Diána Somosné Strommer

Comprehensive and practice-oriented analysis of the supply chain instability

Doctoral Dissertation

Supervisor: Dr. Péter Földesi CSc
Széchenyi István University
Professor and Head of Department of Logistics and Forwarding

Széchenyi Istán University, Doctoral School of Multidisciplinary Engineering Sciences

Author's declaration

No portion of the work referred to in this dissertation has been submitted in support of an application for another degree or qualification of this or any other university or any other institution of learning.

Furthermore, this dissertation contains no material previously written and/or published by another person, except where an appropriate acknowledgement is made in the form of bibliographical references, etc.

Table of content

Figures

Tables

List of abbreviations

BSC	Balanced Scorecard
BWE	Bullwhip effect
D	Detectability
ERP	Enterprise Resource Planning
FB	Forecast Bias
FCA	Forecast accuracy
fcst	forecast
FMCG	Fast moving consumer goods
FMEA	Failure mode and effect analysis
FTA	Fault tree analysis
KPI	Key performance indicators
MOQ	Minimum order quantity
MPI	Manufacturing performance indicators
Nr	number
O	Occurrence
PM	Performance measurement
PMS	Performance measurement system
QM	Quality management
RPN	Risk Priority Number
RQ	Research question
S	Severity
SC	Supply chain
SCM	Supply chain management
SL	Service level
SME	Small and medium sized enterprises
VMI	Vendor Managed Inventory
WHO	World Health Organisation

INTRODUCTION

Goal

Supply chain (SC) instability is impacting the everyday operation of the chains. Even though the performance of the SC is measured from multiple angles, the business, economic, social, and environmental uncertainty result in instable operation. The applied performance measurement approaches' viewpoint is rather analysis of numerous snapshots than analysation of dynamic operation. Regarding the deeper analysis and case studies on ripple and bullwhip effect the focus is on as punctual mathematical modelling as possible, which can lead to better quantification, still the financial and human resource requirements are high.

My goal is building up a bottom-up approach supporting the performance improvement through detection of the symptoms of the instability. The aim is not building up new theoretical approaches but opening further the range of practical application. These methods are assumed on existing solutions, the change is in the interpretation or application of given tools. Using the tools of performance measurement and quality engineering aims to support the better analysis of the bullwhip and ripple effect, leading to a proactive method and toolkit for sensing the supply chain instability that is usable and understandable also for the subject matter experts.

Actuality

Economic environment is continuously facing crisis. It can be due to crucial material availability issue, suddenly rising trends, wars, epidemic outbreak etc. This leads to an environment with low level of predictability. Keeping the smooth operation of an enterprise considering the circumstances is difficult; but keeping a full supply chain under control in transparent operation is even more challenging.

Nowadays supply chain setup is complex and complicated. Huge number of SC echelons are working together, overarching big geographical distances. Level of cooperation need to be high; chains need to work with a transparent and controlled manner (Simchi-Levi et al. 2008). By theory it is possible, but realty shows a different picture.

Beside the transparency, trends are also important. Market trends are changing quickly. Due to the increased number of external impulses that are impacting the customer these changes are happening very fast. Consumer society keeps placing demands based on the latest trends, promoted products and reviews of influencers. Reaction time for companies is very short due to the continuous changes and the high level of competition on the market.

The solutions offered by the literature are limited regarding the adaptability. As the measurement and quantification is complex and complicated, case studies built on given industrial background cannot be used for other cases. These solutions are typically based on mathematical modelling. The application requires high level of understanding on engineering and information technology. Due to this, introducing these models is very cost and resource intensive. In addition, the solution does not presume on the experience of the subject matter experts.

To further support decreasing the gap between literature and practice inverted solutions should also be checked, reviewed, and presented both for experts and the researchers. These approaches can build on technics and tools that are already in place, leading to less resource and cost intensive solutions regarding elimination of the supply chain instability through decreasing the impact of bullwhip and ripple effect.

To reach effective operation it is necessary to use a set of key performance indicators (KPI) that are monitoring the supply chain performance. This analysis approach needs to consider instability measures also. It needs to be a tool to show the impact of it. It also needs to be the tool that support the process improvement in covering the occurred reasons. KPI need to cover not only analytical but also mitigative and indicative purposes. Measures are implemented in every supply chain; however, the application should be advanced to support the performance improvement.

In the past mainly bullwhip effect has been in focus as a symptom of the supply chain instability. That is highly focused on a single way of spread of disruption: from the customer toward the manufacturing. As the economic environment changes it also shows that this is not the only way. COVID-19 and the war situation resulted not only in changes on the demand side but also in challenges at the middle or end of the supply chains. The instability starting from these points is called ripple effect. As from research perspective bullwhip effect is more deeply analysed in my dissertation this phenomenon will be in focus. Research of ripple effect is still in emerging phase. It’s potential increased further due to the new economic circumstances (COVID-19, war, container shortage, chip shortage, etc.).

As learning remains a key factor of effective operation it needs to be used with full potential to improve ourselves and processes or methodologies. The available resources are limited in the practical application, leading to increased needs for solutions that require less resources. Learning and adapting practices from partner areas or research fields can support in fulfilling this requirement.

Motivation

My personal motivation in the investigation of the topic is mainly stems from the practical experience. It has been collected on different levels of supply chain planning and performance measurement. As part of the logistical planning process, I saw the occurrence of the bullwhip effect in multiple industries and supply chain perspectives. The experience showed that the knowledge about the phenomenon is not comprehensive. Even if it is widely researched from practical side, it seems the conversations are lacking some points.

The level of understanding is the highest at the logistics department, but it is still not complete. The knowledge on the phenomenon of partner areas is much lower and it is not in the focus at all. Due to the market complexity, it would be necessary to understand the overall picture of supply chain operation and processes better. On the other hand, the mentioned complexity due to the competition is not only impacting the supply chain processes but also other areas, leading to the need for developing expertise of the partner areas on different topics.

The overall situation requires simplification of the problem. Currently there is a gap between practice and theory that need to be bridged. The knowledge in literature on the bullwhip effect is quite deep but application of the targeted analysis in practice is not that common. The solutions offered by the literature are complex and usable only under special circumstances. Those case studies are also typically built on complicated mathematical models, that are difficult to understand for the subject matter experts working with the inventory and forecast. Finding a solution that can support starting any action in regards the phenomenon is not highly supported.

My goal is using the market experience and the knowledge from the literature review to build up a targeted analysis of the supply chain instability for the everyday practice. I am aiming to find starting solutions that are not resource intensive, so application of them is feasible with limited preparation and investment. Key performance indicators (KPI), performance frameworks and quality engineering are targeted to be analysed to see solutions that fit in to the mentioned requirements.

Structure

The structure of the dissertation is the following. The first chapter aims to present the background of the research. Main definitions are collected that are crucial regarding the supply chain instability. Definition of the bullwhip effect and ripple effect is showing how these symptoms of instability influence the operation of the chain. Sensitive and non-sensitive supply chains are also determined, that shows the cases supporting the occurrence of the mentioned two phenomena. Performance measurement and quality engineering is also scope of the research. Definition of these areas are also present here. To define the basics widely used and accepted books of Chopra, Meindl, Hugos, Ivanov, Fernie, and Sparks are analysed, as the type of resource that is most typically used in practice to collect information.

The literature review is followed by analysation of the articles also that potentially shows the gap between practical and theoretical side. The main question considered here: what are the different directions of scientific groups? Bullwhip effect is the focus of research as this phenomenon is widely available in literature.

Based on the results of the literature review research questions are phrased. These questions are aimed to be answered at the end of the dissertation by the four theses. The methodology is also presented. The dissertation is using mixed approaches, both qualitative and quantitative methods are applied.

The scientific result is presented in the second half of the dissertation. The literature review present in the beginning of my work is the basis of the research. The more specific information that is highly connect to my own results are presented, where the topic is analysed in more details. At the end of the dissertation the findings are summarized in four theses. Potential future research directions are also presented. The focus is on the potential extension of the bullwhip effect examination toolkit. The answer is investigated in performance measurement and quality management. Regarding performance measurement single measures and frameworks are examined both. From the quality management area, the tools used in practice are examined.

As a quantitative analysis case studies are included in the fourth chapter. Checking the industrial example both from primer and seconder sources. As the COVID-19 social and economical changes highly impacted the operation of the supply chains this angle is also examined.

Learnings of quality management field are used in analysation of a survey conducted targeting opinion of subject matter experts. It aims to get better visibility on the experience of professionals working with inventory and/or forecast on the reasons typically leading to the occurrence of the bullwhip effect.

My dissertation aims to bridge the gap between the practical and theoretical approaches. I am working on solutions that are supporting the improvement of processes without high level of resource (human, financial) investment. The goal is not building up new theories but using the existing ones. The process improvement targeted to be reached through on hand opportunities and technics.

1. LITERATURE REVIEW

1.1. Main definitions

This chapter is aiming to introduce the main definitions used in my dissertation. In the literature there are several viewpoints and definitions used regarding the examined area. The author is considering the below approaches as basis of the research.

As the research is focusing on the supply chain instability it will be defined first. Bullwhip and ripple effect are symptoms that are indicating the instable operation of the supply chain. As the scope of the research is also the potential learning from existing processes, related areas are also presented. Performance measurement is highly connected due to the impact of bullwhip and ripple effect on the supply chain performance. Quality management is also a related area. Here the focus is on the tools that can be used to measure the operation. Out of the numerous possible quality tools and methods Failure Mode and Effect Analysis (FMEA) has been chosen. This method is well known both in research and practical environments, it can support to bridge the gap also regarding the instability.

Supply chain instability

Supply chain stability can be characterised by the level of coordination. It improves once actions taken are aligned at all levels of the chain. It requires information sharing between each member of the chain. Besides that, impact of the actions taken should also be considered carefully keeping the supply chain level goal in focus. (Chopra, Meindl, 2016) Increasing the level of coordination is supported by technical and technological development in the past 30 years. Beside the availability of tools, the organisations also needed to learn to use them, it led to competitive advantage for the one's applying them the best. The increased technological knowledge led to the change in focus of market competition. Supply chain efficiency becomes key factor in the competition (Hugos, 2018). Regardless industry or sector high level of collaboration is needed to successfully integrate supply chain functions. Coordinated and stable supply chains are needed to have competitive operation (Fernie and Sparks, 2019).

The resilience of the chain has high impact on maintaining the stable operation. The risks can be categorized in four groups: demand, supply, structure, and process. Demand and supply risks are rather operational one's; these groups include risk of bullwhip effect also. Structure is pointing at the globalised approach's risk and process indicate the volatility. At structure and process side ripple effect is the one that can rather be considered (Ivanov et al., 2019).

Bullwhip effect

Bullwhip effect (BWE) has a strong academic and business interest due to the potential malfunctions that it can cause in the supply chain. The main understanding of the phenomenon is common, still among different research groups interpretation varies highly. The phenomenon was first researched by J.W. Forrester (MIT Sloan School of Management), it is also known as the Forrester effect (Forrester, 1961). The bullwhip effect term was defined in Lee, Padmanabhan and Wang (1997). It was recognized based on the analysis of Procter and Gamble; customer demand fluctuation of the diapers was not explaining the level of variability.

The definition used in books focuses on increasing fluctuation of orders (Chopra and Meindl, 2016; Ivanov et al., 2019; Hugos, 2018). Below definition from Hugos (2018, pp213) is present: "*What happens is that small changes in product demand by the customer at the front of the supply chain translate into wider and wider swings in demand experienced by companies further back in the supply chain*".

Keeping the same perspective Ivanov et al. (2019) focuses on the supply chain impact, as the smooth operation is damaged. Chopra and Meindl (2016) emphasise the impact on the coordination of the supply chain. As the phenomenon leads to increase of costs in multiple areas and decrease in profitability and product availability. Hugos (2018) focuses on the differences on supply chain role and industry level. As the different market view and served markets highly influence the phenomenon.

Ripple effect

Ripple effect occurs once localisation of disruption is not manageable. The impact cascades downstream. It affects the performance through for example sales loss, cost, or service level. Bullwhip effect means typically high-frequency-low-impact risk, in contrast ripple effect is low-frequency-high-impact risk. Ripple effect's impact is more on strategical side. It means exceptional risks, high level of disruption in the chain and deep uncertainty. Prevention is mainly possible through stabilisation of the operation, increasing the flexibility and applying proactive approaches. The resolution of the occurrence starts with stabilisation on short term, and recovery on mid- and long-term. To recover high level of investment and coordination is needed. Outcome of the phenomenon is also rather strategical. Not the operational performance but the annual revenue, profits and overall, yearly performance measures are showing the impact. (Ivanov et. al., 2019)

Research led by Ivanov D. which I strongly agree differentiate ripple effect from bullwhip effect. The stock level variability not necessarily upstream amplified. However, this differentiation is not common in practical circumstances. Due to this, the two phenomena are handled together under the collective term of bullwhip effect in my dissertation. As the goal of my analysis is bridging the gap between practical and theoretical approach, the symptoms of supply chain instability (bullwhip and ripple effect) are not separated to avoid confusion.

Sensitive and non-sensitive supply chains

Based on the learnings from the literature it can be stated that the resilience has high impact on the supply chain stability (Ivanov et al., 2019). Through that it also has impact on the potential occurrence of the bullwhip and the ripple effect. As my work due to the wider literature background focuses rather on the bullwhip effect sensitivity of the chains is also examined from this perspective.

Sensitivity is highly depending on the supply chain setup and characteristics. Basic determination of the supply chain can be through the applied push or pull model. Push strategy covers the make to stock, pull strategy covers the make to order approach (Ivanov et al., 2019). As the dependency on the customer and demand fluctuation is much lover in the make to order setup it means lower level of sensitivity. The geographical and structural organisation of the chains is also impactful. Ivanov et al. (2019) even pointing at the number of the supply chain members during the definition of the bullwhip effect. The increased number of supply chain members also increase the probability of the occurrence. This is true for the geographical distance also. Chopra and Meindl (2016) emphasize the importance of the coordination of the chain that enables the reduction of the bullwhip effect. High distances are working against this approach.

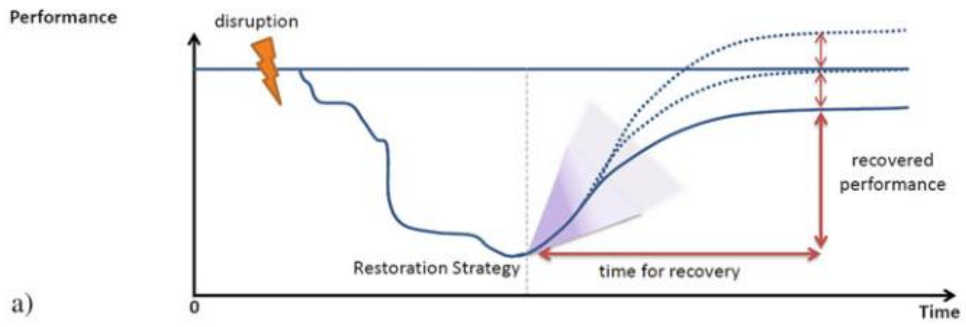
Performance measurement

The performance of any supply chain can be determined by production, inventory, location, transportation, and information. The requirement toward to supply chain is increasing the throughput and at the same time keeping inventory and operating costs on minimum level. This is the main requirement towards the supply chain performance. This goal needs continuous adjustment to find the right balance (Hugos, 2018).

The measurement of the performance typically relates to the cost-time-quality trial. In the past decades the focus changed highly. Currently digitalisation, flexibility, intelligent IT solutions, agility and globalisation is determining the operation, highly influencing the approaches toward the supply chain performance (Ivanov et al. 2019).

Below chart (Figure 1.) shows the importance of the connected research of supply chain performance and the stability. With stable supply chain the performance also expected to be stable. Disruption such as bullwhip or ripple effect leads to decrease in performance. Recovery and long-term impact can be different based on various potential recovery plan. These plans can be supported by a measured process. These support to make the first steps quick and to find the sufficient solution.

Figure 1.: Performance and recovery in disruption



Source: Ivanov et al. 2019

Quality management

As quality is a complex approach it is building on multiple pillars: system, management, and engineering. The interaction of them is both on vertical and horizontal way. This complex approach and connected application make the direct adaptability of best practices impossible. for successful application all the three components need to be customized. Quality system includes the standardized systems and processes. Quality management is ensuring that customer satisfaction is kept in focus. Quality engineering responsible for the creation of the product (Lim, 2020). In my research my focus is on quality management out of these pillars.

Quality management has multiple practical approaches to support the operation focusing on continuous improvement. Those can be diagrams, histograms, charts, or even complex approaches (Luthra et al., 2021). One of these is the Failure Mode and Effect Analysis (FMEA) that is well known and widely used both in research and practical life.

FMEA

Failure Mode and Effect Analysis (FMEA) is used for quality purposes. Risk analysis is in scope due to several reasons from costs and customer requirements to legal and technical questions. FMEA can be defined as "*a specific methodology to evaluate a system, design, process, or service for possible ways in which failures can occur*". The approach is proactive. So instead of problem solving, monitoring waste and quantification of reliability it concentrates on the prevention, elimination, and reduction (Stamatis, 2003).

It was firstly used in aerospace industry. Due to the severe potential impacts of failures on human life prevention is crucial. As the method was described in an understandable way it appeared in other industries and companies and became typical in automotive industry in error and risk reduction (Chiozza & Ponzetti, 2009).

1.2. Bullwhip effect as symptom of the supply chain instability

The definition of the bullwhip effect has already been presented. As the phenomenon has huge impact on the stability of the supply chain deeper analysis is needed. In this chapter the reasons and consequences will be presented and using the method of literature mapping also the scientific landscape of the phenomenon is built up.

1.2.1. Reasons of the bullwhip effect

Traditionally research is focusing on operational consequences and causes of bullwhip effect. Solutions are also covering this perspective with influencing lead time and increasing transparency (Lee et al. 1997, Yang et al. 2021). The main operational reason groups behind the phenomenon have been listed by Lee et al, (1997a) as below:

- *Demand signal processing*: focus is on the retailer's level of the supply chain but applicable on the full chain. Supplier cannot track properly the retailer's signals; the true demand pattern is not getting through the chain.
- *Rationing game*: products with limited supply order can exceed the real needs to secure availability. The issue typically starts from the manufacturer, but it can occur in all levels of the chain.
- *Order batching*: can be caused by periodic review processes and the cost of the orders. Rules and strategies can differ in the chain that can lead to bullwhip effect.
- *Price variation*: promotional plans are not in line with the supply capabilities, and free return policy can worsen it.

Mentioned main areas have been complemented by the lead time parameter (Geary et al., 2006), which is due to the change in the lifestyle of the customers and the supply chain operations. Longer, international chains led to an increase in lead time. The lead time element is still among the operational causes. Studies with the focus on operational reasons of the bullwhip effect assume behaviour of humans are rational (Yang et al. 2021). Even the described categories may seem outdated based on the time, they were defined and are still valid. Digital technology impacted supply chain operation a lot, change of it was mainly visible at information, financial and material flow (Wiedenmann, Größler, 2019). By theory the tools available should support avoiding the bullwhip effect, but the practical experiences are not confirming it. These categories are still valid in practical life.

As human factors have not been considered in these studies, it meant a potential improvement of the bullwhip effect research. As another aspect, irrational decisions and stressful environment were also included as behavioural reason of the bullwhip effect (Sterman, 2006). The number of studies considering the human factors increased; focus topics are information sharing, training and communication, trust in collaboration, human influence in forecasting and reactions on the bullwhip effect (Yang et al. 2021).

The mentioned reason groups can be further broken down to sub-elements (Geary et al, 2006; Potter & Disney, 2006; Bhattacharya and Bandyopadhyay, 2011).

- Demand signal processing
  - inaccurate forecast
  - forecasting strategy
  - handling of stock out
  - misunderstanding of the market information
  - lack of learning
- Rationing game
  - number of supply chain echelons
  - lack of transparency
  - lack of control and synchronization
  - local approach
  - fear of shortage
- Order batching
  - lot size of the order
  - replenishment policy
  - capacity limitations
  - ordering timelines
- Price variation
  - fluctuation of material prices
  - fluctuation of finished goods prices
  - changes in other related costs
  - planned and not planned promotions
- *Lead time*

  - impacting forecasting strategy
  - delay in information flow
- *Human factor*
  - information sharing
  - trust
  - human influence on forecast

1.2.2. Consequences and reduction of the bullwhip effect

Bullwhip effect can have contradictory results, both overstock and stock out as potential outcome. These results are decreasing the supply chain performance and have direct or indirect financial impacts. For example, cost impact can be realized due to lost sales opportunities or via increased warehousing costs. This impact can increase through the chain due to the multiplication effect. This leads to serious consequences on chain level, mainly striking the manufacturing side. Beside the cost, information is also impacted, it gets distorted due to bullwhip effect (Szegedi, 2012). The impact is not only realized on stock level but also highly influencing the capacity utilisation. The production schedules are also impacted by losing the stability (Disney, Lambrecht, 2008; Wang, Disney, 2016). The phenomenon results in uncertainty in planning, and expenses also appear due to production and transportation capacity utilization (Disney et al., 2007).

There are researches showing that collaboration have supportive impact and it can strengthen the system measures so the solution can be close to optimal (Tliche et al. 2019). Today's supply chains are rather considered as complex networks than streamlined chains. Independent and semi-independent echelons are getting into interactions with doubled goals. Beside the global goals of delivering value or service to the customer they also try to maximize profits on local level (Disney, Lambrecht 2007). Due to global and local differences and complex operations, cooperation became much harder. An ideal chain could be characterised by information transparency, coordinated processes and common strategy, having these circumstances realised, the bullwhip effect would less likely happen. However, above characteristics are not likely to happen in real-life circumstances in the foreseeable future. Competitiveness of the industries of the real-world results in incomplete information flow. As to consequence the customer demand information is getting through the chain in a distorted manner (Zarandi, Moghadam, 2016).

For better forecasting processes and accuracy, information sharing is needed. This would not be the final solution just a first step. Highest peaks can be avoided on long term. Beside the information flow lead time should also be considered. Analysation of the bottlenecks from this perspective can highlight critical processes, which can support in having better control, more manageable processes, and lower uncertainty. Once the first steps through information sharing and analysation of the bottlenecks is done, further synchronisation approaches can also be initiated. It can cover both batch sizes and processes (Towill et al.,2007) Based on case studies smoothing of the replenishment rule can result in balanced solution between the bullwhip effect and the customer service level (Ponte et al. 2022).

Although, transparency and information sharing seem to be supportive in decreasing the impact of bullwhip effect, it has been investigated in various research, that it does not always works (Haines et al, 2017). Even if the phenomenon may occur increased level of transparency and information is still important. It is easier to realize the bullwhip effect this way and it is also supporting the resolution of the problem.

1.2.3. Methods of literature mapping

There are several possibilities to find and extract information on published articles. Multiple databases are available, some of those are specified on a given topic some are covering multidisciplinary researches. Below some examples are listed:

- COnnecting REspositories (CORE): The goal is aggregation of all open access content from different systems. It became for 2018 the world's largest aggregator (Notay, 2018).
- Dimensions: it contains multiple data type such as publications, patents, policy documents etc. The linking behind enables the view of the information from a complex analytic context (dimensions.ai).
- Google Scolar (GS): freely accessible search engine that was created in 2004. It includes the most peer reviewed studies (Jensenius et al., 2018).
- Scopus: abstract and citation database. Since 2018 information of open access status has been started to be included.
- Web of Science: global citation database.

All the mentioned platforms support different needs, usage. If visualization is planned based on metadata limitations and possibilities of the visualizing tool need to be checked. It needs to be reviewed in what format data can be extracted and if this format fits the requirements of the visualizing tool.

For visual display we can also find available tools. Some examples are listed below. **VOSviewer** is a supporting tool for visualization of bibliometric data. The landscape in the tool can be generated based on citation, bibliographic coupling, co-citation, or co-authorship relations. Data in VOSviewer can come from Dimensions, Web of Science, Scopus, and PubMed. From these sources, co-authorship, citation based, and occurrence networks can be created (www.vosviewer.com). **Gephi** is also a tool that can be used for visualization and understanding of graphs. Mainly used for further visual analysis of existing graphs but also support csv format (www.gephi.org). **CitNetExplorer** is for analysation and visualization of citation network. It works with Web of Science data (www.citnetexplorer.nl).

For my work I have chosen Dimensions database and VOSviewer visualization tool. First the key word was *bullwhip effect*. The research has been narrowed down for *2016-2019.* Due to the significant impact of COVID-19 2020-2022 is filtered out (based on dimensions ~25% of the articles in 2020-2022 are considering COVID-19). To eliminate the unrelated items filter has also been set in the visualization tool. Only the authors or institutions with *more than five articles* have been included in the landscape.

The landscapes generated show the author and/or institution level connections. This information has been used as basis of categorization of bullwhip effect research approaches. Different networks of authors and institutions on the landscape mark possible grouping of research of the topic. Three approaches have been defined based on this.

1.2.4. Bullwhip effect scientific landscape

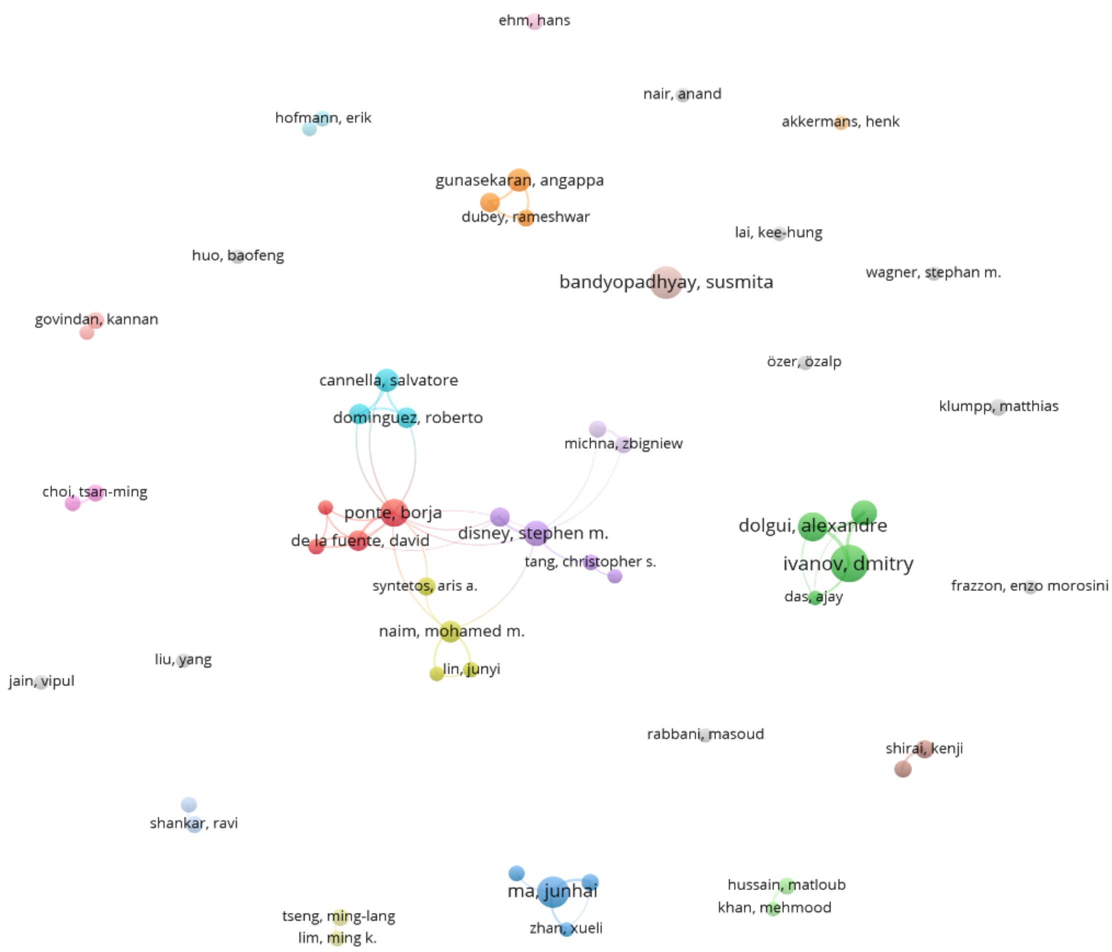
Research of bullwhip effect attracted attention of several researcher from different countries, institutions. Connection between them can also show direction of the research. It can highlight typical aspects and connected areas that are likely to be analysed together with the bullwhip effect. The landscape has been initiated based on data of 2016-2019.

Based on dimensions.ai database bullwhip effect is considered in 10653 research since 1970. The main researchers are Stephen M Disney, Denis R Towill and Dmitry A Ivanov based on the number of studies published. Disney has studies on this field since 1997, many of them in cooperation with Towill under the umbrella of the Cardiff Business School. Towill is also a remarkable person in the bullwhip effect research. He has been working closely with Disney until he passed away in 2015. He played important role in the establishment of the research group at Cardiff University. If the investigation is focusing on the 2016-2019 period Dmitry A. Ivanov is leading the list, more than half of his articles on the topic are from this time. Stephen

M Disney is still on the highest 10 researched but only 15% of the related articles are from the given period. (Strommer, Földesi, 2020b).

Figure 2. shows the landscape of cooperation regarding the bullwhip effect researchers considering 2016-2019 period. To limit the mapping only for the most relevant actors of the area, only the authors with at least five articles are considered in the investigation, which means the 10% of the authors (57 authors matches the criteria). The bigger the mark the higher number of articles are written by the given author. It is visible that Dmitry Ivanov and Stephen M Disney are considered as centre of research groups. Beside them also Ma Junhai and Ponte Borja can be mentioned as significant characters. The map is presenting that direct or indirect connections are formed between several authors. Even so there are still some relevant researchers with no significant collaboration with the other authors in the bullwhip effect subject (Strommer, Földesi, 2020b).

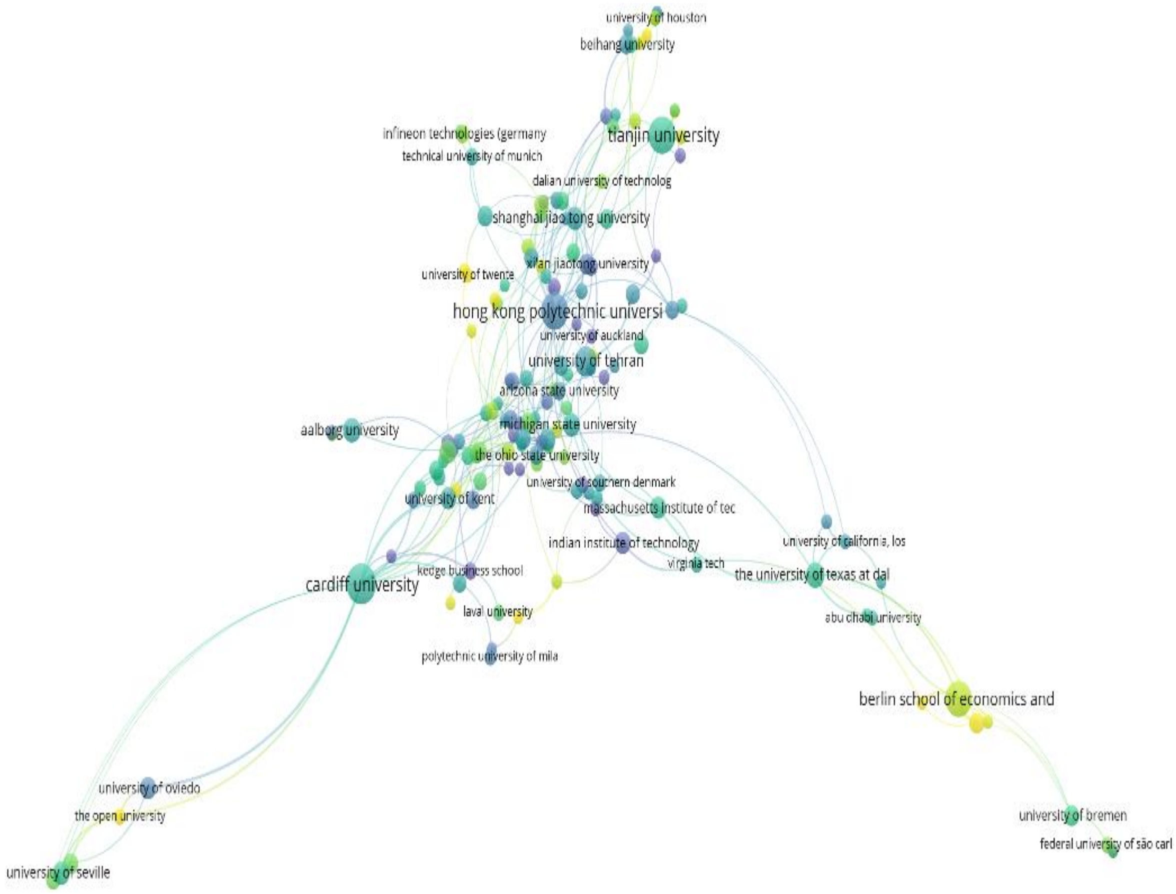
Figure 2.: Bullwhip effect authors 2016-2019



Source: Dimensions.ai database, visualized with VOSviewer software

Figure 2. also presents the cooperation of authors and research groups. Dmitry Ivanov has strong connections with some researchers such as Alexandre Dolgui, but his network is isolated. It is not extended further with other bullwhip effect researchers. In contrast other author communities are more connected with each other. For example, the group lead by Stephen M. Disney is connected both with the one led by Borja Ponte and the one led by Mohamed Naim (Strommer, Földesi, 2020b).

