBA	Stat. days of coverage
SBB	Average sales order
SRS	Special Res. Stock

TABLE 2.5: Safety stock methods adopted by the plant

Depending on the selected safety stock method different parameters and variables are available (Figure 2.35)

SB1

Set Date | Calc.Info | Calculate SS

Status	CalcSSqty	UseCalcSS	Min SS	Actual SS	avgDmd	Safety DS
	982,000	☑	0,000	982,000	119,033	5,00

SB9

Set Date | Calc.Info | Calculate SS

Status	CalcSSqty	UseCalcSS	Min SS	Actual SS	calc MaxSS	maxSS Days	MaxSS Rule	SrvLvl	UseManLT	ManSST LT	Man StdvLT
	401,000	☑	0,000	401,000	572,890	5	D	95,00	☐	12,0	12,000

RP1

Set Date | Calc.Info | Calculate SS

Status	CalcSSqty	UseCalcSS	Min SS	Actual SS	calc MaxSS	maxSS Days	MaxSS Rule	SrvLvl	calc ROP	UseCalcROP	man ROP	actual ROP	ManSST LT	Man StdvLT
	982,000	☑	0,000	573,000	572,890	5	D	95,00	2.287,000	☑	1.111,000	2.287,000	12,0	12,000

SBA

Set Date | Calc.Info | Calculate SS

Status	CalcSSqty	UseCalcSS	Min SS	Actual SS	Safety DS	SrvLvl	avgDmd	UseManLT	ManSST LT	Man.cov.	Use man.co
	819,000	☑	0,000	819,000	20,47	99,00	40,000	☐	0,0	0	☐

SRS

Set Date | Calc.Info | Calculate SS

Status	Avg SRS Qt	CalcSRSqty	SRS Meth	SRS Dur	SRS %
	1.182,000	296,000	P	2	25

FIGURE 2.35: Examples of shown parameters depending on the selected Safety Stock method used

Explanation of SB class of safety stock methods

In the SS method SB1 the SS quantity is calculated as in Equation 2.11:

$$CalcSSqty_{\text{SB1}} = avg.fcstDemand * SafetyDays \tag{2.11}$$

Where *avg.fcstDemand* represents the average of forecast (and dependent demand) in the next 90 calendar days (starting today) and *SafetyDays* refers to the desired number of calendar days of coverage (recommended is a value between *0,5*LT* and *LT*)

In the SS method SB5 (figure 2.36) the SS quantity is calculated as in Equation 2.12:

$$CalcSSqty_{\text{SB5}} = avg.fcstDemand * SafetyDays + Stat.SS(hist2) \tag{2.12}$$

where:

$$Stat.SS(hist2) = R(SL) * MAD * \frac{\sqrt{LeadT}}{p} \tag{2.13}$$

The other additional variables present in this calculation with respect to the previous one (Equation 2.11) are:

- *R(SL)*: service factor based on service level, where *service level* describes the level of service in which the safety stock satisfies customer orders
- *MAD* or mean absolute deviation of monthly consumption in the last 12 month *(Excel: =avedev(month1:month12))*
- *LeadT* or replenishment leadtime
- *p* or period: 30 days are used as period
- *hist2*: indicates that the considered history is from the location and its destination locations

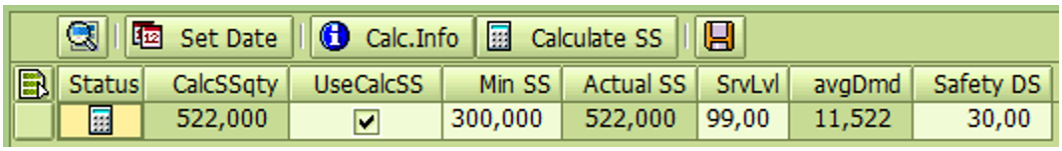

FIGURE 2.36: Visual example of SS method SB5

In the SS method SB8 the SS quantity is calculated as in Equation 2.14:

$$CalcSSqty_{\text{SB8}} = x * \sqrt{MST * \sigma_{\text{D}}{}^2 + \sigma_{\text{L}}{}^2 * \mu_{\text{D}}{}^2} + faccMAD * LT \tag{2.14}$$

where:

- x: Service Factor derived from the service level maintained on the item
- *MST*: Minimum Safety Time (equation 2.15)
- σ_{D}: Standard deviation of Demand
- σ_{L}: Standard deviation of Leadtime
- μ_{D}: Average Demand
- *faccMAD*: forecast deviation = lag between Forecast and History = roundup (LT/30)
- *LT*: Leadtime

$$MST = min\{max(CT, 3), LT\} \tag{2.15}$$

$$CT = EOQ/\mu_{\text{D}} \tag{2.16}$$

In the SS method SB9 the SS quantity is calculated as in Equation 2.17:

$$CalcSSqty_{\mathrm{SB9}} = x * \sqrt{LT * {\sigma_{\mathrm{D}}}^2 + {\sigma_{\mathrm{L}}}^2 * {\mu_{\mathrm{D}}}^2} \tag{2.17}$$

In the SS method SBA the SS quantity is calculated as in Equation 2.18:

$$CalcSSqty_{\mathrm{SBA}} = x * \frac{\sigma_{\mathrm{D}}}{\mu_{\mathrm{D}}} * \sqrt{LT + GR} * avg.fcstDemand \tag{2.18}$$

where:

- *GR*: Goods Receipt Time
- *avg.fcstDemand*: average forecast demand of the next 90 calendar days

In the SS method SBB the SS quantity is calculated as in Equation 2.19:

$$CalcSSqty_{\mathrm{SBB}} = \frac{Orig.Hist.(xmonths)}{Frequency(xmonths)} \tag{2.19}$$

where:

- *Orig.Hist.(x months)*: The quantity of pieces sold from the current location to customers
- *Frequency (x months)*: The number of sales order lines causing the above history data
- *x months*: The number of months is dependent on the location, default is 3 months

Explanation of RP class of safety stock methods

In the SS method RP1 the SS quantity is calculated by using Equation 2.17, in addition a reorder point is calculated as in Equation 2.20:

$$CalcROP_{\mathrm{RP1}} = ActSS + \mu_{\mathrm{D}} * LT \tag{2.20}$$

In the SS method RP2 the SS quantity is calculated by using Equation 2.19 and the reorder point is calculated as in Equation 2.21:

$$CalcROP_{\mathrm{RP2}} = CalcSS + \mu_{\mathrm{D}} * (LT + \sigma_{\mathrm{L}}) \tag{2.21}$$

In the SS method RP3 the higher reorder point between the one calculated by using the method RP1 and RP2 is selected, as in Equation 2.22:

$$CalcROP_{\mathrm{RP3}} = max(CalcROP_{\mathrm{RP1}} \mathcal{I}\, CalcROP_{\mathrm{RP2}}) \tag{2.22}$$

2.5 Goal of the Thesis

2.5.1 Optimizing central steering of the safety stock

In order to mitigate business interruption (BI) risks, Hilti steers the inventory levels actively based on annual average demands. However, high-variance demand patterns have not been considered in the current safety stock steering mechanism. This means that despite the high inventory levels, there is still an high probability of running into avoidable stock outs.

A new adaptive model for risk-based inventory management is proposed, including high-variance demand patterns into the current safety stock steering mechanism. The supply managers are provided with new insights, helping them in a systematic way to reduce the disruption impact on their business and in "take money or take risk" decisions.

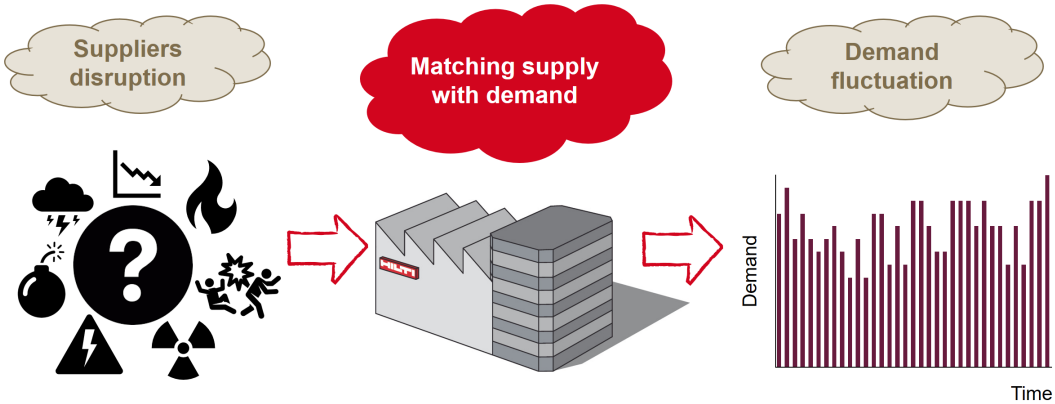

FIGURE 2.37: This research addresses the issue of higly variable demand during a supplier disruption

This research deals with scenarios involving high uncertainty in the upstream flow of materials. Highly unpredictable suppliers disruption events are acknowledged, undoubtedly leading to supply chain resilience approaches for what concern the supply side.

In the downstream flow of materials, instead, many data are generally available in relation to past demand patterns, allowing one to use supply chain risk approaches based on statistics.

A supplier's outage scenario is considered. Mitigation measures to reduce the impact, focusing on safety stock, are treated, according to the already implemented Hilti's risk management process but from a new perspective.

Chapter 3

Literature review

3.1 Supplier risk assessment

A supplier risk assessment it is an audit of a vendor's policies, processes and financial situation in order to decide how risky is for a contracting firm to have business with him. In first analysis, the contracting company needs to identify relevant suppliers for the success and assess their risk level. It is important to have a solid criteria to select risk relevant suppliers, as generally a company does not have capacity to assess all of them. The assessment is generally a form containing a list of the important points to go through during the audits and the needed documentation. Based on the results the contracting company will take corrective measures and address existing risks.

In the literature it is possible to find several conceptualizations of risk. From the marketing point of view, for example, the risk is related to the customer behavior and concerned with the failure in meeting performance or psychological goals and nature and importance of buying goals (Cox, 1967). Manuj and Mentzer (2008) discussed the conceptualization of risk considering different ways to address risk in different disciplines (finance, management, psychology, etc.) founding out three common components present in all of them:

1. Potential losses resulting from the realization of the critical event
2. Losses likelihood, i.e. the probability of the occurrence of an event leading to realization of the risk
3. Significance of the losses consequences

Jüttner et al.(2003), based on a wide literature review and fieldwork findings, suggest that SC relevant risk sources fall into three categories: Environmental risk sources, network-related risk sources and organizational risk sources (see Figure 3.1).

Organizational risk sources lie within supply chain parties boundaries and range from labour or production uncertainties to IT systems. Network-related risk sources arise from interactions between organizations across the SC. Environmental risk sources include uncertainties coming from the SC environment, such as accidents, socio-political actions or acts of God.

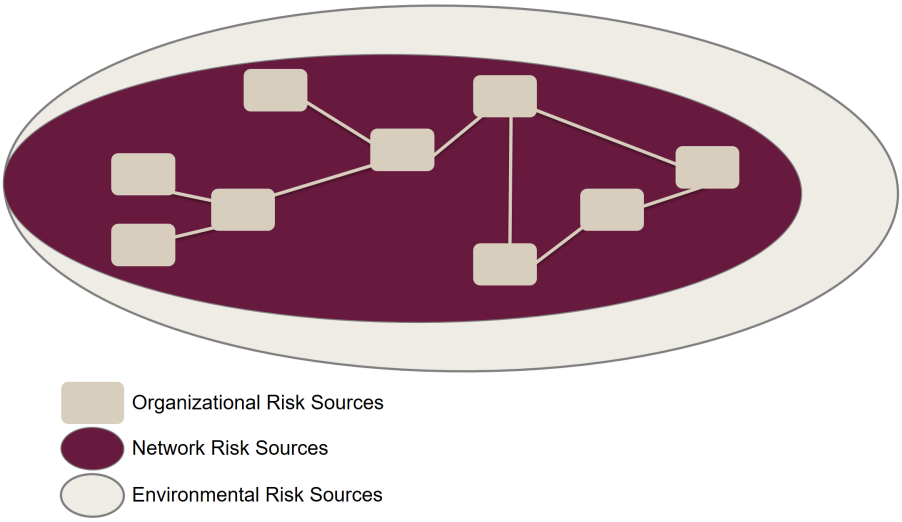

FIGURE 3.1: Risk sources in supply chains (Jüttner, Peck, and Christopher, 2003)

Manuj and Mentzer(2008) classify risks in the SC as quantitative or qualitative. Quantitative risks include lost sales due to stock outs, overstocking, obsolescence, customer discounts, and inadequate availability of components and materials in the supply chain. Qualitative risks include lack of accuracy, reliability, and precision of the components and materials in the supply chain. The second category is not less important than the first one and can have as potential consequences loss of brand equity or termination of a business relationship.

Type of Risk	**Source**
Supply Risks	Disruption of supply, inventory, schedules, and technology access; price escalation; quality issues; technology uncertainty; product complexity; frequency of material design changes
Operational Risks	Breakdown of operations; inadequate manufacturing or processing capability; high levels of process variations; changes in technology; changes in operating exposure
Demand Risks	New product introductions; variations in demand (fads, seasonality, and new product introduction by competitors);Chaos in the system (the Bullwhip Effect on demand distortion and amplification)
Security Risks	Information systems security; infrastructure security; freight breaches from terrorism, vandalism, crime, and sabotage
Macro Risks	Economic shifts in wage rates, interest rates, exchange rates, and prices
Policy Risks	Actions of national governments like quota restrictions or sanctions
Competitive Risks	Lack of history about competitor activities and moves
Resource Risks	Unanticipated resource requirements

TABLE 3.1: Risk classification into different categories (Manuj and Mentzer, 2008)

Manuj and Mentzer (2008) divide the sources of risk into supply risks, operations risks, demand risks, security risks, macroeconomic risks, policy risks, competitive risks, and resource risks (see Table 3.1). The most relevant for the scope of this research, based on this classification, are Supply Risks and Demand Risks, as they directly affect the operations of matching supply with demand.

Supply Risk is the possibility of the occurrence of an event associated with inbound supply, and include reliability of suppliers, single versus dual sourcing, make or buy decisions, centralized versus decentralized sourcing, and security issues. Demand Risk is the possibility of an event associated with outbound flows, and it varies with the nature of the product, with functional products less risky than innovative ones.

In global supply chains, some risky events may happen with a frequency not high enough to base decisions on probabilities, for example, Katrina destroying a sub supplier facility. In these cases, it is impossible to rely on historical data. There are techniques that can be used in these situations to assign probabilities such as the Delphi method (Manuj and Mentzer, 2008). By contrast, when enough historical data are available, it is possible to get reasonably good estimates with statistical based approaches.