Figure 3.: Bullwhip effect institutions 2016-2019



Source: Dimensions.ai database, visualized with VOSviewer software

These connections on organisation level are also interesting to see. Figure 3. presents the institutional landscape. The minimum number of documents by an organization is still considered as five, 10% of the organizations meet these criteria (148 organizations). Based on the mapping Hong Kong Polytechnic University is highly connected to other institutions, it has central position in the network. Cardiff University, Berlin School of Economics and Tianjin University are also significant players with several links. These institutions with the most significant connection chains are not related to each other, only through additional elements. This scientific network is not limited on geographical level, cooperation is found all around the world. It is visible that the network and cooperation on institution level is much more complex, and the collaboration is tighter than on author level. As authors can have relations with multiple institutions through the years, connections are more likely to be generated. Furthermore, a given author can publish under the umbrella of multiple organizations (Strommer, Földesi, 2020b).

As number of institutions presented are high it is worth highlighting the most relevant ones and connect them with the main authors. Cardiff University is represented in author level by Stephen M Disney (in the 2016-2019 period, also by Denis R. Towill in the earlier years). Berlin School of Economics is the institutional background behind Dmitry A. Ivanov, Tianjin University represented by Ma Junhai on the author level summary. Regarding Hong Kong Polytechnic University it is difficult to pick a researcher, several smaller research groups are representing it led by Choi Tsan Ming or Wong Wing-Yee (Strommer, Földesi, 2020b).

1.3. Bullwhip schools

Based on the most relevant authors and institutions it is possible to define schools or approaches regarding bullwhip effect. The landscape outlines research groups based on co-authorship and that led to below categorisation. Different groups are handling the phenomenon from diverse perspective. In the sub-chapters key elements related to the different groups are summarized and presented with some examples related to it.

The three schools defined are the followings: (Strommer, Földesi, 2020b)

- *Bullwhip focus concept*: The researchers of this school are focusing on the phenomenon itself. Research goes deeply into forecasting, information sharing, replenishment, and ordering policies mainly.
- *Supply chain performance concept*: The aim is improving global supply chain performance. BWE is considered as a part of the bigger picture. Focus is performance improvement based on the result of other bullwhip effect research and integration of the potential methods.
- *Customer focus concept*: This aspect uses a different viewpoint. Customer is the centre of the research. More focused on price, promotion, and customer satisfaction. This approach is more practical, market driven.

The approaches mentioned before relating to the scientific landscape as well that is visible on Figure 2. Bullwhip focus concept is in the centre of the visualisation with Stephen M. Disney as a main author. The supply chain performance concept is represented by the research group led by Dmitry Ivanov. The customer focus concept is more fragmented. Less co-authorship can be discovered. Mostly isolated smaller groups or authors belong here. For example, Junhai Ma is part of this group with pricing related research.

Bullwhip focus concept

Cardiff Business School is one of the key institutions for BWE research since the 1990s. The main researchers are Stephen M. Disney and Denis R. Towill. The understanding of the phenomenon is focusing on the swings created by the customer demand growing toward the manufacturing end of the supply chain (Wang & Disney, 2016).

The focus of the research is the replenishment rules, forecasting, ordering policy, trends, and information sharing. Demand signal processing was already mentioned as one of the reasons behind the bullwhip effect in Chapter 1.2.1. It is understood as adjustment of the demand forecast and through this adjusting inventory replenishment parameters. The result can be over-reaction, which can lead to variance amplification. Usage of different forecasting methods can induce the BWE (Dejonckheere et al., 2003). The setup of supply chain can also highly determine replenishment methods used. Vendor managed inventory (VMI) chains and traditional chains differ on this question. VMI concept supports the reduction of the bullwhip effect by elimination of a decision layer and a potential information delay (Disney & Towill, 2003b).

Demand fluctuation and non-zero lead time are among the main reasons too. Bullwhip focus concept investigation is partly targeting this area. There are several case studies based on the topic. Disney and Towill's 2003 study present analytical examination and solution for bullwhip effect in case of a specific ordering policy (Disney & Towill, 2003a). It is also analysed how the reduction of the bullwhip effect meets the inventory performance requirements. As a result, a trade-off has been revealed. Reduction of the phenomenon ends in increase in the performance requirements (Warburton & Disney, 2007).

Information sharing in supply chain is in focus as well. Currently information sharing due to technological development does not have technical barriers through the supply chain. Dejonckheere et al. investigate how traditional supply chain with no information sharing differs from the supply chain where customer demand is known in all levels. The outcome of the research was that information sharing can decrease the amplitude of the bullwhip effect in the chain (Dejonckheere et al., 2004).

The other side of the examination of the bullwhip effect is reducing it. Above mentioned research group consider ten potential principles to reduce the bullwhip effect. These are partly built on causes stated by Lee et al. and on other examples summarized as below (Geary et al., 2006)

- Control system principle: target and control to be harmonized
- Time compression principle: time requirement of task to be minimized, remove waste from the system
- Information transparency principle: transparency for all relevant member with no delay, holistic control
- Echelon elimination principle: number of echelons to be defined based on supply chain goals on the minimum level
- Synchronization principle: events are synchronized
- Multiplier principle: orders can be multiplied mainly between manufacturers and suppliers.
- Demand forecast principle: as forecasting is one of the reasons behind BWE this should be improved by the already mentioned points such as information transparency. Different trend detections and safety factors should be eliminated, harmonized.
- Order batching principle: harmonization of the batching is needed in the chain
- Price fluctuation principle: price changes to be driven and planned
- Gaming principle: double guessing should be eliminated

Supply Chain performance is considered as connected area by this research group too. BWEs impact on performance can be measured based on Likert scale. Scores have been defined based on value streams: process, supply, demand, and control uncertainty. This covers the full supply chain, both abilities to meet production target, problems occurring due to poor performance suppliers, unpredictable demand changes and malfunctions in the information flow (Geary et al., 2006).

Supply chain performance concept

Performance measurement and bullwhip effect research has lot in common. This aspect has been led in the past few years by Dmitry Ivanov based on the number of articles published. Beside the research group lead by Ivanov there are several others who analyse the topic. The focus among these researchers is not the bullwhip effect itself but, it is investigated as a connected field that has impact on the performance of the supply chain. The central principle is ensuring the planned economic performance. To reach this, potential barriers and bottlenecks are analysed. BWE is examined as one of those. The core idea of checking it is the influence on information sharing, forecasting, inventory policies and ordering methods. Via these fields supply chain echelons are highly connected with each other, both global and local performance have significant dependency on BWEs operational occurrence.

Supply chain performance is highly affected by numerous different factors. These can be for example number of echelons and cooperation of them, coordination of the global concept, having common understanding on performance goals in the chain. In addition to the mentioned elements demand uncertainty (amplification of variation of demand) and differences in forecasting are also important factors (Ducq & Berrah, 2009).

For Dmitry Ivanov, the core of the research are control theory, ripple effect, and disruption in the supply chain. Bullwhip effect is an important area influencing the mentioned topics. The direction is the analysis of the dynamics and performance in the supply chain. Ripple effect is one of the fields extensively studied by Ivanov, "*describes a downstream propagation of the downscaling in demand fulfilment in the SC as a result of a severe disruption (or a series of disruptions)"* (Dolgui et al., 2019). It has been proven that missing control during disruption causes bullwhip effect. Ripple effect is considered when the disruption is not coming from the customer but from different element of the chain (Ivanov et al. 2019, Ivanov et al., 2015). The phenomenon got more attention due to the changes of the past few years. COVID-19, wars, transportation difficulties led to numerous potential disruptions that is not originated from the customer echelon of the SC: Supply chain behaviour changes during this period, and panic reaction can be observed, however coordination can allow elimination of bullwhip effect. Based on the research ripple effect and bullwhip effect are on negative interrelation which leads to backlog accumulation resulting in destabilization of inventory (Dolgui et al., 2019). The main contrast between BWE and ripple effect is summarized from several perspective. Central thoughts are in recovery timing and in affected performance. Bullwhip effect is more focused on short term actions and effect on performance is also connected to this, it occurs regarding current performance, and it means operational risks (Ivanov et al., 2019).

Information sharing can be considered as key element regarding the bullwhip effect and the supply chain performance also. It is considered as potential to decrease risk in case of disruption, and it has been proven by analysis that it improves supply chain resilience and robustness (Hosseini et al., 2019). Information distortion has negative effect such as heavy fluctuation of orders on manufacturer side leading to unreliable picture on inventory level on multiple part of the supply chain. Increased number of echelons increase the uncertainty as well. The solution to ensure timely and valid customer demand information is transparency which decides in long term orientation and needed to consider rather global than local perspective (Otto & Kotzab, 2003).

Information sharing is highly connected with forecasting, and transparency can help in improvement of the quality of the forecast in supply chain. Collaborative environment can lead to collective forecasting which can decrease uncertainty, improve forecast, and reduce probability of bullwhip effect (Ramanathan, 2014).

Information transparency in the supply chain is an important question from the performance perspective. This is also crucial regarding the bullwhip effect. Supply chain performance can be improved via collaboration and information sharing and at the same time this can be also a tool to solve bullwhip effect or at least reduce it. Information management has impact on forecasting, ordering policies and inventory too and supply chain performance can highly depend on it.

It can be also recognized that the direction of research is performance measurement, BWE appear as a smaller part, component of research. Staying with the example of Dmitry Ivanov bullwhip effect is not the centre of the research. Ivanov is focusing on supply chain disruption, ripple effect and control theory. Bullwhip effect is appearing in the research as influencing factor. The research made is more likely to be carried out first on performance measurement and then on bullwhip effect.

Customer focus concept

Beside the two concepts mentioned above a third approach also exist. The starting point in this perspective is the customer, ordering and inventory policies are not relevant directly for the customer, and the global performance of the supply chain is out of scope for this perspective. The more relevant information regarding bullwhip effect are price and promotions. In the literature not only supply chain related impacts of BWE are investigated but also more customer and sales focused outcomes. Bullwhip effect can result in lost sales and service level problems (Trapero & Pedregal, 2016).

There have been several research papers in this area and the approaches show that promotions and prices are one of the major causes of the bullwhip effect. Market demand and supply are commonly considered as cause of price dynamics. Different results are also presented regarding pricing. Tai et al. conclude that last period price and demand have larger impact on bullwhip effect than the current period. This shows that pricing strategy (steady or dynamic) should be defined based on last period result (Tai et al., 2019). Competitor behaviour is also analysed regarding the price. Bigger bullwhip effect is expected if competitors influence the prices more and this fierce competition leads to bigger bullwhip effect (Ma & Bao, 2017).

As it has been proven by an A. C. Nilsen survey promotional activities play important role in retail stores. Based on this constant price does not seems satisfactory to maximize profit.

This goes contrary with BWE theoretical research regarding stabilization of prices. From marketing perspective, it has been studied that promotion can be beneficial even for supply chain system if it is properly designed. With greater frequency of the deals, peaks expected to be smaller. Su and Geunes' study shows the coexistence of the bullwhip effect and increased system profit. Several factors need to be considered here: discount needs to be set judiciously; proper number of customers need to be interested to buy the discounted product; decreased price should not lead to significant level of forward buying. Profit generated with promotion partly ends up at the retailer level, extra costs mostly realized at supplier level. This needs to be counted as well to see if it worth to implement activity. It needs to be defined if the cost of bullwhip effect is higher than the potential extra profit generated (Su & Geunes, 2012).

Besides promotions customer satisfaction is also important. Service level is considered as a quantitative measure for the supply chain (Bandyopadhyay & Bhattacharya, 2014). Several research studies show how changes of service level requirement influence the level of bullwhip effect. Based on Khosroshahi et al. by increasing the required percentage of service level impact on bullwhip effect will also increase. The higher service level is required the more impact on bullwhip is expected. As the service level requirements in the practice are getting higher and higher this aspect and the cost related to it are also worth to be checked. The reason behind this correlation is that higher service level requires greater order size fluctuation (Khosroshahi et al., 2016).

Table 1 summarise the different schools of the bullwhip effect. The comparison is based on the focus of the different approaches, measurements applied, suggested resolution.

Table 1.: Summary of bullwhip schools

	Bullwhip focus concept	Supply chain performance concept	Customer focus concept
Key Author(s)	Disney S.M., Towill D.R.	Ivanov D.	Fragmented group (eg. Junhai Ma)
Focus of research	Replenishment rules Forecasting Ordering policy Trends	Supply chain performance Stability	Customer Price Promotions
Measurement	Likert scale, Mathematical modelling	SC performance is measured as total	Role in the competition, Price variation Planning horizon
Resolution	Actions based on reason groups (eg. Harmonized batch sizes, minimum level of SC echelons)	Information sharing Forecasting transparency	balance in promotional planning, Increased market knowledge
Bullwhip effect	Core of the research	Influencing factor	Role of customer and human factor in the occurrence

Source: Author's edition

2. METHODOLOGY

2.1. Research questions

Based on the literature review following research questions (RQ) have been phrased:

- RQ1: In spite all research made do bullwhip effect and ripple effect still exist?
- RQ2: Is there a comprehensive performance measurement or does a quality engineering toolkit exist to detect the bullwhip effect and/ or the ripple effect?
- RQ3: If the answer for RQ2 is „no“, is it possible to have?
- RQ4: Is it real need to have one?
- RQ5: Are there any sectoral differences regarding the needed approaches to handle the bullwhip effect?

The first question is referring to the existence of the bullwhip and ripple effect as symptoms of the supply chain instability. Based on this, further questions are phrased. The second is checking the potential in performance measurement and quality engineering for practical use. The third and fourth are investigating a possible application and real need for this. Finally, the sectoral differences are also questioned regarding the approaches.

2.2. Methodology

The supply chain instability is part of everyday operation. This work is investigating the symptoms or drivers of it, which are the ripple and the bullwhip effect. As the focus of the research is the bullwhip effect due to the wider scientific background, the literature review's starting point is the phenomenon. Beside the introduction of the bullwhip effect a scientific landscape has also been created. Based on the defined research groups of authors the connected research area of performance measurement has been defined. Regarding performance measurement both frameworks and single measures are considered in the research. Balanced Scorecard has been selected as a framework and forecast accuracy, forecast bias and service level as typically used supply chain measures.

The thesis uses a mixed approach, both applying qualitative and quantitative methods to present the research. On qualitative side case studies are presented, which are presenting the occurrence of the bullwhip effect based on literature review and practical experience. These show examples of the presence of the phenomenon. On quantitative side a survey has been conducted among supply chain experts. Benchmarking is also used as the quality engineering and performance measurement approaches are used.

Presented case studies conduct dual background: primary (personal experiences) and secondary research (market studies). Beside the above written presenting types of examples of the application of FMEA tools are also part of my thesis, where visualization is done using the practical experiences and the theoretical framework.

In my research I also initiated a survey, which was conducted online with 76 respondents filling out it. The respondents have been subject matter experts working with inventory and/or forecasting. The aim of the survey was to collect information on the factors that are influencing the bullwhip effect. The questions are not directly concentrating on the phenomenon rather from the perspective of the reasons behind it. The questionnaire consists of three parts. The opening questions are indirectly analysing if the respondent experienced the symptoms of the bullwhip or not. The next part focuses on some selected elements impacting the effective operation of the supply chain. The aim is to see how these elements are present in real chains. The third part is a pairwise comparison that matches seven core factor using the Ross's series that are significant regarding the bullwhip effect. The survey also checks the background of the respondents: industry, supply chain role, company size. This information is also applied as differentiation during the analysis of the result.

The results of the survey have been analysed using the following methods. Regarding the opening questions lead time has been further analysed and industry, supply chain role level differences have been investigated. Based on the questions of the second part of the survey a Pareto analysis has been initiated both on total and industrial level. Beside that risk matrix has also been built up on total and industrial level showing the differences of the impact. The pairwise comparison has been analysed applying inferential statistics. The survey led to ranking of the analysed factors and the relative importance has also been analysed. To see the level of agreement between the respondents the value of the Kendall coefficient of concordance was also measured.

This work is an explorative study, it is based on a literature review and leads to a mixed analysis approach including both qualitative and quantitative analysis. Qualitative methods supported in better understanding of the topic and confirmed the necessity of further research of it. Case studies and benchmarking showed what are the practical situation compared to the literature explanations. Quantitative side presented the current gaps experienced in practice that should be supported to be covered.

The main limitation of the research is regarding the survey. The number of respondent due to the specific criteria is limited. This leads to limitation in analysis of all industrial segments or supply chain roles on the topic. Even though the application of the survey enables the testing of the approach, representative results were not expected on this research. It aimed testing the method and the results considering the incompleteness of the data.

The above phrased research questions summarise the basis of the dissertation. Methodology is supporting it in reaching the results. As this research has a dual nature – both practical and theoretical – the approach applied was also mixed in my study. Qualitative, quantitative methods and benchmarking both have been used in my dissertation.

3. SUPPLY CHAIN INSTABILITY ANALYTICS TOOLKIT

3.1. Performance measurement

Bullwhip effect and performance measurement are highly connected areas. Bullwhip effect phenomenon is impacting the operational performance. Due to this impact the common research of the two area needs to be considered. As stated by Kaplan and Norton: "*No measure, no improvement*." (Kaplan, Norton, 1992) Performance measurement is appearing in several research. The area has strong industrial connection and interest behind. It can have a huge impact on the operation of any supply chain. The areas of research are mainly connected to management, information technology and systems or engineering.

Performance measurement framework is established to measure and enhance the efficiency of the supply chain. It is an enabling tool for managers to manage supply chain in an efficient way, supported with information regarding the needed enhancement to achieve excellence. It is fundamental to reach and sustain competitive advantage (Balfaqih et al., 2016). There can be different reasons to develop and establish performance measurement system (PMS). PMS can support in identification of success, understanding if customer needs are met, perceiving business processes, making decisions, enabling, and tracking progresses. It can also take part in bottleneck, problem, or waste identification or in finding the improvement potentials (Gunasekaran & Kobu, 2007).

There are several ways to approach performance measurement, such as models like SCOR or BSC model, process-based technics that are building on the process-based analysis of the supply chain or perspective-based models building on generic measures. Those also consider interrelationship between them and hierarchical approach checking that metrics on the different level of hierarchy in the SC (Jagan et al., 2018). These models are from time to time reorganized, such as Tableu de bord which is the French concept of the Balanced Scorecard. This model has operative focus and aims to direct repair the found deviations (Daum, 2005). This tool started as a reporting tool but adapting to the requirement it became a performance analyser tool. The tool is supporting the definition of action plans that ensure the achievement of the goal (Bourguignon et. al., 2004). There are models that are highly determined by the structure of it such as the performance pyramid. This hierarchical method is breaking down the company vision first to market related and financial indicators, then to the level of business operating systems. Finally, the model is breaking down the vision to operation level (Kurien, Qureshi, 2011).

Table 2.: Comparison of performance measurement tools

Features	*BSC*	*Performance pyramid*	*Tableau de bord*	*SCOR*
key indicators	yes	no	yes	yes
perspectives	yes	no	no	yes
non-financial	yes	yes	yes	yes
strategy	top down	bottom up	top down	top down
network	yes	no	yes	yes
operations	yes	yes	yes	yes
orientation	both	process	both	process
management tool	yes	no	yes	no
reporting	yes	no	yes	no

Source: Strommer, Földesi, 2018

Table 2 shows the comparison of the Balanced Scorecard, Performance pyramid, Tableau de bord and SCOR model. The comparison is based on the upcoming questions (Strommer, Földesi, 2018):

- Are the key indicators defined in the given metrics?
- Does the model define different viewpoints, perspectives or categories of measures?
- Are the measured parts beyond financial attributes?
- What strategy is the model following: bottom up or top down?
- Is the model designed to measure a company or capable of measuring a network or chain?
- Is the analytics broken down to operational level?
- Customer or company point of view is followed? process or result oriented measures are used?
- Management tool: is the measurement designed partly or fully to support strategical decision-making process?
- Is the aim of the model fully or partially report about the status of the performance?

One of the main requirements towards the performance measurement tools are that they shall be able to handle complexity and support efficiency. This is true for all the examined methods, and this is one of the elements what makes them widely used. As among the requirements stated by the users there are no two equals such as among the methods there will be no uniform content that makes them adaptable for various scenarios. Another basic requirement is going beyond the financial metrics and gain better efficiency. This is also part of all the checked methods. They can handle well non-financial metrics. That helps the growth of efficiency and effectiveness of operations (Strommer, Földesi, 2018).

In several use cases Key Performance Indicators (KPI) are used to group, measure, and track performance. KPI provide information on different areas such as inventory, quality etc. The goal is to identify waste and implement improvement actions. Performance improvement processes and actions are initiated based on these measures (Lindberg et al. 2015).

3.2. Balanced Scorecard and bullwhip effect

Balanced Scorecard is a performance measurement framework. Application of it is less common in the bullwhip effect analysis. Still due to the balanced structure the logic is close to the complex supply chain viewpoint. This sub-chapter shortly introduce the Balanced Scorecard and shows the connections in the literature with the bullwhip effect.

The Balanced Scorecard (BSC) is a frequently used measurement system which is not limited to measuring financial results. The idea was developed by Robert S. Kaplan and David P. Norton in 1992. The tool is mainly supporting the work if the strategical goal is clear, and the number of the measured metrics are limited. For structuring the result Balanced Scorecard use four perspectives: (Kaplan, Norton, 1992)

1. Financial perspective
2. Customer perspective
3. Internal business perspective
4. Innovation and growth perspective.

This model can measure operative processes, but the aim is to support the strategy and long-term changes. The key point in Balanced Scorecard is to stay flexible and adaptable with keeping the ability to handle the complexity of measures. The main groups of indicators stated in the model are important in all enterprises and the breakdown of the measurement enables the customization of the system even on enterprise level. Besides the above written the company can also decide regarding the weight of the perspectives based on unique preferences. With regards of the perspectives, it is also important to find a way to connect them and point out the parts where they can influence each other (Chytas et al. 2011).

Balanced Scorecard applies the trade-off point of view. It shows that the decisions made have several angles. In order to see the full perspective, it is necessary to think in systematic way (Magalhaes et al., 2019). This works well with the 7R (right product, in the right quantity and the right condition, to the right place at the right time for the right customer at the right price) approach followed by the logistics operation ((2000) SEVEN “RIGHTS” OF LOGISTICS). The flexibility offered by the Balanced Scorecard supports handling supply chain as whole network, but also remaining customizable on echelon level. Due to the structure the flexibility of the model is not turning out to be overcomplication, as the perspectives determines the content of the frame (Szander et. al., 2014).

Using this method, the two main pillars which were mentioned already can go hand in hand. The cost pressure can be reflected in the financial perspective, but also the customer satisfaction can be taken into consideration. The added benefit of the model is that the already mentioned points can be connected to the disciplines of internal business processes and development of the internal processes can not only be shown but also could be helpful with other factors. Furthermore, innovation and growth/adaptability can be also integrated into the complex evaluation of the operation, strategy. Basically, the model tries to answer the question of how the company succeeds with the non-financial indicators to support the financial goals and targets (Kurien, Qureshi, 2011).

Differentiation between the perspectives could be based on the observed period as well. Financial perspective shows the financial results of the company, the already made decisions, and the changes occurring due to them. In contrast the other segments mainly focus on the future. What are the areas which can impact future results? How can their improvement help from financial point of view? The limited number of measures also concentrate the focus of decision makers on the focus areas and information does not need to be selected or searched out from huge datasets (Kurien, Qureshi, 2011).

Connection of the bullwhip effect and the Balanced Scorecard

As it has been described before the common research of the BSC and the bullwhip effect is not typical. Even though, connection between the two is quite close. Balanced Scorecard's four main perspectives are: innovation and growth, internal business, financial and customer. Bullwhip effect reasons are also categorized originally in four main groups: demand signal processing, rationing game, order batching, price variation. The connection between the KPI can be established for example as below in Table 3.

Innovation and growth perspective contains the measures that support the process improvement actions with long term focus. Bullwhip effect's rationing game reason group also contains the chain level reasons like number of echelons, local vs global approaches or lack of control and synchronization. The KPI that shows the mentioned reasons of the rationing game group focuses on chain level questions, can be used to support the improvement actions. With this approach rationing game reason group can be connected to the innovation and growth perspective of the Balanced Scorecard.

Table 3.: Balanced Scorecard perspectives connected to the bullwhip effect reasons

Balanced Scorecard		**Bullwhip effect**	
Innovation and growth	improvement actions long term focus deeper understanding of performance	**Rationing game**	affecting the whole chain strategical aspect
Internal business	existing processes operational metrics	**Order batching**	replenishment policy time frame
Financial	costs related measures	**Price variation**	promotional impact price changes
Customer	customer satisfaction loyalty	**Demand signal processing**	forecasting uncertainty estimation based planning

Source: Strommer, Földesi, 2021a

Internal business perspective places the focus on the metrics related to the existing, operating processes. Regarding BWE order batching contains process related reasons: the applied ordering and replenishment strategy, timelines used. The BWE order batching reasons can highly be connected to the purposes of the internal business perspective of the BSC.

Financial perspective relates to price variation. Price related changes can have huge impact on the forecast, level of inventory. These unplanned price changes (both increases and decreases) lead to inventory related oscillation. This result can be reported in the KPI and involves financial expenditures. As the financial perspective of the BSC shows the quantified impacts it can be matched with the BWE reasons connected to price variation.

Customer perspective aims to point on customer focus and relationship with the customer. Demand signal processing also touch this topic. It is highly impacted by information sharing and forecasting methodology used by the different echelons. These all are based on the initial information from the customer. These aim to reach the highest possible level of customer satisfaction.

Table 4. shows indicators that can be potentially used to show the presence of the bullwhip effect categorized in the Balanced Scorecard perspectives based on the mentioned logic.

The innovation and growth perspective represents mostly long-term strategical logic. Connected to this chain level measures and characteristics are measured here. With initiating change - for example on level of harmonization of KPI - the cooperation can be improved on long term. This can support avoiding the bullwhip effect with better information flow and high level of transparency.

Table 4.: Indicators to detect bullwhip effect in the Balanced Scorecard structure

Innovation and growth	• Number of supply chain echelons • Number of harmonized local KPI • Number of occurrence of shortages
Internal business	• Safety stock level, • Lot size
Financial	• Bias, • Price level fluctuation, • Number of promotions
Customer	• Forecast Accuracy • Service level

Source: Strommer, Földesi, 2021a

Internal business in contrast has echelon level focus. Inventory changes, lot size, ordering timelines can be used mainly to measure the bullwhip effect for analytical purposes. Using BSC for tracking the bullwhip effect can support to establish better internal processes.

Financial impact is mainly realized due to price related changes. Fluctuation of finished goods or material prices and promotional activities are potentially resulting in unplanned market reaction. This response from the market can start the oscillation. For better manageability forecast bias should also be considered. This way not only the reason of the phenomenon is monitored but also gives opportunity for the proactive approach.

Regarding the customer perspective service level and forecast accuracy are measures that can be used. Service level can connect to customer satisfaction and forecast accuracy can support improvement on the quality of the estimation. Both metrics are sensitive for the presence of the bullwhip effect. Phenomenon causes negative change in their value.

Balanced Scorecard is a good framework to group the metrics that shows the presence of the bullwhip effect. The reasons of the BWE fit well with the BSC structure. Using the measurement system is potentially supporting the detection of the phenomenon by giving opportunity to have better control on it. It is also basis of process improvement actions that lead to the elimination of the bullwhip effect. Balanced scorecard can be used as indicator framework of the BWE.

3.3. Measurement on different levels of the supply chain

The different levels of the supply chain have variant challenges, specific operating characteristics. Therefore, priorities are different as well. These preferences drive the local goals. To simplify the network four levels can be differentiated: supplier, manufacturer, distributor, customer. Measures on different elements of the supply chain are summarized in the upcoming sub-chapters.

Supplier

Supplier is the first element of the simplified chain. Raw materials or semi-finished goods can be supplied by the supplier to the manufacturer. Even though the common final goal of the chain is satisfying the customer's needs this requirement is less tangible in this part of the chain due to the number of echelons in between. This distance also means difficulty regarding the accurate information. Here the harmonization toward the global interest is through implementation of common goals with the strategy of the manufacturing location. The most important support needed here is regarding the lead time and adaptability to ad-hoc changes. The flexibility of the full chain can be determined by an unsupportive supplier.

There are several common points with manufacturing regarding the KPI as in several cases a supplier has also some assembly or preparatory activity on the product. Manufacturing performance indicators can also be applicable for supplier (Manotas, Cadavid, 2007). The difficulty can also come from the high number of production plants served by the same supplier with totally different rules and requirements. As one supplier can be part of several chain a lot of different requirements need to be met. This makes it even more difficult to set up a harmonized KPI system or processes (Cousins at al., 2008).

From stock keeping perspective supplier tries to minimize the amount stored. To ensure this the offered batches are usually quite big to reach the economy of scale. This result in the proper level of capacity utilization and minimizing the money kept on stock. As producing or preparing these bigger batches are time consuming, mid- and long-term planning are essential. These plans enable the supplier to have proper capacity utilization not only on short term (Cousins at al., 2008). Besides the planning the reaction time also need to be in focus. Big batches reserve high percentage of the capacity and increase the reaction time; it is difficult to make changes in production without decreasing the productivity. To ensure advanced planning on supplier side all elements in the chain should be able to provide high quality forecast mid and long-term and avoid the short-term changes (Waters, 2010).

Sharing risk is an aim for a supplier as sourcing raw materials and semi-finished goods can not only mean opportunity. Special items may not be sellable for other partners on the market. Changing strategy or portfolio can generate not needed stock which can easily result in loss. Sharing the risk can enable the manufacturer by more flexible conditions (like faster reaction or smaller batch) and on the other hand secure the supplier from the lost sales (Wisner et al, 2012).

Manufacturer

Manufacturing locations are sourcing raw material or parts from different suppliers, producing the finished goods, and sending it to the distribution centre for further trading. If the plants would only consider local goals the production would run in quite high batches, lead time would be longer, and no finished goods stock would be in the location. Furthermore, the production plan would be set based on the best overall utilization of the equipment and workforce. Price and availability of raw material would have high impact on the produced item and quantity. This is not likely to happen as distribution centres, wholesalers and retailers have limited storage capacity, the customer may not only need the most profitably produced product, but seasonality also needs to be considered and the willingness to wait is also limited on the side ode the other echelons.

The main KPI used in manufacturing are also called MPI (manufacturing performance indicators). These metrics not only need to take into consideration the goals of the plants but also the fulfilment of the requirements from the distributors. To improve industrial performance benchmarking is also widely used. Numerous case studies can be found which support to identify and improve the poor performing areas. Those studies also show benchmark results and processes that support the implementation. Key performance indicators can be used to investigate full processes but also different areas such as product quality. To cover all areas below KPI categories can be set (Lindberg et al., 2015).

- Energy KPI: energy input and produced output, it can be for example electricity or biomass
- Raw material KPI: under raw material we can understand some chemical elements or water. Raw material input can be also divided by produced output
- Operational KPI: comparison on actual and planned process is under here, it can be e.g., time or needed workforce.
- Control performance KPI: the main point here is the outcome of the production so comparison can be made on quality problematic items compared to the total.

- Maintenance KPI: Maintenance is needed for the proper operation, but it cost money so too much can be pull back on reaching goals. Here we can compare for example maintenance cost vs total output cost in each time period.
- Planning KPI: under this KPI capacity utilization should be determined.
- Inventory and buffer utilization KPI: Here the task is also finding the balance. Inventory cost money, but buffer is needed. The proper items and quantity need to be identified. For quantify average inventory can be checked.
- Equipment KPI: The condition of the used equipment is highly affecting the operation. It needs to be monitored to make sure proper maintenance plan is defined. here real and predicted performance can be compared.

Distributor

The distributor echelon differs significantly from the manufacturing. The distributor is not working anymore with semi-finished goods and production. The role is usually division of goods among e.g., regions or countries. Here the customer is closer, so the information distortion is smaller. For this point of the chain the priorities are different. Economies of scale have indirect importance. It is also important that neither raw material nor semi-finished goods are used or stored on this level. Due to this only finished goods are in the focus. As the stock means waste of capital, the goal is to keep the level low. Overall goal is maximizing the turnover with the minimum possible inventory kept.

Since customer satisfaction is the goal for the full supply chain importance of distributor is high as being a face of the company. This is the echelon where the customer service level can be measured, and improvement actions can be taken. Service level calculation differs company by company (and can also vary on particular levels of the chain) but the essential of it is the same. The placed and the fulfilled orders are compared with each other. There can be some correction used for example to exclude phased out products, new products, or items not available for the segment. It is crucial to find the balance between the cost elements and the level of service (Sawik, 2014).

Part of the cost mentioned before is coming from stock keeping. Dead stock generated in the supply chain means difficulty. These items are usually strenuous to sell due to for example price, lack of customer need or better offer from the competitor. To avoid dead stock, obsolete stock or long coverage forecast quality need to be improved. To measure this quality for example forecast accuracy and forecast bias can be used. These two measures show how good the forecast is. The accuracy is a metric to show the relation of real sales data and the forecast (usually in the beginning of a frozen period e.g., 1 month), bias show if the estimations are above or below the real number, so the portfolio or group of products are over or under forecasted (Rushton et al., 2010).