Christopher S. Tang (2006) addresses the issue of Supply Chain Risk Management along two dimensions:

1. Supply Chain Risk
    - Operational risks
    - Disruption risks (Section 3.2)
2. Mitigation Approach
    - SCRM strategies (Section 3.1.1)

The first dimension considers the risk level of certain events. Operational risks include uncertainties in terms of supply (cost, lead time) and customer demand. Both uncertainties lead to fluctuations around the average levels that the production and inventory planning phases are generally based on. Disruption risks address the issue of major disruption events as a consequence of natural and man-made disasters such as floods, hurricanes, earthquakes, tornadoes, blizzards, fires or economic crises such as currency evaluation or bankrupt cases. Usually, the business impact associated to disruption risks is much greater than the one associated to operational risks.

3.1.1 SCR mitigation strategies

Christopher S. Tang (2006) reviewed various quantitative models for managing supply chain risks and various supply chain risk management (SCRM) strategies examined in the literature. In his review four basic approaches to mitigate the impact of supply chain risks are considered:

1. Supply Management
2. Demand Management
3. Product Management
4. Information Management

Each approach is then developed considering various inter-related issues.

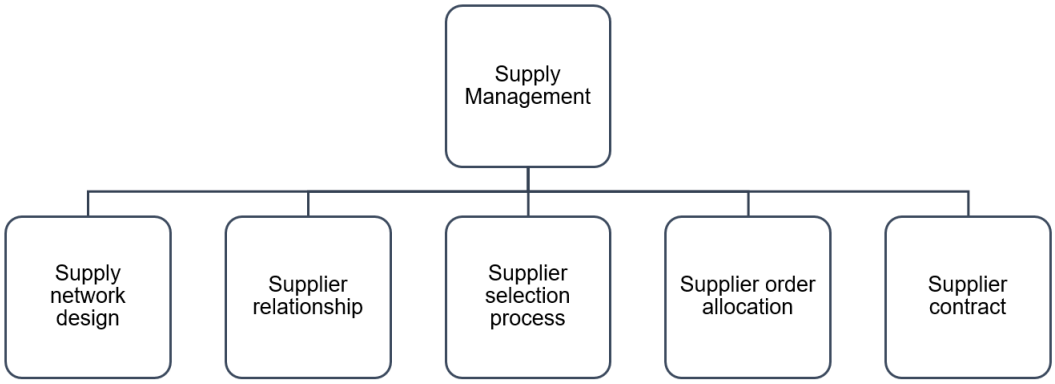

FIGURE 3.2: Supply Management Strategies

Supply management strategies can be used to mitigate various supply chain operational risks (Figure 3.2). The supply network design should consider issues like network configuration (available suppliers, manufacturing facilities, distribution centers and warehouse), product assignment (which facilities should process components or finished products), customer assignment (which facilities at an upstream stage should handle the demand from downstream stages), production planning and transportation planning.

Four types of supplier relationships are identified: vendor, preferred supplier, exclusive supplier and partner. The differences among the categories are in terms of types of contracts, lengths of contracts, type of information exchange, pricing scheme, delivery schedule, etc.

Regarding the supplier selection process, it is possible to refer to a review provided by Boer et al. (2001) in which the process is divided into three steps:

- Supplier selection criteria: Commitment to establish cooperative/long term relationship, supplier's technological capability and financial stability, business continuity plan, quality, delivery, price.
- Determination of approved suppliers: Classification of all suppliers into approved or disapproved.
- Final supplier selection

When a supplier set is chosen it is needed to determine ways to allocate the order quantity among the selected suppliers. The operational risks related to this area can be divided into:

- Uncertain demand
- Uncertain supply yield
- Uncertain supply lead time
- Uncertain supply capacity
- Uncertain supply cost

The most common types of contract one can find in literature in case of uncertain demand are:

- Wholesale price contracts
- Buy back contracts
- Revenue sharing contracts
- Quantity-based contracts: quality flexibility and minimum order

Supply management strategies show lack of effectiveness under inflexible supply mechanisms, for instance in industries in which the supply capacity is fixed (e.g. fashion goods manufacturing).

In those cases, a lot of companies tried to use different demand management strategies (Figure 3.3) to dynamically control uncertain demands. When it is possible to implement these strategies, the result is generally a better match between the modified demand and the fixed supply.

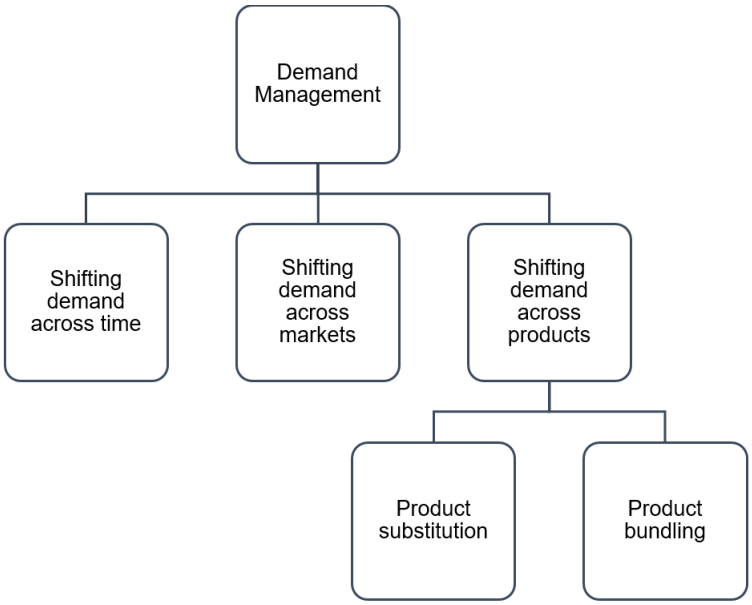

FIGURE 3.3: Demand Management Strategies

Shifting demand across time allows a company to reduce the demand uncertainty over the replenishment lead time periods, by using pricing mechanisms such as advance-commitment discount, peak load pricing, etc. Reducing the standard deviation of the demand over the replenishment lead time would result in inventory reduction for the entire supply chain.

Product substitution and product bundling would help a company to shift demands across products to satisfy more customers without incurring the risk of overstocking (Tang, 2006).

MacDuffie et al. (1996) conducted an empirical study based on the effects of product variety increase. Product variety enables a company to gain market share and revenue, but on the other hand imply higher manufacturing complexity translated in higher manufacturing cost and higher demand uncertainty translated in higher inventory cost. As production and inventory costs tend to increase as product variety increases it is critical for a company to determine an optimal product portfolio that maximizes the profit.

Product management strategies (Figure 3.6), such as postponement models, are an effective way to reduce variability in a supply chain and they can be classified based on operating modes MTS and MTO and demand forecasts. However, there are no models in the actual literature dealing with MTO systems with forecast updating. Another manner to reduce variability in a supply chain can be reversing the sequence of manufacturing processes (Tang, 2006).

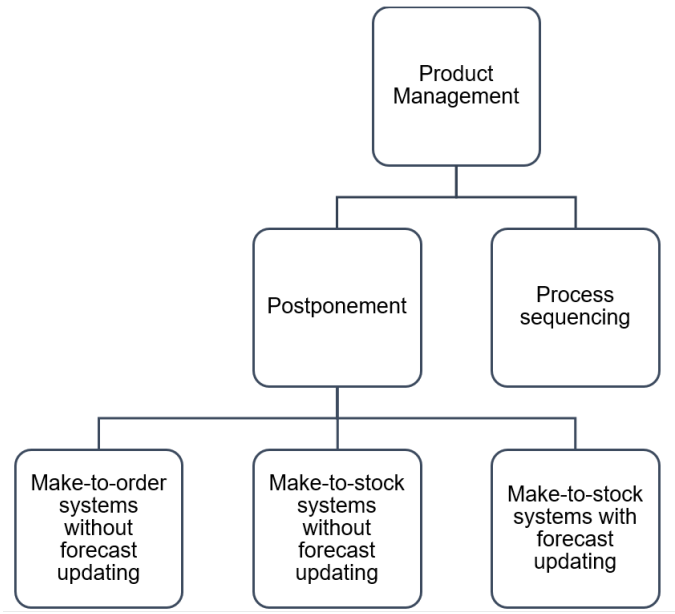

FIGURE 3.4: Product Management Strategies

Most consumer products can be classified as fashion products or functional products. The difference between the two categories relies on life cycles and on demand uncertainties levels. The functional products have lower levels of demand uncertainties and longer life cycles than the fashion ones (Fisher, 1997).

It is evident that, in presence of supply chain risk, the two categories of products need different information management strategies (Figure 3.5).

When dealing with short life cycles products (i.e. fashion products), a retailer could place more than one order over the selling season in case of short replenishment lead times. In the literature review conducted by Tang (2006) is considered the so called "quick response" system in which a retailer places one order prior to the beginning of the selling season and another during the selling season.

Clearly, the second order allows the retailer to obtain a more accurate demand forecast by using the actual sales data.

In literature are available stochastic dynamic programming models with demand forecast updating to analyze the quick response system. It is demonstrated that by implementing these models, companies achieved higher customer service level and lower inventory level. The reader is referred to Tayur et al. (2012) for a review of quantitative models.

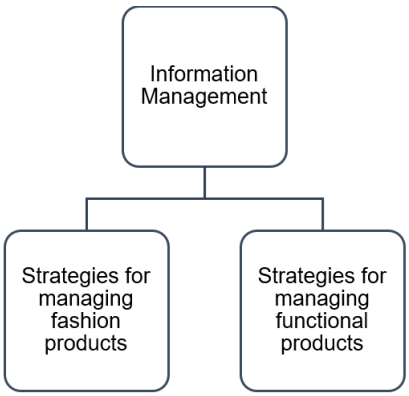

FIGURE 3.5: Information Management Strategies

When dealing with long life cycles products market information is critical for accurately forecast the demand. Upstream supply chain partners (wholesalers, distributors, manufacturers and suppliers) usually forecast the demand based on the orders placed by their downstream partners. This planning strategy would create a "bullwhip effect", phenomenon in which the orders show an increase in variability up the supply chain, even in case of stable customer demand. The direct consequence would include higher inventory as well as lower customer service.

To reduce the bullwhip effect the causes should be first identified. Four root causes of the bullwhip effect are demand forecasting, batch ordering, supply shortage and price variations (Lee, Padmanabhan, and Whang, 1997). Lee et al. (1997) propose strategies to mitigate the bullwhip effect including information sharing, vendor managed inventory and collaborative forecasting and replenishment planning.

When there is information sharing, the retail would share actual demand, inventory level and demand forecast information (beneficial to the manufacturer only). In the vendor managed inventory strategy, the retailers delegate the ordering and the replenishment planning decisions to the manufacturer that in this way get direct access to customer demand and retailers' inventory position.

Collaborative forecasting expects manufacturer and retailer to develop mutually agreeable demand forecasts jointly. Both parties would generate an initial demand forecast. The manufacturer would base it on his market intelligence on products, while the retailer on customer's response to pricing and promotion decisions. They would reconcile the differences to obtain a common forecast.

Jüttner et al.(2003) consider four generic strategies, adapted to SC contexts, companies adopt in order to mitigate risk. These four strategies are below shortly described.

- Avoidance

The first occurs when risks associated with operating in a given market or geographical area are considered to be unacceptable. Some examples of avoidance are dropping specific products, markets, suppliers, customer organizations.

- Control

Control strategies are generally the most widespread and include vertical integration, increased stock, buffer inventories, excess capacity in production and imposing contractual requirements on suppliers.

- Cooperation

Cooperative responses involve joint agreements among organizations in the SC, rather than unilateral control, to achieve uncertainty reduction. Such strategies improve supply chain visibility and understanding, to share information on exposures and to prepare joint business continuity plans. They are mostly restricted to initiatives with key suppliers.

- Flexibility

Flexibility increases responsiveness while leaving the predictability of factors unchanged. Examples are postponement strategies, multiple sourcing, and localized sourcing with its short lead-times and potential for quick responses.

3.2 Supplier disruption

In today's increasingly dynamic and turbulent world, companies are exposed to various low-probability, high-impact risks that can disrupt their supply chains. These events include natural and man-made disasters such as fires, equipment failures, labor disputes, supplier defaults, political instability, and terrorist attacks.

Raw material moves through various processes, geographic and political regions, changes ownerships and transportation modes before reaching the final customers. All of these processes expose potential nodes where supply chains are vulnerable to disruptions (Ghadge, Dani, and Kalawsky, 2013).

Supply chain disruptions and the related operational and financial risks represent one of the most critical concern facing corporations competing in today's global marketplace (Craighead et al., 2007).

Disruptions are unavoidable and all supply chains are inherently risky. Craighead et al. (2007) define a *disruption* as an unplanned and unanticipated event restricting the flow of material, information or money within the supply network. Moreover, they define the *severity* of such events as the number of entities within a supply network whose ability to move goods and materials has been hampered by the disruptive event.

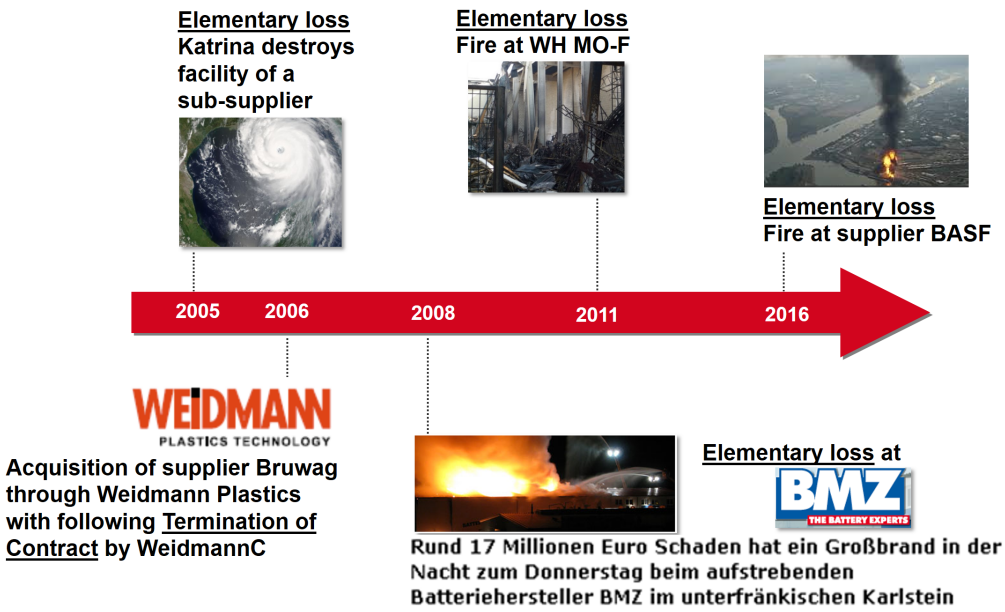

FIGURE 3.6: Over the last 10 years various events have disrupted supply chain operations repeatedly

Simchi-Levi et al. (2015) investigate how managers usually deploy sub-optimal countermeasures, assigning resources to mitigate risks that would not cause significant damages. As a consequence the leave their companies exposed to important risks, difficult to be quantified and predicted and hence difficult to be managed.

One obstacle to analyzing disruption risks is that operational disruptions are both difficult to predict and have a highly uncertain impact on performances. Another common obstacle is data availability, for example, data related to sub-suppliers, and suppliers' transparency.