From the distributor point of view not only the customer satisfaction and forecast quality need to be in focus but also the lead time. During the planning process of planning all time related actions need to be advised such as production time and delivery time. Proper buffer is also needed so administrative tasks can also be included in this frame (Rushton et al., 2010).

Customer

The focus on the customer's need is inevitable. The measures and the weight of the customer can differ based on industry, product, or sales strategy. Even considering these differences the importance of the customer stays on the high level. Based on this the metrics should be defined considering the main priorities of the customer.

From the customer perspective the evaluation of the product or service is only happening when it is handed over. As a result of this handover value of the purchased items is not only very important but partially needs to be considered as well. This touchpoint between the user and the seller can be used to include additional value (e.g., warranty, delivery conditions, gifts, special packages, …) As mentioned, customer focus is a must so this kind of opportunities can and should be used to differentiate from the competitors. In today's market price is not the only element adjudicated the market share and position of a company or supply chain (Harrison, Hoek, 2008).

Customer focus on the final product delivered as mentioned before. Even if the core of the value is created on the manufacturing side customer will concentrate on the value in hand and not the process of the generation. Customer has much more opportunity to compare competitor products and to analyse the market trends. Easy and widely available sources are making harder to fully satisfy customer needs (Harrison, Hoek, 2008). The customer measures the product or service and the value it generates. The focus is on the level of fulfilment of needs.

There is a conflict between logistics' aims and customer's expectations. In the fierce competition users want to personalise the goods available at the market as much as possible. It may seem small change but if it is checked from supply chain point it means much greater effort. For example, 0,33l and 0,5l bottles are available on the market but the group of customers start to ask for 0,4 l bottles. From the user perspective it is a slight change in size which fits better to his or her lifestyle. For the supply chain it means new product to be developed, new packaging, different production requirement, product tests, etc. It is not only energy consuming but also costs time and money. There can also be a risk when the item is launched onto the market that customers do not like the final product at all and the change will not be profitable.

The other conflict is on the time perspective. Most of the cases the different echelons on the chain are located far from each other. It can happen that the supplier, the manufacturing, and the sales of the product are located on different continents. In contrast the customer request and require product to be available nearby and on the needed format, quantity, and quality. The customer does not take into consideration how far the product needs to travel to get the aimed shape. Long lead time is not accepted in most cases. This is opposed to the company's interest as for them stock means cost, money input with questionable return.

The cooperation needs involvement from all levels. This can be fruitful but also difficult. In the upcoming pages some of the potential risks and opportunities are collected.

KPI of the different actors

Based on the description of the different echelons of the supply chain we can determine some performance indicators that are relevant and crucial to support their operation. In Table 5. Three examples are presented for each of the mentioned supply chain levels. Beside those there are also a common example. This is the service level. It can be calculated in all relations of the chain describing the quality of the provided service which is important for each level.

Table 5.: Indicators of different supply chain levels

Supplier	Manufacturer	Distributor	Customer
Forecast accuracy	Capacity utilisation (Throughput)	Ratio of on time shipments	Order fulfilment rate
Cost of inventory	Maintenance cost	Inventory turnover rate	Service accessibility
Minimum order quantity	Cycle time	Forecast accuracy	Defect rate
Service level			

Source: Author's edition

The three defined measure on echelon level shows the focus. Supplies try to minimise the inventory; this is supported by accurate forecast and the defined MOQs. Manufacturing tries to reach the highest turnover using the capacity on the maximum, minimizing the costs and the time requirement. Distributor is highly influenced by the market. In order to reach high performance considering forecast accuracy is crucial. Beside that availability is also crucial with a manageable level of inventory. These elements are supported by ratio of on time shipments and inventory turnover rate. Customer is focusing on the product or service itself. It needs to be in perfect condition (defect rate), in case of any problem service needs to be available and the request need to be filled within a reasonable timeframe.

Risks

Considering all the echelons of the chain we can see that the different levels can benefit from each other. At the same time, it needs to be assumed that they need to define and eliminate the risk which is endangering them through these connections. In Table 6 the risks are presented which are threatening the operation on the chosen stakeholder: Table 6 summarize the risk of the common work in the supply chain (Strommer, 2019).

Table 6.: Risks of common work

Risks	supplier	manufacturer	distributor	customer
supplier		look for another source	change requirement	discontinuation of product
manufacturer	time/quality		demand fluctuation	demand changes
distributor	delay, quality, MOQ	flexibility, transparency		inaccurate forecast

Source: Strommer, 2019

Regarding the **supplier** the closest contact is with the manufacturer. Due to the competitive environment in cooperation with the manufacturer level of service and collaboration are very important. Manufacturer can look for other sources or even insourcing of the process can be feasible. For the supplier it is essential to make a product or service unique or the collaboration fruitful for all parties. The distributor and the customer have indirect effect. Mainly changed or discontinued market demand has impact on their processes. It can result in huge overstocks and poor capacity utilization (Strommer, 2019).

The **manufacturer** is in convenient contact both with distributor and supplier. From the supplier side the main risk is on the reliability. Manufacturing has several fixed requirements. Not only are the legal and mechanical requirements important but also the customer's requirement on product quality. This results in high standard requested from the supplier. The other risk is on time delivery. Delay endangers the on-time availability and has effect on the capacity utilization. Production plans need to be changed if possible or if not, it results in loss (Strommer, 2019).

Adaptation is also requested from the other side. Even the steadiest products can be promoted or positioned differently in the market. If it is not estimated properly on the forecast and information is not shared the manufacturing can be in trouble in serving these requirements. This demand fluctuation can be determined as a risk between production plants and the distribution. Customer has similar impact on the manufacturer. Without any promotion or price change market's need can increase or decrease. It can be the result of political or economic changes, new products of competitors or some newly presented risk about the product. It results in the same risk for manufacturer. Here the result can also be overstock or not perfect capacity utilization. In extreme case it can also cause shut down or reconstruction of production lines (Strommer, 2019).

For the **distributor** the customer is already close contact. Market trends and guided promotions can give inputs on expected sales level, but it will still be just expectations. Here the risk is partly coming from the political and economic situation which is very difficult to be predicted. The other risk is coming from the market behaviour. The competitors can have huge impact on results of the activities. Also new products can change the demand, make customers switch from one product or product group to the other. Overall, with all these difficulties the result can be inaccurate and not reliable planning (Strommer, 2019).

The risk also exists on the other side. Lack of flexibility and lack of transparent operation can make the cooperation with the manufacturing difficult. Without a certain level of flexibility, it is not possible to adapt at all to customer's needs. The flexibility can also be limited by the supplier. Minimum order quantity (MOQ) can be very high, which means high needed demand to be able to consume the full portion. Quality is also highly depending on the supplied materials and time perspective is highly impacted as well (Strommer, 2019).

Opportunities

Besides the risks there are also opportunities in the collaboration of the echelons. If it can be managed on chain level, the efficiency of the supply chain can be increased. To ensure cooperation in the full chain first it is good to see it on smaller level (Strommer, 2019).

Supplier and manufacturer share interest in several elements. Introduction of new products means risk for both parties. To eliminate or reduce this kind of risks sharing information is a great support. Collaboration can result in higher flexibility toward the manufacturer and can support on handling the risk of overstock on the newly introduced product. Change of processes can also result in development. Alignment of processes and strategies can enable operation with lower stock. By this harmonization the parties can also learn from each other and develop themselves (Strommer, 2019).

Manufacturer and distributor are mainly in conflict due to the changing customer need. Regarding planning, strategy, and changes both parties should be informed. This transparent communication enables the manufacture to utilize the capacity on a high level, which results in more efficient level of production cost. With better planning the company driven changes on demand (like price changes, volume deals) can be built in the manufacturer's planning also. This will lead to decrease in the level of uncertainty. The harmonization of priorities can also help. Both sides should be on the same understanding to reach the chain level goal. It can also help on echelon level as the goals and strategy can focus on the appropriate elements (Strommer, 2019).

The distributor has high impact on the customer satisfaction as this member is the face of the company. In most of the cases final demand is highly influenced by strategical decisions (e.g., price) on the distributor side. But demand can also highly differ due to the change of environment and change of customer's needs. More advanced forecast can support better service levels. Market estimation surveys or market research can be conducted to reach the mentioned service levels. Based on that the portfolio can be amended to better fulfilled customer needs. The forecast can also be changed so the manufacturer also produces the proper products (Strommer, 2019).

Possibilities

Based on the preferences of the different echelons of the supply chain below checklist can be generated to improve operation (Strommer, 2019).

- What KPI are used currently?
- Are the currently used KPI showing the performance improvement areas on the echelon level?
- What is the current way of collaboration used in the supply chain?
- What are the potential risks?
    - Is there any connection point with the competitors (e.g., same supplier)?
    - Are all the relevant quality standards used to guarantee quality?
    - Are the contracts rescuing the position in case of bigger changes?
    - Does the relevant party share information in regard to the changing market demand?
- What are the potential opportunities?
    - Does the relevant party share on information on changing market demand?

- Is there any common strategy introduced regarding planning?
- Is there any harmonization in place regarding processes?
- Is there any alert system introduced tackling the unexpected changes?

As collaboration needs different methods and levels depending on the circumstances there is no ready-to-use solution. Going through this checklist is a very basic step which can give a frame for initiating elemental changes and to increase cooperation and collaboration to a higher possible level.

3.4. Frequently used forecasting methods

As forecasting is a key element in the analysis of the bullwhip effect this sub-chapter shows the basic models and technics used that are influencing the outcome. Foley and Khavkin (2019) describe the rule of the forecast in the long-term planning: *"forecast … provides a scorecard to evaluate if strategy is appropriate and effective".* It creates value, strategic choices, growth, and margin expectations are reflected in it. It needs to be updated periodically, considering the changes in the plans and circumstances. Risks and opportunities must also be added (Foley, Khavkin, 2019). Forecasting is a projection of a value that is an expected demand for a service or good.

Based on Paul Saffo (2007) "*the forecaster's task is to map uncertainty, for in a world where our actions in the present influence the future, uncertainty is opportunity*." Forecast cannot be considered as simple prediction as it is built on a logical background. Forecaster needs to be able to explain and defend this logic (Saffo, 2007).

Saffo (2007) defines six rules that need to be considered in forecasting. These are below:

- Define a cone of uncertainty: Intuition and personal judgement is part of the forecasting. But these are broadened by overlooked possibilities and examined assumptions. The cone of uncertainty is filled with these inputs that builds the logic behind the forecast.
- Look for the S Curve: It refers on the dynamics of the change, it most likely not following a straight line
- Embrace the thing that don't fit: It relates to the S curve. Forecasters need to be able to see the top and bottom lines of the curve.
- Hold strong opinions weakly: It refers to too high dependency on one information that seems strong. That information should not be overemphasized.
- Look back twice as far as you look forward: information collected from the past events can help understanding properly the present indicators.

- Know when not to make forecast: It highlight that even if we consider circumstances with dramatic changes there will be steadier element than changes.

To choose the proper forecasting application and methodology several factors need to be considered. The targeted level of accuracy, available historical data, forecasted period (short-, mid-, or long-term), context of the forecast and the time dedicated to analysing data are factors influencing the choice of forecasting technic. The applied forecasting should make the better use of the available historical data and additional inputs (Chambers et al.,1971).

Forecasting methods have wide scale. From simple mathematical functions to complex time series. The easier methods are mainly applied for series with low level of fluctuation and predictable seasonality. It is also useful for product with smaller risk, such as best before date or invested money. The series with higher level of unpredictability require more complex solution. These cases are using complex statistical models. Below paragraphs are presenting some of the technics used in practice.

One of the simplest methods is the **average method**. Here the trends are not considered. The amount of forecasted demand is calculated based on the historical data. The **moving average** is more connected to the demand changes. It calculates the overall trend in the data set. The calculation is based on the historical data. The planning is operating based on a determined trend cycle. **Naïve method** is also one of the simple technics. The forecast is set at the last observation value. The **seasonal naïve method** is based on the same logic, but it is specified for cases with high seasonal changes. Here the forecast is set to the same value as the last observed from the same season. **Drift method** is also based on the naïve. It allows overtime increase or decrease of forecast. The amount of change is considered the average change (Hyndman, Athanasopoulos, 2018).

The more complex prediction models are built on statistical models. They are based on time series. The basis of the connection are the statistical models. It is assumed that based on the historical data the time series are in linear or non-liner connection with others (Hyndman, Athanasopoulos, 2018). **Cubic spine** is an example. It is a special spine interpolation, frequently used to avoid Runge's phenomenon (oscillation at the edges of the interval due to polynomial interpolation). The provided forecast is suitable for not highly oscillating behaviour (Appadu et al, 2021).

Exponential smoothing is a method with long history (proposed in the 1950's). The method is using weighted average from the historical data, with the weight getting smaller by the growing time distance in the past. The most recent historical data gets the highest weights.

It has multiple interpretation, the simplest is called **simple exponential smoothing**. The targeted dataset for this method is not containing seasonality or trends. In the calculation the weights decrease in an exponential curve. **Holt's linear trend method** is extending the scope of exponential smoothing by possibility to handle trends. To generate the forecast two equation is considered, one for normal and one for trend. As the display trend here is only increase or decrease it tends to over forecast. To avoid this a new parameter is introduced to "dampen" the trend to a flatline in the longer future. It is called the **dampen trend method**. Beside the trends seasonality can also be handled in an extended scope in **Holt-Winters' seasonal method.** This method contains a forecast equation and three smoothing equations, one for the level, one for the trend and one for the smoothing component (Hyndman, Athanasopoulos, 2018).

Due to the wide range of available IT solutions, several software-based forecasting tools can be defined. These are capable of analysis of the data. During this analysis they can check a range of methods to find the closest. These tools are for example ADD*ONE or SAP APO.

The forecast is a complex statistical number considering historical inputs, trends, and seasonality. Still, it is just showing an expectation. To ensure operational efficiency the continues measurement of the quality of the expectations is necessary.

3.5. Single measures for all echelons of the supply chain

This chapter shows single measures that are typically applied in supply chains in multiple levels. To ensure chain level goals common metrics need to be identified. These measures can be personalized according to the circumstances, but calculation and basis need to be the same to be comparable. There are several performance measurement tools, frameworks, systems applied in the different industries. The metrics integrated in them are customised for the user company or the chain. Still there are some metrics that are typically used in practice. These measures are integrated in the key performance indicator system at several industries and applicable at all levels of the supply chain. These metrics are the followings: forecast accuracy, forecast bias, and service level. Below sub-chapters present a possible way of calculation and the subject of measure.

The common in the below metrics are that all of them can be applied in all levels of the supply chain. The scope of the measure can always cover two viewpoints. First is comparison with the connected parties, second is comparison to the final customer. The other common point is the scope of measurement. All three measures consider the forecasting as basis, calculation is built on the demand value.

For the calculation below abbreviations can be used:

S actual sales quantity

D_c customer demand

D_{-1} demand of the previous echelon

F forecasted quantity

F_x fixed forecasted quantity (x month ago)

Forecast Accuracy (FCA)

The forecast accuracy aims to analyse the deviation between the actual- and the forecasted demand. This comparison gives information on the quality of the forecasting. The targeted value of the metric can differ based on industry or segment. It can be influenced by frequently changing products and market requirements (e.g., fashion) or economical changes (e.g., COVID-19). The calculation can be initiated in multiple different way. It can be absolute value of the difference, but it can also be calculated as percentage (Moller et al.,2021).

Various measures are in use to evaluate the forecast quality. Difference is mainly on penalization of the errors. However, the negative and positive deviations of the same magnitude assumed to result in the same loss, penalized symmetrically. The most widely used methods are MFE (mean forecast error), MAPE (mean absolute percentage error) and RMSE (root mean squared error) (Moller et al., 2021).

In several cases due to the length of the supply chain comparison of the current forecast and the sold quantity do not give sufficient information. Lead time can be two months or even longer (e.g., sales in Europe with production in Malaysia or China). In this case the earlier forecast can be considered as the signal for the production. From supply chain and production perspective the length of the chain needs to be considered also in the measures. It is more informative regarding the performance of the chain and/or echelon. In this case forecast accuracy measure is based on a two months ago fixed quantity. Calculation of the forecast accuracy is as follow. The customer demand is compared to a fixed forecast (fixed period depending on the supply chain characteristics), it is shown in equation (1):

$$FCA = D_c/F_x \quad (1)$$

As the calculation of the forecast accuracy is based on the forecasted quantities and the demand the value is changing once the bullwhip effect is present. Phenomenon is firstly visible in the demand fluctuation. In case of significant peak or drop of order the measure will be moved out of the targeted interval. If everything is sold according to the plans BWE should not occur. Once the value of the FCA is out of the tolerated interval it means significant drop or peak that is a signal of the bullwhip effect.

Forecast Bias (FB)

Beside the forecast accuracy it is also important to see how big the difference from the plan might be. Bias shows the trends if forecasting is above or below the actual sales. It shows if the given product is over or under forecasted (Wan, Sanders, 2017).

Forecast bias and forecast error need to be separated. Forecast error is "*the deviation of the customer forecast from the final order*". Forecast bias means "*structural or strategical deviation*". In case of positive bias, the customer due to systematic or strategical reason inflate their demand forecast, which is the result of the rationing gaming (Seitz et al., 2020). Thereby analyzation of the bullwhip effect results can be highly supported with the bias results.

This KPI worth to be tracked monthly, so it can show the trends of sales of the selected product. It can also point out monthly peaks and support reaction. Using forecast bias the product portfolio can be split considering the tendencies of the market. Revision of planning can be executed to improve quality. Higher product variety leads to increase in complexity. Due to this quality of the forecast cannot be kept on the highest level. To support the estimation process forecast bias showing the tendencies can be used (Wan, Sanders, 2017).

Bias can be connected to operational performance and bullwhip effect elimination due to tracking result. Tracking of tendencies can increase quality of the forecast and it can also support in the identification of the gaming behaviour (Seitz et al., 2020).

Calculation of forecast bias (Eq. (2)) is a comparison of the actual volumes and the plans. The result can be both positive and negative. If the bias is positive the product is over forecasted, if it is negative, it is under-forecasted.

$$FB=(D_c-F)/F \quad (2)$$

From process improvement perspective usage of the latest forecast is not enough in several cases due to the length of the supply chain. Lead time need to be taken into consideration in case of long supply chains and supply networks. This can be supported by fixed period for forecast. It can be for example two months: which can cover delivery time and reaction both on supplier and manufacturing level. In this case fixed forecast needs to be used in the equation (Eq. (3)).

$$FB=(D_c-F_x)/F_x \quad (3)$$

Bias calculation is also based on demand and forecast. It has a targeted interval that is showing and acceptable level of difference. As result of bias calculation shows the direction of the deviation, it gives further information on the bullwhip effect. As direction of bias can be visible, actions for first step can be calculated and used within the supply chain.

Service level (SL)

Importance of service level is justified by fierce competition of the market. Multiple replacement products are competing for the market share. Service level shows the availability that is crucial to reach the customers. Service level also has influence on demand, as products with higher service level typically have higher demand (Buhniya et al., 2021). Through this forecast is impacted.

Service level shows the percentage of fulfilled orders compared to requested quantity. It can be introduced in all levels of the supply chain (Eq. (5)). Differentiation in calculation can also be introduced based on product classification or any predetermined criteria (Sereshti et al., 2021).

At the customer end of the chain, it gives advice also on customer satisfaction (Eq. (4)). Nonetheless it still can be informative also between other members of the chain. It can point out where the problem has happened that resulted in poor performance. It can also potentially highlight gaps in forecasting procedure. As this metric compares requested and supplied quantity only actual data can be used.

$$\text{CSL (customer service level)} = 1-((D_c-S)/D_c) \quad (4)$$

$$SL = 1-((D_{-1}-S)/D_{-1}) \quad (5)$$

The service level in practical use is attached with a target. The targeted service level can differ on industry level. It is typically the highest in food industry due to short shelf life of products. Once the value is out of the target it needs to be check what is behind. As the calculation is showing peak demands which can lead to bullwhip effect, it can be immediate filtering option to react on the occurrence.

Combination of the KPI

In practice mentioned KPI are commonly used together. This combined usage can highlight additional information. Using only forecast accuracy, this measure does not give any information if the product is over or under forecasted. This information is given by the forecast bias.

Service level is mainly important due to customer focus approach. It is worth to check CSL and SL between other members. Checking SL and FCA together can be explanatory. Sufficient service level should be pairwise with proper forecast accuracy and positive or close to zero bias. There can be some exceptional cases (like sales of dead stock) but normally values of the mentioned KPI together should answer product accessibility related questions.

Both mentioned KPI aim to reach better forecast. It is crucial to have proper inventory control. Lack of accurate planning results lower effectiveness and quality (Moller et al, 2021)

Supporting a better demand planning can impact the bullwhip effect. As demand management is one of the core reasons behind the phenomenon, improvement of the field is essential. As all the mentioned KPI are calculated based on forecast, demand, and real sales value so they can show the bullwhip effect. Using them in a targeted way to indicate the phenomenon can increase the flexibility and decrease the level of negative impacts.

FCA, FCB and SL are not only connected to each other but also reflect other areas such as inventory. Over or under forecasted products cannot be considered as optimal regarding the kept stock which can also be a possible impact of the presence of the bullwhip effect. There are still questions to be answered such as: Can any of the mention KPI be used to predict bullwhip effect? Can any of the KPI show the presence of the bullwhip effect?

Detecting the bullwhip effect with indicators in use

As tracking of the bullwhip effect is essential (Fu et al. 2015) it is important to integrate the measures in the set of key performance indicators (KPI) in use. There are several metrics that are applied to keep daily operation under control and to support mid- and long-term improvements (Behzadi et al. 2020). KPI used in the supply chain can be analysed during the investigation of the bullwhip effect. The value of the KPI is impacted by the presence of the phenomenon. Measures can initiate preliminary, on the spot and subsequent analysis. From this perspective metrics can be categorized in three different groups (Strommer, Földesi, 2022):

- Indicator

  These KPI are potentially showing in advance or in early phase the occurrence of the bullwhip effect. Target is immediate action to reduce probability of the occurrence among as many members of the supply chain as possible.

- Mitigative

  These measures can be used to eliminate or at least decrease the impact of the BWE. Those are reflecting the occurred phenomenon. Using these metrics degree of oscillation can be reduced.

- Analytic

  These KPI are supporting deeper understanding of the phenomenon's background. Mostly used for further investigation once the problematic period is over. It can also be the basis of process improvement actions.

Indicator KPI

These KPI are potentially showing in advance or in early phase the occurrence of the bullwhip effect. The main goal is to use them to avoid the phenomenon or the most critical consequences. Monitoring these measures can support immediate actions toward the solution of a specific problem (Strommer, Földesi, 2022).

Forecast bias and forecast accuracy can possibly be used for this purpose. In the calculation of these KPI current demand situation is compared to historical forecast meaning. Expectations and realization are compared. The exact timing of the frozen period is adaptable based on the supply chain and industry characteristics (number of echelons, geographical distances, etc.). The indication due to this can be realized on time. When bullwhip effect is present forecasted numbers are not covering real demand. These two KPI are indicating deviation from the forecast. If the bullwhip effect is present forecast accuracy decrease and absolute value of bias will be higher (Strommer, Földesi, 2022).

Change of bias and accuracy can be caused by other factors as well. These can be for example IT issue, when the system is not showing realistic numbers or handling of returned goods. These cases can result in bias or accuracy change, but the root cause can be identified, and the issue can be solved shortly (Strommer, Földesi, 2022).

These metrics are widely used due to adaptability and scope. Based on the length of the chain measures such as lead time, number of echelons etc. can be customized. Meanwhile the essential of KPI remain the same. Planned and actual quantities are compared to each other showing if the customer demand has any unachievable fluctuation considering flexibility of the chain (Strommer, Földesi, 2022).

Using forecast accuracy and forecast bias small deviations are noticeable giving a chance to check whether it is caused by something known or something unpredictable. It is also possible to take steps in advance if the bullwhip effect is predicted based on investigation. These steps can reduce potential losses. It can shorten the range of the bullwhip effect, the number of effected echelons (Strommer, Földesi, 2022).

In addition to indicative purpose forecast accuracy and bias can be used for analytic purpose regarding the bullwhip effect too. It can give information on the quality of used forecasting methodology having significant impact on the bullwhip effect (Strommer, Földesi, 2022).

Mitigative KPI

In this case the goal is to eliminate the impact of the existing bullwhip effect. The widely used measure that can be applied for this is the service level. The metric reflects the existing situation. Low service level value can indicate the bullwhip effect as stock level was not sufficient to cover incoming orders. The measure cannot be applied for indication due to the scope, but it can be used to reduce the negative impact. Service level is applicable when the demand is higher than the available quantity (Strommer, Földesi, 2022).

Realization of the presence of the bullwhip effect is important to reduce the impact. It enables proactive approach instead of reactive. Due to this, potential financial losses can be prevented and degree of oscillation of the bullwhip effect can be decreased. Action can drive to positive result both on echelon level and on chain level (Strommer, Földesi, 2022).

On echelon level for example, substitute products, delay of promotional activity or compensative discount can be offered to cover the sales gap generated. These activities will not terminate the bullwhip effect, the sales results will be impacted less severe (Strommer, Földesi, 2022).

It can also support the chain level action. As the extraordinary order can be handled in place, the further parts of the chain do not need to be impacted. Exceptional information on the market situation can change manufacturing plans or orders sent to the supplier. All of these are small steps, but at the end significant financial impact can be prevented. It can also support non-financial areas (Strommer, Földesi, 2022).

The mentioned example is showing a case with information flow from customer toward production. It can also work inversely. For example, focusing on fulfilment rate information on change of production due to missing part can be communicated. That enables distribution and retail level to develop solution to decrease the impact (Strommer, Földesi, 2022).

Service level is highly monitored in most of the supply chains due to the importance of customer focus approach. It is easy to extend the current way of using it with some additional check points. As the KPI is present the task is to incorporate the usage into mitigation of the bullwhip effect. This metric is calculated by all echelons of the supply chain (Strommer, Földesi, 2022).

Service level is mainly useful for outstanding orders. If the order can be served from available stock this KPI does not show any difference. Nonetheless this still can be problematic. For sales that is significantly under expectations forecast bias or accuracy can be used. It can be also pointed out using inventory management metrics (Strommer, Földesi, 2022).

Analytic KPI

Analytic metrics help to determine the impact of the occurred bullwhip effect. For analytic purpose it worth to check first the mentioned three KPI as they can show trends and tendencies. If reoccurring fluctuation of accuracy or bias is typical, seasonality that is not considered in the plans might occur. It also needs to be considered if SL, FCA or bias value are low on long term for a given product or product group. This also show inappropriate forecast. To introduce corrective measures highlighted metrics can support to select products, product groups or time periods (Strommer, Földesi, 2022).

Beside the measures showing the presence of the bullwhip effect, there are ones showing the consequences. They can be used once it has been determined which product or area is impacted. These are KPI showing the consequences. These measures cannot be used for indication or immediate action. The focus is rather on echelon level than on chain level. Metrics are showing cost and non-cost related impacts not focusing on cooperation of the supply chain members (Strommer, Földesi, 2022).

Fluctuation of these KPI can be caused by several other reasons beside the bullwhip effect. KPI which can be used to justify whether bullwhip effect has happened are potentially used to precondition process improvement activities (Strommer, Földesi, 2022).

In this category pattern KPI potentially impacting bullwhip effect are listed. These are also important because cost in the supply chain is increased by them as well. Supply chain and industry specific factors can be considered during the selection of the measures which support focus to be placed on critical areas. Below some potentially impacted KPI are listed as examples (Strommer, Földesi, 2022).

- level of inventory and inventory turnover
- capacity utilization
- development of the safety stock
- lead time and delivery time of goods
- warehousing and transportation costs

Listed measures are supply chain related impacts. Nonetheless, beside the immediate reflection on measures' effect is more complex. It has financial consequences both immediately and on long term due to the need for time and cost to return to the standard status.

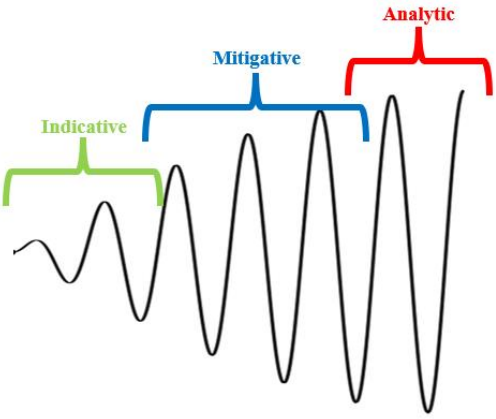
Time aspect

Time is a crucial aspect regarding the bullwhip effect. As time passes impact of the phenomenon is getting higher due to increasing degree of oscillation. Based on time passed bullwhip effect can be split into three phases: early phase, intense phase, recovery phase (Strommer, Földesi, 2022).

In the early phase the first signals of the occurrence are present. The intense phase is already noticeable at multiple levels of the supply chain. The recovery period starts once the phenomenon has already decayed; the consequences are appearing. By this time the impact has reached all levels of the supply chain (Strommer, Földesi, 2022).

Figure 4. is showing in timely manner the application of mentioned KPI and grouping. In the figure demand is presented as flow through supply chain from customer to manufacturer and supplier level. Moving from left to right indicates time passed and progress within the chain. In early phase the signal is only present at customer-retailer level of the supply chain. Forecast accuracy and bias can be used with indicative purposes. At the intense phase the phenomenon is already reached more actors of the chain and it is present in service level metrics. Here service level can be used together with accuracy and bias to indicate impacted products. The analytic purposes are in scope at the latest stage. By this point most of the chain members are already impacted, recovery has started (Strommer, Földesi, 2022).

Figure 4: Time aspect of the KPI



Source: Author's edition

Integrating targeted analysis of the bullwhip effect can increase the supply chain performance. As used KPI already are applied no extra resource or process change is needed to be added. Only perspective and approach change are required. Measures are already known and used; the task is to show the different method of use (Strommer, Földesi, 2022).

Identification of the presence of the bullwhip effect can show the relevant reasons of phenomenon that are impacting a given chain. This supports targeted process improvement actions and on long term mitigation of occurrence. The most affected products can also be determined (Strommer, Földesi, 2022).

In a continuously changing environment this subsequent analysis enables the process to be investigated from a different perspective. Additional information can possibly be explored. Combination of preliminary, on the spot and subsequent analysis give chance to evaluate the process considering all perspectives. The analysis can be specified based on the characteristics of the given chain member and considering the main attributes of the chain (Strommer, Földesi, 2022).

Conclusion reached by indicator and mitigative KPI should also be integrated to subsequent analysis. It is supplemented by potential listed measures to see all the aspects. Investigation of the whole scope gives chance initiating process improvement actions that are targeting the reduction of the impacts caused by the bullwhip effect (Strommer, Földesi, 2022).

3.6.Tools of Failure Mode and Effect Analysis (FMEA)

The definition of the FMEA has been phrased in Chapter 1.1. This part aims to go in details regarding the relation of FMEA and BWE and applied tools. The goal of application is minimizing probability of the effect of the failure. In each case estimation is made based on occurrence, severity, and detection. Application can be both qualitative, and quantitative. According to Stamatis (2014) a good FMEA consists of:

- identifying potential failures
- identifying causes and effects of it
- prioritizing the identified failures (based on occurrence, severity, and detection)
- providing follow up and corrective action

The basis is the customer as prioritization and definition of critical factors are based on customer requirements. Improving processes and quality, avoiding problems are with the aim of maximizing customer satisfaction (Stamatis, 2003).

To reach the goal of FMEA and avoid failure customer assumptions need to be done. This assumption needs to show that problems have different priority. This priority is based on occurrence (O), severity (S), and detection (D). Occurrence shows frequency or probability of the failure. Severity shows the effect or seriousness of the problem. Detection shows if failure can be detected before it reaches the customer (Stamatis, 2003).

Types of FMEA

There are four types of FMEA: System, Design, Process, and Service. These can be described as followings:

- System FMEA is used to analyse systems in early or design stage by concentrating on potential failures between functions of the system caused by the system. It helps in the selection of the optimal system.
- Design FMEA means analysing products before production has taken place. Focus is on potential failures due to design problems and as a result, critical and significant characteristics can be detailed. List of parameters can be defined which are basis of proper testing and inspection.

- Process FMEA analyse manufacturing and assembly processes. Focus is on failures caused by processes, and it results in a list of critical and/or significant characteristics, recommended actions to address these.
- Service FMEA analyses the service before it reaches the customer. It focuses on system or process deficits related failures and critical tasks; bottlenecks can be defined. It eliminates error and monitors the system.

FMEA and the bullwhip effect

Common research of FMEA and the bullwhip effect is not typical. In ScienceDirect there are twelve articles as result of *"bullwhip effect" AND "FMEA"* research. Out of these, seven articles includes both of them. The focus of these articles is mainly risk assessment and quality management. FMEA is spotlighted in multiple articles as risk assessment method (Wan et al., 2019; Venkatesh et at., 2015; Rostamzadeh, 2018; Giannakis & Papadopoulos, 2016) or as a supportive tool in analysing phase (Giannakis &Luis, 2011; Hosseini & Ivanov, 2020; Lyu et al., 2009). Bullwhip effect is present in these articles as a supply chain risk (Wan et al., 2019; Venkatesh et at., 2015; Rostamzadeh, 2018; Giannakis & Papadopoulos, 2016; Hosseini & Ivanov, 2020) or as potential improvement area that is developed due to the FMEA approach's results (Giannakis &Luis, 2011; Lyu et al., 2009) Bullwhip effect is mainly connected to FMEA approach in literature as potential risk. Beside the role of forecasting risk, bullwhip effect is also considered as so called 'chaos risk' that is impacting quality processes. It covers over- and unnecessary reactions and consequences of them (Faisal, 2006).