Due to these limitations risk-management processes practically need to be restricted to the status of only a handful suppliers and part numbers. These tend to be suppliers providing major assembly components and with a large portion of the total component costs (Simchi-Levi, 2015).

The distinctions between supply chain resilience, risk, and uncertainty are often unclear. The issue is amplified by the fact that some consider risk and uncertainty as synonyms, without separating these two distinct concepts (Melnyk et al., 2014). It's important to differentiate the risk due to fluctuations around the average into 2 cases (see Table 3.2):

Risk Category	Typical Situation	Approach
Operational Risk	Standard deviation on average demand	Supply Chain Risk
	Supplier's performance variability	
Disruption Risk	Outliers, peak demands	Supply Chain Resilience

TABLE 3.2: Different approaches to the risk

3.2.1 Supply chain risk approaches include statistics

Companies have to deal with the possibilities of experiencing situations that can negatively influence them. With high exposure to disruptions, it is important that supply chains manage risks proactively. However, not all future events are equally unknown.

From past experiences it is possible to get insights on which events could occur, their occurrence probability and the impact. Firms can forecast the likelihood of such events over a certain time horizon and determine how to react in case of occurrence. Events with a higher likelihood and important potential impact need greater preparation (Melnyk et al., 2014).

In Figures 3.7 a graph represents supply chain risk approaches and supply chain resilience approaches. The decision between the two different ways depend on the impact of the disruption to the company and on the probability of occurrence.

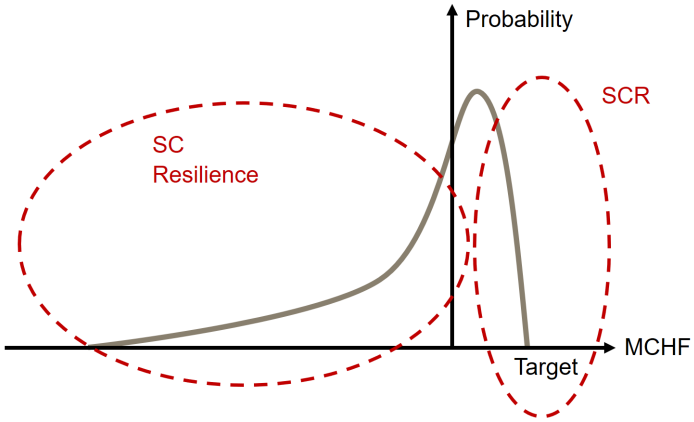

FIGURE 3.7: Supply chain risk is compared with supply chain resilience

3.2.2 Uncertainty means unpredictability

On the other side, uncertainty is a concept related to unpredictability. In case of inability to either develop a probabilistic estimate or list all possible alternative outcomes related to a decision or an event we talk about uncertainty. In this context uncertainty is defined as the perceived inability to accurately predict something (Milliken, 1987). Uncertain events are typically events a company has not experienced in the past.

Once the concepts of risk and uncertainty have been opportunely separated, it is possible to provide an important rule of thumb for resilience: If faced primarily by risk, the most appropriate strategies should include investments in improving resistance; if dealing with uncertainty, it makes more sense to invest in improving recovery capabilities (Melnyk et al., 2014).

3.2.3 Supply chain resilience approaches allow managers to turn disruptions into opportunities

A way of dealing with disruption is to develop resilient SC systems. When talking about resilience, P. Trucco et al. (2018) refer to the ability of a global supply chain to anticipate, reorganise and deliver continually its main function, despite the impact of external and internal shocks to the system.

Resilience can be seen, in other words, as proactive efforts to be better positioned than competitors to deal with and to gain advantage from disruptions. These definitions focus on capabilities of a supply chain in mitigating disruptions happening somewhere in the network, possibly turning them into an opportunity to gain competitive advantage.

Resilience is a property that supply chain managers can shape and influence. It can be obtained through various types of actions such as (Melnyk et al., 2014):

- Investing in the ability to identify potential problems as close to the event occurrence as possible (e.g. information technology, early supply chain partners' warnings, forecasts, performance monitoring, demand sensing)
- Designing supply chains able to be reconfigured quickly in case of environmental changes (e.g. investing in flexibility)
- Creation of cushions in terms of:
  - Inventory
  - Capacity (e.g. human resources with high capability and/or experience, excess operating capacity)
  - Safety lead times (e.g. redundancies)
- Improving security to protect the system from theft, damage or counterfeiting (e.g. firewalls, quarantine)
- Designing contingency plans so that the various groups know what to do in case of shocks and their responsibilities (e.g. training, rehearsing, insurance)
- Changing either flows or product specifications in response to supply chain problems (e.g. transportation alternatives, variable bills of material)
- Applying investments in other areas that can be drawn on by the firm in case of realization of a shock (e.g. marketing position, brand equity, SC capital, relationships with suppliers or customers, supplier or customer loyalty, revenue management)

Some of these actions, as investments in safety stock or increased lead time buffer, are direct investments. However, indirect investments as investments in customer loyalty, brand equity or relationships with customers, can also have an impact on resilience, as they offer capabilities that the firm can draw on to deal with unexpected breakdowns in its systems. Two broad strategies for SC resilience which Rice and Caniato 2003 focus on, are flexibility and redundancy. Investing on flexibility involves creating capabilities within the organization to redeploy already existing capacities and assets across different areas. Differently, investing on redundancy implies additional capacity that would be used to replace potential capacity loss generated by a breakdown. Both approaches require investments in infrastructure and resources prior to the point of need. In general, the attempts to achieve higher supply chain resilience cannot focus only on a limited number of nodes, neither on a set of isolated investments and actions. The dynamics of supply chain disruptions induced by inter-dependencies across the network lead to the need of coordinated and collaborative resilience strategies, involving all the relevant actors of modern global supply chains (Trucco, Petrenj, and Birkie, 2018).

Chapter 4

Proposed model

4.1 Demand decomposition

4.1.1 Extracting seasonality and trend from data

The first step of creating the model consists of mathematically decomposing one time series into multiple series. The demand of a tool over the last three years is taken into consideration and broken down into three constituent components.

- *Trend*, representing the underlying long-term growth rate of the demand pattern.
- *Seasonality*, representing the cyclicality over time. Patterns repeating with a fixed period of time are generally present in the analyzed data.
- *Noise*, representing the random behavior which cannot be attributed to the previous two categories. It consists of the residuals of the original time series after the seasonal and trend effects are cleaned.

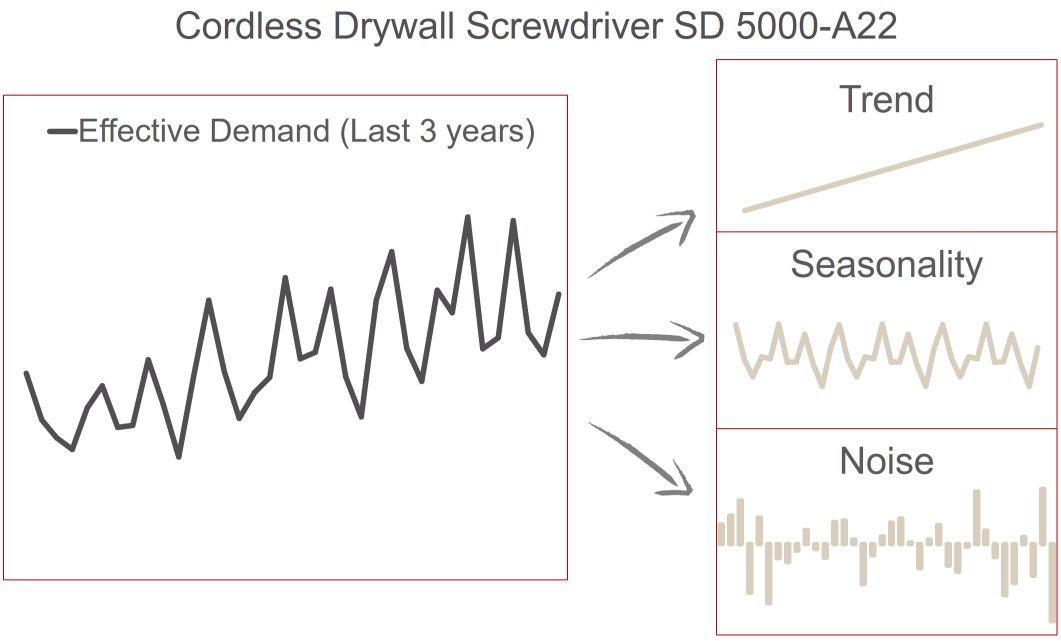

FIGURE 4.1: Last 3 years demand of an Hilti tool decomposed into constituent elements

The three components are shown separately in the right hand side of Figure 4.1. These components can be added together reconstructing the data pattern in the left side of the same figure. The noise component is what is left over after seasonal and trend elements are subtracted from the overall time series.

This can be useful in explaining why a demand pattern presents a decreasing behavior in the short-term and picks up in the long-term. For the example data, the last 3 years sales data of a *Cordless Drywall Screwdriver*, which has an important seasonal component, have been looked at. By using decomposition it is possible to remove this seasonal effect from a time series. The remaining signal has a clear trend, which in this case is an evident positive trend.

Trend, central moving average

The first step of the demand decomposition consists in smoothing out demand data over the year by following a weighted moving average (MA) procedure. To perform the decomposition it is extremely important to use a moving window of the same size of the cyclical component. After testing the validity of different moving windows by using a correlation test, it turns out that the most common seasonality factor was year-based. In the example of the item *Cordless Drywall Screwdriver* the following correlation factors [0,1] have been obtained (Table 4.1):

Correlation factor (Year vs. Year)		
1 vs. 2	2 vs. 3	1 vs. 3
0.89	0.85	0.79

TABLE 4.1: Correlation check confirms 12-months seasonality

The average sales value for each month has been produced by averaging over the previous and next six months (for September, March is included twice, the values of that month have been selected and then divided by 12 to obtain a monthly figure). As confirmed by the correlation tests, analyzed trends are generally annual, which is why the MA includes all data from every month of the year. The moving average done this way is a centred moving average of order 12. This step allows to understand the underlying trend component, cleaning the demand pattern from outliers and from there it is possible to calculate the seasonal component. Inevitably, some data is lost from the start of the sample, in which there are not six preceding months. The aim of the MA procedure is calculating its linear regression equation.

For the scope of this research it is interesting to obtain and analyze a linear trend model. Once calculated the MA values are assumed to have a linear trend. A linear regression on the MA values has been performed to approximate the equation of the underlying trend. Slope m and intercept q have been obtained and, therefore the trend component has been deduced. The coefficient of determination R^2 [0-1] is also attached to every calculation, returning a statistical measure of how close the MA data to the fitted regression line are (Figure 4.2).

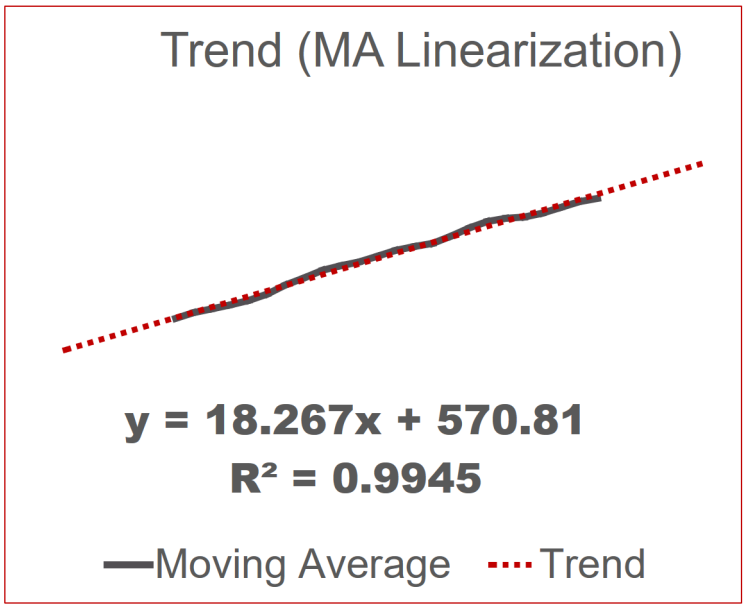

FIGURE 4.2: The trend is quantitatively obtained by linear regression of the moving average

Linear regression of MA	
m	18.3
q	570.8

TABLE 4.2: Slope m and Intercept q of the MA linearization define the trend

Seasonality, multiplicative or additive model selection

The next step requires to select between an additive or multiplicative model. The difference relies on the behavior of the seasonal element. If the seasonal component varies according to the underlying trend, the best solution will be using a multiplicative model. In the other case, if the seasonal component remains consistent in size, even if the growth rate is increasing, an additive approximation model will be better to describe the time series. This information can be easily obtained by looking at the graph. The selected example shows that the seasonal variation has a slightly increasing behavior along the time, and increases according to the long-term growth. Hence, it suggests that a multiplicative model is more accurate in this specific scenario. The developed tool decomposes demand data by using both additive and multiplicative models and automatically selects the one that better approximates the real demand pattern. The automatic selection is driven by the lower standard deviation of the residuals. The decomposition formula varies depending on the model.

FIGURE 4.3: Numerical example of decomposition in trend and seasonal components

Cordl. dryw. screwdr. SD 5000-A22					Additive		Multiplicative	
Month		Dem	MA	Trend	Seas	Avg Seas	Seas	Avg Seas
Oct-15	1	**835**		582		311		1.34
Nov-15	2	**643**		600		-47		0.96
Dec-15	3	**571**		619		-231		0.76
Jan-16	4	**522**		637		-9		0.98
Feb-16	5	**693**		655		-38		0.96
Mar-16	6	**784**		673		346		1.35
Apr-16	7	**613**	696	692	-83	-58	0.88	0.92
May-16	8	**622**	716	710	-94	-56	0.87	0.92
Jun-16	9	**891**	728	728	163	196	1.22	1.23
Jul-16	10	**708**	741	746	-33	-93	0.96	0.90
Aug-16	11	**491**	756	765	-265	-306	0.65	0.65
Sep-16	12	**825**	780	783	45	78	1.06	1.08
Oct-16	13	**1,135**	810	801	325	311	1.40	1.34
Nov-16	14	**842**	834	820	8	-47	1.01	0.96
Dec-16	15	**650**	859	838	-209	-231	0.76	0.76
Jan-17	16	**756**	875	856	-119	-9	0.86	0.98
Feb-17	17	**819**	887	874	-68	-38	0.92	0.96
Mar-17	18	**1,227**	907	893	320	346	1.35	1.35
Apr-17	19	**894**	928	911	-34	-58	0.96	0.92
May-17	20	**922**	940	929	-18	-56	0.98	0.92
Jun-17	21	**1,179**	950	947	229	196	1.24	1.23
Jul-17	22	**821**	974	966	-153	-93	0.84	0.90
Aug-17	23	**656**	1,003	984	-347	-306	0.65	0.65
Sep-17	24	**1,135**	1,024	1,002	111	78	1.11	1.08
Oct-17	25	**1,333**	1,036	1,020	297	311	1.29	1.34
Nov-17	26	**938**	1,040	1,039	-102	-47	0.90	0.96
Dec-17	27	**801**	1,055	1,057	-254	-231	0.76	0.76
Jan-18	28	**1,176**	1,074	1,075	102	-9	1.10	0.98
Feb-18	29	**1,084**	1,092	1,094	-8	-38	0.99	0.96
Mar-18	30	**1,476**	1,104	1,112	372	346	1.34	1.35
Apr-18	31	**935**		1,130		-58		0.92
May-18	32	**981**		1,148		-56		0.92
Jun-18	33	**1,461**		1,167		196		1.23
Jul-18	34	**1,001**		1,185		-93		0.90
Aug-18	35	**911**		1,203		-306		0.65
Sep-18	36	**1,159**		1,221		78		1.08

When assuming an additive decomposition (Figure 4.4) the seasonal variations around the trend-cycle do not change with the level of the time series. In this case the model follows Equation 4.1:

$$Demand(t)_{\text{add}} = Trend(t)_{\text{add}} + Seasonality(t)_{\text{add}} + Noise(t)_{\text{add}} \tag{4.1}$$

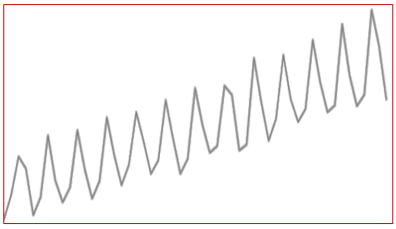

FIGURE 4.4: Additive decomposition is used when the seasonality is not proportional to the time series level

Alternatively, if the seasonal variation increases when the time series values increases, a multiplicative model is more accurate. The decomposition model in this case follows Equation 4.2:

$$Demand(t)_{\text{mult}} = Trend(t)_{\text{mult}} * Seasonality(t)_{\text{mult}} * Noise(t)_{\text{mult}} \tag{4.2}$$

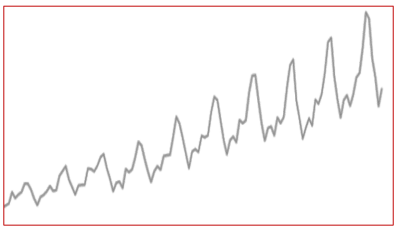

FIGURE 4.5: Multiplicative decomposition is used when the seasonality varies with the time series level

For a multiplicative model the next step requires calculating the ratio between the real demand data and the corresponding moving average figures. For an additive model, it is necessary to deduct instead of divide. This calculation gives a series of number representing the seasonal element of the raw data. In order to obtain more reliable seasonal coefficients and smooth out some of the noise in the data, the seasonality coefficients are averaged with the ones of the corresponding month in other years (for example, seasonality coefficient from January 2017 and January 2018 are averaged between themselves. The same process has been done for all the coefficients of the different months). This method was used to generate the columns *"Avg Seas"* in Figure 4.3.

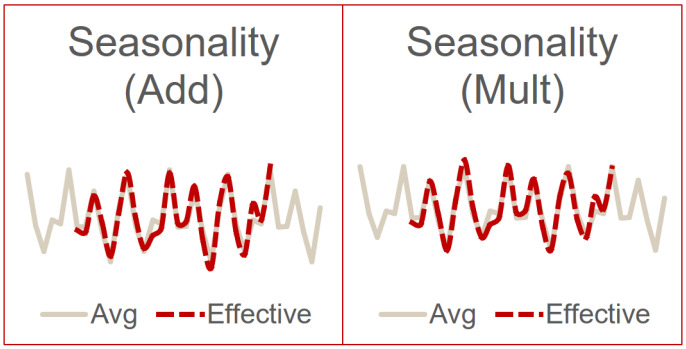

FIGURE 4.6: Average seasonality is calculated with both additive and multiplicative models

4.1.2 Examining residual random noise

The above approximation stages have already extracted most of the original time series data. The residual random noise component is what is left over after fitting the time series model. In other words, it is possible to quantitatively obtain the random element simply by deducting from the observed real values the corresponding fitted values, which are the sum of trend and seasonal components.

For an additive model, the noise component is calculated by isolating the random term in Equation 4.1, as shown below in Equation 4.3:

$$Noise(t)_{\text{add}} = Demand(t)_{\text{add}} - Trend(t)_{\text{add}} - Seasonality(t)_{\text{add}} \tag{4.3}$$

In case of a multiplicative model, the noise component is calculated as shown below in Equation 4.4:

$$Noise(t)_{\text{mult}} = \frac{Demand(t)_{\text{mult}}}{Trend(t)_{\text{mult}} * Seasonality(t)_{\text{mult}}} \tag{4.4}$$

Residuals are generally useful when checking whether or not the model has sufficiently registered the information in the real data. A good approximation model leads to residuals with the following properties:

- Residuals are *not correlated*. If there is correlation it means that additional information is left in the residuals. That information should be included in the approximation method. As a consequence the variance of the residual terms is constant along the horizontal axis. As shown in Figure 4.7, the vertical width of the scatter plot does not appear to have a particular increasing nor decreasing behavior across the fitted values. Due to this observation it is possible to assume that the variance of the residuals is constant.

- The noise is a random fluctuation around the average value. It means that the residuals *have zero mean*. In case the mean is not null, the approximation method is biased. Overcoming this issue is relatively easy: if the residuals have a certain mean value, it is possible to simply add that value to the overall model and the bias problem is solved.

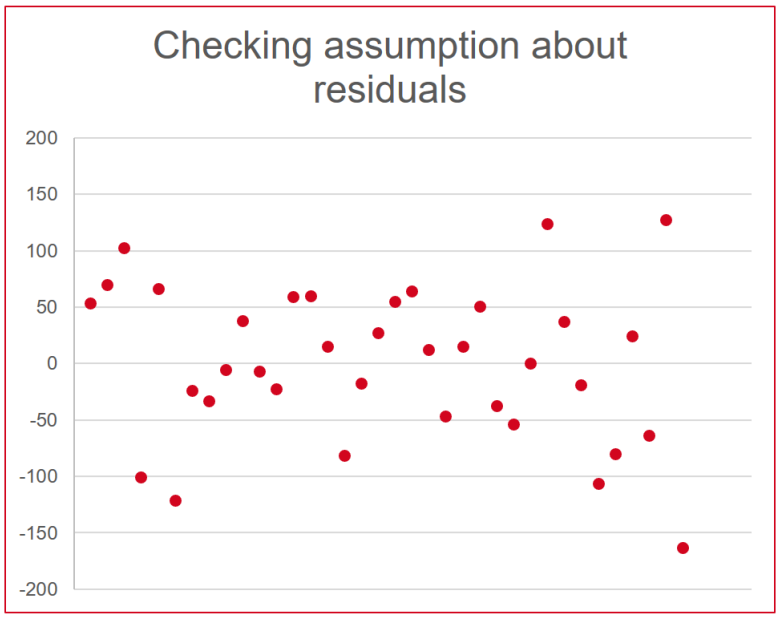

FIGURE 4.7: Noise component scatter-plot to check residual randomness *Cordless Drywall Screwdriver*

As a last step to check the assumptions of residuals, the Anderson–Darling normality test in Minitab has been used. The test allows to check whether a normal distribution adequately describes the residuals data set. The result is expressed as a P-value between 0 and 1. If the P-value is large, the residuals pass the normality test. Otherwise, there is evidence that the analyzed data does not comply with one of the regression assumptions.

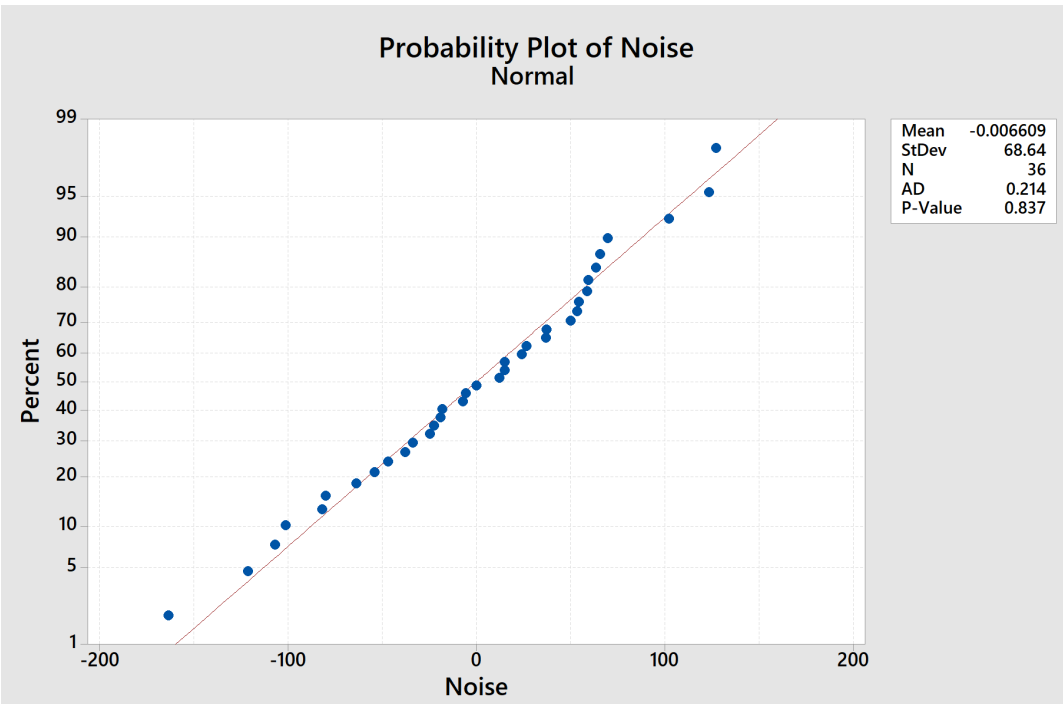

FIGURE 4.8: Normality test of Residuals *Cordless Drywall Screwdriver*

The normality test has P-value=0.837, which means that the data is consistent with the assumptions of regression. There is no strong evidence against the hypothesis of non-normal data. However, few outliers are shown in the Probability Plot. Since the P-value is high there is no need to take further actions regarding the existing outliers.

Reconstruct the signal and forecast the average demand for next year

The actual demand can be recomposed as sum of trend and seasonality. In Figure 4.9 the original time series and the reproduced one are plotted in the same graph. The difference between real data signal and reconstructed signal represents the random noise component. The demand has been rebuilt by using both the multiplicative and the additive model. For this data set, both models represent a good approximation of the real data. However, the multiplicative model leads to a lower standard deviation of the noise component. Therefore, for the reasons thoroughly explain in Section 4.2.1, the additive model is discarded.

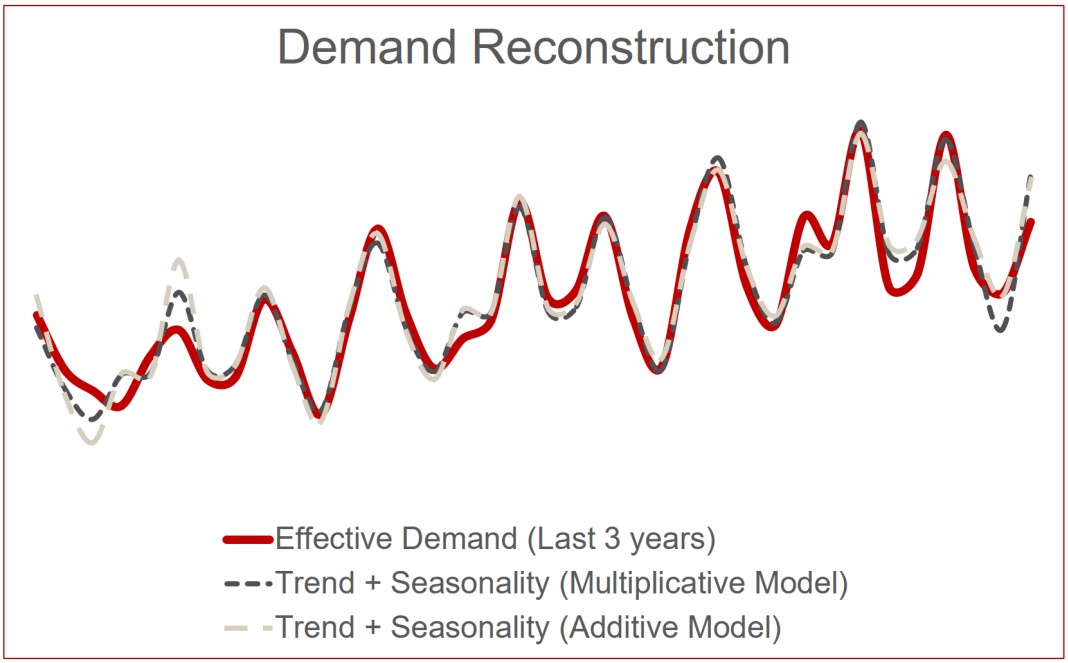

FIGURE 4.9: Reconstruction of the original demand signal by combining predictable components *Cordless Drywall Screwdriver*

Demand decomposition has been used in for the calculation of the standard deviation of the random component in the demand pattern, in order to size the safety stock. However, the different decomposed elements can also be used to forecast the behavior in future years.

The central moving average technique estimates the next period's demand data by averaging the data of periods immediately before and next. MA model is a smoothing forecast technique. It smooths out the effects of irregularities within the

data. However, it is possible to use the already computed seasonality coefficients in order to take into account the effects of seasonality.

Another way to calculate forecasts is using exponential smoothing methods (Brown, Holt, Winters). Forecasts produced using exponential smoothing methods allow to place weight on more recent observations. They are composed by weighted averages of past observations, with exponentially decaying weights as the observations become older. In other words, they incorporates the whole time series, placing the biggest weight on the current data, and weights on older observations exponentially decreasing over time.

$$Forecast_{\mathrm{t+1}} = \alpha * Demand_{\mathrm{t}} + (1 - \alpha) * Forecast_{\mathrm{t}} \tag{4.5}$$

Equation 4.5 explains Brown's simple exponential smoothing method. In this equation, $Forecast_{t+1}$ represents the calculated value for period *t+1*, $Demand_t$ is the actual demand value of the current period *t* and $Forecast_t$ is the calculated value for the current period. α is the smoothing constant [0-1]. If α is small (i.e., close to zero) the weight given to recent observations is low and the forecast adjusts to patterns in time series very slowly. Contrarily, if α is big (i.e., close to one) the weight given to recent observations is high and the model will be able to promptly chase changes in time series patterns.

The first step in building an exponential smoothing model is to generate a forecast for the first period in the time series. The most common procedure consists in setting the calculated value of the first period equal to the actual value. For the current analysis the initial forecast has been determined this way.

The second step in a Brown's model is the selection of the smoothing coefficient α. The approach used in the present work consists in calculating the monthly sales forecasts during the last three years, for which the real data are available, with different values of α. Nine different scenarios have been computed, with the smoothing coefficient varying from 0.1 to 0.9 with steps of 0.1. At the end, the mean square error (MSE) has been calculated for each case. The value of α with the lowest MSE is the value considered for the forecasts in the future, while all the others are discarded.