The main advantage of introducing FMEA logic and concept to measurement of BWE in practice is the different viewpoint and the developed technical background. To apply these tools, cross functional cooperation is needed but the steps to take and tools to use are already in hand. To have connection in scientific area is also important, as it gives higher availability of information to potential users.

Application of FMEA tools - Fault Tree Analysis (FTA)

Fault Tree Analysis is a relatively old method first used by Bell Telephone Laboratories. Since then, it has been improved and adopted, and nowadays it is one of the most widely used tool for reliability and safety studies. In this approach, the undesired event is described, and analysed to find all combination of basic events that has led there. Basic events are the basic causes, which can mean several different things from human error to environmental condition (Xing, Amari, 2008). The logical connections are visualized in a graphical representation. It is a logical framework that show how the system fails. This support us understanding how the operation can be successful (Xing, Amari, 2008).

FTA can be used to visualise reasons and sub reasons of the bullwhip effect. Figure 5 shows the theoretic version of it. It visualizes reasons which are in the literature part of the thesis also collected in Chapter 1.2.1. Making this visualisation not only helps the understanding of the phenomenon, but also supports finding the most relevant reason groups. Once it is defined it is easier to place the focus on the required field. Visualization can be used to pass the information regarding the problem without going into details (Strommer et al. 2022b).

This structure can be further specified by real life examples, which is visible on Figure 6. The lowest level of the tree is filled up with authentic reasons. These examples have been collected in informal interviews with supply chain professionals about their experience on the bullwhip effect. "*Applied forecasting method not working*" refers to the tool generating the forecast based on the trends. Maybe some setup of the algorithm is not correct, accuracy under the targeted percentage (value depends on industry, product or even county level). These are driving low-quality forecast which is going through the supply chain. Planning mistakes and misunderstanding of trends lead to the same consequences. These are examples that can drive the bullwhip effect from demand perspective. Personal decision can also appear in system modification without real background data, leading to buffers on products resulting in unnecessary production and increased level of inventory (Strommer et al. 2022b).

Human factor is filled by potential errors of the subjective decisions made by the person. It can be influenced by information. Decision on level of information needs to be shared is not always clear. This can lead to distorted or limited level of shared information. Fear of shortage, low level of trust and subjective decision lead to stocking up on given products (Strommer et al. 2022b).

For rationing game, the example is also split to two categories. Supply chains with 100+ echelons (warehouses, plants, headquarters, sales locations, training centres, testing stations, etc.) are extensive. Smooth and complete information flow is impossible at this level. Complexity can also come from geographical extent. Example on Figure 6. is present in several companies' operation. Missing control can be the result of incomplete information flow. It can be caused by wrong processes or by the mentioned distances. Localized targets without harmonization also decrease the chain level control and transparency (Strommer et al. 2022b).

Figure 5.: FTA of the bullwhip effect reasons

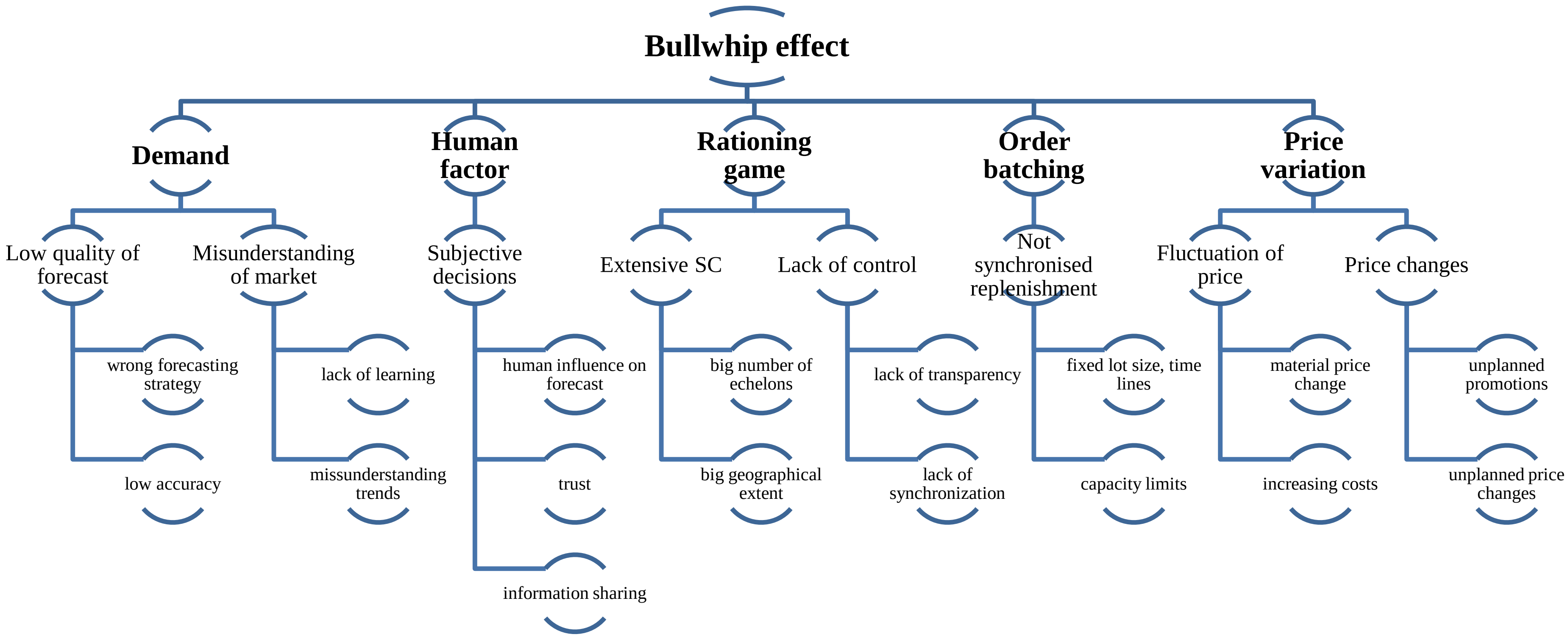
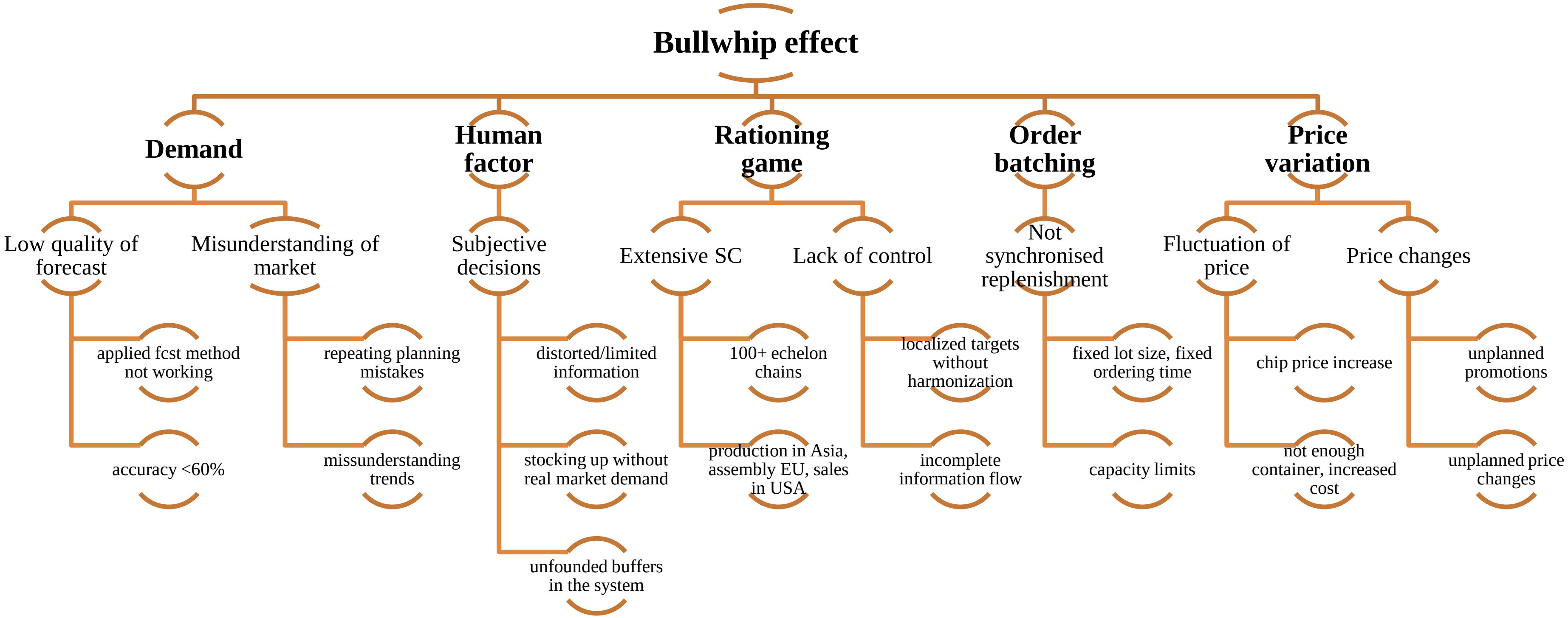


Figure 6.: FTA of the BWE reasons example



Order batching shows difficulties of replenishment. Fixed lot sizes and ordering timelines are against flexibility. Long distances lead to higher lot sizes due to economical quantity perspective. These lot sizes can differ on manufacturing location level and on distributor level. It leads to disharmony in the chain level processes and decreases flexibility (Strommer et al. 2022b).

Price variation reasons are also presented in Figure 6. For example, current situation with the chip price influences the product of finished goods, or the delivery problems from Asia due to increased demand and increased prices. Price related issues can also hinge on companies. Price increase or promotion without planning can impact demand significantly (Strommer et al. 2022b).

Figure 6. shows that corporeal examples can be placed into the chart replacing theoretical reasons. Considering one case this technic can highlight the main drivers or most relevant reasons of BWE. It can be used as a visual executive summary and support cross functional cooperation. The visual interpretation gives broader understanding of the whole are (Strommer et al. 2022b).

Application of FMEA tools - Ishikawa

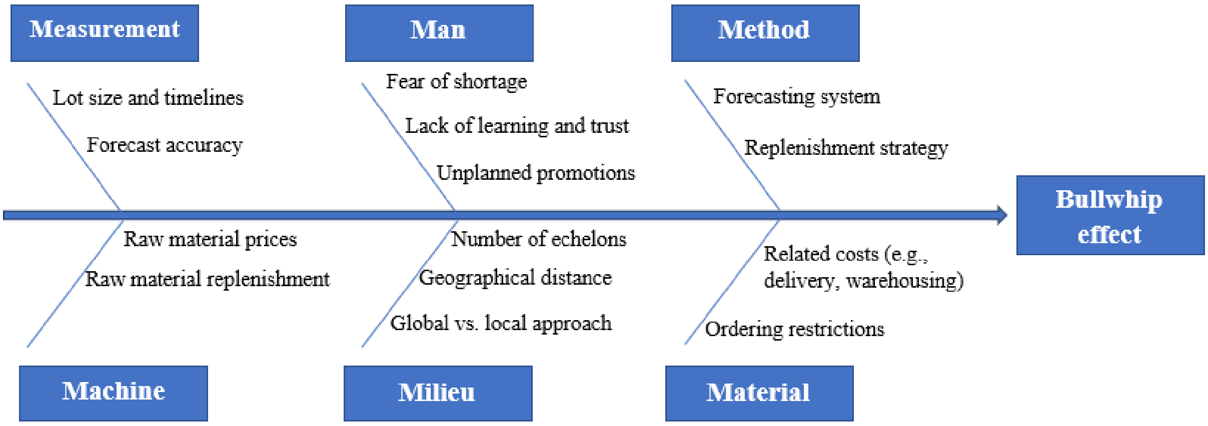
Ishikawa diagram is tied to Kaoru Ishikawa. Key elements considered by him were the followings: costumer demand need to be defined first, instead of the symptoms causes need to be handled, quality management is a responsibility for all divisions, and it needs to be priority for them, quality begins and ends with learning and most (95%) of the problems in the organization is resolvable by simple tools (Stefanovic et al. 2014). These are showing that aims and purposes of FMEA are all integrated in the Ishikawa approach as well.

Ishikawa diagram is also known as cause-and-effect or fishbone (because of the shape) diagram. It is a diagram-based approach supporting thinking through possible causes of a problem. The main steps are as followed: identification of the problem, identification of the major factors involved, description of possible causes, analysation of the diagram. There are typical categories used for grouping problems: people (man), methods, machines, materials, measurement, environment (milieu) (Liliana, 2016). The listed categories are also known as the 6M of production, aiming to support the waste reduction and process simplification (Yahya, 2021).

The 6M approach is typically used with Ishikawa, in my dissertation I am also using this approach to categorise issues during visualisation. The Ishikawa diagram beside summarisation and visualisation, also breaking down main issues to manageable elements. This method can also be used for visualising the bullwhip effect. As the diagram has its' own grouping methodology, it leads to a new perspective for categorizing reasons. Figure 7. shows the Ishikawa of the bullwhip effect reasons using 6M categorisation.

Measurement group represents measurable issues, and the points connected to measurement failures. In the example of bullwhip effect these are the strict given timelines, lot sizes and accuracy of the forecast. Category Man shows reasons that are connected to human behaviour and decisions. Fear of shortages, lack of learning and trust, and unplanned promotions (or any unplanned events) can be listed here. Method contains system related problems. Forecasting and replenishment strategy can differ within the chain that complicates cooperation. Forecasting system can also work incorrectly (Strommer et al. 2022b).

Figure 7.: Ishikawa – bullwhip effect reasons



Source: Author's edition

Machine stands for mainly the manufacturing background. Raw material prices and replenishment policy applied can impact operation of the chain downstream. Milieu means the environment, characteristics of the chain itself. Increased number of echelons and big geographical distances can have negative impact on transparent operation and control of the chain. The bigger the distance the higher the chance for localized approaches, which misses to connect with global goals. Material category means raw material and connected issues. Limited availability of products, increase of material prices, or any related costs lead to fluctuation of the price which can start demand fluctuation (Strommer et al. 2022b).

The application of the Ishikawa for mentioned purpose has already been presented in a case study. It also presents causes of the bullwhip effect in Lexmark (Disney et al., 2013). Practical application has also been initiated by the author. Examples are present in Chapter 4.3 regarding each case studies (Strommer et al. 2022b).

Further FMEA tools

This sub-chapter shows three further method that is frequently used in FMEA process: Pareto chart, risk matrix and pairwise comparison.

Pareto chart

Pareto chart allows user to focus on the most important factors. Using weighted list of issues, the chart shows the ones that are resulting in the greatest cumulative effect. The principle itself is based on the 80-20 rule. It means that in most of the cases the 80% of the problems are due to 20 percent of the causes. Beside the manufacturing nowadays the method is used for several different purposes (e.g., sociology, marketing). The tool is supporting both efficiency and effectiveness (Solanki et al., 2021).

Pareto chart aims to support prioritization of the risks. To generate the Pareto chart Risk Priority Numbers (RPN) need to be defined. This measure is a multiplication of three components: probability of the occurrence (O), weight or severity of the error (S) and difficulty of detection or resolution (D) (Can, Erbiyik, 2016). Beside the prioritisation, the tool also supports to visually summarize the problems by indirectly driving the focus of observers on most critical areas.

Risk matrix

It is a matrix formed during risk assessment. There are two axes of this matrix. These two sides are mostly probability of occurrence and severity of consequences. The matrix shows which risks are the most critical (Abul-Haggag, Barakat, 2013). These elements are also used for RPN which is the basis of the Pareto chart.

The risk matrix is usually colour coded. Red, amber, and green colours are used to visually differentiate the risks presented, red is marking the not acceptable and green is marking the acceptable (Gray et al., 2019).

Pairwise comparison

Pairwise comparison is a method used to compare a group of elements (such as decision, product, or factors). Judgement is happening individually, and comparison always opposes two elements. As a result, those can be weighted, based on the importance quantifiable measures can be set to show the emphasis (Silverstein, 2001). It is a ranking method and gives more information than direct ranking of all alternatives. Pairwise comparison handles the disadvantage of the Likert-type scale. It uses forced choice method and with this response style bias can be reduced. However, the method does not allow similar preference of two or more elements (Sung, Wu, 2018).

Beside the mentioned advantage of the method disadvantages can also be listed. Limited number of elements can only be handled by pairwise comparison. Increasing number of paired elements would result in extremely long (10 examined element would mean 45 pairs) and time-consuming work for the participants (Sung, Wu, 2018; Iijima et al. 2020).

4. USE CASES

This chapter is collecting use cases regarding the bullwhip effect phenomenon. Analysis of it is important but necessity needs to be determined. To support this, non-sensitive cases are resolved. Special circumstances of the past years impacted the operation of the supply chains. It is also examined how the COVID-19 impacts relate to the bullwhip effect phenomenon. This chapter also contains two case studies experienced by the author that are showing the presence of the bullwhip effect. One of them is from the food industry while the other is from the machine manufacturing industry. Besides own experience examples from literature are also presented.

4.1. Non-sensitive cases regarding bullwhip effect

Importance of the bullwhip effect phenomenon is indisputable in a typical supply chain. Considering what makes a supply chain sensitive for bullwhip effect is still merit. Sensitivity is depending on the setup of the supply chain. Characteristics that are supporting the bullwhip-friendly environment need to be selected. This supports to make decision whether examination is relevant or not.

Supply chains that are likely to experience bullwhip effect can be categorized as sensitive. Based on the main reasons of the bullwhip effect these chains are characterised by big number of echelons; long geographical distances; push strategy approach; mass production with high probability for substitution.

To determine the cases that are not sensitive for the bullwhip effect connection between the causes of the phenomenon and the operational supply chain characteristics needs to be found. This enables defining non-sensitive chains. This chapter shows the relevant supply chain characteristics. From bullwhip effect perspective length of supply chain, time requirement of operation and applied strategy are crucial.

Supply chain characteristics

Description of the supply chain can be executed from several perspectives. It can consider for example location or industry. From a different view point it can examine length of the supply chain (and the number of echelons) and the applied strategies. From bullwhip effect perspective, it is vital to work with time and strategy perspective.

Supply chains became through the years complex and complicated networks with heterogenous cooperation models and operational characteristics. Connections are located all around the globe in different regions and industries. Complex generated networks are competing under these complex circumstances (Sun et al, 2020). This setup is caused by fierce competition of the market. Need of outsourcing of processes and adaptation of strategies are present and consequence of this complex network and continuous adaptation to the market is a greater risk of supply chain disruption (Chang, Lin, 2019).

This complexity has an impact on the lead time. Supply networks are typically multiple echelons supply chains facing longer delivery time and greater uncertainty due to complex outsourced processes. Longer lead time also impacts inventory level in the chain and leads to increased stock levels to cover potential forecast error. Beside lead time, from vertical or horizontal cooperation, it more likely leads to disruptions (Chang, Lin, 2019)

Increased level of lead time also makes harder to respond to disruption. Due to distance in the chain real-time announcement of disruption event cannot reach supplier on time. This is due to the time needed for physical fulfilment of the changed demand. In the end, due to delayed reaction of the supplier impact on customers can hardly be eliminated. In contrast shorter supply chains are shorter in replenishment time and more flexible in demand change. Early awareness can support more agile way approach (Chang, Lin, 2019).

Lead time reduction plays an important role in reducing the probability of the bullwhip effect and scales down operational costs. The impact is the highest on manufacturing and remanufacturing level (Lin et al., 2021).

Beside lead time and length of the supply chain applied strategy is also important. Supply chains typically operate with push or pull strategies. Mostly these systems are not present on their own but in a mixed way. Still there is a lead concept applied in the supply chains. Main difference is visible regarding the approach of serving the customer. Push system uses inventory to satisfy customer demand. In contrast pull system uses production to satisfy demand. Push system is characterized by high-capacity utilization but leads to higher inventory. Pull system requires more flexibility in demand processes and manufacturing and may lead to long delivery lead time (Liu et al., 2020).

Non sensitive cases

Today’s supply chains are typically containing numerous echelons, scope of the chains is not limited by geographical borders. There are also intertwining of chains, common and conflicting interests need to be handled in huge networks. For the bullwhip effect mentioned characteristics are ideal to make the phenomenon happen. Complexity in the supply chain and unpredictable circumstances can result in decreasing transparency and control. It also leads to less harmonized processes and strategies.

Despite complex, globalized supply chains and network there are still different approaches. In these extents bullwhip effect may not occur, or it does not lead to any problem. Below characteristics of the supply chain that are immune to the phenomenon are collected based on the main reasons of the bullwhip effect (defined in Chapter 1.2.1.). In Table 7 bullwhip effect reasons are presented with cases where these characteristics are less likely to appear.

Table 7.: Bullwhip effect reasons and non-sensitive cases

BWE reason group	BWE reasons	Non-sensitive cases
Demand signal processing	inaccurate forecast	Pull supply chain
	forecasting strategy	
	handling of stock out	
	misunderstanding of market information	
	lack of learning	
Rationing game	number of echelons	Short supply chain: • number of echelons
	lack of transparency	
	lack of control and synchronization	
	local approach	
	fear of shortage	
Order batching	lot size of the order	Short supply chain: • geographical distance
	replenishment policy	
	capacity limitations	
	ordering timelines	
Price variation	fluctuation of material prices	Product type, local sources
	fluctuation of finished goods prices	
	changes in other related costs	
	planned and not planned promotions	

Source: Strommer, 2021

Unpredictable market can be controlled better in case of pull strategy supply chains. Dependency on customer demand fluctuation is smaller and, in these cases, there is less focus on forecasting. Monitoring of market trends and customer needs are also important here. Nonetheless, potential loss generated by forecasting mistakes is smaller.

The length of the supply chain is one of the influencing factors. Long supply chains are more complex, there are multiple echelons involved and mostly multiple countries leading to difficulty in achieving transparency and high level of overall control and is more difficult to avoid local approaches. In contrast, short supply chains are more controllable. Shortness can mean number of echelons or geographical distance. In both cases complexity is reduced, and cooperation has less difficulty. It also decreases the fear of shortages as transparency and control makes degree of predictability higher. In these cases, it is much easier to avoid the reasons mentioned under rationing game. Smaller geographical distance can also support in harmonization of processes. Policies, used measures, timelines and other mechanisms applied on echelon level can be harmonized much easier. Considering reasons under order batching groups shorter supply chains can make the occurrence of listed reasons less likely.

Price related reasons are more difficult to avoid. Still shorter size of the chain and geographical distance can have positive influence on operation. From promotional perspective planning with limited number of echelons is much easier and predictable. In addition, usage of local material sources can also be supported. Price changes can still happen, but availability is more plannable, so related costs are less problematic. Type of the product can also impact degree of sensitivity. Special, made to order products are less sensitive for the phenomenon.

Table 7 has collected in which cases supply chains can appear non-sensitive for the bullwhip effect. Length of the supply chain is impacting the phenomenon. With increasing number of echelons joining a network becomes less controllable and transparent. Shortening of geographical distance also supports manageability. Products are accessible easier, and changes can be pushed through faster. The shortest, from maker to customer chains are limited from both mentioned perspectives. Due to the length bullwhip effect has no room to develop and increase degree of oscillation.

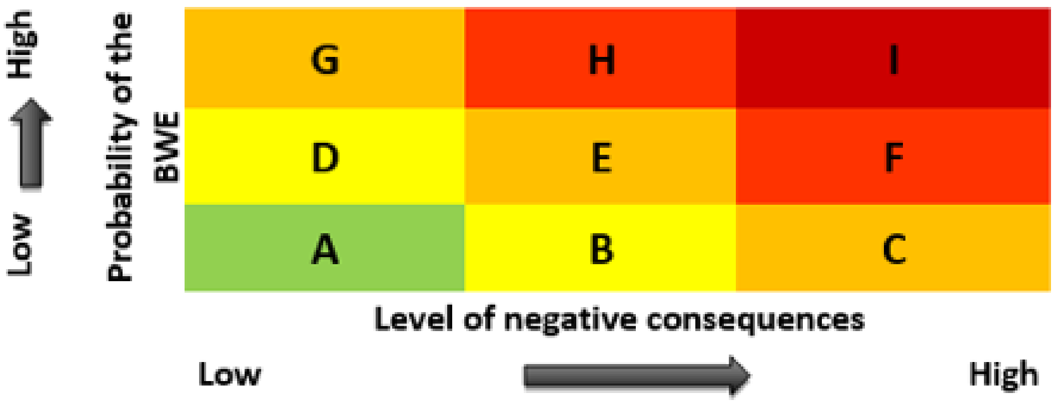
Pull supply chains are representing a different way of working. This model is less sensitive for the bullwhip effect as presence on the market is different than push chains. Customer's importance is not smaller in these cases, but the role in the business process is different. Due to this even if trends need to be monitored importance of day-to-day forecasting is smaller.

There are also some special products that are not surrounded by the phenomenon. These are for example limited edition items with given number of produced quantities. We can list here also make-to-order crafts items that are unique. Figure 8. shows a risk matrix presenting probability of the bullwhip effect and expected level of negative consequences.

Consequence can be understood as cost. If the bullwhip effect occurs it leads to performance decrease, that has a cost related side. This is included in the matrix with three levels of intensity (low, medium, high). The other axis is probability of the occurrence. This is based on the characteristics of the chain producing the product and specific features of the product.

Low probability typically goes with pull strategy and/or short supply chains with high possibility of control and transparency. High probability goes with push strategy make to stock products (mass production items). Differentiation on consequence axis is mainly based on the cost impact. Some additional specification factors can also be considered here e.g., industry. For example, food industry would mean smaller consequences relative to other industries on cost level. Nevertheless, if overstock is generated due to shorter shelf life it is less chance to figure out any solution.

Figure 8.: Risk matrix -bullwhip effect theory



Source: Author's edition

As example craftsman to user business can fit into cell A as both consequences and probability is low. Contrary (cell I) with high probability and high level of consequences global supply chains can be mentioned with push strategy sales and expensive product. Some of the electronic devices can be mentioned here. Beside seasonality changing technology and trends are also increasing unpredictability. Length of the chain has high influence on the bullwhip effect and the geographical extent due to the uncertainty generated by the complex and complicated network.

In between extremes all different supply chain setups shall be considered. For cell B pull strategy car manufacturing can be mentioned as example. Probability is low but potential consequences are still needed to be considered. For cell H high probability of occurrence and medium consequence external product packed with normally sold items as gift can be an example. Planning of these items are always a risk as it is not known how the market will accept them. Forecasting can go astray and can result in oscillation.

Establishment of any rule that can punctually define the grouping of the enterprises is hard. Several factors need to be checked at the same time as length of the chain, profile of the company, producing and sales strategies. In addition, exceptions can be determined based on unique characteristics. This matrix is just helping to understand level of influence bullwhip effect can make. Based on this a proper level of source can be allocated to tackle the issue on company level.

4.2. COVID-19 and the bullwhip effect

"COVID-19 is an infectious disease caused by a newly discovered coronavirus." (WHO, 2020) In December 2019 the first case has been identified in China. On 11th March 2020 the disease become declared as a pandemic by the World Health Organisation (WHO). The virus has disastrous impact on health and high fatality rates. Society and economy have also been heavily impacted all around the world (WHO, 2020). The impact of the pandemic is also global considering the supply chains. 94% of businesses experienced disturbances due to COVID-19. This includes the Fortune 1000 list (Fortune, 2020). The pandemic started from China, quickly impacting the Chinese economy. The impact has not stopped there due to the important role of the county in worldwide supply chains. It led to the most critical disruption appeared in recent decades, challenging supply chains globally (Govidan et al, 2020).

To control the pandemic situation preventive actions have been announced in countries to limit the spread of the disease and to keep it under control. Supply chains have been influenced by these policies either in supply, demand, or in logistics. It can be defined as long-term disruption and high uncertainty (Grida et. al, 2020). There are characteristics that define the threat for supply chains due to epidemic outbreaks. These include mentioned disruption with unexpected scale, propagation of disruptions in the chain and disruption in infrastructure (logistics, supply, demand) (Govidan et. al, 2020).

The unprecedented situation shows the need for analysis of supply chain resilience in theory and in practice. The position tested flexibility and reactivity of supply chains. Global, lean structured supply chains highly tend to suffer from the impact of restrictions (Ivanov & Dolgui, 2020).

The pandemic situation is relevant from bullwhip effect research perspective given that fact that long-term disruption could not be estimated. Health risk ended in closed manufacturing locations, delays in material flow and delivery of finished goods, decreasing number of operators (Ivanov, 2020).

Asian countries needed to pause their plants, that resulted in delay of materials and finished goods. Availability of products (raw material as well as finished goods) in the supply chain reduced and became unpredictable. Not only the production side but also customer's behaviour was impacted. The demand of some products such as antiseptic materials or medical supplies had increased unprecedentedly, along with much of the non-perishable goods (panic stocking). Tourism and mobility sectors have experienced the most severe decline in their economic performance, due to travel restrictions issued to decelerate spread of the illness (Ivanov, 2020; Jomthanachai et al. 2021). As mentioned above, some products (mainly medical and protective items) got highly in focus. Availability issues mainly concerned Western countries with high dependency on global supply chain. To support supply reorganizational actions needed to take place, workforce have been mobilized and underused facilities needed to get new roles (Shokrani et al, 2020).

From supply chain perspective, the difficulty was justified by the unpredictable and unplannable further steps both on production and on customer decisions. As several reasons behind the bullwhip effect is due to the uncertain market situation probability of occurrence of it has increased. At the same time level of competition to keep the desired role on the market has not decreased, circumstances made it fiercer (Xuluo, 2021). Disruption impacted both national and international level networks. Adjusting to the new demand and needs meant major obstacke (Jomthanachai et al., 2021).

Sarkis et al. (2020) defined significant weaknesses of the supply chain:

- Upstream chains due to limited transparency have difficulty in finding bottlenecks.
- Global structure aggravates impact of events shocking the supply chains.
- Limited knowledge on downstream demand and missing stress tests.

Some proposals are also formulated. Transparency and engagement need to be increased, local and global chains need to be handled in a different way, agile approaches need to be considered and deeper usage of digital tools to manage buyer-supplier relationship are crucial (Sarkis et al, 2020). These can support in long-term more resilient supply chains.

Comparison of bullwhip effect reasons and COVID-19 impacts

Bullwhip effect is impacted by diverse decisions made in the supply chain. This is influenced by social, health, regulatory and economic environment. Generally, supply chain planning is based on trends and expectations based on them. This is frequently modified by changes of the market. Considering the continuously changing environment trends still supported operational planning.

Based on the results of literature review I am comparing the bullwhip effect phenomenon's reasons and COVID-19 impacts. This comparative analysis is showing how restrictions made due to pandemic supported occurrence of bullwhip effect phenomenon.

COVID-19 led to a new situation, one of the most difficult adversities has been the lack of mid- and long-term view. Trends based on past years became unreliable and useless. New lifestyle and regulations lead to significant change in the market requirements, customer needs. This environment is ideal for occurrence of the bullwhip effect.

Table 8 connects bullwhip effect reasons and COVID-19 impacts with each other. As the environment generated by the pandemic situation could be described mainly by uncertainty and unpredictability, it provides ideal conditions for occurrence of the BWE.

Demand signal processing reason group is focusing on forecasting that is based on trends and estimations. Trends which were typical earlier and were used as basis of planning changed completely due to the change in people's lifestyle (quarantine, mobility restrictions), therefore understanding and predicting the demand became much more complicated. Market requirements are dynamically changing which led by announced economic and political changes. Level the predictability is low at all levels of the supply chain. Missing closing dates of regulations and unknown next steps further complicate adaptation of the forecast.

Rationing game reason group focuses transparent operation of the supply chain. It became even more important than earlier. Need for control and harmonization became higher due to high level of uncertainty. Global level decisions and control faced difficulties due to the various rules applied, local approaches needed to be subordinated to central decisions. Due to delays in production, missing materials and capacity limitations fear of shortage get more into focus. Fulfilment of orders became more demanding, but competition has not decreased.

Harmonization and global thinking are not only relevant regarding forecasting but also replenishment and inventory policies. Different local order batching approaches easily lead to harmful impact on supply chain level considering circumstances. In light of extraordinary circumstances, keeping inventory and replenishment policies and usual ordering timelines became severe. Due to disruption of logistics operation lead times increased or became unpredictable, capacity limitations appeared both upstream and downstream of supply chains. Keeping inventory at desired levels became more difficult.