The smoothing coefficient that minimizes the mean square error for the *Cordless Drywall Screwdriver* data set is $\alpha = 0.3$. Table 4.3 reports different MSE obtained with different values of smoothing coefficients and with the multiplicative model based on moving averages.

Method	**MSE**
Brown α = 0.1	12,432
Brown α = 0.3	**7,846**
Brown α = 0.5	11,933
Brown α = 0.7	19,784
Brown α = 0.9	31,432
MA multiplicative	**4,670**

TABLE 4.3: Mean square error for exponential smoothing model with different values of α and MA multiplicative model are compared

In Figure 4.10 the forecast obtained with the exponential smoothing method and with the multiplicative method are compared. Both methods provide a good approximation of the real demand during the months in which data are available. However, the MSE is lower for the moving averages based model, which will be selected to calculate the average demand for the future year.

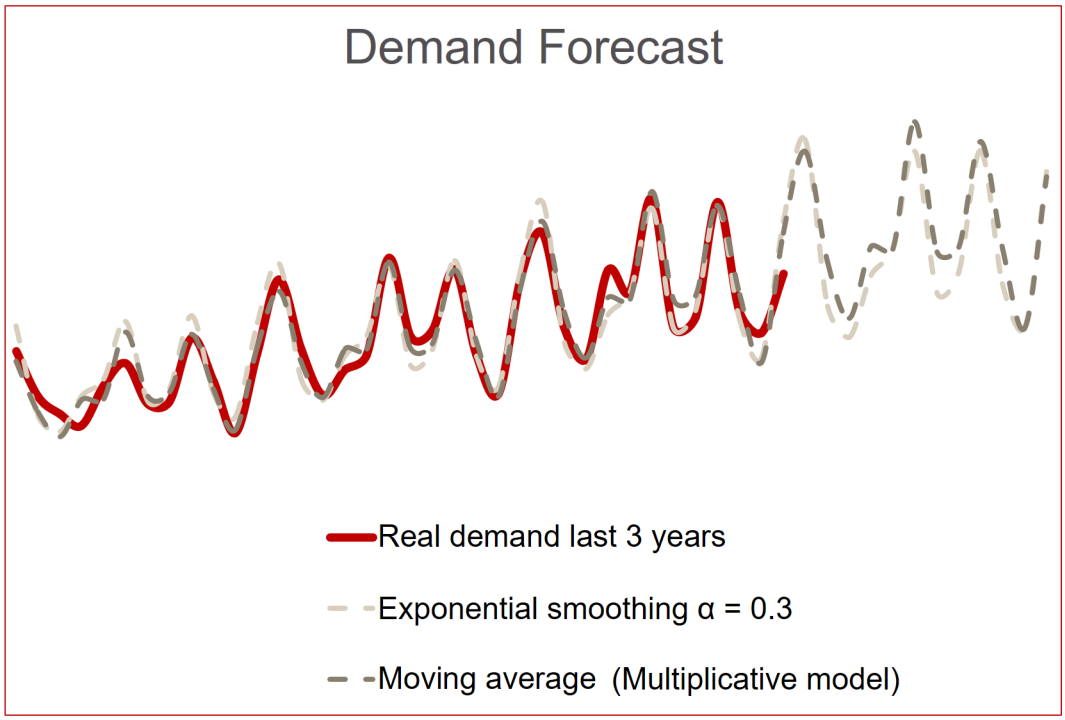

FIGURE 4.10: Demand forecast with MA multiplicative model and with exponential smoothing are compared

Once it has been proven that the moving averages model based on a multiplicative decomposition is the one that best approximates the real demand, it is possible to calculate the average demand for the next twelve months. Table 4.4 shows the yearly average demand for the last 3 years and the predicted one for the next year. As there is an important positive trend it is expected that the sales during the 2019 will be higher.

Year	Average sales [PC/month]	Type of data
2015-2016	683	Effective
2016-2017	920	Effective
2017-2018	1105	Effective
2018-2019	1290	Forecast

TABLE 4.4: Average demand data along the years

The average demand for the next year will take into account trend and seasonal components. The random noise component will be considered through the standard deviation of noise, explained in Section 4.2.1.

4.2 Safety stock per supplier calculation

4.2.1 Standard deviation of noise is calculated for every finished item

The demand decomposition process explained above is needed in order to calculate the standard deviation of the residuals. Predictable components of demand patterns, such as trend and seasonality, are not part of the Safety Stock calculation. Since it is possible to forecast them, they will only be taken into account during the production planning phases. The SS exists only to cover potential unpredictable events and assure a certain Service Level (SL). Therefore, in order to size the SS, the standard deviation σ of the random component is taken into consideration.

Equation 4.6 refers to a sample of *n=36*. The term *n-1* represents the number of degrees of freedom or, in other words, the number of data of the time series that are independent.

$$\sigma_{Noise} = \sqrt{\frac{\sum_t Noise(t)^2}{n-1}} \tag{4.6}$$

Std Dev of Noise	
Add model	Mult model
82.3	68.9

TABLE 4.5: Standard deviation of Noise calculated with additive and multiplicative models *Cordless Drywall Screwdriver*

Once the standard deviation of the noise has been calculated, it is possible to proceed with sizing the safety stock. The standard deviation calculation tool selects the lower value between multiplicative and additive model. This way the value used for further analysis is always the one coming from the model that better approximates the raw data.

In this specific example the standard deviation calculated with the multiplicative decomposition model is lower. Therefore, the value $\sigma = 68.9$ *pieces* is selected for the analysis and the one obtained with the additive model is discarded.

4.2.2 Standard deviation of noise is aggregated at components' level

Following the above described process, the standard deviation of the demand pattern, due to the random component, has been calculated for all the finished products of interest. In the production plants there is only a components' safety stock since the finished items are assembled to order (ATO). Therefore, the next steps consist of assigning standard deviation calculated for the finished items to the respective components. This way the consumption of components will be known in terms of average and standard deviation and it will be possible to define a needed SS. In order to accomplish this step, it is necessary to find the constructive relations between finished items and components in the bills of materials. Once these relations have been obtained, it is possible to use them as scaling factors in order to report the standard deviations of the finished item at the components' level.

In order to explain the aggregation method, let's assume a case in which there are three different components and six different finished items (Figure 4.11):

- 1 piece of prod. A requires 2 pieces of comp. X
- 1 piece of prod. B requires 3 pieces of comp. X and 2 pieces of comp. Y
- 1 piece of prod. C requires 1 piece of comp. Y
- 1 piece of prod. D requires 2 pieces of comp. Y and 1 piece of comp. Z
- 1 piece of prod. E requires 4 pieces of comp. Z

Table 4.6 contains all the ratios between component and finished item as obtainable from the constructive bill of materials of the products.

Component	BOM ratio	Product
X	2:1	A
X	3:1	B
Y	2:1	B
Y	1:1	C
Y	2:1	D
Z	1:1	D
Z	4:1	E

TABLE 4.6: BOM ratios example [Component:Product]

Figure 4.11 shows a simplified scheme of the possible relations between parts and finished products. A bill of material is composed by different components but it could also happen that different products share the same component with different requirements.

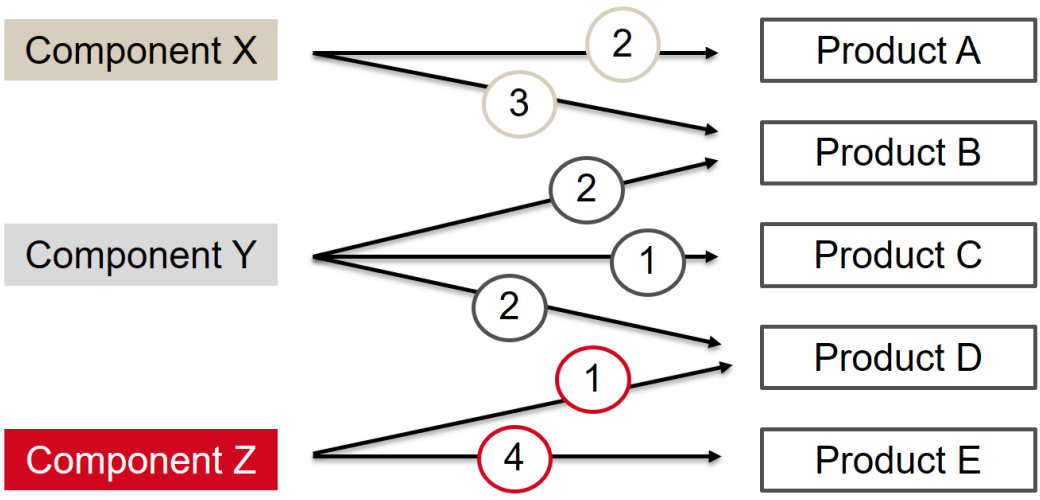

FIGURE 4.11: Example of possible relations between components and finished items. The number in the circle indicates the BOM ratio

Data aggregation from finished item to components is done by using Excel. The Excel table will contain as many lines as the number of arrows. In the table of the example of Figure 4.11 there will be seven lines. The component Y is repeated three times, as its consumption will be dependent from three different finished products' sales.

After applying the demand decomposition explained in the previous sections, the products' demand patterns are broken down into trend, seasonality and noise. Trend and seasonality can be used in order to forecast the average demand during the next year while the random noise component is taken into account through the standard deviation of the noise. Data involved in the aggregation process from finished products' level to suppliers' level are:

- Forecasted average demand during next 12 months [PC/month]
- Standard deviation due to random noise component σ_{Noise} [PC/month]

The average consumption of a single component due to a single finished item is simply calculated by multiplying the average demand of the product and the BOM ratio. In Equation 4.7 the first subscript before the comma indicates the component which calculates the average consumption. The second subscripts indicates the products which cause the consumption.

$$AvgConsumption_{\mathrm{X,A}} = AvgDemand_{\mathrm{A}} * BOMratio_{\mathrm{X/A}} \tag{4.7}$$

Once the average consumption of all the components due to all the finished items has been calculated, to obtain the overall components' consumption, it will simply have to be summed up, as in Equation 4.8:

$$AvgConsumption_{\mathrm{X}} = \sum_{P} AvgConsumption_{\mathrm{X,P}} \tag{4.8}$$

The standard deviation of the consumption due to the random noise component is treated similarly to the average consumption, with the only difference that the variance of the consumption will be summed up, since it is mathematically not possible to directly sum standard deviations. As a first step, the standard deviation of the consumption for a single component due to a single finished item is calculated (Equation 4.9):

$$\sigma_{\mathrm{X,A}} = \sigma_{\mathrm{A}} * BOMratio_{\mathrm{X/A}} \tag{4.9}$$

Once the standard deviation of the consumption of all components due to all finished items has been obtained, it is possible to square them in order to get the variance of the consumptions due to the random noise. The overall standard deviation of a component's consumption is determined by calculating the square root of the sum of all the variances (Equation 4.10):

$$\sigma_{\mathrm{X}} = \sqrt{\sum_{P} (\sigma_{\mathrm{X,P}})^2} \tag{4.10}$$

Let's now apply the above equations to an hypothetical data set. Let's assume the data in Table 4.7 represent the forecasted average demand for the next year [PC/month] and the standard deviation of the demand due to the random noise [PC/month] for the five products of Figure 4.11.

Product	Avg Dem [PC/month]	StdDev Noise [PC/month]
A	10	4
B	15	5
C	30	2
D	10	2
E	5	1

TABLE 4.7: Numeric example of average demand and standard deviation due to noise

The average consumption of each component due to the different products it is part of, is calculated, as shown in Equation 4.7 by multiplying the forecasted average demand and the BOM ratio. Same procedure, as reported in Equation 4.9, is done in order to obtain standard deviation at component level as effect of the standard deviation of the random noise of finished products. This way it is possible to fill in the two consumption columns in the right side of Table 4.8.

Products	Demand		Ratio	Comp	Consumption	
	Avg	StdDev			Avg	StdDev
A	10	4	2	X	20	8
B	15	5	3	X	45	15
B	15	5	2	Y	30	10
C	30	2	1	Y	30	2
D	10	2	2	Y	20	4
D	10	2	1	Z	10	2
E	5	1	4	Z	20	4

TABLE 4.8: From forecasted demand of products to consumption of components through the BOM ratio

At this step average and standard deviation of consumption has been computed for each component and they need to be summed up. Summing up the average consumptions has been done as shown in Equation 4.8. The obtained values are reported in Table 4.9.

Comp	Avg Cons
X	65
Y	80
Z	30

TABLE 4.9: Average consumption of components due to different products is aggregated

The aggregation of standard deviations has been done as shown in Equation 4.10. First, the variances are obtained. The computed variances are shown in Table 4.10.

Comp	StdDev	Variance
X	8	64
X	15	225
Y	10	100
Y	2	4
Y	4	16
Z	2	4
Z	4	16

TABLE 4.10: Variances of components' consumption due to different products are computed

Finally, the variances are summed up and the square root of each sum of variances is calculated, as showed in Table 4.11

Comp	Sum of Variances	Aggregated StdDev
X	289	17.00
Y	120	10.95
Z	20	4.47

TABLE 4.11: Standard deviation of components' consumption [PC/month] is aggregated

It is now possible to summarize the computed values of average consumption [PC/month] and standard deviation of consumption [PC/month] for each component. Furthermore, the coefficient of variation (CV) can be calculated. The CV is calculated as ratio of the standard deviation to the mean and it allows comparison between different components to interpret the relative magnitude of the variability. For example, the standard deviation of the consumption of the component X is the 26% of the mean. Figure 4.12 shows a summary of the final results.

Component	Avg Cons	StdDev Cons	CV
X	65	17.00	26%
Y	80	10.95	14%
Z	30	4.47	15%

TABLE 4.12: Average and standard deviation of consumption in physical units are obtained

4.2.3 Calculation of the safety stock value in monetary units

Once the average demand of finished items and the standard deviation due to random noise have been aggregated at components' level, components' monthly average consumption for the next year is known as well as the standard deviation around the average value.

The next step requires the calculation of the safety stock value per supplier.

Let's assume that the three components X, Y and Z of the previous example are all supplied by the same supplier. Figure 4.12 shows the considered scenario.

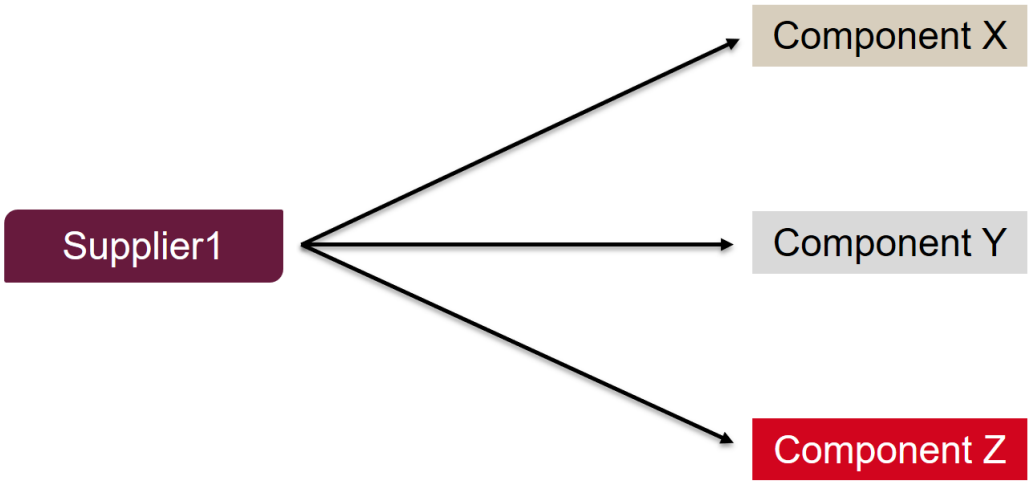

FIGURE 4.12: To calculate the safety stock value per supplier it is needed to aggregate components' safety stock values

In order to compute the safety stock value, it is needed to know the purchase cost of each component in Swiss Francs per piece [CHF/piece]. The average consumption of each component in monetary terms [CHF/month] is obtained by multiplying the component cost [CHF/piece] and the average consumption in pieces [piece/month]. The same is done in order to get the standard deviation of components' consumption in monetary units [CHF/month].

Table 4.13 shows the obtained results for the considered example. Average value and standard deviation of purchase volume (PVO) are reported in the right side of the table. The coefficient of variation remained unchanged.

Component	Cost [CHF/piece]	Avg PVO [CHF/month]	StdDev PVO [CHF/month]	CV
X	200	13'000	3'400	26%
Y	300	24'000	3'286	14%
Z	100	3'000	447	15%

TABLE 4.13: Consumption values in monetary units are obtained

By following the same procedure used to to get components information from sales products information, it is possible to aggregate one level further from components to suppliers. Since it is not possible to aggregate physical consumption of physically different components and the interest is on the stock value, this step is carried out by considering only monetary unit of measures.

Equation 4.8 has been used in order to sum up all the forecasted components' average consumption for the next year and obtain the overall monthly average purchase volume at each supplier [CHF/month]. In this case the first index of the equation represents the supplier and the summation is done accounting all the components supplied by that considered supplier. Similarly, Equation 4.10 has been used to compute the standard deviation of the monthly purchase volume at each supplier around the average value.

Table 4.14 represents the final results obtained for the suppliers of the example.

Supplier	**Overall Avg PVO [CHF/month]**	**Overall Stddev PVO [CHF/month]**	**CV**
Supplier1	40'000	4'750	11.9%

TABLE 4.14: Average and standard deviation of the purchase volume at supplier are obtained

It is possible to observe that the coefficient of variation (CV) is lower than the minimum of the coefficients of variation obtained for all the components (Table 4.13). The variances at aggregated level are always lower than the variances analyzed at detailed level.

The safety stock value is calculated scaling the purchase volume value to the effective months of coverage the company needs in its inventories.

In the example, the company purchases pieces from Supplier1 for an overall average value of 40'000 [CHF/month]. If the company decides, in order to mitigate the risk, to have six months of safety stock coverage, the total safety stock value will be calculated as:

$$40'000[\frac{CHF}{month}] * 6[months] = 240'000[CHF]$$

The additional step introduced by the present work consists on the introduction of the standard deviation into the calculation of the safety stock value. In the example, the overall needed consumption of the components from Supplier1 varies in average of 4'750 [CHF/month] around the average value of 40'000 [CHF/month]. If the company decides to cover this fluctuation, it will need to store in its inventory during the six months the following value:

$$(40'000[\frac{CHF}{month}] + 4'750[\frac{CHF}{month}) * 6[months] = 268'500[CHF]$$

The final purchase volume of the different items depends on the set service level. Once components' average consumption and standard deviation have been calculated it is possible to plan the physical order of the units. The planning phase depends on economical consideration explained in details in Section 4.2.4.

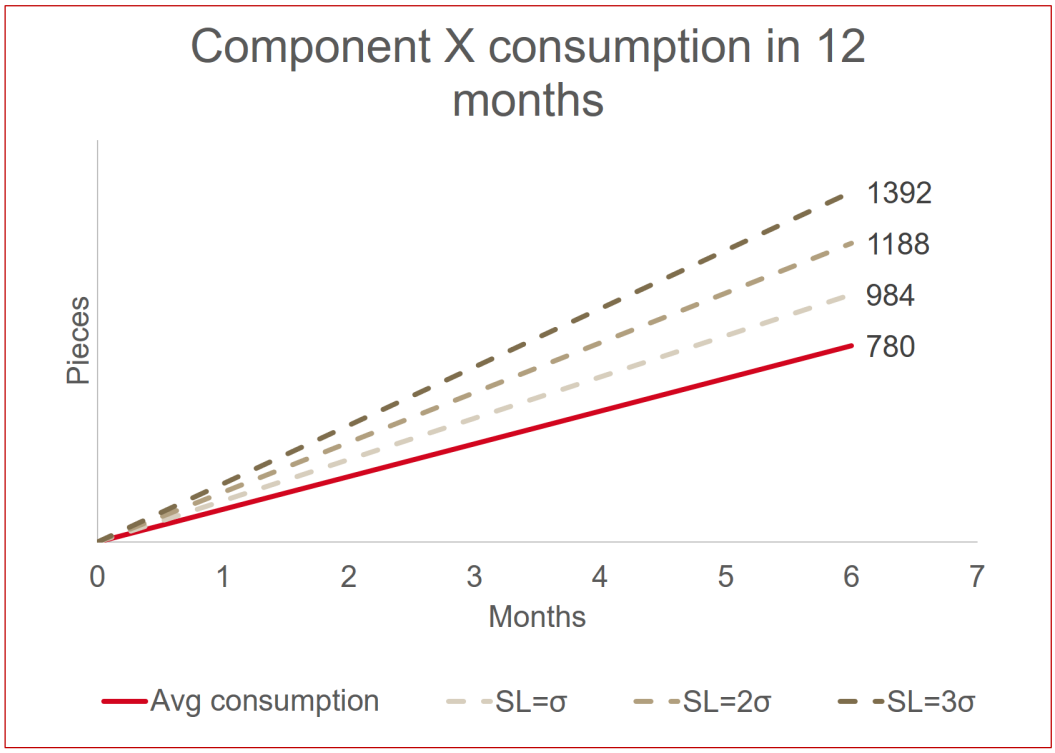

FIGURE 4.13: Physical consumption of component X in a year based on different service levels

Figure 4.13 shows the consumption of the component X calculated during a mean time to recover of six months and calculated by considering different service levels.

The following section presents economical criteria to follow in order to decide which level of variability to include into the safety stock steering mechanism.

4.2.4 Economical criteria for additional safety stock implementation

Service level driven decision

The service level (SL) driven decision consists in assessing how much it costs to the company assuring a set service level of three sigma. The service level measures the probability that all the demand is completely satisfied without delay, from stock to customers. This criterion should be used for "must have" components when the impact of a stock out of those components is over acceptable thresholds set by the company itself.

In statistics, the three sigma rule of thumb represents a conventional heuristic rule used as well in many empirical sciences. It states that for approximately normal variables almost all possible values fall within three standard deviations of the mean, accounting for about 99.7% of the set (Leonard, 2009).The three sigma rule of thumb connects to another result, known as the three sigma rule and derived from Chebyshev's inequality. This rule affirms that also in case of non-normally distributed data set, at least the 88.8% of cases the results lie within 3σ intervals.

In this context, the service level represents the amount of statistical uncertainty the company wants to cover, in order to assure a certain percentage of product availability in the inventories in case of a disruption.

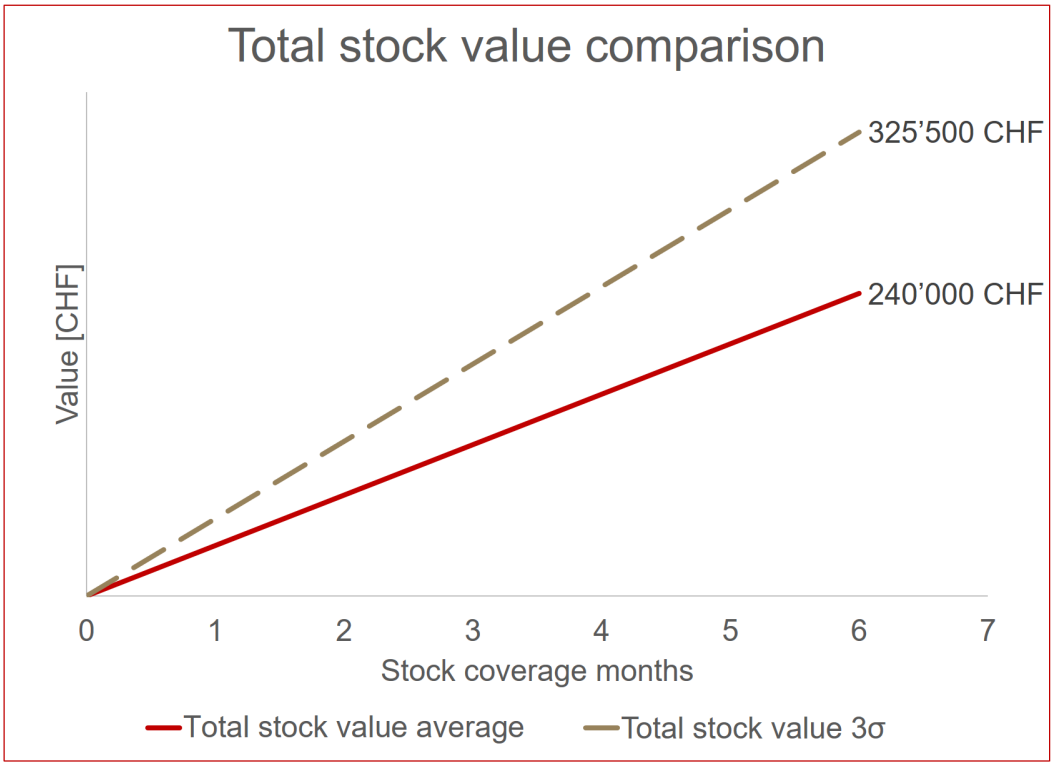

FIGURE 4.14: Total stock value of component X, Y and Z with a stock coverage of 6 months based on different service levels

Figure 4.14 represents the stock value calculated per Supplier1 under the assumption that the company decided to have six months of coverage in its inventory due to risk mitigation reasons. The red curve represents the stock value in case of safety stock coverage of six months under the assumption of constant demand. The dashed line shows the stock value in case of SL=3σ. In the considered example of Supplier1 the stock value obtained under the assumption of average consumption is equal to 240′000 [CHF]. The stock value needed to assure a SL of 3σ is equal to:

$$(40'000[\frac{CHF}{month}] + 3 * 4'750[\frac{CHF}{month}]) * 6[months] = 325'500[CHF]$$

It means that in case the company sets a service level of three sigma it needs to increase the safety stock value for Supplier1 of 85′500 [CHF].

The yearly cost of the safety stock keeping cost can be assumed to be the sum of two different cost components:

- Fixed capital cost [CHF/year]
- Physical stock keeping cost [CHF/year]

The fixed capital cost component can be taken into account by considering an interest rate equal to 12% calculated by finance department, to be applied on the stock value. The physical stock keeping cost is, under normal condition, approximately around 4%. As the physical capacity of the Hilti warehouse is fully used at the moment, it is necessary to store several materials in external warehouses. This results in extra costs like costs for external warehousing as well as transport from the production plant to the external warehouse and back. Due to these reasons in the following model the physical stock keeping cost index is assumed to be 8%.

Equation 4.11 summarizes the assumptions used to calculate the overall safety stock keeping cost:

$$SSKeeping = FixedCapital + PhyisicalStock = (12\% + 8\%) * StockValue \quad (4.11)$$

Equation 4.11 applied on the example of Supplier1 leads to an additional cost of 17′100 [CHF/year] the company needs to afford in order to keep the additional stock to assure a service level of 3σ.

In a real case of a real supplier supplying many components to an organization, the stock keeping cost can easily increase representing generally an important investment. Providing a service level of three sigma for all the components can be very expensive. The next decision criterion allows managers to take decisions by relaxing the hypothesis of a set service level.

Cost driven decision

Mitigation measures are justified when the potential impact exceeds the mitigation cost. The cost driven decision criterion compares the expected additional stockout cost due to profit variability to the expected additional stock holding cost.

The implementation of the additional safety stock to cover the variability of the profit is appropriate if the extra stock holding cost is lower than the extra stock out cost. In that case a low investment would allow the company to be protected from a huge risk and save a lot of money due to stockout. Equation 4.12 expresses the relationship that, if satisfied, justify the implementation of the additional stock:

$$\Delta StockoutCost > \Delta StockHoldingCost \tag{4.12}$$

The expected additional stockout cost in case of demand variability can be calculated by multiplying the stockout impact BI [MCHF/month] to the mean time to recover and the relative probability of the stockout realization, as in Equation 4.13:

$$StockoutCost = (BI_{(\mathrm{SL})} - BI_{\mathrm{Avg}}) * MTTR * (SL - 0.5) * P \tag{4.13}$$

In Equation 4.13, the value of *0.5* refers to the average BI curve based on average demand. The term SL refers to the scenario of peak demand during the mean time to recover. In the same equation, the term P is related to the probability that the disruption occurs.

In order to justify the safety stock implementation, the additional stockout cost needs to be bigger than the stock holding cost. The stock holding cost can be calculated by introducing the purchase volume PVO [MCHF/month] in Equation 4.11, as showed by Equation 4.14:

$$StockHoldingCost = (PVO_{(\mathrm{SL})} - PVO_{\mathrm{Avg}}) * MTTR * (12\% + 8\%) \tag{4.14}$$

In equation 4.14, the additional safety stock value is obtain by multiplying the additional purchase volume in case of demand variability to the mean time to recover. This term is then multiplied to *20%* in order to estimate the extra stock holding cost.

In Equation 4.13 and 4.14 the terms BI12 and PVO depend on the service level. Figure 4.15 shows the two curves computed based on annual average demand and considering a certain service level.