Table 8.: Bullwhip effect reasons and COVID-19 impacts

BWE reason group	BWE reason	COVID impacts
demand signal processing	inaccurate forecast	due to dynamically changing needs
	forecasting strategy	cannot adapt quick enough; no strategy for disruption
	handling stockout	more frequent occurrence, products with previously stable demand are now impacted
	lack of learning	no historical information to rely on
	misunderstanding of the market	unpredictable and rapid change of regulations
rationing game	number of echelons	increased complexity
	lack of transparency	multiple countries, different regulations, different exemptions
	lack of control	difficulty in planning due to the continuously changing regulations
	fear of shortage	missing products, cancelled productions are increasing the need to fulfil demand
order batching	lot size	production capacity limitations, problematic raw material supply
	replenishment policy	
	capacity limitations	difficulty both on production and delivery side
	ordering timelines	lead times are extended and unpredictable
price variation	fluctuation of ordering price	supply issues of raw materials and semi-finished goods
	fluctuation of the finished goods prices	production issues, skewing demand
	changes of other costs	increasing cost due to the limited capacity
	planned and unplanned promotions	less chance to serve the extra requirements

Source: Strommer, Földesi, 2021b

Considering the market situation unplanned fluctuation of the price can deepen problems, increase degree of oscillation of bullwhip effect. Several costs related to supply chain operations increased due to the virus indirectly (availability of drivers, operators, restrictions on borders, restrictions on sales locations, availability of containers, etc.). Change in market needs also had an impact on price level. The pandemic situation led to preference changes on demand side and added some products to the most needed products' list. Due to increased need for home office possibilities demand for laptops, office chairs, webcams, monitors, etc. expanded. Some daily products as toilet rolls, yeast, flour, sanitizer products also faced increase due to panic stocking. Beside these micro mobility, sport, and indoor entertainment also get in focus. Demand for boardgames, books, bicycles, scooter, treadmills etc. also increased.

The COVID-19 pandemic generated an economic environment full of unpredictable regulations and restrictions. As part of adaptation to new lifestyle people modified their needs to adopt to modified circumstances leading to a shift of market needs compared to the 2019's general consumption characteristics. Due to missing preparation and long-term perspective operational processes needed to be adopted in all levels of the supply chains affecting forecasting drastically.

Various restrictions applied in different countries increased operational complexity. As a result of typically high number of supply chain echelons cooperation and control of common operation become tougher. Replenishment and inventory control also faced difficulties as capacity limitations occurred on multiple levels of the supply chain.

Finally, impact of the pandemic also affected the price level. Missing materials and human resource, production and delivery capacity issues increased costs in general. Potential promotions needed to face availability issues and delivery delays. Considering this gaining better position on the market became more troublesome. Operation of the market and main requirements did not change by the pandemic, but the circumstances made fiercer the competition.

As consequences of COVID-19 not-only forecasting, replenishment, and transparent operation but also price changes impacted the market leading to an excellent environment for the bullwhip effect phenomenon.

Several case studies have been published on bullwhip effect in COVID-19 situation. These studies provide very useful basis for future cases. It builds up historical date for potential future crisis. At the same time, it is worth to record the lessons learned during pandemic situation. Globalized supply chains have very limited level of reacting to disruptions; they lack an appropriate flexibility due to their huge complexity. Regionalization approaches may support higher flexibility where checking the trade-off between cost and flexibility may be beneficial.

COVID-19 is a very special situation; it is not likely to happen in the same way again, but other changes can still lead to crisis in supply chains. Finding out best practices of handling the pandemic situation and use them on long term crisis management shall be significant.

4.3. Case studies on the presence of the bullwhip effect

Two different industrial examples of the author are presented in Chapter 4.3.1 and 4.3.2 from food industry and from machine manufacturing industry. In Chapter 4.3.3. similar examples from the literature are summarised.

4.3.1. Food industry example

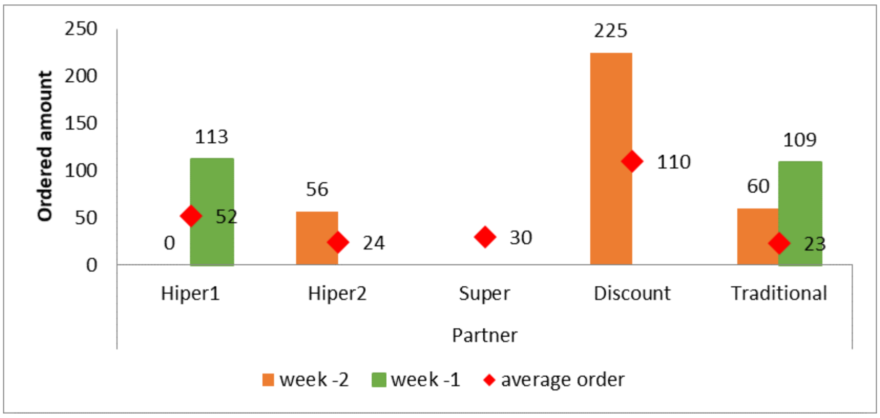
This example shows the impact of missing product on the chain. Examined product was unavailable for longer period. As this industry is strongly competitive with several substitute products customers and retail partners reaction is in focus. The example has been checked from the distributor's perspective. The length of unavailability was six weeks, and the reason was material availability issue. The problem was communicated 1,5 weeks in advance to all customers (Strommer, 2017).

The examination aimed to show the reaction of different partners (Figure 9). The retail partners can be grouped in below categories:

- Hyper 1: A hypermarket where the order is generated by the system.
- Hyper 2: A hypermarket with human involvement in ordering.
- Super: The category contains all the supermarkets.
- Discount: This category contains the discount stores.
- Traditional: It contains all little grocery stores which can be found all over the example country.

As information has been sent out, ordered amounts compared to the average weekly orders in two weeks period before the shortage has been checked. The average is based on a one-year period (Strommer, 2017).

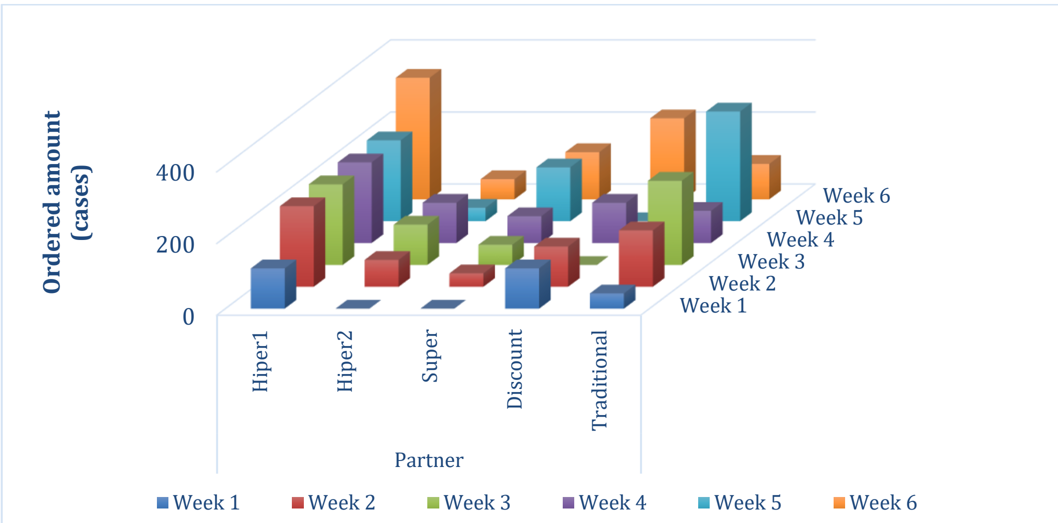
Figure 9.: Weekly orders compared to average



Source: Strommer, 2017

It is visible that the partners ordered over the average before the out-of-stock situation as it was expected. They built stock before the problematic period. Stock building approach was different on partner level. Hyper 2 and Discount ordered right after the information was sent out for 2 weeks. Hyper 1 ordered extra quantity only in the second week. Here it is visible that system generated order's manipulation is a bit slower. Super does not make any order, here the used process is stock level-based ordering. Based on that no quantity was required, communication of the problem was not successful this case. Regarding traditional trade order is visible on both weeks because of high number of partners. Information flow and reaction time resulted in prolonged ordering (Strommer, 2017).

Figure 10.: Orders during the shortage



Source: Strommer, 2017

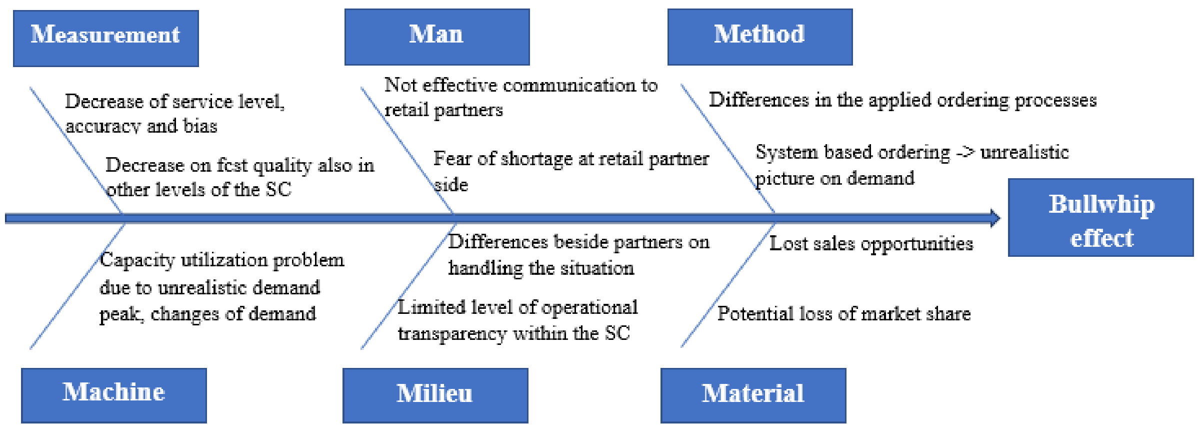
Difference is also occurred during shortage period (Figure 10.). Hyper 1 orders are system orders, quantity is not modified by the purchaser. As the stock started to be sold out quantity has been increased. This increasing tendency is also true for the Super. Orders here are based on stock and as it has started to be sold out quantities started to increase (Strommer, 2017).

Hyper 2 and Traditional channel have no or small orders in the first weeks, but later orders started to come due to the sell-out. Here information sharing seems to be more successful. Discount orders are following the same pattern as early no focus has been placed on information shared regarding the shortage (Strommer, 2017).

This example shows that bullwhip effect can develop even if a given level of information is shared. Due to fierce competition fear of shortage and lost sales opportunities are generating orders. If these orders would be served once availability problems are solved coverage would be long. This is even more problematic as the example shows in a food industry case. Extra products are likely to be obsolete and responsibility of the distributor level is high. Information sent to manufacturing need to be filtered, and real quantities need to be defined to avoid production for obsolete (Strommer, 2017).

In case all mentioned KPI dropped significantly at the level of distributor. Due to lack of product accuracy, bias and service level of presented product are low. The same impact also occurs at manufacturing and supply level if orders placed by customer (retail partner) are directly communicated to them (Strommer, 2017). This emphasizes further the understanding of the market and operational transparency within the supply chain. Figure 11. presents the mentioned factors related to the bullwhip effect in an Ishikawa frame. It broadens the understanding of the issue and emphasise the main actors. It also generates actions groups based on the characteristics of them.

Figure 11.: Ishikawa – food industry case study



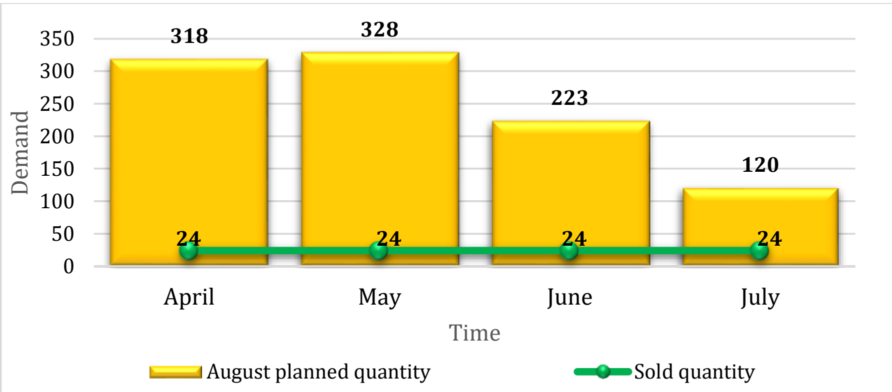
Source: Author's edition

4.3.2. Machine manufacturing industry example

Below example shows possible impact of promotional activity. The company operates in machine manufacturing industry. Manufacturing sites are mostly located in Asia and sales is on global level resulting in effectiveness regarding costs but also means long lead time and smaller flexibility. The example is from the Eastern European market. Due to geographical distance planning of required quantities need to happen at least 12 weeks in advance. In case of huge, planned volume peaks this period needs to be even longer (16-18 weeks in advance). Subject of investigation is a well rotating item of portfolio offered with an add-on (gift) free of charge. Goal of the promotion was increasing sales without price discount using the attractivity of the gift. The selected add-on was attached to multiple popular products in this promotion creating sets of products and gifts. This gift is not the product of the company, it was bought from an external supplier. Due to expected huge sales opportunity ordered quantity needed to be determined 1 year in advance and change was not accepted within this period flexibility of the supplier of the gift is low (Strommer, Földesi, 2020a) which can be directly attached to order batching reason group of the bullwhip effect, due to strict regulation of quantity and ordering timeline.

The promotion was planned for a trimester, fixed four months period (from May to August). Figure 12. shows how the expectations changed regarding August sales quantities. Four months in advance quantities were above 300 pieces. This expectation was decreased by 100-100 pieces in June and July and final quantity was 5 times lower than the last expectation from June, more than 10 times lower than the original plans. First sales figures showed that the gift is much less attractive than the expectations (Strommer, Földesi, 2020a).

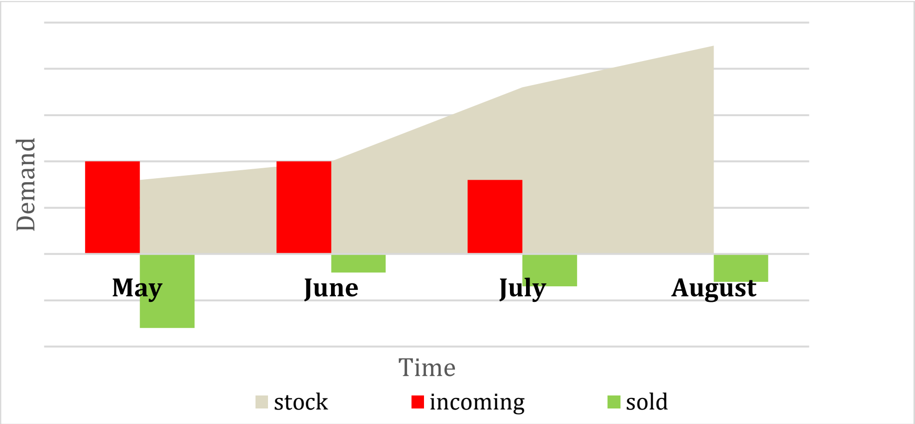
Figure 12.: August forecast changes April-July period



Source: Strommer, Földesi, 2020a

Based on this we can see that market requirements were detected incorrectly. Results of this over-planned promotion are presented on Figure 13. It shows how stock situation changed on the promoted tool. The peak visible from June onwards is unnecessary. Sell out requires 4-5 months resulting in increase in inventory cost and requires additional effort and money to reach the market (Strommer, Földesi, 2020a).

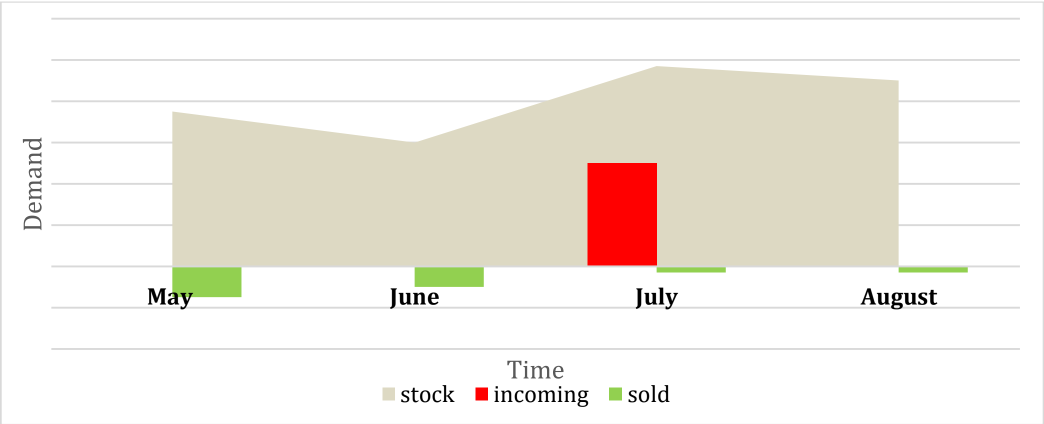
Figure 13.: Stock of the examined tool



Source: Strommer, Földesi, 2020a

As the add-on is a product of an external company flexibility is much lower. As it was described quantities has been defined a year in advance. Due to this the problem and cost generated are much bigger in this case. The item cannot be sold on its own, it needs to be attached to a product or used as a gift. Due to this significant input is needed for stock clearance. By the beginning of the promotion most of the total quantity has already been shipped, last dispatch happened in July. As visible on Figure 14. last dispatch was unnecessary (Strommer, Földesi, 2020a).

Figure 14.: Stock of the examined add-on



Source: Strommer, Földesi, 2020a

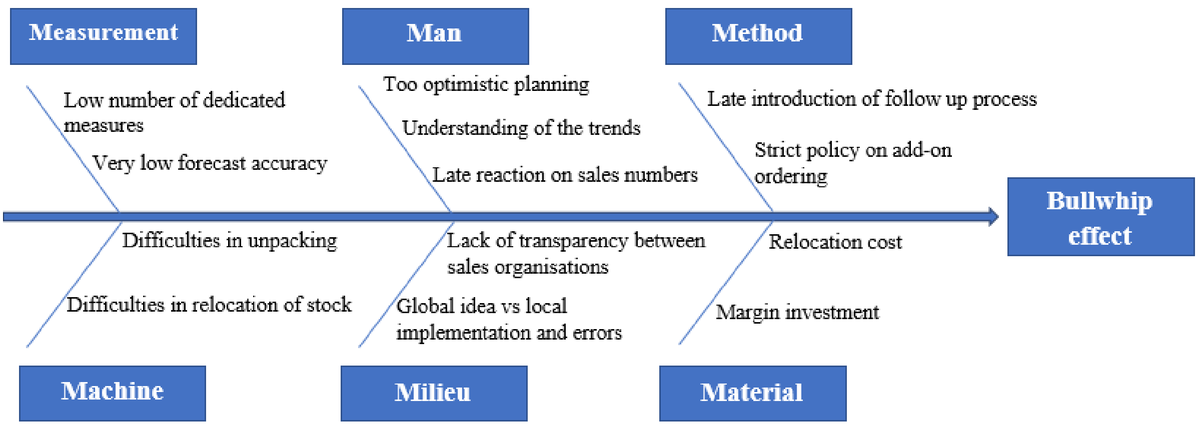
The generated overstock has cost impact in this case as well. The sell-out is even more difficult in this case as this item cannot be sold, can only be used as free of charge additional item spoiling the profitability of the product. The problem here was not only over-planning but also the long time needed for making decision. Last dispatch received in July could have been cancelled if overplanning is admitted on time, latest by end of May. Due to the contract that would mean cost but here it worth to check the cost impact: cost of sell out, warehousing and delivery OR the penalty for the decreased quantity have higher impact on figures.

In this example some of the reasons of the bullwhip effect can be listed:

- inaccurate forecast
- forecasting strategy
- misunderstanding of the market information
- ordering timelines and quantities
- fear of shortage
- planned and not planned promotions

Applying the Ishikawa tool below summary can be built up regarding the presented occurrence of the bullwhip effect (Figure 15.). It organizes the mentioned elements based on a different perspective. Measurement shows the low quality of forecast, Man shows the human errors made on estimations, Method shows the difficulties resulted by the strict process followed, Machine shows the difficulty of handling overstock, Milieu shows the strategic level difficulties faced and Material shows the cost related impacts.

Figure 15.: Ishikawa – machine manufacturing industry case study



Source: Author's edition

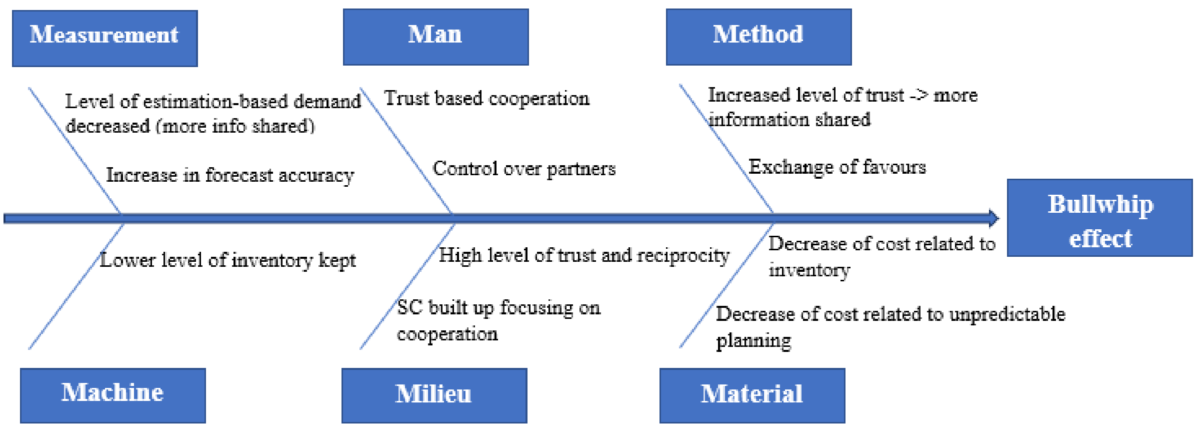
4.3.3. Empirical examples on reduction of bullwhip effect

In the literature there are studies aiming to improve performance of the supply chain by reducing or eliminating the impact of the bullwhip effect. This sub-chapter shows examples of these empirical studies.

Cao et al. connect the approach of guanxi and the increase of supply chain performance by decreasing the bullwhip effect. Guanxi is a form of social capital focuses on interpersonal and interorganisational relationships. It results in continued exchanges of favours over time. Guanxi has three main components: trust, information sharing and control. These components are also connected to supply chain performance. Bullwhip effect is taken into consideration due to the impact of information sharing. Trust and reciprocity are basic requirements that must exist to enable it. Connection is here due to core benefits of guanxi that are the mentioned two elements. The study shows that in appropriate circumstances guanxi can reduce probability of the bullwhip effect. Still useability is limited by multiple factors such as competitiveness of business environment (Cao et al., 2014).

Figure 16. shows the application of Ishikawa diagram at the core ideas of Guanxi to reduce the probability of the occurrence of the bullwhip effect. The focus is on trust and information sharing from multiple perspectives. Once the reciprocity and trust are built on the daily operation exchange of favours can work which leads to a two-way dependency on a positive manner. It also supports decreasing the level of unpredictability of demand estimation.

Figure 16.: Ishikawa - Guanxi approach to decrease bullwhip effect

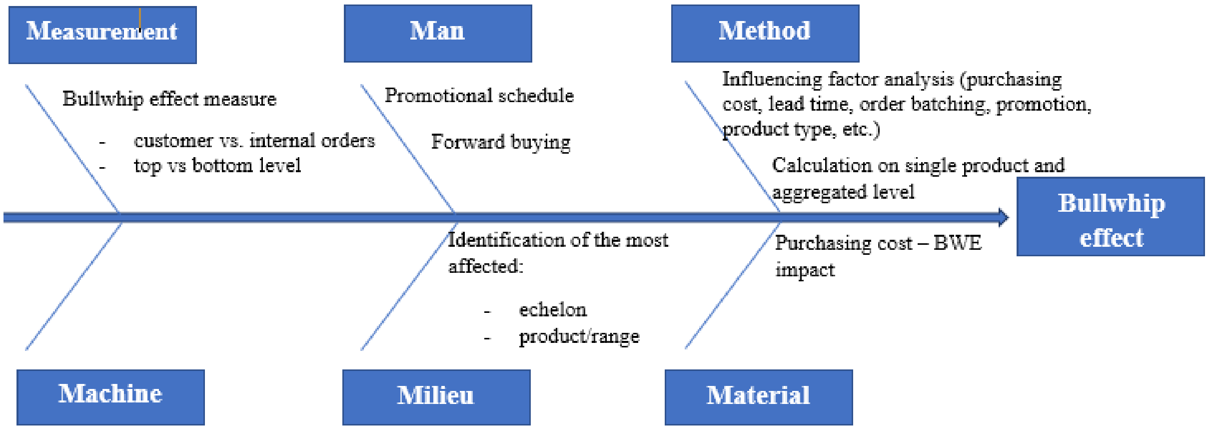


Source: Authour's edition based on Cao et al, 2014

Pastore at al. examine spare parts industry. Based on the examination of two years data the calculation showed that both on aggregated and on single product level demand variability increases in the chain moving from final customer to external suppliers. The findings also show that rotation of products have impact on probability of the bullwhip effect. Fast-moving items are more impacted by the bullwhip effect then slow movers. This is mainly due to forward buying possibilities when dealers prefer to stock up fast-moving items. It was also presented in the result that promotional periods are influencing forward buying, so indirectly the bullwhip effect (Pastore et al. 2019).

On Figure 17., Ishikawa chart shows that the focus of the analysis is wide. Calculation of the bullwhip effect is happening on two dimensions: customer versus internal orders and top versus bottom level. The investigation is also from multiple angles regarding the product portfolio. It is considering single product and aggregated level. Considering the bullwhip effect influencing factors such as lead time or order batching has been collected from the literature and analysed regarding the impact on the phenomenon. As it is also visible in Ishikawa focus here is rather on the supply chain planning and information flow then on the production side.

Figure 17.: Ishikawa – data analysis approach – spare parts industry

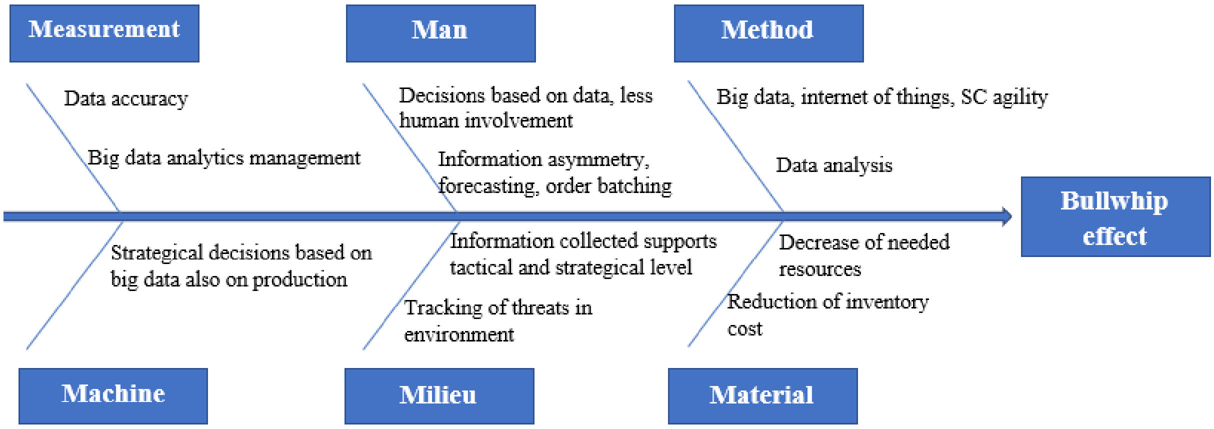


Source: Authour's edition based on Pastore et al, 2014

Hsu et al.'s study suggests a multicriteria decision-making integrated framework to mitigate the bullwhip effect. An electronic equipment producer company is the scope of the empirical study here. Supply chain agility is supposed to be used to reach this goal that is a multidimensional concept. It enables rapid adaptation to the market, reduction of inventory in quick respond to the customer. Big data is also supporting the approach as agility leads to data centric operation. As a result, the main reasons of the bullwhip effect have been defined in the given context (information asymmetry, batch ordering and demand forecasting). The resolution through supply chain agility approach is by actively shared information, improvement of data accuracy and timely detection of threats in the environment. Big data support is through development of IT infrastructure, cloud technology and the internet of things; and data visualisation support (Hsu et al. 2021).

Figure 18. shows on the split of 6M the suggested approach to enable the reduction of the bullwhip effect occurrence. This study focuses on using the full potentials of today's technological opportunities. Suggestion is usage of big data to reach more predictable supply chain operation. To reach this high level of data accuracy and integration of big data analytics management is needed. It leads to less human involvement (less resource requirement) on processes and potential decrease of errors due to estimations and subjective decisions. It aims to create an environment with less inventory but still proper service.

Figure 18.: Ishikawa – Supply chain agility concept



Source: Authour's edition based on Hsu et al, 2021

5. ASSESSMENT OF THE PHENOMENON BASED ON PROFESSIONALS' OPINION

5.1. Details of the survey

To analyse operational difficulties due to bullwhip effect survey has been conducted. It aimed to collect opinions of different business professionals about supply chain. Respondents working with forecast and/or inventory were targeted for the analysis. They are mainly covering supply-, demand-, production planning, procurement roles or connected areas. The survey was generated in Google Forms, and it was distributed online. The transcript of the bilingual (English and Hungarian) survey is in Appendix 1.

The questions have been focusing on different reasons of the bullwhip effect phenomenon. The connection of the BWE reasons and the survey is presented in Appendix 2. The table shows that all main reason groups of the phenomenon are present in the survey in multiple stages.

It had three main parts: opening questions have been investigating experience on fluctuation of the stock level and perception regarding the lead time. It has been followed by a part covering perceptions regarding some selected factors impacting effective operation of the supply chain. The opening questions are indirectly analysing if the respondent experienced the symptoms of the bullwhip or not. The second part has been built up based on the main reasons of the bullwhip effect determined in the literature. The survey has aimed to see if respondent experiences below factors or not. Some questions could result in subjective outcome and highly influenced based on the opinion of the respondent. Still, they show experience on supply chain processes and potential issues. As the examination is not limited for example on industrial level, these questions enable to collect inputs from different sectors. Beside the existence it also has been investigated, how harmful the impact is. The third angle has been focused on potential improvement. If the harmful impact is realized, is it possible to eliminate it without negatively influencing the whole chain. Below list shows the covered areas:

- long lead time between production and sales
- number of supply chain echelons
- long (intercontinental) geographical distance
- operation with transparent processes
- incomplete information flow
- applied forecasting strategy
- not properly planned price changes and/or promotions
- defined lot sizes/minimum order quantities or values

The third part consisting of a paired comparison where seven factors have been compared within each other. The aim was different factors are ranked. It has showed which element is the most crucial of the daily work of respondents. It has given an interesting overview once it has been summarized. Beside an overall ranked list of the factors, concordance has also been checked. It has shown if ranking is only a collection of individual lists, or it has any agreement.

The final part of the survey has been important from grouping purpose. It has collected information about the respondents' professional background. The requested information were industry, profession, level of the supply chain[1], size of the company, and length of applied forecasting period.

Result of the survey has been processed with tools typically applied in quality management. Pareto chart has been used to represent first part of the questions. This part has given information on occurrence, severity, and detection. These are the core of the chart as this information provide RPN which has not only been supporting a Pareto approach but also can be used to build up a risk matrix of the three elements. Based on the second part of the survey pairwise comparison has been initiated and ranked list of factors and level of agreement could be simulated. As a result of the background data collection not only the overall but also industrial level could have been analysed.

5.2. Professional background of the respondents

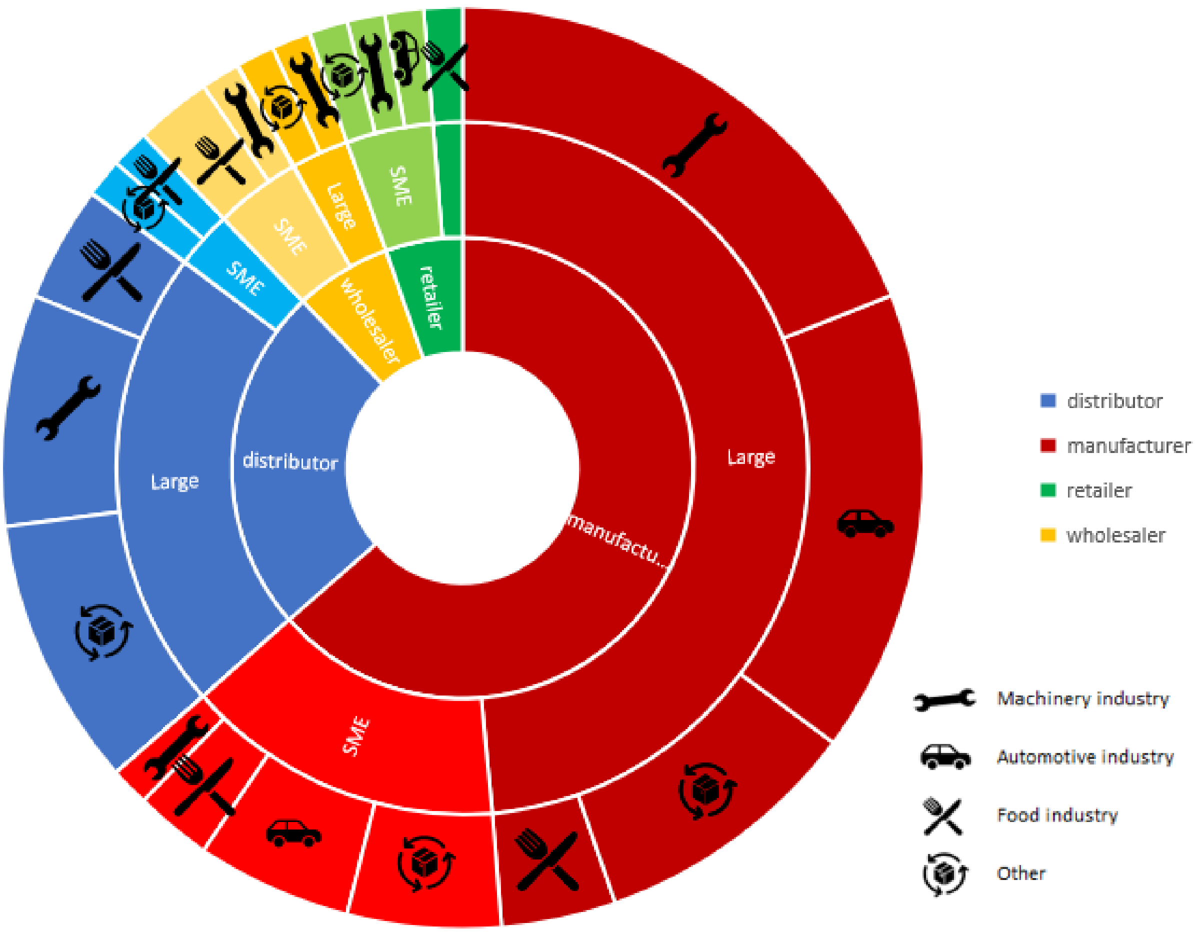
The survey has been filled by 76 respondents. The respondents were mainly from supply, demand, and production planning position. Figure 19. shows the ratio of the size of the supply chain role company and industrial segments. Supply chain role has been marked using colour coordination. SME part is visible with lighter display of information. Industrial segmentation has been marked on the chart by symbols.