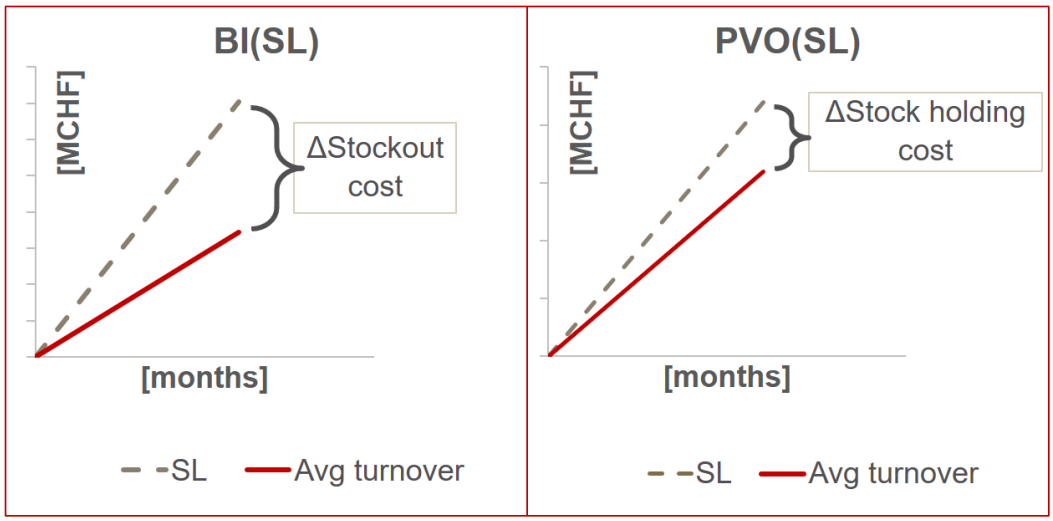

FIGURE 4.15: Business interruption and purchase volume depending on an arbitrary service level

Chapter 5

Study Case

5.1 The model is applied to a selected supplier

The model explained in the previous chapters allows the company to integrate the demand variability into the central steering of the safety stock. The model has been tested on a supplier in order to formulate a stock optimization proposal to the Hilti production plant in Thüringen (Austria), where most of the Hilti tools are produced.

Currently, 577 Hilti suppliers are actively monitored in the BI risk tool. Table 5.1 shows ten of the most critical suppliers in the tool and for which the stock is centrally steered.

Name	BI12 [MCHF]	PVO [MCHF]
BASF SE	656.00	6.50
Evonik Resource Efficiency GmbH	405.70	1.60
EMS Chemie (Deutschland)	389.90	2.30
Michel Adrian AG	367.07	1.00
Herzog GmbH	322.00	4.70
Plaston AG	319.50	12.80
Coveris Flexibles Deutschland GmbH	302.80	1.60
Imerys Aluminates GmbH	299.40	1.60
Heinz Haenggi Stanztechnik	292.00	1.30
Panasonic Industry Europe GmbH	285.00	10.50

TABLE 5.1: Top 10 BI critical suppliers

The Swiss supplier *Michel Adrian AG* has been considered for the analysis. The business interruption risk calculated for 12-month time horizon is almost equal to 370 [MCHF] although a relatively low purchasing volume of 1 [MCHF].

The supplier developed and delivers many sophisticated metal items and has three production sites in Switzerland. The warehouse is not completely separated from the production. That means that the safety stock physical availability at supplier can be affected in case of elementary loss. The mean time to recover in the elementary incident scenario is estimated to take about five months.

In case of insolvency the tooling can be taken out and relocated to other suppliers. In the considered scenario the mean time to recover is estimated equal to four months, needed to relocate the products to another supplier.

Hilti actively purchases 120 component numbers from *Michel Adrian AG* which enter in the bill of material of 700 sales products in different versions (e.g. tools and spare parts).

Figure 5.1 shows an extract of the relationship table main Excel file where the data is managed. The same component number appears in as many rows as the number of finished products it is part of. The selected example shows a *Washer 33x42x1* which is present in the bill of material of different versions of a *Breaker TE 500*. The component is as well sold directly to the customer as a spare part.

A	B	C	D	E	F	G
Comp number	Comp name	Sold item Number	Sold item Name	Avg sales quantity [PC/month]	Std dev sales due to noise [PC/month]	BI_12 CHF
390979	Washer	2060164	Breaker	18.4	11.37	167,238
390979	Washer	274720	Breaker	132.5	80.09	798,277
390979	Washer	274736	Breaker	13.5	8.04	35,477
390979	Washer	274700	Breaker	4.8	2.86	27,325
390979	Washer	274731	Breaker	73.4	41.70	190,099
390979	Washer	274706	Breaker	19.8	10.55	106,290
390979	Washer	274716	Breaker	32.5	15.40	309,795
390979	Washer	274732	Breaker	67.7	31.15	243,531
390979	Washer	274722	Breaker	62.3	25.44	397,264
390979	Washer	2060163	Breaker	33.4	12.64	208,782
390979	Washer	2017053	Breaker	14.4	5.17	116,923
390979	Washer	274718	Breaker	74.6	26.51	449,102
390979	Washer	2139645	Breaker	18.7	6.57	107,460
390979	Washer	2055616	Breaker	34.8	10.24	139,323
390979	Washer	274734	Breaker	49.4	14.43	146,145
390979	Washer	274730	Breaker	208.0	55.88	356,536
390979	Washer	274715	Breaker	66.1	17.06	277,276
390979	Washer	438572	Breaker	95.2	23.68	527,482
390979	Washer	274717	Breaker	454.4	111.75	3,974,620
390979	Washer	390979	Washer	18.8	4.48	119
390979	Washer	274701	Breaker	235.4	54.59	1,279,122
390979	Washer	274735	Breaker	31.0	6.39	181,982
390979	Washer	274703	Breaker	230.8	43.24	1,289,113
390979	Washer	274704	Breaker	90.1	14.80	443,592

FIGURE 5.1: The relationship table for supplier *Michel Adrian AG* allows to assign relevant information to all components

In each row of the Excel file the BI12 due to the lost profit, impacting the company when the final product is in stockout, is assigned to the considered component, as well as average sales quantity, coming from company's sales report. In the same way the standard deviation of the sales due to the random noise component is also assigned to the component number, calculated considering as well the BOM ratio, according to process explained in details in Section 4.2.1. One can notice that the BI12 contribution coming from the spare part sales is significantly lower than the one coming from the sales of a tool.

This way, the contribution of each sold item is attached to every component supplied by the selected supplier. The relevant information needed to calculate the safety stock value and the business interruption impact are:

- Business interruption impact
- Average sales quantity
- Standard deviation of sales due to random component

It is now possible to aggregate all the rows related to the same component, in order to obtain a final value for each supplied part for those three figures. The aggregation operation is done by pivoting the relationship table. The average sales quantity for different rows of the same component are summed up, as well as the BI12 ones.

Component	Sum of Avg sales quantity [PC/month]	Standard deviation due to noise	Sum of BI_12
1019	40.25	14.12	81.77
6179	9.58	4.65	50,378.25
13916	20.67	4.83	3,686.24
23197	28.50	10.11	6,402.74
30092	29.83	6.83	13,480.13
49141	61.58	7.56	108,094.04
75312	76.83	10.35	60,606.58
76492	312.25	75.13	1,039,018.50
201774	81.83	12.74	41,168.72
202164	24.00	7.98	8,308.26
232749	797.00	83.68	3,693,762.87
237758	22.42	5.92	3,842.79
237772	600.50	52.97	5,131,019.10
268168	32.92	7.49	209,715.86
277835	36.75	9.32	69,538.65
278417	104.17	12.40	124,920.10
278735	6.92	3.19	54,468.86
278955	429.33	35.18	2,356,627.95
278960	126.67	15.24	182,688.65
279486	283.17	23.33	5,279,787.79
279527	706.63	41.74	3,358,067.51
279701	735.00	94.80	115,793.88
280159	717.00	169.47	7,531,825.34
280160	9.58	11.60	70.36
280620	108.17	9.79	99,841.81

FIGURE 5.2: Pivot table allows easy aggregation of components' information

The standard deviations are aggregated by summing up the variances and taking the square root of the obtained variances sum. Aggregation processes are carried out according to Equation 4.7, 4.8, 4.9 and 4.10.

Figure 5.3 shows the formula used in the calculated field of the pivot table for the standard deviation.

A	B	C
Calculated Field		
Solve Order	**Field**	**Formula**
1	StdDev due to noise	=SQRT(SUM('Var sales due to noise [PC^2]'))

FIGURE 5.3: A calculated field is used to aggregate the standard deviation

Figure 5.4 shows an extract from the final Excel table containing the overall components' overview. In that table the data has been aggregated in physical units and reported in monetary terms by multiplying the cost of component per piece, listed in column D. The coefficient of variation has been calculated and listed in column H.

A	B	C	D	E	F	H
Component	**Avg Cons [PC/month]**	**StdDev Cons [PC/month]**	**CHF/PC**	**Avg Cons [CHF/month]**	**StdDev Cons [CHF/month]**	**CV**
1019	40.3	14.1	0.14	5.6	2.0	35%
6179	9.6	4.7	0.30	2.9	1.4	49%
13916	20.7	4.8	2.51	51.9	12.1	23%
23197	28.5	10.1	8.51	242.5	86.0	35%
30092	29.8	6.8	0.14	4.2	1.0	23%
49141	61.6	7.6	0.37	22.7	2.8	12%
75312	76.8	10.4	0.02	1.5	0.2	13%
76492	312.3	75.1	0.05	15.5	3.7	24%
201774	81.8	12.7	0.05	4.1	0.6	16%
202164	24.0	8.0	0.90	21.6	7.2	33%
232749	797.0	83.7	0.18	146.6	15.4	10%
237758	22.4	5.9	1.64	36.8	9.7	26%
237772	600.5	53.0	1.58	946.4	83.5	9%
268168	32.9	7.5	0.46	15.0	3.4	23%
277835	36.8	9.3	0.99	36.2	9.2	25%
278417	104.2	12.4	0.76	78.6	9.4	12%
278735	6.9	3.2	0.37	2.6	1.2	46%
278955	429.3	35.2	0.13	53.7	4.4	8%
278960	126.7	15.2	0.17	21.5	2.6	12%
279486	283.2	23.3	0.24	67.4	5.6	8%
279527	706.6	41.7	0.22	157.2	9.3	6%
279701	735.0	94.8	0.16	118.0	15.2	13%
280159	717.0	169.5	0.17	122.7	29.0	24%
280620	108.2	9.8	0.45	48.5	4.4	9%

FIGURE 5.4: Each component is listed with average and standard deviation of the consumption in physical and monetary terms

Once the components' overview has been computed, it is possible to perform the last aggregation step at supplier level. Table 5.2 shows the overall average monthly purchase volume and the standard deviation around the average value calculated for the supplier *Michel Adrian AG*.

Supplier	Average PVO [CHF/month]	StdDev PVO [MCHF/month]
Michel Adrian AG	85'036.3	9'702.6

TABLE 5.2: Average and standard deviation of purchase volume (PVO) calculated for supplier *Michel Adrian AG*

In the central steering of the safety stock, the required safety stock to mitigate the risk is expressed in terms of months. The supply teams define a mean time to recover (MTTR) for each supplier. The safety stock is interpreted as coverage months stored in the inventories in order to reduce the mean time to recover until an acceptable BI value.

In the present work only one overall safety stock is assumed. After the model has been applied, only one safety stock value is calculated. Supply managers together with the suppliers will decide where to physically store it. In case of the supplier *Michel Adrian AG*, the most critical MTTR assessment states that in case of elementary loss five months are needed to restore the normal supply situation. Therefore, the MTTR is set to five months.

Figure 5.5 shows the calculator which has been created in Excel to compute the required months of safety stock.

A	B
Supplier	***Michel Adrian AG***
MTTR [months]	5
Avg PVO [MCHF/month]	0.0850
StdDev PVO [MCHF/month]	0.0097
BI12 [MCHF]	367.1
BI_MTTR [MCHF]	152.9
Acceptable BIeff [MCHF]	0.0
SS months required	5.0

FIGURE 5.5: The excel calculator provides the safety stock months given an acceptable BI effective

The calculator requires the mean time to recover as an input. It takes the business interruption impact in twelve months as well as the average purchase volume and the standard deviation from the tables shown in the previous section. It calculates the business interruption impact scaled to the provided MTTR figure and requires the acceptable BI effective level as an input. In the analyzed example, the acceptable BI effective is of zero million Swiss Francs. Therefore, the required safety stock months are five. It means that the safety stock will cover the whole mean time to recover.

Table 5.3 shows the values of σ, 2σ and 3σ computed in order to depict the different curves of safety stock value and business interruption impact depending on the service level set by the company.

Avg value [MCHF/month]	0.0850
σ [MCHF/month]	0.0097
2σ [MCHF/month]	0.0194
3σ [MCHF/month]	0.0291
CV	11.41%

TABLE 5.3: Different service levels are calculated

Figure 5.6 shows the business interruption impact for the company evolving from the moment of the disruption to the end of the mean time to recover.

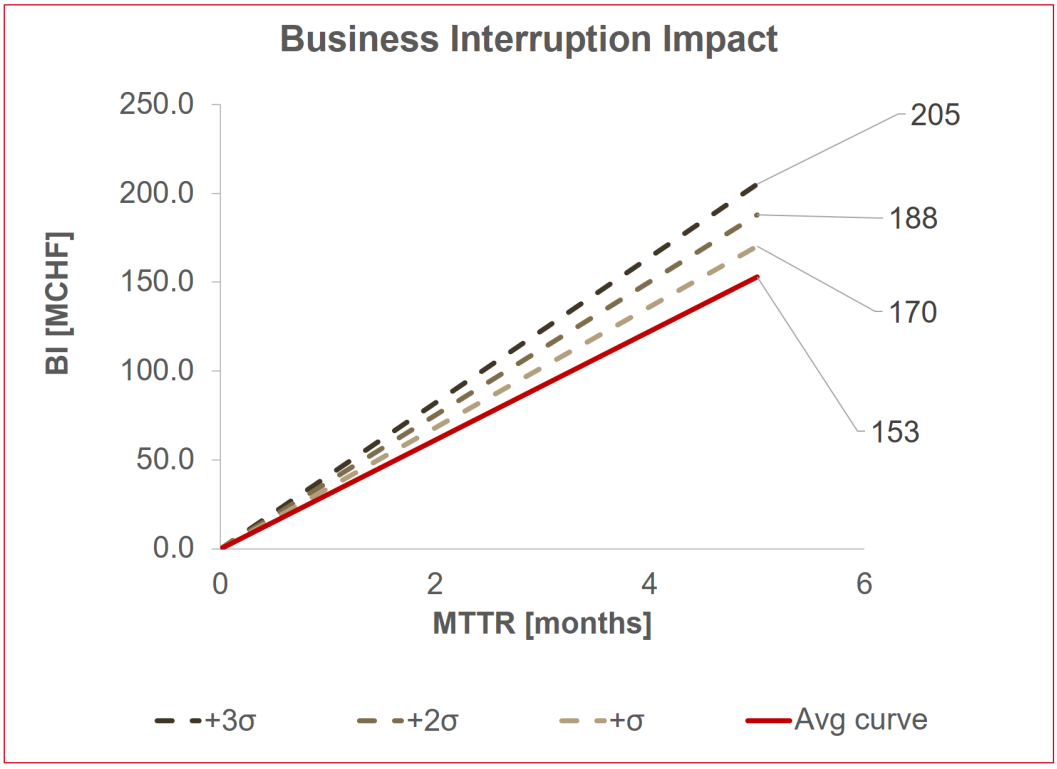

FIGURE 5.6: Business interruption impact for supplier *Michel Adrian AG*

The potential impact after five months varies between a lower value of 153 [MCHF], calculated by considering average demand, and an upper one of 205 [MCHF], computed by assuming a peak in the demand during the MTTR. The safety stock value has been calculated as well under the same condition.

Figure 5.7 represents the safety stock curves as a function of the service level. The SS value calculated on average demand is equal to 0.43 [MCHF]. The same is calculated considering a service level of 3σ that will include 0.57 [MCHF].

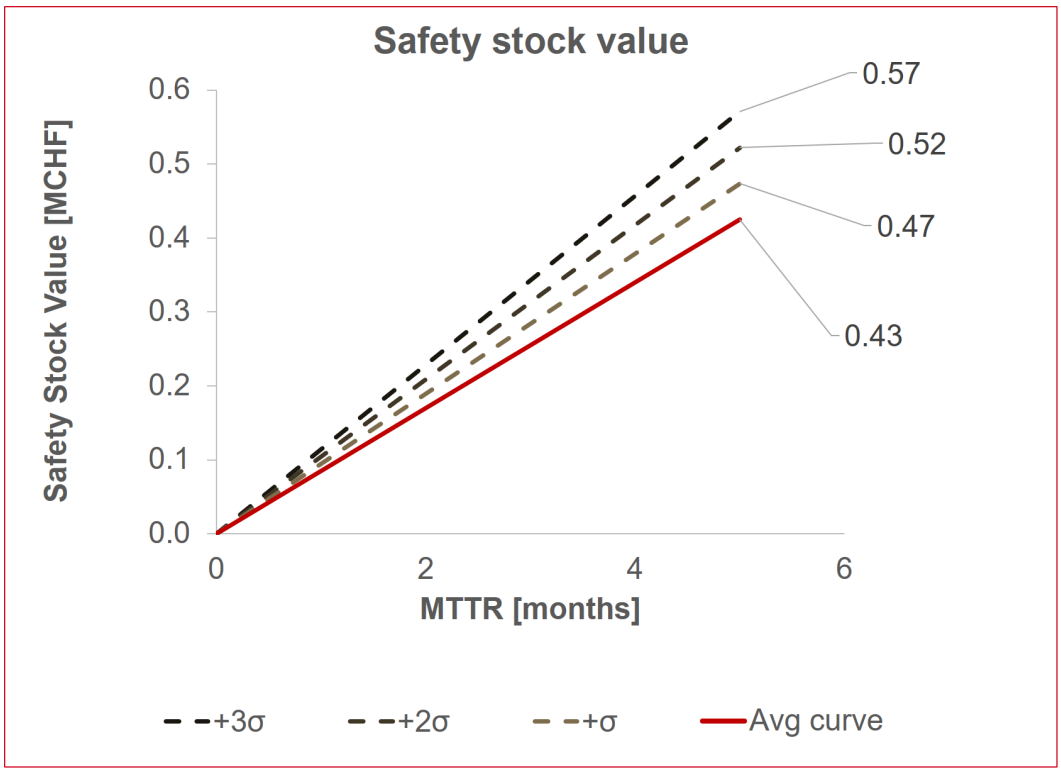

FIGURE 5.7: Safety stock value for supplier *Michel Adrian AG*

Hilti is currently steering the safety stock only based on average consumption. That means that in the considered case of supplier *Michel Adrian AG* the BI impact during the MTTR is considered to be equal to 153 [MCHF]. The company, due to strategic reasons, needs to reduce the business interruption impact to zero. Therefore, a safety stock of five months is needed. The safety stock value under those conditions is equal to 0.43 [MCHF].

However, the historical sales pattern presents an important variability. Due to the random component of the variability of the data it has been calculated that the real business impact could be equal to 205 [MCHF]. The safety stock able to cover such fluctuation include higher number of components for a total value of 0.57 [MCHF].

The first decision criterion presented in section 4.2.4 assumes the company sets a service level of 3σ. This way, it would be possible to cover almost all the stockout risk. In this case the company should increase the safety stock value of about 140'000 [CHF].

Under the assumption of:

- Fixed capital cost = 12%
- Physical stocking cost = 8%

The additional yearly stock holding cost to sustain in order to maintain the additional stock is equal to 28'000 [CHF/year], which leads to a total stock holding cost of 114'000 [CHF/year].

The second decision criterion presented in section 4.2.4 compares the additional stockout cost to the additional stock holding cost according to Equation 4.13 and 4.14. The decision criterion has been applied by considering a service level of 3σ but it could another value have been used.

The additional stockout cost is calculated under the following assumptions:

- During the last risk audit it was found that automatic fire detector system is not available in all facility areas and many zones of the plant are not protected from a potential fire. Besides, only a basic response plan is available with potential for improvements. Due to those considerations, the probability of an elementary loss affecting the capability of the supplier to supply the parts is set to 5%
- The random component of the demand pattern follows always a normal distribution. Therefore, the probability associated to a service level of 3σ is assumed to be equal to 0.99

Which lead to:

$$(205 - 153) * (0.99 - 0.50) * 5\% = 1.274$$

The additional stock holding cost is calculated as follows:

$$(0.57 - 0.43) * (0.12 + 0.08) = 0.028$$

As Equation 4.12 is satisfied, the additional safety stock is recommended. If the company invests in increasing the inventory levels it would achieve an important coverage against business interruption with a relatively low investment.

The same approach has been used in order to analyze the supplier *Saxonia-Franke d.o.o.*. The relevant BI risk data for this supplier is included in Figure 5.8.

A	B
Supplier	***Saxonia-Franke d.o.o.***
MTTR [months]	6.0
Avg PVO [MCHF/month]	0.2667
StdDev PVO [MCHF/month]	0.0110
BI12 [MCHF]	68.7
BI_MTTR [MCHF]	34.4
Acceptable BIeff [MCHF]	0.0
SS months required	6.0

FIGURE 5.8: Supplier *Saxonia-Franke d.o.o.* is analyzed for comparison

The supply manager responsible for the supplier *Saxonia-Franke d.o.o.* extimated a mean time to recover equal to six months. Furthermore, the analysis is performed considering that the acceptable BI effective is zero. That way the needed safety stock results to be equal to six months.

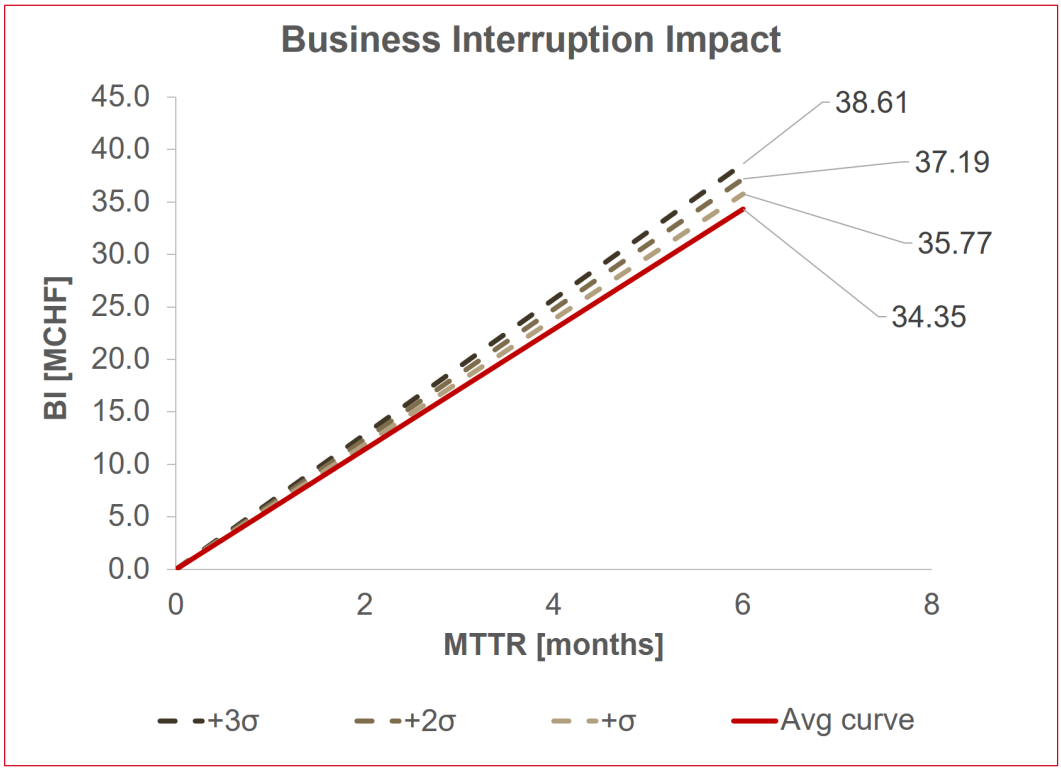

FIGURE 5.9: Business interruption impact for supplier *Saxonia-Franke d.o.o.*

The overall standard deviation of the consumption is 0.011 [MCHF/month]. This value leads to a coefficient of variation equal to 4.14%, against the one obtained for supplier *Michel Adrian AG* of 11.41%. This means that the components purchased from *Saxonia-Franke d.o.o.* are used to produce finished items which have a demand random fluctuation lower than the ones produced by using the components purchased from *Michel Adrian AG*.

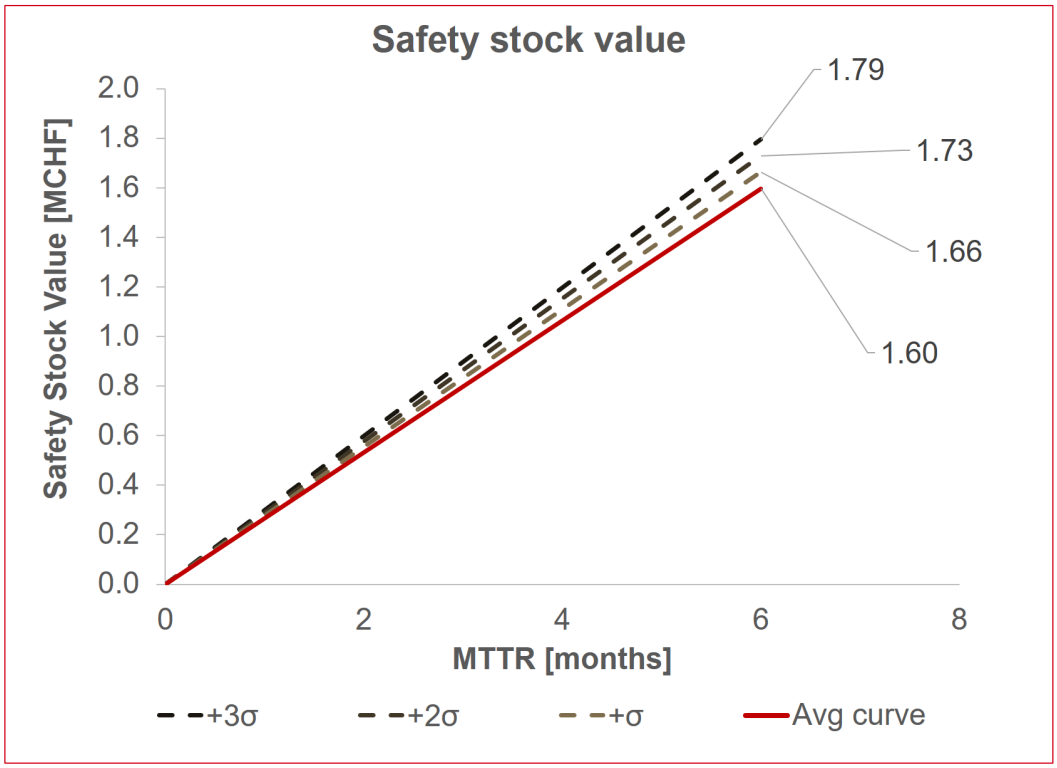

FIGURE 5.10: Safety stock value for supplier *Saxonia-Franke d.o.o.*

The convenience of the safety stock increase is discussed according to the second criterion explained in Section 4.2.4. The cost driven criterion is applied by considering three different values of service level and the following assumptions for the stockout cost:

- The probability of a disruption occurrence is assumed to be equal to 1%, after consideration on the financial stability of the company.
- The random fluctuation of the demand can be approximated as normal distributed. Therefore, a service level of 0.99 associated with 3σ, of 0.97 with 2σ and of 0.84 with σ

Table 5.4 shows the obtained results of additional stockout cost and additional stock holding cost for *Saxonia-Franke d.o.o.*.

SL	Stockout cost	Stock holding cost
σ	0.021	0.040
2σ	0.013	0.026
3σ	0.005	0.013

TABLE 5.4: Stockout cost and stock holding cost for supplier *Saxonia-Franke d.o.o.*

In this specific scenario the additional safety stock to cover the demand variability is never recommended, as the mitigation measure results more expensive than the expected stockout cost for all the three considered service levels.

Chapter 6

Conclusions

Hilti counts with a well established risk management setup. The supply chain risk management process is clearly defined. Critical suppliers are listed based on their business interruption impact on the company and criteria to manage them in a consistent way are in place. Unexpected outage due to an elementary loss, insolvency, termination of contract or forced disruption are systematically monitored in the business interruption risk tool.

Supply managers of the different business units are responsible for the implementation of mitigation measures, with the support of the cross-functional Sourcing Excellence team. The most important mitigation measure to reduce the impact of a disruption is the safety stock.

To reduce the potential lost profit impact to an acceptable level, the company defines a certain amount of months of coverage for each component. The overall process depends on such a definition. If the mitigation measures for a supplier cover the whole mean time to recover, the company relies on the fact that a disruption at that supplier will have no effective impact on the business.

The current practice determines the number of risky components to physically store in the inventories by multiplying the required months of risk safety stock to the average turnover of components. The variability of the demand is considered in the safety stock initially calculated by the plant. However, when the new risk inventory is defined, the initial requirement is overwritten. Hence, the new value does not take into account that during a disruption it is possible to have high fluctuation on the potential profit and on components' consumption. Despite high inventory levels, in case of a disruption, the company could still easily run into stockout.

This thesis is based on the implicit assumption that for components which have experienced high random fluctuation in the past, an high-variance demand pattern is likely to happen again in the future. The proposed model projects the demand behavior in the next year by analyzing the trend and the seasonality of the previous three years through different decomposition and forecasting methods, such as moving average and exponential smoothing.

A tool in Excel has been developed to quantitatively calculate the various components of the demand and select the best approximation method. All the non-forecastable elements are treated as random noise. Subsequently, the standard deviation of the random noise is aggregated at component level and used to size the safety stock according to a set service level.

The inventory value, calculated at supplier level, is obtained and discussed according to two main decision criteria. A first criterion is driven by the service level, while a second one is a decision method based on cost comparison.

The application of the proposed model allows a company to:

- Reduce the stockout risk by increasing awareness of the effects of demand fluctuation on the management of the risk inventory
- Potentially reduce the overall inventory levels by proactively reacting to forecasts instead of basing the steering mechanism to the prior year's data

Other companies can find interesting ideas to implement in their risk management system by following the solid one already existing in Hilti.

Moreover, future research could be focused on two further potential main improvements:

- Reliability of mean time to recover assessments should be improved and a statistical method to evaluate possible discrepancies should be implemented
- Other parameters which could impact the sizing of safety stock, such as the lead time variability, should be included in the proposed model to have a broader picture

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