73% of the respondents work in three industrial segments: machinery (32%), automotive (25%) and food (16%) industry. Based on the size of the company (number of employees) the ratio: 75 % of the responses are from large companies (more than 250 employees), and 25% is from SME's companies (less than 250 employee).

[1] Supply chain role has been defined based on the Beer distribution game's four stage: manufacturer, distributor, wholesaler, retailer. This simplified four-stage setup is widely used in literature for sufficient modelling of operational frame of supply chains.

The role in the supply chain was also considered in the survey. From retailer and wholesaler position only, limited feedback was received as only 5% of the respondents work in retail and 7% of them work as wholesalers. Regarding the distributor role a bit more then fourth of the respondents (26%) is working at this level of the supply chain while the highest portion, 62% of the responds are from manufacturing background.

Figure 19.: Background of the respondents



Source: Author's edition

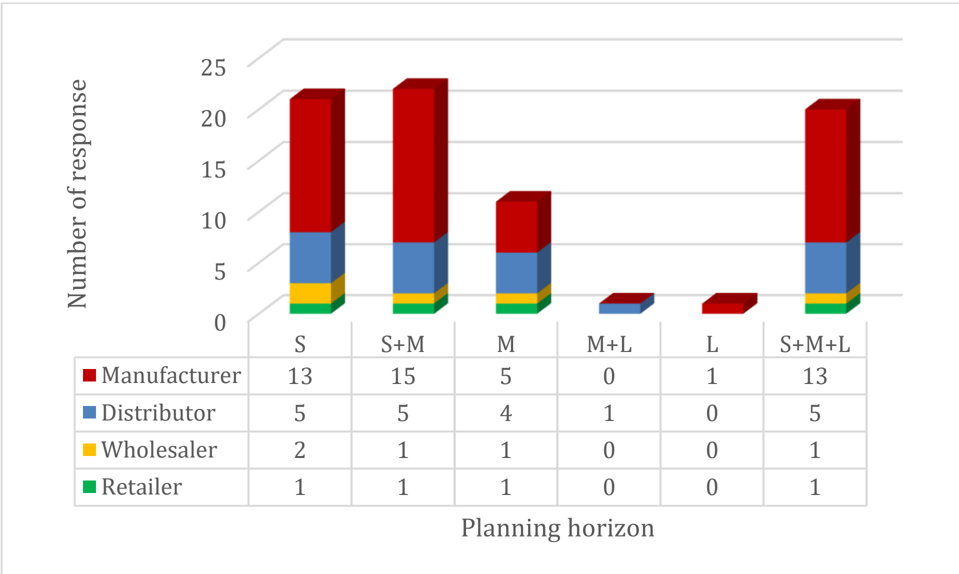
As the survey has been highly focusing of planning and forecasting activity, the planned period has also been checked. The forecasting period shows high differences. Short-term planning (6 months or less) is in process at 83% of the responses, mid-term (6-12 months) forecast is at 71% and long-term (longer than 12 months) forecast is only 29% of the response. Table 9. shows the split of planning horizon

Table 9.: Planning horizon split in the whole multitude

Nr. of response	Short	Mid	Long
Short	21	22	0
Mid	22	11	1
Long	0	1	1
All		20	
Sum	63	54	22
%	83%	71%	29%

Figure 20. shows the preferred planning horizon on supply chain echelon level. The overall results are also visible here. Having only mid and/or long-term planning is not typical, only 13 respondents are having planning without short term perspective. Role level split shows that manufacturers consider short term planning in the highest portion in all cases: only short-term, short and mid-term and all three planning horizons. For distributor, wholesaler, and retailer level the split is equal between the mention three terms.

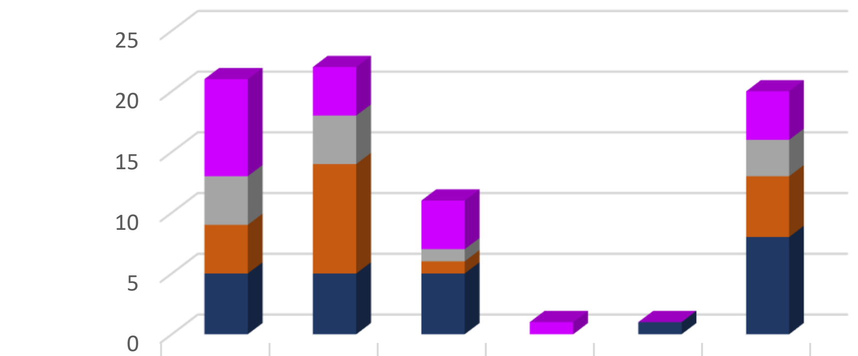
Figure 20.: Planning horizon on supply chain role level



Source: Author's edition

Considering the same analysis on industry level Figure 21. shows the applied planning horizon. The automotive industry is most likely using the short and mid-term planning. Only long or mid- and long- term planning is not marked at all. Same experience can be highlighted for the food industry and in addition only mid-term planning has been present just for a single case. Typically, short term estimations are needed which is emphasised also by the characteristics of the industry. For machinery industry short-, mid- and long-term planning are the most common.

Figure 21.: Planning horizon on industry level



	S	S+M	M	M+L	L	S+M+L
Other	8	4	4	1	0	4
Food	4	4	1	0	0	3
Automotive	4	9	1	0	0	5
Machinery	5	5	5	0	1	8

Source: Author's edition

5.3. Hypotheses

Based on the questions of the survey below hypotheses have been stated. These are only referring to the analysis of the survey. The results of this hypotheses form the basis of one of the final theses of this work.

H_1: The respondents working for large companies experience unreasonable fluctuation of stock level

H_2: The length of the accepted lead time differs highly based on industrial segment

H_3: Respondents consider the length of the supply chain as crucial factor regarding the effective operation

H_4: The ranking of the pairwise comparison differs on industry level

H_5: The concordance value expected to be low ($W<0,3$). The professionals have different view on the bottlenecks regarding efficient operation.

H_6: The concordance value is higher if the calculation is narrowed down to industrial segment (e.g., automotive industry) ($W_{industry}>W_{overall}$)

5.4. Perception of the bullwhip effect

Two questions have been focusing on the presence of the bullwhip affect in the survey. The first question is focuses on fluctuation's experience of the stock level (*Do you experience fluctuation of the stock level (raw material, semi-finished or finished goods)?*). The second investigates if this fluctuation is considered reasonable or not (*Do you consider the fluctuation of the stock level reasonable? Please rate in a 1 to 5 scale, where 1 is reasonable and 5 is not reasonable*).

A Chi-squared test has been initiated to see statistical connections within the sample. Connection has been examined between scaled unreasonable fluctuation and professional background date. The scaled data has been checked on company size, supply chain role, industry, and planning horizon level. Based on the results only one statistical connection has been identified which is between the size of the company and the scaling of the reasonability. (P values: company size: 0,035; supply chain role: 0,258; industry: 0,606; planning horizon: 0,474)

In most of the cases fluctuation of stock level has been recognised by the respondents (98,5%). Regarding the reasonability of the fluctuation Table 10. shows the results separated on company size level. The outcome of the 1-5 scale have been aggregated in three groups. Rates 1 and 2 are combined as reasonable fluctuation. Rates 4 and 5 are combined as highly not reasonable fluctuation. Rate 3 is considered as not reasonable fluctuation. Considering the overall completion 72% of the respondents have experienced so called not reasonable stock level changes (rated the question 3, 4, or 5) and 46% of the total have rated this fluctuation highly not reasonable.

The SME companies are divided from this perspective. Almost half of the respondents have considered reasonability as value 3, which covers that the changes of stock level can be explained in half of the cases. 32% of the answers are in the highly unreasonably rated categories. There is no industry level consistency in it, we can find automotive, food and construction industry. The reasonable rating is also showing multiple industry.

Table 10.: Reasonability of fluctuation

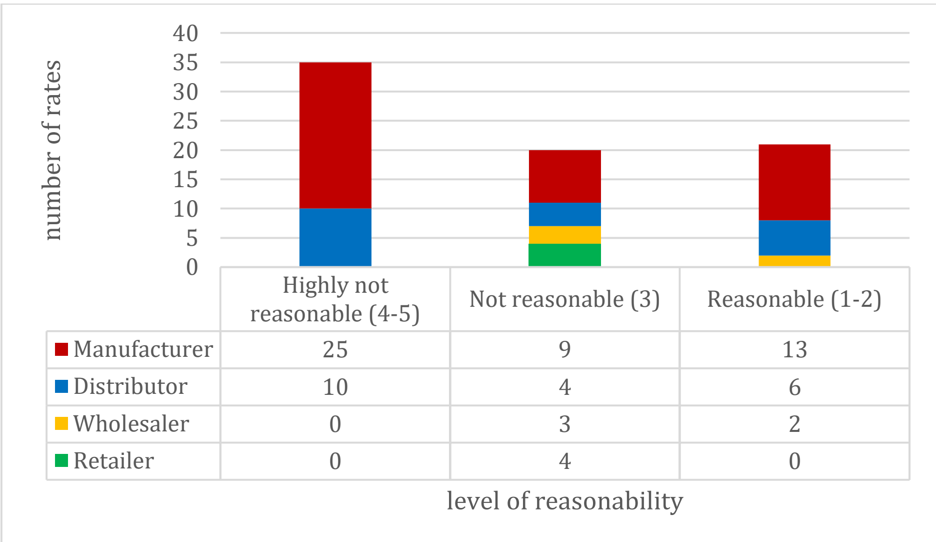
Reasonability of fluctuation	SME	Large	Total
1	21%	30%	28%
2			
3	47%	19%	26%
4	32%	51%	46%
5			

Source: Author's edition

Half of the large companies (51%) have rated stock level fluctuation highly unreasonable. All mentioned industries can be found at this rating. Supply chain echelon perspective is presented on the below chart. Highly unreasonable fluctuation is typical for manufacturing and distribution (Figure 22.) which can be explained by the distance from the customer. With the increasing number of echelons between customer and examined member reasonability is decreasing. These companies are typically planning all three time horizons. Manufacturer segment also have significant portion on reasonable side. These are large companies, mainly from machinery industry with short and mid- term planning horizon. Retailer and wholesaler respondents do not experience high level of unreasonable fluctuation. This also explains the theory of distance from customer mentioned earlier.

On industrial split reasonable stock level fluctuation is mainly considered in the machinery industry. In contrary the smallest portion is for automotive with this rating, this industry in 68% has rated fluctuation highly not reasonable. For food industry all ratings occurred in similar portion.

Figure 22.: Level of reasonability by supply chain role



	Highly not reasonable (4-5)	Not reasonable (3)	Reasonable (1-2)
Manufacturer	25	9	13
Distributor	10	4	6
Wholesaler	0	3	2
Retailer	0	4	0

Source: Author's edition

As both inventory management and forecasting activity are involving human inputs rating of the above questions is subjective, these are based on the experience of the respondent. Also, level of fluctuation is based on impulses and feelings of the person. Objective answer would only be possible in 100% automatised activities without any human involvement.

5.5. Lead time expectations

Lead time is a crucial factor in most of the supply chains. In food industry limitations are higher due to expiry date. In other industries rapidly changing trends can result in time pressure. In the survey length of acceptable lead time was also considered. The result is visible on Figure 23. shown on total level and separated for the 3 main industries as well.

The survey has shown that accepted timelines can be different on industry level. Food industry mainly considers 20-30 days of lead time as maximum acceptable based on the answers received for these questions (83% of the respondents answered in this range). However, in some cases shorter timings could be recognized due to the special segment of the industry: dairy products. The other with surprisingly low lead time acceptance can be identified in the alcohol segment (7 days).

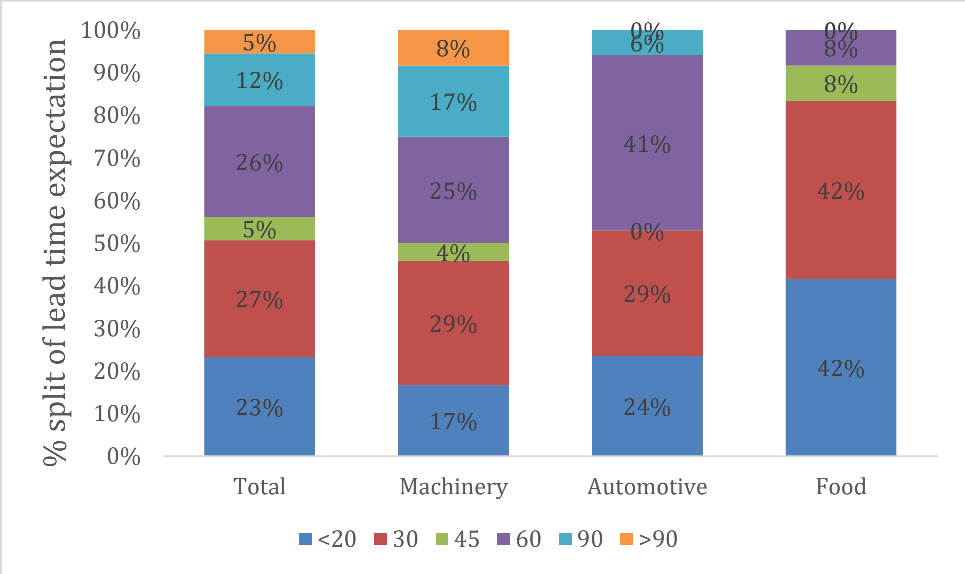
The machinery industry is more heterogenous as the ratio between 30 and 60 days could be visible on a 25-25% ratio. The other half of the segment is very diverse as there are respondents where only less than 20 days are accepted lead time and 25% is accepting 90 days or more.

Automotive industry is dominated by 60 days of expected lead time, 41% of the respondents marked this period. Longer lead time is not typical. 30 days and less than 20 days also has significant portion.

The acceptance of lead time is visibly different (Figure 23) on industry level, still based on statistical calculation (Chi-squared test) lead time parameter and the industry are independent ($p=0{,}13$). Calculation has also been initiated in connection with company size ($p=0{,}07$); planning horizon ($p=0{,}25$) and supply chain role ($p=0{,}34$). The result of the Chi-squared test shows the same, the lead time and all the chosen parameters are independent.

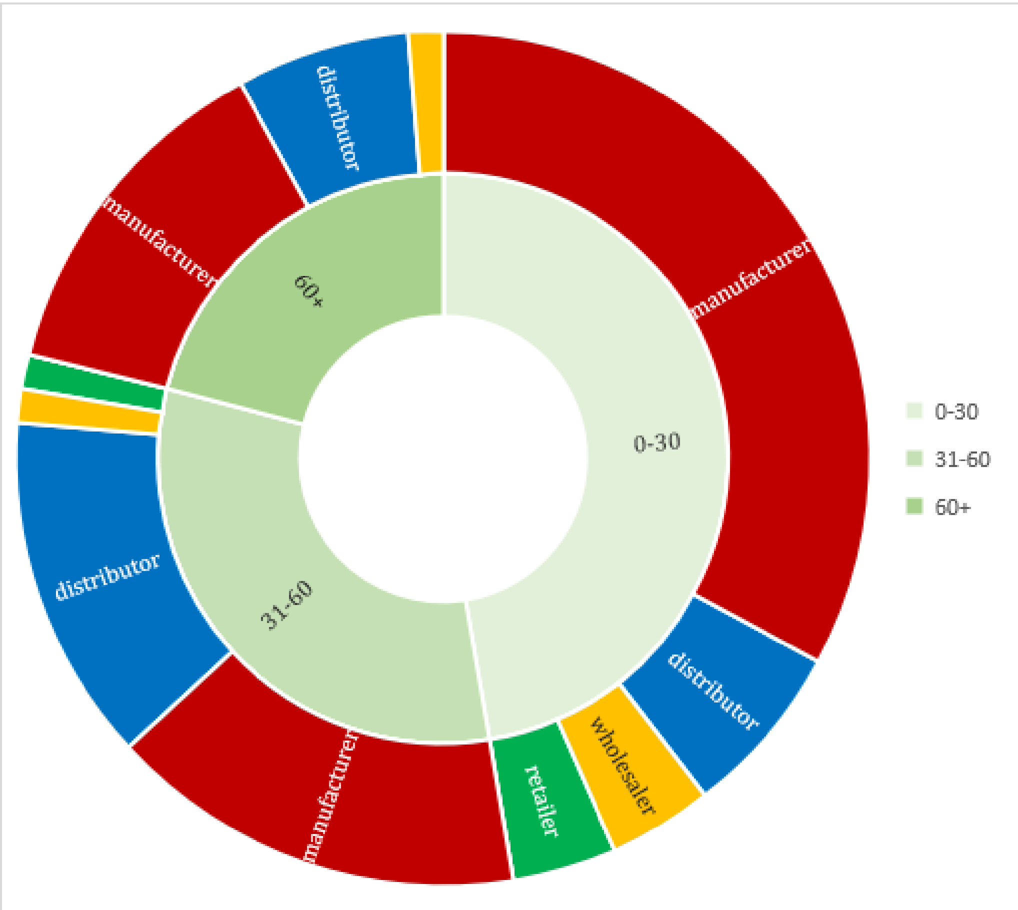
Lead time expectations can be summarized in three groups where supply chain role level can be identified as visible on Figure 24. Manufacturing has the highest portion on 0-30 days. It is needed to enable flexibility. In addition, considering long time request of transportation of goods in many cases, manufacturing site cannot afford to wait long for materials. Wholesaler and retailer responds are also rather here, as they are the segments directly facing the customer and quick availability is also important here.

Figure 23.: Lead time expectations



Source: Author's edition

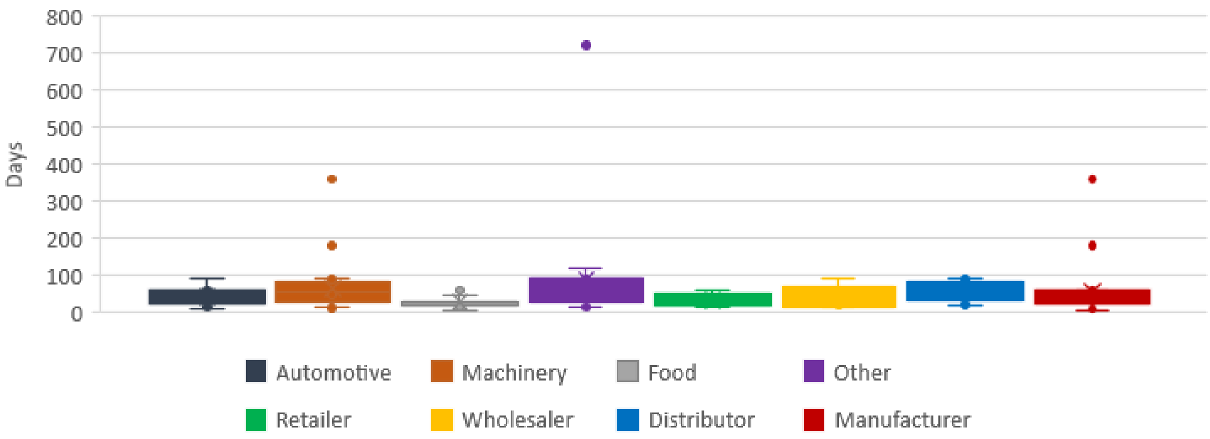
Figure 24.: Lead time on supply chain role level



Source: Author's edition

The extremes in the result were 7 days and 720 days. 7 days were reported for a large company in food segment, 720 days in medium sized company in other segment, specifically steel industry. Diary business also had some responds within these extremes with 2 weeks of expected lead time. On the other hand, in machinery industry half a year or one year lead time can also be acceptable. Figure 25. shows that the extremes are from manufacturing supply chain level. The two charts show the accepted timings in days and the extremes are visible as stand-alone dots. From industry perspective machinery industry has mentioned outstanding values are present. The mentioned 720 days is visible as described under 'other' category.

Figure 25.: Extremes of the lead time on industry and supply chain role level



Source: Author's edition

5.6. Pareto analysis

Methodology

Pareto chart is presented on Figure 26. The calculation is based on the logic presented in Chapter 3.6. The chart is made using RPN number. It is the multiplication of the O, S and D value (Eq. (6)). Occurrence (O) value is determined based on the experienced presence of below factors. The calculation is made on factor level, all the elements are checked separately. If respondent faces these factors it is weighted with 1 if not it is weighted with 0. Severity (S) value is based on the experienced level of impact regarding the analysed factors. Those have been rated from 1 to 5. In the equation the responded values are summarized. Finally, detection (D) is based on the potential elimination opportunity. Here also a yes/no question has been formed considering if the impact of the factor can be eliminated or not without negative impact on the supply chain performance. If the answer is yes on this question it is weighted with 1, no is weighted by 0.

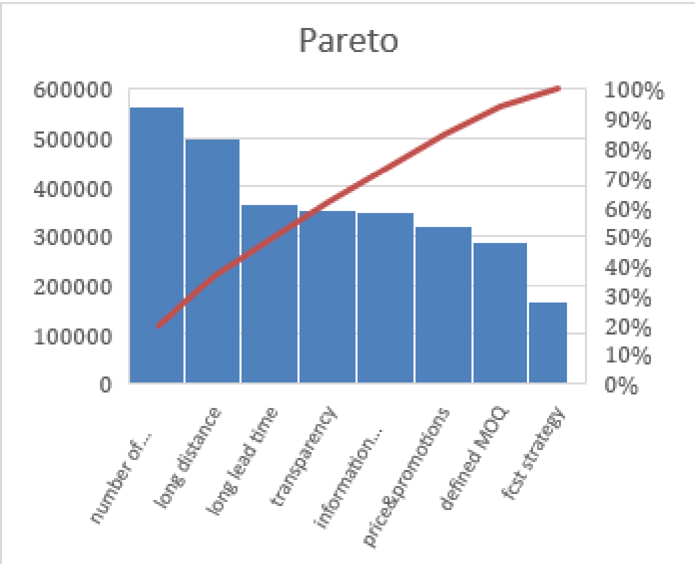
RPN= O*S*D= O (Number of 'Yes') * S (sum of the given rate) * D (Number of 'No') (6)

Factors which have been examined in the survey are below:

- long lead time
- high number of echelons
- long (crossing continents) geographical distance in the supply chain
- lack of transparency (roles, responsibilities, flow of goods, allocation process, changes (e.g. price), etc.)
- lack of information sharing
- applied forecasting strategy
- not properly planned price changes, promotions
- defined minimum order quantity

Result

Figure 26.: Pareto chart - bullwhip reasons



Source: Author's edition

Table 11. shows the used weights of RPN calculation. The highest RPN number is marking *high number of supply chain echelons*. 71% of the respondents' have experienced presence of the factor in the chain they work for. This factor is rated by 49% of the respondents at the level of 4 or 5 serosity. The attitude regarding resolution is rather negative, only 42% see opportunity to solve this factor without any harmful impact. *Long geographical distance* is also situated in

the beginning of the chart. Division of ratings is very similar to the first item. The difference to this come as 20% of the respondents do not work in supply chain with long geographical distance. This is the highest ratio of the not experienced category. *Long lead time* is the third factor in the list. Distribution of the ratings is similar to the first and second item. Among the three, this item has the highest severity rating, but it also has the most optimistic approach regarding possible resolution (Strommer et al, 2022a).

Checking the 80% marker two category still need to be checked. These are *the lack of transparency and lack of information sharing*. The missing information is experienced by 83% of respondents, and severity is at value 4 or 5 for 68%. At the same time 76 % has considered this factor resolvable. Transparency is preceding the information flow in the list due to lower rating on possible resolution. Less than 10% of the respondents have considered that this factor can be improved (Strommer et al, 2022a).

Three factor is out of the 80% scope. These are *price changes and promotions, defined MOQ and the applied forecasting strategy*. Price and promotional factor and MOQ are both experienced by more than half of the respondents. The impact rate is close to equal portions, approximately third of the respondents have considered these factors impact low, medium, and high. The possible resolution is also above 55%. The applied forecasting strategy has only been considered problematic by third of the respondents. Beside this resolution is also considered manageable (70% have marked this item as it can be eliminated without negative impact on efficiency) (Strommer et al, 2022a).

Table 11.: Summary of the rating of the Pareto factors

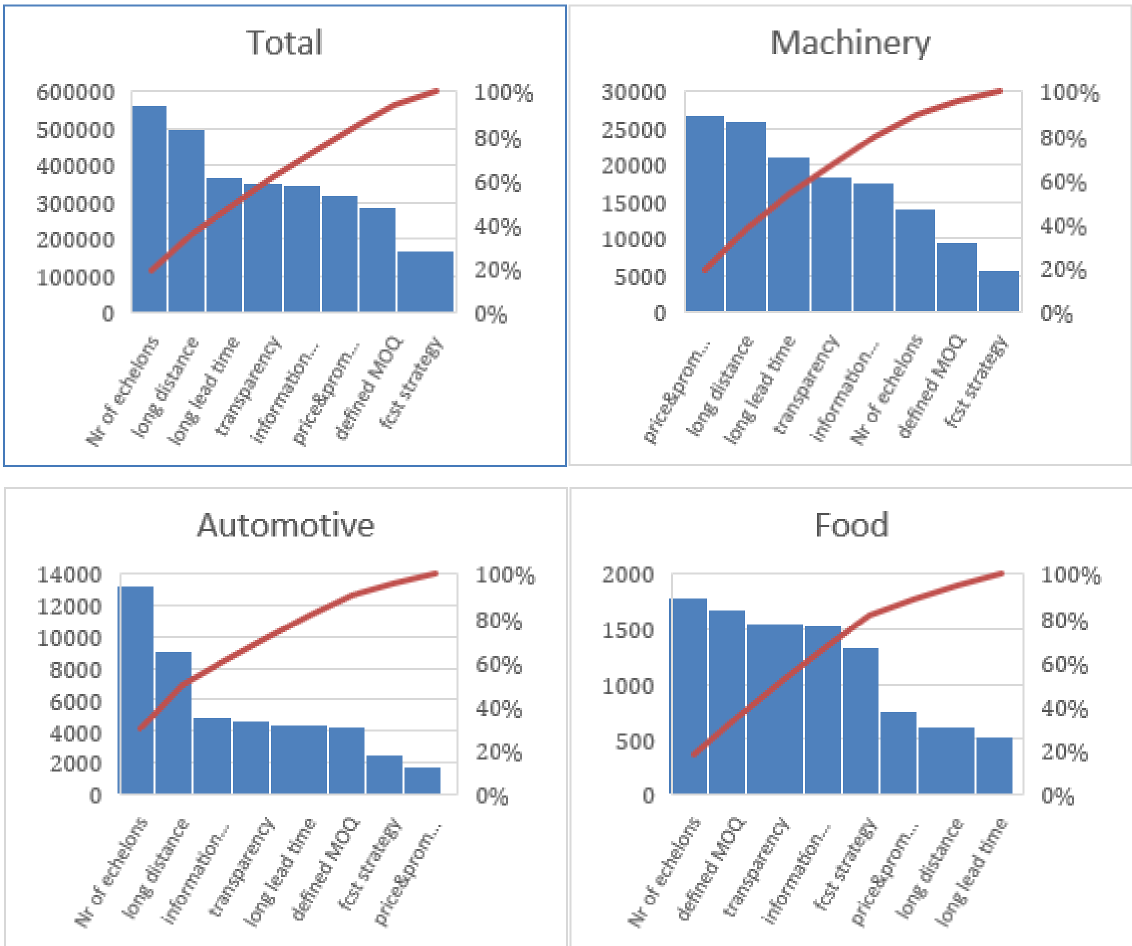
Factors	**Do you experience?**		**Level of impact**						**Resolution**	
	yes	**no**	**0**	**1**	**2**	**3**	**4**	**5**	**yes**	**no**
long lead time	39%	61%	5%	17%		25%	53%		39%	61%
high number of echelons	71%	29%	8%	25%		18%	49%		42%	58%
long geographical distance	70%	30%	20%	14%		18%	47%		43%	57%
lack of transparency	68%	32%	1%	21%		26%	51%		66%	34%
lack of information sharing	83%	17%	1%	5%		25%	68%		76%	24%
applied forecasting strategy	34%	66%	0%	17%		21%	62%		70%	30%
price changes, promotions	67%	33%	7%	30%		22%	41%		63%	37%
defined MOQ	53%	47%	1%	39%		25%	34%		57%	43%

Source: Author's edition

The Pareto analysis was made also for the three highest portion industry in the sample. The result differs on industrial level. Figure 27. shows the Pareto chart of the whole multitude (in a blue frame) and the chart for machinery, automotive and food industry.

If Pareto chart is examined on industry level order of the factors is showing the highest level of similarity between the total and the automotive industry. The high number of supply chain echelons has the highest rate in automotive and food industry as in the total. Long geographical distance is rated as second at machinery and automotive industry. Lower importance at food industry is due to expiration date, long distance is not typical in these chains. The same reason can be visible regarding lead times. In food segment long lead times are not acceptable due to the product categories.

Figure 27.: Industrial level Pareto



Source: (Strommer et al, 2022a)

Lack of transparency and lack of information sharing has similar judgement in the total and in the industrial split. Forecasting strategy has not been rated as most important in any of the industries however the highest grade has come from the food industry. Regarding the MOQs the biggest difference is at the food segment, there the defined MOQ is the second most important factor.

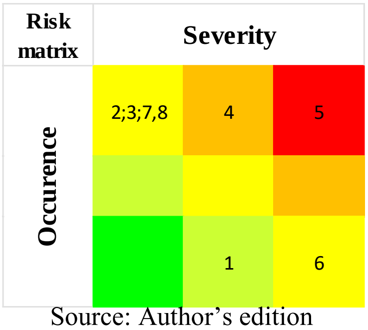
Rating of the price changes and promotions is showing extremes in different industries. In machinery industry this factor has been rated as the most crucial, in opposition in the automotive segment, this is the less important.

5.7. Risk matrix of the factors

The risk matrix is presenting the factors based on occurrence and severity. The matrix contains factors marked with a number based on below list:

1 long lead time
2 high number of echelons
3 long geographical distance
4 lack of transparency
5 lack of information sharing
6 applied forecasting strategy
7 price changes, promotions
8 defined MOQ

Figure 28.: Risk matrix



Source: Author's edition

Figure 28. shows the Risk matrix based on 76 respondents. The most critical risk is *lack of information sharing*. It is occurring in the examined supply chains and the respondents consider it impactful regarding operation. *Lack of transparency* is also considered as high risk, as level of occurrence is high, and severity is medium.

These two factors are highly subjective elements. As the technical background (industry 4.0, developed ERP systems, online information sharing, instant data transfer, etc.) is highly developed in the past 30-40 years understanding of these elements changed. Beside availability of information, it is also referring to developed processes, routes of communication and subjective decision on which information need to be shared (Strommer et al, 2022a).

The *high number of supply chain echelons; long geographical distance; price changes and promotions; and the defined MOQs* are occurring frequently but severity is rated on low level. These should be handled once riskier elements are under control. *Long lead time* and *applied forecasting strategies* are occurring only on a limited number of instances. Still due to the medium and high severity it needs to be kept in focus (Strommer et al, 2022a).

Figure 29.: Risk matrix on industrial level

Machinery			
Risk matrix	Severity		
Occurence		3;7	
	2;8	4	1;5
		6	

Automotive			
Risk matrix	Severity		
Occurence		4	2;5
		3;8	
	7		1;6

Food			
Risk matrix	Severity		
Occurence			5
	2	4	6;7
	1;3	8	

Source: Strommer et al, 2022a

The setup of the risk matrix also differs on industrial level. It has been checked for the 3 most represented industries presented on Figure 29. The common point is the high severity and occurrence of the 5th factor, information sharing. This is in red zone for food and automotive industry and in orange zone with high severity in machinery industry. Similarities can be found regarding missing transparency (Factor Nr.4). In machinery and food industry middle severity and occurrence are typical, in automotive occurrence is high. Factor 2 and 8 (number of echelons and defined MOQ) is in the green zone for machinery and food industry (Strommer et al, 2022a).

Industrial characteristics are also driving differences. Such as place of first and third factors (long lead time and geographical distance) in food segment. Due to shelf life these are not characterising the food chains. The second factor is considered more serious in the automotive industry which could be due to frequently applied just in time approaches (Strommer et al, 2022a).

5.8. Pairwise comparison (methodology and result)

Methodology

The pairwise comparison's factors included the main reasons behind the bullwhip effect aiming to analyse the perception of the professionals on them. In the survey below factors have been defined:

- uncertainty of forecast
- excessive lead time (due to number of echelons, and/or geographical distance)
- lack of information sharing, transparency
- defined order quantities (overstock due to high MOQs)
- applied replenishment strategy

- fluctuation of prices
- misunderstanding of the market (changes, demand)

The forming of pairs is based on the Ross's series (Ross, 1934), as the regular layout distort result of the survey. The pairs built up is visible in Table 12.

Table 12.: Pairs based on Ross' series

I.			II. (continuation I.)			III. (continuation II.)		
E1		E2	E7		E1	E6		E3
E7		E5	E4		E3	E7		E2
E6		E1	E5		E2	E1		E5
E3		E2	E1		E4	E4		E6
E6		E7	E3		E5	E3		E7
E1		E3	E2		E6	E5		E6
E2		E4	E5		E4	E4		E7

Source: Author's edition based on Ross 1934

The result of the survey has been analysed in Microsoft Excel applying following methodology. Each respond has been analysed individually. First a preference matrix has been defined based on the indicated factors. Based on the this the preference frequency (a) has been determined (sum of the rows), followed by the examination of the inconsistent triads (d) using equation (7). Based on the 'd' value 'K' also has been calculated (Eq. (8)) to see consistency of the inconsistent triads.

$$d = \frac{n \cdot (n-1) \cdot (2n-1)}{12} - \frac{\sum a^2}{2} \quad (7)$$

$$K = 1 - \frac{d}{d_{\max}} \quad (8)$$

To determine the final ranking of the factors 'p' preference ratio has been calculated. Using standard normal distribution 'u' to transform the 'p' value resulted in relative value that is defining order of factors based on the respondent's preferences. Below calculation has been used to resolve the single respondents ranked list.

Beside the analysation of the single records, the summary has also been examined. In order to have any overall ranking a summarized preference matrix has been created showing that the relative preference is calculated and an overall ranking is available. Calculation of the 'p' is different, as the number of respondents is also considered. The 'p' value is calculated according to equation (9).

$$p = \frac{a + m/2}{m \cdot n} = \frac{a + 0{,}5}{n} \quad (9)$$

To evaluate the overall ranking, degree of agreement needs to be defined and for that Kendall's coefficient of concordance (W) can be used. If the value of 'W' is 0 the result means complete disagreement, if it is 1 it means complete agreement. To calculate the 'W' fluctuation of the sum of rank value needs to be defined first (Eq. (10), (11)).

$$\Delta = \sum_j (R_j - \overline{R_j})^2 \tag{10}$$

$$\Delta_{max} = \frac{k^2 \cdot (n^3 - n)}{12} \tag{11}$$

Based on these, value of the 'W' can be calculated based on equation (12).

$$W = \frac{\Delta}{\Delta_{max}} = \frac{\Delta}{\frac{1}{12} \cdot k^2 \cdot (n^3 - n)} = \frac{12 \cdot \Delta}{k^2 \cdot (n^3 - n)} \tag{12}$$

If value of 'W' is higher than 0 but lower than 1 significance need to be analysed. If tied values occurs 'L' correlation coefficient need to be considered (Eq. (13)). Calculation of the 'W' value need to be modified according to equation (14).

$$L = \frac{\sum_d (t^3 - t)}{12} \tag{13}$$

$$W = \frac{\Delta}{\frac{1}{12} \cdot k^2 \cdot (n^3 - n) - k \cdot \sum_L L} \tag{14}$$

If the W value is greater than 0 but lower than 1 significance need to be analysed. For this the p value need to be calculated (using the Chi distribution). If the calculated p value is lower than α (.05 or .01) H_0 hypothesis can be rejected, H_1 can be accepted. This case it means that if H_1 hypothesis is accepted, agreement between respondents is statistically significant.

Ranking

Table 13.: Overall ranking

Nr.	Factor	Ranking	Relative
1	uncertainty of the forecast	1	100%
2	excessive lead time (due to number of echelons, and/or geographical distance)	3	64%
3	lack of information sharing, transparency	4	61%
4	defined order quantities (overstock due to the high MOQs)	5	19%
5	applied replenishment strategy	7	0%
6	fluctuation of prices	6	6%
7	misunderstanding of the market (changes, demand)	2	66%

Source: Author's edition

The pairwise comparison has been carried out in received 76 samples and resulted in different rankings. Following question has been asked regarding the comparison: *Based on your experience which factor is resulting in unintended fluctuation of the stock level in your supply chain?* As a result, an overall ranking has been created which is present in Table 13. as supplemented with the relative importance of the factors. (Strommer et al, 2022a)

As ranking can be influenced by several factors it has also been checked for the three most represented industries. Result of this analysis can be found in Table 14 which shows the total and the industrial level ranking. The consistency in the first place is visible. For the other 6 factors there is no such similarity, only partial. Different focus and characteristic of the food industry are already visible here. Rating of lead time is connected to shelf life of the products. Automotive and machinery industry shows similarities if only order is checked. (Strommer et al, 2022a)

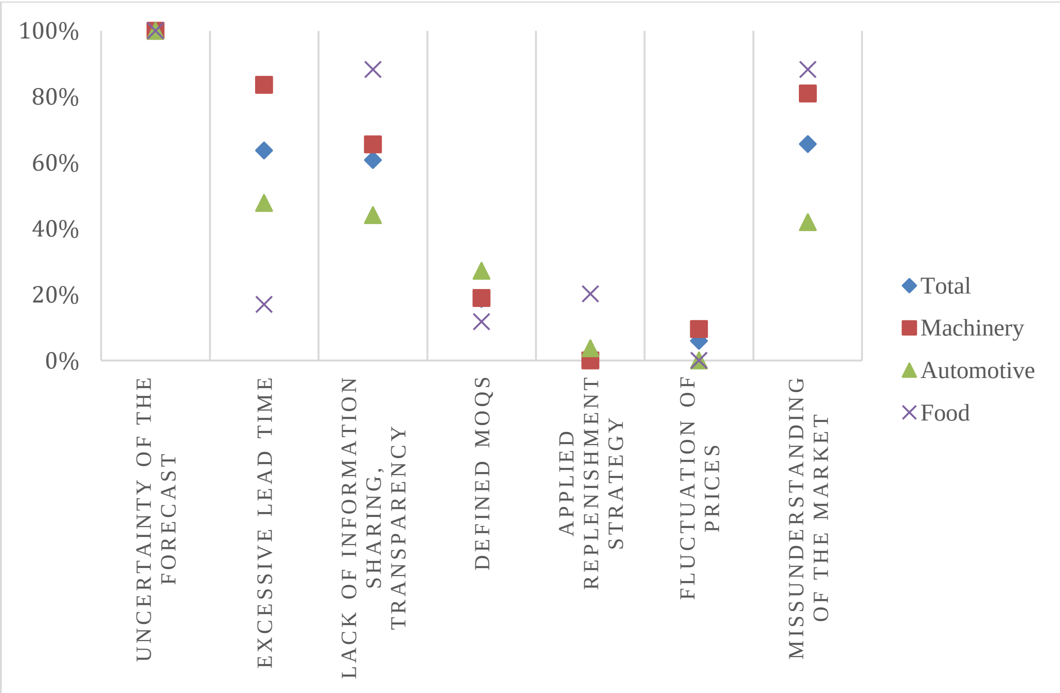
Similarities and differences of the ranking can be understood better if relative importance of the factors is also checked as seen on Figure 30. It presents the preference compared to other elements. The first rated factor, uncertainty of the forecast has received 100% rating on relative importance at all industries. It means that uncertainty of the forecast is rated more important than all other factors. As opposite, applied replenishment strategy and fluctuation of price have low rating at all industrial segments (under 20%). Other factors are rated divers on industrial level. Food industry place relative importance of lead time low (17%), at the same time, information sharing and transparency, and misunderstanding of the market is considered among the most important elements (88%). Automotive industry also considers mentioned two factors important, but here lead time is also highly rated compared to other factors (more than 40%). This is due to the differences in the industrial characteristics. Machinery industry shows big differences in relative importance. Beside forecast lead time and understanding of market are crucial (more than 80%), but replenishment strategy and price are remarkably down rated (less than 10%) (Strommer et al, 2022a).

Table 14.: Ranking on industrial level

Factor	Ranking		
Total ranking	Machinery	Automotive	Food
Uncertainty of the forecast	1	1	1
Misunderstanding of the market	3	4	2
Excessive lead time	2	2	5
Lack of information sharing, transparency	4	3	2
Defined MOQs	5	5	6
Fluctuation of prices	6	7	7
Applied replenishment strategy	7	6	4

Source: Author's edition

Figure 30.: Relative importance of the ranking on industry level



Source: Author's edition

Checking relative importance is showing how factors are considered compared to others. The second ranking of lead time at machinery and automotive industry means different approach from the respondent. In machinery industry lead time is very important, 84% against other factors. This means that beside forecast all other factors are less important. For automotive it is only 48%, so lead time's rating is only more important than half of the other factors (Strommer et al, 2022a).

If overall ranking is analysed on industry level, we can see differences. Machinery industry has 4 factors out of 7 that is rated above 65% and 3 factors below 20%. It shows that the first 4 factors are rated highly problematic and compared to others the last 3 is not as important. The view is similar with food industry, 3 factors are above 80% and 4 below 20%. Automotive shows a difference as uncertainty of the forecast is rated against all the others but rating of the other 6 factor is more balanced. The 3 higher rated factor has 42-48%, the lover rated ones below 27%. This means that ranking is not as obvious as in the other two segment. The ratings above 80% show that beside uncertainty of the forecast most of the other factors are rated less important. When it is around 45% ranking is not that clear. The factors are not preferred against most of the others (Strommer et al, 2022a).

Comparison of the ranking can also be drawn between supply chain levels and company sizes as summarized in Table 15. The experience is the same as the industrial comparison. The highest influence on unintended stock level fluctuation is due to uncertainty of the forecast. Only retailer level of the supply chain has different view on this. The thirdly rated factor is similar beside the different supply chain levels, it is the misunderstanding of the market. Other similarities are not typical beside these groups. From the company size perspective similarity beside the first place is regarding the lead time, rated as second and the defined MOQs, rated as fifth. Other factors are considered differently (Strommer et al, 2022a).

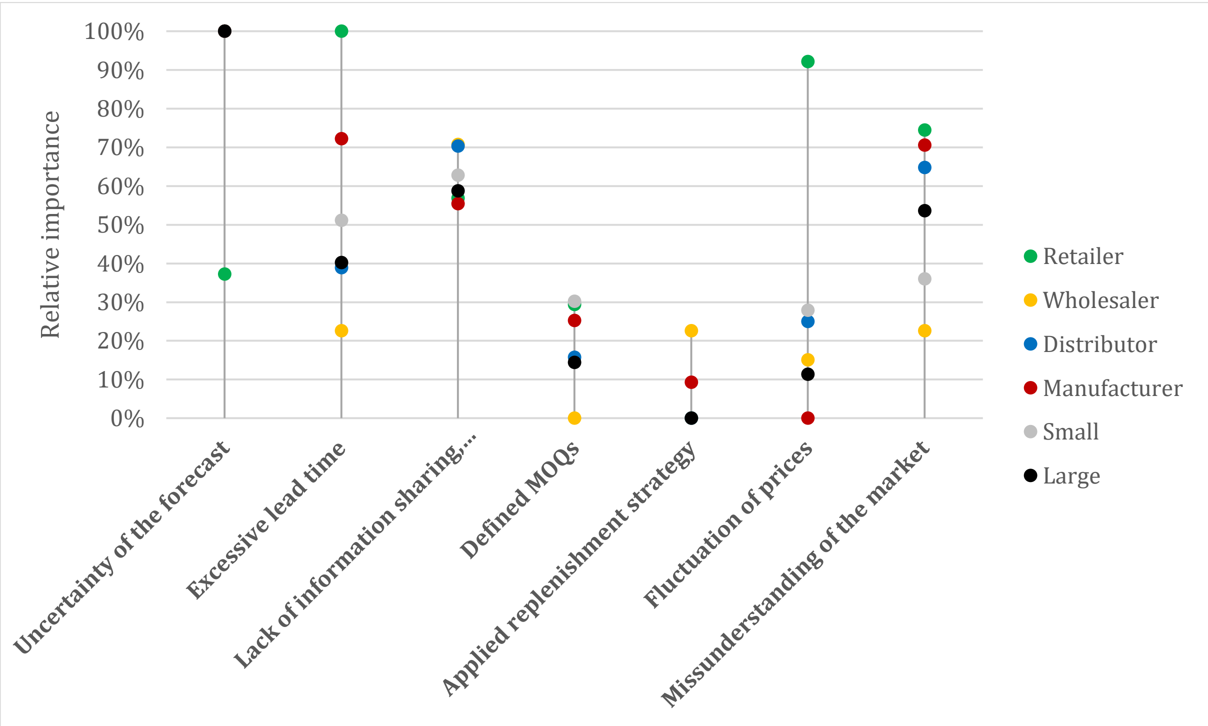
The relative importance has been checked for company size and supply chain role also visualized on Figure 31. The importance of the forecast uncertainty is inevitable. Only retail segment has not 100%. As opposite, MOQs and replenishment strategies are rated on low level. In average importance is 18% for the MOQ and only 4% for replenishment strategy. Rating of the other four factors is diverse. Regarding place in the ranking and importance differences can be also found. Misunderstanding of the market is rated as third most important in supply chain level split at all levels. Still relative importance is moving on high scale. For wholesaler it is only 23% in contrary for the retailer’s 75%, and manufacturing’s 71%. Lead time’s relative importance is also moving on a wide scale. The level of agreement regarding it is the strongest at the manufacturing and retail levels (Strommer et al, 2022a).

Table 15: Ranking on company size and supply chain echelon level

Factor	Ranking					
Total ranking	**SME**	**Large**	**Retailer**	**Wholesaler**	**Distributor**	**Manufacturing**
Uncertainty of the forecast	1	1	5	1	1	1
Misunderstanding of the market	4	2	3	3	3	3
Excessive lead time	3	3	1	3	4	2
Lack of information sharing, transparency	2	4	4	2	2	4
Defined MOQs	5	5	6	7	6	5
Fluctuation of prices	6	7	2	6	5	7
Applied replenishment strategy	7	6	7	3	7	6

Source: Author's edition

Figure 31.: Relative importance of the ranking on company size and SC role level



Source: Author's edition

Level of agreement

To evaluate the overall ranking, degree of agreement needs to be defined using Kendall's coefficient of concordance (W). As the survey has respondents from different countries, industries, supply chain role and company size, it has not only been calculated for the whole multitude but also for selected groups. The overall results are presented in Table 16. (Strommer et al, 2022a).

Value of concordance for the whole multitude is 0,245. This is almost the lowest within the examined groups. Only the small sized companies' response had lower value. As 89% of the responds came from Hungarian location, I have also checked the concordance for these respondents. W value for this group is 0,259 and it is still significantly low but higher than the total (Strommer et al, 2022a).

Business filter resulted in improvement in level of agreement regarding automotive and machinery industry. Regarding food industry level of concordance is slightly higher than the total. Acceptance of the hypothesis is based on the p value. Applying it considering the sample size and the W value the H_1 hypothesis can be accepted for all cases. The respondents have agreement regarding ranking of the factors on industrial level (Strommer et al, 2022a).

Table 16.: Concordance values

Analysed multitude	W	p-value	Sample number	α= .05	α= .01
Total	0,24525	8,4181E-22	76	ACCEPT	ACCEPT
Hungary based	0,25907	1,6185E-20	68	ACCEPT	ACCEPT
Automotive	0,32967	5,5578E-07	20	ACCEPT	ACCEPT
Food	0,25978	4,6930E-03	12	ACCEPT	ACCEPT
Machinery	0,36941	2,9916E-09	23	ACCEPT	ACCEPT
Small	0,13005	2,1658E-02	19	ACCEPT	REJECT
Large	0,62590	2,9912E-36	47	ACCEPT	ACCEPT
Retailer	0,45696	8,9402E-02	4	REJECT	REJECT
Wholesaler	0,32388	1,3711E-01	5	REJECT	REJECT
Distributor	0,20818	3,4418E-04	20	ACCEPT	ACCEPT
Manufacturing	0,32267	1,8832E-17	47	ACCEPT	ACCEPT

Source: (Strommer et al, 2022a)

Checking the data set based on the size of the company resulted in interesting outcome. The small sized companies have high difference in opinions. In contrary large companies have the highest level of agreement on preference list. The agreement between respondents from small sized companies is not statistically significant (Strommer et al, 2022a).

Investigation can also be done based on the supply chain level. From this extent, retailer level's respondents seem to have the strongest consistency. Due to the low number of samples H_1 hypothesis is rejected. Even dough value of 'W' seems lower, due to the higher sample based on p value H_1 hypothesis can be accepted for distributor and manufacturing level of the supply chain (Strommer et al, 2022a).

It is also important that the result cannot be generalized. The difference on industry, supply chain echelon and company size level shows that subjective opinion is different based on several factors. On these differentiations the respondents face variant difficulty, working environment and opportunity. These are highly influencing subjective decision of the person (Strommer et al, 2022a).

5.9. Evaluation of the hypotheses of the survey

Based on the survey six hypotheses have been formed regarding the expected outcomes. The results are summarized below

H_1: The respondents working for large companies experience unreasonable fluctuation of stock level

Table 10 shows that large companies experience the unreasonable fluctuations in most of the cases (51%) meaning this hypothesis can be accepted.

H_2: Length of accepted lead time differs highly based on industrial segment

To confirm this hypothesis lead time have been checked in the whole multitude and in the most represented three industries: machinery, automotive and food industry. Figure 23. shows the responses categorised in 6 groups. In food industry accepted period is the shortest meaning the longest reported lead time could be 60 days. For automotive 30-60 days is the most typical and in machinery industry the time acceptance is within wide barriers.

The hypothesis can be accepted as in food industry no longer than 60 days can be accepted. In contrary in machinery industry 8% of the respondents accept 90 days or more as lead time.

H_3: Respondents consider length of the supply chain as crucial factor regarding effective operation

The hypothesis is confirmed from both sides. Length of the supply chain can consider number of members or geographical distance. The Pareto chart shows (Figure 26.) for the whole multitude that these two factors are considered with highest impact on effective operation. Considering industrial level split (Figure 27.) the hypothesis is also confirmed. Long geographical distance is the second in machinery and automotive industry and high number of echelons is first both at automotive and food industry.

H_4: Ranking of the pairwise comparison changes on industry level

Table 14. shows the ranking for the whole multitude and for the industrial segments. The similarity is only occurring in the first place, uncertainty of forecast is considered as the most problematic resulting the acceptance of the hypothesis

H_5: Concordance value is expected to be low (W<0,3). Professionals have different view on bottlenecks regarding efficient operation.

The hypothesis can be accepted as concordance value is 0,245 for the whole multitude.

H_6: The concordance value is higher if the calculation is on industry level (e.g., automotive industry) ($W_{industry}>W_{overall}$)

The hypothesis can be accepted as concordance value is higher for all checked industrial segments:

$$W_{machinery}(0,369)>W_{automotive}(0,329)>W_{food}(0,259)>W_{total}(0,245)$$

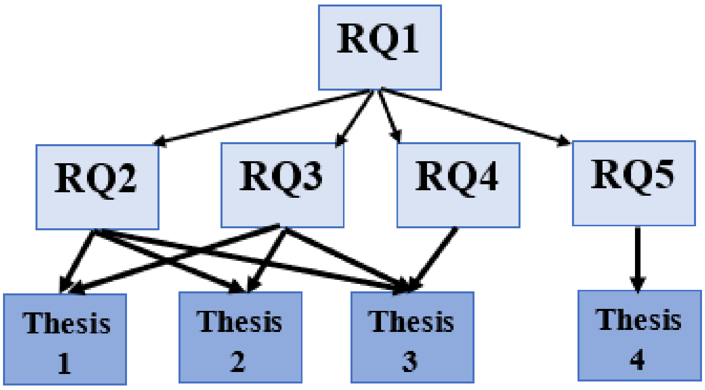
6. THESES

The business network and environment are complex and complicated. Focus needs to be divided between several relevant and important area. Supply chain instability is only one factor. Bullwhip and ripple effect are symptoms of the instable operation. As both phenomena are intangible and hard to be precisely defined mostly no capacity can be dedicated to only monitor the occurrence. Targeted analysation is typically missing. Nonetheless the impacts are still harmful. Most of the practical approaches are based on case studies that are only working under special circumstances and requires the understanding of the mathematical background. The results gained in the studies are difficult to interpret. Due to the competition cost pressure is also high. Companies cannot allocate much resource on investigation of single element of the performance. The opportunities are rather on application of the existing resources (employees, measures, systems) and tools (KPI, performance frameworks).

My dissertation aims to investigate the potential elimination of the supply chain instability. Specially concentrates on the bullwhip effect. For this, the ideas presented are resource friendly first steps that can support to build up a more conscious operation of the supply chain. Below methods are using existing measures or tools. Change is mainly in the approach or the field of utilisation.

Referring to the research questions phrased in Chapter 2.1. the summary of the findings is presented in the theses. The connection between the research questions and the four phrased theses are present in Figure 32. Research question 1 examines the existence of the supply chain instability, the existence of the bullwhip and ripple effect ("In spite all research made do bullwhip effect and ripple effect still exist?"). This question is validated by the results of the case studies and even the further questions. Question 2 is on the existence of the performance measurement or quality engineering toolkit regarding the detection of the bullwhip effect (Is there a comprehensive performance measurement or quality engineering toolkit exist to detect the bullwhip effect and/ or the ripple effect?) and question 3 is checking based on this if the answer is now the need for one ("If the answer for RQ2 is „no", is it possible to have?"). These questions relate to the first, second and third theses. In these the potential usage of PM tools (BSC and single metrics) and quality engineering tools (FMEA tools) is stated. Research question 4 is checking if the need for these tools is valid ("Is it real need to have one?"). This question is answered by the third thesis showing practical potential of the usage of the quality engineering tools. Research question 5 is on sectoral differences ("Are there any sectoral differences regarding the needed approaches to handle the bullwhip effect?"). This is connected to the fourth thesis showing the results of the survey that explains the differences between the understanding of the bullwhip effect on sectoral and supply chain role level.

Figure 32.: Research questions and theses



Source: Author's edition

Thesis 1.

Bullwhip effect reasons can be matched with the Balanced Scorecard structure. This enables the proper categorization of measures and reaching higher potential control on BWE phenomenon.

Balanced Scorecard (detailed analysis of the topic on Chapter 3.2.) as a frame support the users to see the applied measures in a transparent and structured way. Due to this the KPI are not only showing single results but as part of a measurement system they can be analysed from the required perspective. As the BSC is used in a personalized way the integrated measures can support the chosen goals. This framework is likely to be applied for logistic purposes due to the balanced structure.

The goal of the BSC can be targeted toward the recognition, reduction, and prevention of the presence of the bullwhip effect. To reach this purpose the potential reasons of the phenomenon should be matched with the perspectives. Once the two side is matched metrics need to be defined. Table 17. shows the matching of the Balanced Scorecard perspectives, and the bullwhip effect reasons. It also shows potential KPI to be used in each segment of the scorecard.

At this point also the chain and industry specific characteristics are defining the relevant and critical measures. In the Balanced Scorecard structure, it is also possible to use weights. All the measures currently in use should be considered. In addition, potential further metrics can be added considering the chain specific characteristics. Once the relevant measures are collected Balanced Scorecard structure should be used to create the needed frame.

Table 17.: Balanced Scorecard perspectives, bullwhip effect reasons and measures

Balanced Scorecard		Bullwhip effect		Potential measures
Innovation and growth	improvement actions long term focus deeper understanding of performance	**Rationing game**	affecting the whole chain strategical aspect	• number of supply chain echelons • number of harmonized local KPI • frequency of shortages
Internal business	existing processes operational metrics	**Order batching**	replenishment policy time frame	• Safety stock level, • Lot size
Financial	costs related measures	**Price variation**	promotional impact price changes	• Bias • Price level fluctuation, • Number of promotions
Customer	customer satisfaction loyalty	**Demand signal processing**	forecasting uncertainty estimation based planning	• Forecast Accuracy • Service level

Source: Author's edition

BSC is grouping the chosen metrics based on the purpose of the application. The characteristics of the examined chain determine the range of measures. The frame can be set up this way to detect and eliminate bullwhip effect. As the final step, target of the BSC usage also needs to be considered. It can be a long-term analysis focusing on the evaluation of processes aiming at the improvement of the operational work. This results in decreasing probability of the occurrence of the phenomenon. Besides this the goal can also be better visibility of the emerging phenomenon. This gives opportunity to deal with to consequences and reduce the impacts generated.

Balanced Scorecard is a good framework to group the metrics that shows the presence of the bullwhip effect. The reasons of the BWE fits well with the BSC structure. Using the measurement system is potentially support the detection of the phenomenon. This gives opportunity to have better control on it. It is also basis of process improvement actions that leads to the elimination of the bullwhip effect. Balanced Scorecard can be used as indicator framework of the BWE.

Thesis 2.

Usage of proper performance metrics can indicate the presence of the bullwhip effect. The proper set of KPI can indicate the phenomenon.

Bullwhip effect is a phenomenon with both scientific and business importance. The occurrence leads to decrease in performance, direct and indirect costs. The current competitive environment puts pressure on the supply chain operations. To gain advantage on the market, supply chain needs to be competitive as well. At the same time the capacity to improve processes is also limited. Human and cost level limitations narrow down the possibilities.

Currently scientific and practical approaches are separated. There are several case studies and best practices to support handling the bullwhip effect. However, these are specialized on the studied environment and characteristics. Adaptability of these best practices are very limited. Mostly high level of mathematical knowledge is required for the implementation.

Forecast accuracy, forecast bias and service level (detailed analysation of these indicators are in Chapter 3.5.) are key performance indicators that are used in multiple industry in all levels of the supply chain. The aim of the usage is improving the quality of the estimations to reach higher level of customer service. These KPI are comparing the estimations with the real demand value. Forecast accuracy shows the deviation between the actual sales and the forecasted demand. Bias also shows the direction of this deviation if the product is under or over forecasted. Service level is giving information on the quality of the service, it compares the ordered and delivered quantities.

Bullwhip effect is influencing the value of these metrics, as in all calculation the demand is playing important role. The measures are showing the deviation from the targeted value. Forecast accuracy and bias are currently mainly supporting extraordinary cases. Such as allocation planning in case of shortage or indication of need for selling the overstock. In daily use it is less in focus, they are rather used to evaluate the performance of the employees or system. Service level is more considered also in the daily operation, due to the customer focus approach. This measure is mainly used for local, echelon level purposes, mainly for monitoring of the unexpected bottlenecks.

Targeted usage of these measures can support conscious operation on chain level. It can help in early recognition and more successful handling of the phenomenon. As the KPI are existing and known in the chain the additional resource requirement is not high.

Based on the scope of the mentioned indicators it can be used from bullwhip effect extent in three different timing. FCA and FB can indicate the presence of the bullwhip effect in early stage. This can support to avoid the spread of the phenomenon within the chain. The SL is supportive regarding the mitigative actions. It can clearly highlight the points where the firefighting is needed. For analytic purpose all the mentioned indicators can be used. They support to determine the time periods when the demand was out of the targeted frame. They can also support to see if there is any unplanned trend or seasonality that need to be considered.

This approach is not aiming to solve all the negative impacts of the bullwhip effect in one step. The goal is giving a solution to make the first step. This solution is using the existing resources and processes. It adds a new perspective to a tool in use. The requirement is slight change on the way of reading and understanding of the measures and higher awareness of the phenomenon. On mid-term it can have process improvement effect also, as it leads to better visibility on the bullwhip reasons of the examined chain or echelon.

In the continuously changing environment this subsequent analysis enables the process to be investigated from a different perspective. Additional information can possibly be explored. Combination of preliminary, on the spot and subsequent analysis give chance to evaluate the process considering all the perspectives. The analysis can be specified based on the characteristics of the given chain member and considering the main attributes of the chain. Easy adaptation is due to the measure's flexibility.

The conclusion reached by indicator and mitigative KPI should also be integrated to the subsequent analysis. It is supplemented by the potential listed measures to see all the aspects. The investigation of the full picture gives chance initiate process improvement actions that are targeting the reduction of the impacts caused by the bullwhip effect.

Thesis 3.

Quality management approach can support the detection of the instability of the supply chain. FMEA tools can be applied in analysation of it.

Bullwhip effect analysis and FMEA tools (Chapter 3.6) are not connected with each other based on the literature. FMEA tools are aiming to support the quality management and the process improvement purposes. This does not mean that they are not able to cover other areas. Even if the common research so far was not typical, the potential is there to improve the performance through the connection of them. The goals are not far from each other. The process improvement approach is also part of the aims of bullwhip effect analysis. The phenomenon can be handled better through targeted improvement of processes.

One of the difficulties regarding the bullwhip effect is the limited tangibility. Due to this the overall understanding of the phenomenon can be low. Adaptability of the best practices or case studies is also limited due to the number of factors that needs to be considered. In addition, limited resources are available, that further complicate the analysis. To ensure better visibility of the phenomenon, application of existing resources and processes can be the solution. With proper summarization and logical visualization, the level of understanding can increase.

FMEA is applied frequently considering the most bullwhip relevant supply chains. These are complex networks that has multiple echelons. The cooperation needs to be kept under control. This is also true from quality perspective. FMEA aims to maximize the customer satisfaction through reaching the highest potential of the product or service.

FMEA apply multiple tools to visualize problems, processes, or hierarchical connections. These tools can support the bullwhip effect also. Application of fault tree analysis and Ishikawa diagram is possible regarding the bullwhip effect (Figure 5,6,7,11,15,16,17,18). This visual approach has two main advantages:

- **increase the level of understanding**: People of related departments can understand better the bullwhip effect. They can see the consequences of mistakes or decisions they make (for example sales department can see the potential impact of the unplanned promotions). It can be also used as part of executive summary to highlight areas where process improvement approach would be needed.
- **highlight the main reason of bullwhip effect in the analysed chain**: The reason behind the phenomenon is available in the literature but still it differs chain by chain. To see the realistic picture that considers the practical circumstances the visual tools of FMEA mean great support. It can draw the attention to the most crucial point, highlight the areas where actions need to be taken.

Beside the mentioned visualization tools others can also be implemented such as Pareto chart (Chapter 5.6.). From bullwhip effect perspective it can be a prioritisation tool. This ensure that the most problematic element is handled first. This also can bridge the gap in understanding between departments. During the data collection people with different scope and focus can be involved. As a result, the priority list should consider all the different aspects.

A survey has been conducted among logistics professionals. Based on the questions Pareto analysis have been executed. Results are available in details in Chapter 5.6. The survey intended to collect information on bullwhip effect relevant factors influencing the effective operation of the supply chain. The elements examined are the following:

- long lead time
- high number of echelons
- long (crossing continents) geographical distance in the supply chain
- lack of transparency (roles, responsibilities, flow of goods, allocation process, changes (e.g., price), etc.)
- lack of information sharing
- the applied forecasting strategy
- not properly planned price changes, promotions
- defined minimum order quantity

As a result of the pareto analysis the daily work is impacted the most by the length of the supply chain (number of echelons, geographical distance) and the long lead time. Pareto analysis highlights the fields that need to be further investigated. Using the example, the chain itself cannot be shorted immediately but improvement actions can be initiated. Such as additional warehouse capacity, bigger production buffers to increase flexibility, faster delivery options (such as railway or air), additional production locations, etc.

Risk matrix can also be used from the quality management toolbox. Here instead of the three angle (occurrence, severity, detectability) only two considered: severity and occurrence. Using this method, we can also highlight critical elements. In the risk matrix built based on the survey (Figure 28, 29) lack of information sharing and lack of transparency is highlighted as frequently occurring, serious risk. These elements are also supportive in initiation of improvement action. Such as more clearly defined roles and responsibilities, introduction of regular meetings, harmonization of the KPI setup.

In my work I examined the applicability of two visualisation tool typically used by FMEA: Ishikawa and fault tree analysis and three ranking and prioritization tool: Pareto chart, risk matrix and pairwise comparison. All mentioned tool is applicable also for the bullwhip effect investigation.

Thesis 4.

Based on the perceptions of the supply chain members the reasons behind the bullwhip effect can be weighted, the main reason can be determined.

The perception of the bullwhip effect reasons have been examined by a survey (detailed analysis of data in Chapter 5.). A survey has been sent out to supply chain professionals working with inventory and forecast. The aim was the investigation of the influence of the bullwhip reasons on their work. The analysis has been executed through two different methods. First is a general question regarding the experience on the stock level changes. Below questions have been asked:

- Do you experience fluctuation of the stock level (raw material, semi-finished or finished goods)? (Yes/No)
- Do you consider the fluctuation of the stock level reasonable? Please rate in a 1 to 5 scale where 1 reasonable – 5 unreasonable

In most of the cases fluctuation of stock level was recognised by the respondents (98,5%). The level of reasonability is according to Table 10. in Chapter 5.4. Based on the results 28% of the respondents consider the fluctuation reasonable (marked 1 or 2 on the scale). 46% experience not reasonable fluctuation of the stock level, the bullwhip effect.

For more detailed analysis seven factors have been determined. These factors are considered as bullwhip effect reasons:

- uncertainty of the forecast
- excessive lead time (due to number of echelons, and/or geographical distance)
- lack of information sharing, transparency
- defined order quantities (overstock due to the high MOQs)
- applied replenishment strategy
- fluctuation of prices; and misunderstanding of the market (changes, demand).

These factors have been compared using pairwise comparison. The result has been analysed on sample level and for the whole multitude. The outcome is a ranking of these factors both on total level and on groups of responders (company size, industry, supply chain role level). The level of agreement needed to be checked. For this the Kendall’s coefficient of concordance (W) have been used.

The concordance has also been determined on different levels (Table 16.). Beside the whole multitude it has also been checked for the highest represented industries of the sample, for the different supply chain levels and the different company sizes.

Based on the calculated p value both on 95 and 99% significance level the agreement of the whole multitude is statistically significant. The value is also accepted on industry level. Considering the value of the ‘W’ the result shows that the industrial level analysis shows stronger agreement between the respondents than the overall. This is also true for the company size and the supply chain level-based split.

The W value is only rejected for two groups: retailer and wholesaler. This is due to the low number of responses received. On 99% significance level it is also rejected for the small companies group. This can be explained by the various industrial segments appearing in this group.

As based on the result an overall order of factors can be determined. It also visible from the numbers that once the analysis is narrowed down to samples with similar background (such as industry) the level of agreement is increasing.

89% of the respondents of the survey are working in Hungary. As this portion is quite big the results are mainly applying to Hungarian companies. From industrial perspective the presence of machinery, automotive and food industry is intense. This also influence the overall ranking. This means that the result has limitations. Results confirm that using pairwise comparison is applicable to get ranking of the main bullwhip effect factors. This means that using this technic the bullwhip effect reasons can be prioritized and targeted actions can be initiated.

Further research directions

The research has several possibilities to be continued and deepened. Range of analysed indicators can be extended. This extension can be supported by a survey checking the used measures in all levels of the supply chain. The goal is to find further metrics used in all levels of the supply chain in multiple industries. Beside the extension of the range practical measures can also support the more detailed explanation of the application. This needs different industrial areas to be checked in order to have a comprehensive picture.

Analysing of possibilities is important but practical usage of it needs to be supported as well. Beside publications more practical methods are needed. Video sharing platforms such as ‘youtube’ can be a solution for sharing videos showing how the application of metrics can work. It can break the first barriers down if it shows that improvement potential is higher than the extra workload. Beside online solutions offline ones should also be considered. The information can be shared on trainings or courses. In Hungary for this approach MLBKT (Magyar Logisztikai, Beszerzési és Készletezési Társaság - Hungarian Association of Logistics, Purchasing and Inventory Management) can be a potential partner.

Application of a survey can not only support regarding applied measures but also regarding performance measurement tools. Beside the applied tools it can also highlight the advantages and disadvantages showing the realistic requirements toward the frameworks. Retaking the survey to analyse a chosen supply chain is also a potential next step. It can lead to more detailed information and action plan both from pairwise comparison or the other questions. The list of factors can also vary based on the circumstances.

In analysis it worth to choose a tool that also logs time date question by question. Seeing on respond level the time spent on each question can highlight the factors that are the most questionable. In the current analysis this information was not tracked.

As FMEA turned out to be an area that has adaptable tools this direction can be further analysed. Other existing FMEA tools can be checked if they can be applied. In addition, it can also be highlighted with deeper understanding of quality processes how bullwhip effect can be part of standard FMEA processes. Nevertheless, it is also crucial to see what set of information is worth to check regarding the bullwhip effect as inputs to FMEA.

Besides FMEA quality management and quality engineering has several further best practices. Those can also be checked to see if there is any similarity in scope or way of working that can lead to potential connection with the examined area.

SUMMARY

As my goal is bridging the gap between practice and theory the literature review is first built on widely accepted books. This is the source that is likely to be used in practice. Based on the learnings I continued the analysation concentrating on symptom of the supply chain instability. The analysis is using a literature mapping technique resulted in extension of research scope to the area of performance measurement.

The analysis regarding performance measurement was both focusing on single measures and measurement framework. Regarding the single measures forecast alignment, forecast bias and service level has been checked. Both measures have influence on the value of the bullwhip effect. Application of a different viewpoint during the operational usage can support the detection of the BWE. Balance Scorecard has been further investigated as a framework. It's perspectives and reasons of the phenomenon have much in common. Using the structural advantages bullwhip measurement can support the reason level elimination of it.

The other partner area checked is the quality management. Out of the several methods and models FMEA has been chosen, as it is widely used in practice and commonly appear also in research. Out of the tools available under the umbrella of quality management visualisation, risk assessment and ranking tool has been further investigated. Fault tree analysis and Ishikawa diagram has been used as organisational and visualisation tool; Pareto chart and risk matrix has been chosen as risk assessment tool; and pairwise comparison has been used as ranking tool.

The analysation has been followed by case studies both from primer and seconder sources. These case studies are showing the occurrence and handling of the bullwhip effect from multiple angles. Beside presentation of the cases Ishikawa diagram is also built up for all to have visual summarisation.

Case studies are followed by a survey analysing the perception on the bullwhip effect and the reasons of the phenomenon. The aim was building up a method that can determine the main reasons of the bullwhip effect which enables to eliminate it by targeted improvement of the processes. The analysis applied Pareto chart and risk matrix to determine the factors highly influencing the efficient operation. It also used pairwise comparison to show the ranking of the bullwhip reasons. This approach can support having comprehensive understanding of the weak points and bottlenecks and enabling taking the first step in the analysed SC in order to decrease level of instability. The analysis showed the sectoral differences through the result. It also strengthened the assumption that understanding of the bullwhip effect is very diverse and there are still informational gaps on the phenomenon.

MAGYAR ÖSSZEFOGLALÓ

Disszertációmban először a szakirodalmi háttér fogalmai keretének tisztázását végeztem el. Célom a gyakorlat és elmélet közötti távolság csökkentése, a fogalmi alapokat széleskörben elfogadott szakkönyvekre fektettem, hiszen ez a gyakorlati szakemberek által preferált forrás. A munkám az ellátási lánc instabilitást kiváltó tényezőre koncentrálva folytattam, melyhez a tudományos térképkészítés technikáját alkalmaztam, ez alapján terjesztve ki a kutatás területét a teljesítmény értékelésre.

A teljesítmény értékeléssel kapcsolatos elemzés mérőszámokra és mérési rendszerekre egyaránt vonatkozott. A mérőszámok tekintetében az előrejelzés pontosságát (*FCA),* az eltérés mértékét (*FB)* és a kiszolgálás színvonalát (*SL)* vizsgáltam. Az említett mutatók mindegyikére hatással van az ostorcsapás effektus. Számításuk során új nézőpont alkalmazása elősegítheti a jelenség felismerését. Mérési rendszerként a Balanced Scorecard vizsgálatát végeztem el, melynek perspektívái nagy hasonlóságot mutatnak az ostorcsapás effektus okaival. Ez a szerkezeti előny kihasználható az ostorcsapás okainak felismerésére és megszüntetésére.

A minőség menedzsment területén számos modell és módszertan használata jellemző, melyek közül a kutatás során a gyakorlat és elmélet által egyaránt alkalmazott FMEA módszertan került kiválasztásra. Az alkalmazott eszközök közül vizualizációs, kockázat felmérő, illetve sorrend alkotó módszerek kerültek kiválasztásra. A hibafa és az Ishikawa diagramm a rendszerezett megjelenítés, a Pareto diagram és a kockázati mátrix a kockázat felmérés, a páros összehasonlítás pedig a sorrend alkotás területén került alkalmazásra.

A vizsgáltom esettanulmányok bemutatásával folytattam, melyik primer és szekunder forrásokat egyaránt alkalmaznak. Ezek az ostorcsapás effektus megjelenését és kezelését mutatják több szemszögből. A tapasztalatok bemutatása mellett Ishikawa diagramm alkalmazásával rendszerezetten is bemutatom a tapasztalatokat.

Az esettanulmányokat egy kérdőíves elemzés követi, amely az ostorcsapás effektus okaival kapcsolatos tapasztalatokat vizsgálja. A cél egy módszertan felépítése volt, ami segít a vizsgált esetben az ostorcsapás effektus kiváltó okait rangsorolni ezáltal célzott fejlesztésre ad lehetőséget. Munkám során Pareto diagramot és kockázati mátrixot alkalmaztam a hatékonyságot hátrányosan befolyásoló tényezők meghatározására, páros összehasonlítást pedig az okok rangsorolására. Ez a módszer átfogó képet a szűkkeresztmetszetek kapcsán és lehetővé teszi az első lépés megtételét, ami az ellátási lánc instabilitásának csökkentéséhez vezet. Az elemzés során megjelenő ágazati eltérések megerősítették azt a feltételezést, mely szerint a jelenség sokrétűen értelmezhető, és információs hiányosságok jellemzik.

REFERENCES

Abul-Haggag, O. Y., Barakat, W. (2013): Application of Fuzzy Logic for Risk Assessment using Risk Matrix, International Journal of Emerging Technology and Advanced Engineering, Volume 3

Appadu, A. R., Kelil, A. S., Tijani, Y. O. (2021): Comparison of some forecasting methods for COVID-19, Alexandria Engineering Journal, Volume 60, Issue 1

Bandyopadhyay, S. & Bhattacharya, R. (2014). Solving a tri-objective supply chain problem with modified NSGA-II algorithm, *Journal of Manufacturing Systems*, 33, 41-50

Balfaqih, H., Nopiah, Z. M., Saibani, N. & Al-Nory, M. T. (2016). Review of supply chain performance measurement systems: 1998–2015, Computers in industry, 82, 135-150

Behzadi, G, O'Shullivan, M. J., Olsen, T. L. (2020): On metrics for supply chain resilience, European Journal of Operational Research, volume 287

Bhattacharya R., Bandyopadhyay S. (2011): A review of the causes of bullwhip effect in a supply chain; The International Journal of Advanced Manufacturing Technology volume 54, pages1245–1261 (2011)

Bourguignon, A., Malleret, V., Nørreklit H. (2004): The American balanced scorecard versus the French tableau de bord: the ideological dimension, Management Accounting Research 15 (2004) 107–134

Buhniya, S., Pareek, S., Sarkar, B. (2021): A supply chain model with service level constraints and strategies under uncertainty, Alexandria Engineering Journal, Vol. 60, pages: 6035-6052

Can, E., Erbiyik H. (2016): Determination of the Risks That Are Emerged from the Use of Aerial Photographs in the Mapping Activities for Landslide Movements by FMEA and Pareto Analysis Methods and Suggested Solutions, Procedia Engineering, Volume 161

Cao, Q., Baker, J., & Schniederjans, D. (2014). Bullwhip effect reduction and improved business performance through guanxi: An empirical study. International Journal of Production Economics, 158, 217–230. https://doi.org/10.1016/j.ijpe.2014.07.030

Chambers, J. C., Mullik, S. K., Smith, D. D. (1971): How to Choose the Right Forecasting Technique, Harvard Business Review, Volume: July 1971

Chang, W-S, Lin, Y-T (2019): The effect of lead time on supply chain resilience performance, Asia Pacific Management review, Vol. 24, 298-309

Chopra, S., Meindl, P (2016): Supply Chain Management: Strategy, Planning, and Operation, Sixth edition, Pearson Education Limited, 2016

Chytas P., Glykas M., Valiris G. (2011): A proactive balanced scorecard, International Journal of Information Management 31 (2011) 460–468,

Cousins P. at al. (2008) Strategic Supply Management, Harlow, England: FT Prentice-Hall, ISBN: 978-0-273-65100-0

Daum, J. H. (2005): French Tableau de Bord: Better than the Balanced Scorecard? Der Controlling Berater, No. 7, pp. 459-502.

Dejonckheere, J., Disney, S. M., S. M., Lambrecht, M. R. & Towill, D. R. (2003). Measuring and avoiding the bullwhip effect: A control theoretic approach, *European Journal of Operational Research*, 147, 567-590

Dejonckheere, J., Disney, S. M., Lambrecht, M. R. & Towill, D.R. (2004). The impact of information enrichment on the Bullwhip effect in supply chains: A control engineering perspective, *European Journal of Operational Research*, 153, 727-750

Disney, S. M., Farasyn, I., Lambrecht, M. R., Towill D. R., Van de Velde, W. (2007): Controlling bullwhip and inventory variability with the golden smoothing rule, European J. of Industrial Engineering (EJIE), Vol. 1, No. 3, 2007

Disney, S. M., Lambrecht, M. R. (2008): On replenishment rules, forecasting, and the bullwhip effect in supply chains, Foundations and trends® in technology Information and Operations Management, volume 2 (1)

Disney, S. M., Hoshiko, L., Polley, L., Weigel, C. (2013): Removing bullwhip from Lexmark's toner operations, POMS 2013 24th Annual Conference, Denver

Disney, S. M. & Towill, D. R. (2003a). On the bullwhip and inventory variance produced by an ordering policy, *Omega*, 31, 157-167

Disney, S. M. & Towill, D. R. (2003b). The effect of vendor managed inventory (VMI) dynamics on the Bullwhip Effect in supply chains, *International Journal of Production Economics*, 85, 199-215

Dolgui, A., Ivanov, D. & Rozhkov, M. (2019). Does the ripple effect influence the bullwhip effect? An integrated analysis of structural and operational dynamics in the supply chain. *International Journal of Production Research*, 58, 1285-1301

Ducq, Y. & Berrah, L. (2009). Supply Chain Performance Measurement: management models, performance indicators and interoperability, *IFAC Proceeding Volumes*, 42, 2053-2058

Faisal, M., N. (2006): Supply Chain Risk Management: A Framework, SCMS Journal of Indian Management, Volume 3., April-June, 2006.

Fernie, J, Sparks, L. (2019): Logistics and Retail Management: Emerging issues and new challenges in the retail supply chain , fifth edition, Kogan Page Limited, London, United Kingdom

Foley, C. F., Khavkin, M (2019): How companies should prepare their forecast, Harvard Business Review, Volume: April, 2019

Forrester, J. W. (1961): Industrial Dynamics, MIT Press

Fortune. (2020). 94% of the Fortune 1000 are seeing coronavirus supply chain disruptions: Report. Retrieved December 10, 2020, from https://fortune.com/2020/02/21/fortune-1000-coronavirus-china-supply-chain-impact/

Fu, D, Ionescu, C, Aghezzaf, E-H, Keyser, R (2015): Quantifying and mitigating the bullwhip effect in a benchmark supply chain system by an extended prediction self-adaptive control ordering policy, Computers and Industrial Engineering, volume 81

Geary, S., Disney, S. M. & Towill, D.R. (2006). On bullwhip in supply chains – historical review, present practice and expected future impact, *International Journal of Production Economics*, 101 (1), 2-18

Giannakis, M., Luis, M. (2011): A multi-agent based framework for supply chain risk management. Journal of Purchasing and Supply Management 17 (2011) 23-31

Giannakis, M., Papadopoulos, T. (2016): Supply chain sustainability: A risk management approach, International Journal of Production Economics, Volume 171, Part 4., pp 455-470, https://doi.org/10.1016/j.ijpe.2015.06.032

Govidan, K., Mina, H., Alavi, B. (2020): A decision support system for demand management in healthcare supply chains considering the epidemic outbreaks: A case study of coronavirus disease 2019 (COVID-19), Transportation Research Part E, Volume 138, 101967

Gray, G., Bronn, D., et al. (2019): Assessing aeromedical risk: a three-dimensional risk matrix approach, Heart 2019; volume 105:s9-s16

Grida, M., Mohamed, R., Zaied, A. N. H. (2020): Evaluate the impact of COVID-19 prevention policies on supply chain aspects under uncertainty, Transportation Research Interdisciplinary Perspectives, Volume 8, 100240

Gunasekaran, A. & Kobu, B. (2007)., Performance measures and metrics in logistics and supply chain management: a review of recent literature (1995–2004) for research and applications, *International Journal of Production Research*, 45 (12), pp. 2819-2840

Haines, R., Hough, J., Haines, D. (2017): A metacognitive perspective on decision making in supply chains: Revisiting the behavioral causes of the bullwhip effect, *International Journal of Production Economics*, 184, 7-20

Harrison A., Hoek R. (2008) Logistics Management and Strategy Competing through the supply chain 3rd edition, Harlow, England: FT Prentice-Hall, ISBN: 978-0-273-71276-3

Hyndman, R. J., Athanasopoulos, G. (2018): Forecasting: principles and practice, OTexts; 2nd edition,

Hosseini, S., Ivanov, D. & Dolgui, A. (2019). Review of quantitative methods for supply chain resilience analysis, *Transportation Research Part E,* 125, 285-307

Hosseini, S, Ivanov, D. (2020): Bayesian networks for supply chain risk, resilience and ripple effect analysis: A literature review, Expert Systems with Applications 161 (2020) 113649

Hsu, C.-H., Yang, X.-H., Zhang, T.-Y., Chang, A.-Y., & Zheng, Q.-W. (2021). Deploying Big Data Enablers to Strengthen Supply Chain Agility to Mitigate Bullwhip Effect: An Empirical Study of China's Electronic Manufacturers. Journal of Theoretical and Applied Electronic Commerce Research, 16(7), 3375–3405. https://doi.org/10.3390/jtaer16070183

Hugos, M. (2018): Essentials of Supply Chain Management, fourth edition, John Wiley and Sons Inc, New York, United States

Iijima, Y, Okumura, Y, et al. (2020): Assessing the hierarchy of personal values among adolescents: Acomparison of rating scale and paired comparison methods, Journal of Adolescence, volume 80

Ivanov, D. (2020): Predicting the impacts of epidemic outbreaks on global supplychains: A simulation-based analysis on the coronavirus outbreak (COVID-19/SARS-CoV-2) case, *Transportation Research Part E,* 136

Ivanov, D., Dolgui, A. & Sokolov B. (2015). Supply Chain Design with Disruption Considerations: Review of Research Streams on the Ripple Effect in the Supply Chain, *IFAC-PapersOnLine*, 48-3, 1700-1707

Ivanov, D., Dolgui, A. (2020): Viability of intertwined supply networks: extending the supply chain resilience angels towards survivability. Position paper motivated by COVID-19 outbreak. International Journal of Production Research, volume 58, issue 10

Ivanov, D., Tsipoulanidis, A., Schönberger, J. (2019): Global Supply Chain and Operations Management, Springer, Switzerland-Cham

Jagan Mohan Reddy. K, Neelakanteswara Rao. A & Krishnanand. L (2018). A review on supply chain performance measurement systems, *Procedia Manufacturing* 30 (2019), 40-47

Jensenius F. R., Htun M., Samuels D. J., Singer D. A., Lawrence A., Chwe M. (2008): The Benefits and Pitfalls of Google Scholar, Cambridge University Press

Jomthanachaia, S., Wong, W-P., Soh, K-L, Lim, C-P. (2021): A global trade supply chain vulnerability in COVID-19 pandemic: An assessment metric of risk and resilience-based efficiency of CoDEA method, Research in Transportation Economics, https://doi.org/10.1016/j.retrec.2021.101166

Kaplan, R. & Norton, D. (1992). The Balanced Scorecard Measures That Drive Performance, *Harvard Business Review*, pp. 71-79, 1992

Khosroshahi, H., Husseini, S.M. & Marjani, M. R. (2016). The bullwhip effect in a 3-stage supply chain considering multiple retailers using a moving average method for demand forecasting, *Applied Mathematical Modelling*, 40, 8934-8951

Kurien G.P., Qureshi M.N (2011).: Study of performance measurement practices in supply chain management. International Journal of Business, *Management and Social Sciences* Vol. 2, No. 4, 2011, pp. 19-34

Lee, H. L., Padmanabhan, V. & Whang, S. (1997a). Information distortion in a supply chain: the bullwhip effect, Management Science, 43, 546-558

Lee, H. L, Padmanabhan, V. & Whang, S. (1997b): The Paralyzing Curse of the Bullwhip Effect in a Supply Chain," Sloan Management Rev.

Lim, J. S. (2020): Quality Management in Engineering: A scientific and systematic approach, CRC Press, Taylor and Francis group, Boca Raton, United States

Lin, J., Zhou, L., Spiegler V. L. M., Naim, M. M., Syntetos, S. (2021): Push or Pull? The impact of ordering policy choice on the dynamics of a hybrid closed-loop supply chain, European Journal of Operational Research, Lindberg C. F., Tan S. T., Yan J. Y., Starfelt F. (2015): Key performance indicators improve industrial performance, The 7th International Conference on Applied Energy – ICAE2015, *Energy Procedia* 75 (2015) 1785 – 1790

Liu, L. Xu, H., Zhu, S. X. (2020): Push verse pull: Inventory-lead time trade off for managing system variability, *European Journal of Operational Research*, 287, 119-132

Luthra, S., Garg, D., Agrawal, A., Mangla, S. K. (2021): Total Quality Management (TQM): Principles, Methods, and Applications

Lyu, J., Chung, S-Y, Chen, T-L (2009): Integrating RFID with quality assurance system – Framework and applications, Expert Systems with Applications 36 (2009) 10877-108882

Ma, J. & Bao, B. (2017). Research on bullwhip effect in energy-efficient air conditioning supply chain, *Journal of Cleaner Production*, 143, 854-865

Magalhaes, R. F., Danilevicz, A. de M., Palazzo, J. (2019): Managing trade-offs in complex scenarios: A decision-making tool for sustainability projects, Journal of Cleaner Production, Volume 212

Manotas D. F, Cadavid L. R. (2007) Lean manufacturing measurement: the relationship between lean activities and lean metrics; Estudios Gerenciales Volume 23, Issue 105, Pages 69-83 https://doi.org/10.1016/S0123-5923(07)70026-8

Moller Christensen, F. M., Solheim-Bojer, C., Dukovska-Popovska, I., Steger-Jensen, K. (2021): Developing new forecasting accuracy measure considering Product's shelf life: Effect on availability and waste, *Journal of Cleaner Production*, Volume 288

Notay B. (2018): CORE becomes the world's largest aggregator, Jisc scholarly communications, https://scholarlycommunications.jiscinvolve.org/wp/2018/06/01/core-becomes-the-worlds-largest-aggregator/

Otto, A. & Kotzab, H. (2003). Does supply chain management really pay? Six perspectives to measure the performance of managing a supply chain, *European Journal of Operational Research*, 144, 306–320

Pastore, E., Alfieri, A., & Zotteri, G. (2019). An empirical investigation on the antecedents of the bullwhip effect: Evidence from the spare parts industry. International Journal of Production Economics, 209, 121–133. https://doi.org/10.1016/j.ijpe.2017.08.029

Ponte, B., Dominguez, R., Cannella, S., Framinan, J. M. (2022): The implications of batching in the bullwhip effect and customer service of closed-loop supply chains, International Journal of Production Economincs, Vol 244

Potter, A., & Disney, S. M. (2006). Bullwhip and batching: an exploration. International Journal of Production Economics, 104(2), 408–418.

Ramanathan, U. (2014). Performance of supply chain collaboration – A simulation study, *Expert Systems with Applications*, 41, 210-220

Ross R.T. "Optimum orders for the presentation of pairs in the method of paired comparisons". Journal of Educational Psychology, 25 (1934); 1934. 375-382

Rostamzadeh, R, Ghorabaee, M. K., Govidan, K., Esmaeili, A., Nobar, H. B. K. (2018): Evaluation of sustainable supply chain risk management using an integrated fuzzy TOPSIS-CRITIC approach, Journal of Cleaner Production 175 (2018) 615-669

Rushton A., Croucher P., Baker P. (2010) The Handbook of Logistics and Distribution Management 4th edition, London: Kogan Page, ISBN 978 0 7494 5714 3

Saffo, P. (2007): Six Rules for Effective Forecasting, Harvard Business Review, Volume: July-August 2007

Sarkis, J., Dewick, P., Hofstetter, J. F., Schröder, P. (2020): Overcoming the Arrogance of Ignorance: Supply-Chain Lessons from COVID-19 for Climate Shocks, One Earth, volume 3, issue 1

Sawik T. (2014) On the fair optimization of cost and customer service level in a supply chain under disruption risks, Omega, Volume 53, https://doi.org/10.1016/j.omega.2014.12.004

Seitz, A., Grunow, M., Akkerman, R. (2020): Data driven supply allocation to individual customers considering forecast bias, International Journal of Production Economics, Vol. 227

Sereshti, N., Adulyasak, Y., Jans, R. (2021): The value of aggregate service levels in stochastic lot sizing problems, Omega, Vol. 102

Silverstein, D. A. (2001): An Efficient Method for Paired-Comparison, Journal of Electronic Imaging, 2001

Simchi-Levi, D., Kaminsky, P., Simchi-Levi, E., Shankar, R (2008): Designing and Managing the Supply Chain: Concepts, Strategies and Case Studies; McGraw-Hill Education, 2008

Solanki, A. B., Rathod, A., Thakkar, J., Shah, G. (2021): Application of quality tools to reduce in rejection of ice cream cones: A case in ice cream cone making company; Materials today: Proceedings, volume 47, part 17

Shokrani, A., Loukaides, E. G., Elias, E., Lunt, A. J. G. (2020): Exploration of alternative supply chains and distributed manufacturing in response to COVID-19; a case study of medical face shields, Materials & Design, volume 192, 108749

Stamatis, D. H. (2003): Failure, mode and effect analysis: FMEA from theory to execution, second edition, American Society for Quality, Quality Press, Milwauke, 2003

Stamatis, D. H. (2014): Introduction to Risk and Failures: Tools and Methodologies, CRC Press, Taylor and Francis Group, Boca Raton, Florida, 2014

Stefanovic, S, Kiss, I., Stanojevic, D., Janjic, N. (2014): Analysis of Technological Process of Cutting Logs Using Ishikawa Diagram, Acta Technica Corviniensis, Bulletin of Engineering

Sterman, J.D. (2006): Learning from evidence in a complex world. American Journal of Public Health Volume 96 (3), 505–514.

Su, Y. & Geunes, J. (2012). Price promotions, operations cost, and profit in a two-stage supply chain, *Omega*, vol. 40, issue 6., 891-905

Sun, J., Tang, J., Fu, W:, Chen, Z., Niu, Y. (2020): Construction of a multi-echelon supply chain complex network evolution model and robustness analysis of cascading failure, Computers and Industrial Engineering, Vol. 144

Sung, Y-T, Wu, J-S (2018): The Visual Analogue Scale for Rating, Ranking and Paired-Comparison (VAS-RRP): A new technique for psychological measurement, Behavior Research Methods, volume 50

Szegedi Z. (2012): Ellátási lánc menedzsment, Kossuth publisher, Budapest

Tai, P. D., Duc, T. T. H. & Buddhakulsomsiri, J. (2019). Measure of bullwhip effect in supply chain with price-sensitive and correlated demand, *Computers & Industrial Engineering*, 127, 408-419

Tliche, Y., Taghipour, A., Canel-Depitre, B. (2019): Downstream demand inference in decentralized supply chains European Journal of Operational Research., Volume 274 (1), pp.65-77

Towill D. R., Zhou L., Disney S. M. (2007): Reducing the bullwhip effect - Looking through the appropriate lens; in. International Journal of Production Economics 108, pp 444-453

Trapero, J. R. & Pedregal, D. J. (2016). A novel time-varying bullwhip effect metric: An application to promotional sales, *International Journal of Production Economics*, 182, 465-471

Venkatesh, V.G., Rathi, S., Patwa, S. (2015): Analysis on supply chain risks in Indian apparel retail chains and proposal of risk prioritization model using Interpretive structural modelling, Journal of Retailing and Customer Service 26 (2015) 153-167

Wan, C., Yan, X., Zhang, D., Qu, Z., Yang, Z. (2019): An advanced fuzzy Bayesian-based FMEA approach for assessing maritime supply chain risks, Transportation Research Part E 125 (2019) 222-240

Wan, X., Sanders, N. R. (2017): The negative impact of product variety: Forecast bias, inventory levels, and the role of vertical integration, International Journal of Production Economics, 186, 123-131

Wang, X. & Disney, S. M. (2016). The bullwhip effect: Progress, trends and directions, *European Journal of Operational Research*, 250, 691-701

Warburton, R. D. H. & Disney, S. M. (2007). Order and inventory variance amplification: The equivalence of discrete and continuous time analyses, International Journal of Production Economics, 110, 128-137

Waters D. (2010) Global Logistics, London: Kogan Page, ISBN 978 0 7494 5703 7

Wiedenmann, M. & Größler, A. (2019). The impact of digital technologies on operational causes of the bullwhip effect – a literature review, Procedia CIRP 81, 552-557

Wisner J. D., Tan K-C, Leong G K. (2012) Principles of Supply Chain Management, Manson, USA: South-Western, ISBN 10: 0-538-47546-3

World Health Organisation (2020): WHO Director-General's opening remarks at the media briefing on COVID-19 - 11 March 2020, https://www.who.int/director-general/speeches/detail/who-director-general-s-opening-remarks-at-the-media-briefing-on-covid-19---11-march-2020

www.vosviewer.com

www.gephi.org

www.citnetexplorer.nl

Xing L., Amari S.V. (2008) Fault Tree Analysis. In: Misra K.B. (eds) Handbook of Performability Engineering. Springer, London.

Xuluo,Y. (2021): Measuring the bullwhip effect with market competition among retailers: A simulation study, Computers and Operations research, Volume 132

Yahya, N. bin (2021): Port Kaizen Implementation: A Malaysian Port Experience, Journal of Arts & Social Sciences, Vol 5., Issue 1., pp 69-85

Yang, Y., Lin, J., Liu, G., Zhou, L. (2021): The behavioural causes of bullwhip effect in supply chains: A systematic literature review, International Journal of Production Economics, Volume 236

Zarandi, M.H.F, Moghadam, F.S.(2016): Fuzzy knowledge-based token-ordering policies for bullwhip effect management in supply chains Knowledge and Information Systems, Issue 2, pp. 1-25

(2000) SEVEN "RIGHTS" OF LOGISTICS. In: Swamidass P.M. (eds) Encyclopedia of Production and Manufacturing Management. Springer, Boston, MA . https://doi.org/10.1007/1-4020-0612-8_871

Publications of the author

Diana Strommer, Norina Szander, Péter Földesi (2022b): Visualisation of the bullwhip effect phenomenon applying quality management tools. Accepted for 22nd Scientific Conference on Business Logistics in Modern Management, Osijek, Croatia, 6-7. October 2022.

Diana Strommer, Péter Földesi (2022): Bullwhip effect evaluation with indicators in use. Accepted for 22nd Scientific Conference on Business Logistics in Modern Management, Osijek, Croatia, 6-7. October 2022.

Diana Strommer, Norina Szander, Péter Földesi (2022a): Application of quality management tools in analysation of the bullwhip effect, Presented on: 21st International Symposium on Inventories, Budapest, 22-26 August 2022

Diana Strommer, Peter Földesi (2021b): COVID-19 impact on BWE research, IDK21 Pécs

Diana Strommer (2021): Bullwhip effect for all? Non sensitive supply chains, FIKUSZ'21

Diana Strommer, Peter Földesi (2021a): Connection of the Balanced Scorecard and the bullwhip effect, 21th Scientific Conference on Business Logistics in Modern Management, Osijek, Croatia

Diana Strommer, Peter Földesi (2020b): Contemporary scientific landscape of the bullwhip effect research, 20th Scientific Conference on Business Logistics in Modern Management, Osijek, Croatia

Diana Strommer, Peter Földesi (2020a): Az ostorcsapás effektus gyakorlati hatásai és elkerülése a megfelelő teljesítmény mutató rendszer alkalmazásával, DOSz KTO VI: Winter Conference, Gödöllő, Hunagry

Diana Strommer (2019): Potentials of KPI Synchronization in the supply chain, 15th Annual International Bata Conference for Ph.D. Students and Young Researchers

Diana Strommer, Peter Földesi (2018): Comparison of logistics performance measurement tools, Acta Technica Jaurinensis, vol 11

Diana Strommer (2017): Bullwhip effect in the FMCG industry, 13th Annual International Bata Conference for Ph.D. Students and Young Researchers

Norina Szander, Diana Strommer, Peter Földesi (2014): Recognizing the bullwhip effect by applying logistics performance measurement tools, 11th International Conference on Logistics and Sustainable Transport, Celje, Slovenia

APPENDIX

Appendix 1.: Survey/ Kérdőív

Kedves Kitöltő!

Strommer Diána vagyok, utolsó éves doktorandusz hallgató a Széchenyi István Egyetemen. Kutatásomban az ellátási láncok teljesítőképességével és az ostorcsapás effektussal foglalkozom. Az alábbi kérdőív kitöltésével nagyban hozzájárul a munkámhoz. A kérdőívben válaszokat tervezési, beszerzési, készletezési területről várok (készletgazda, gyártástervező, supply planning, demand planning, purchasing). Nagyon köszönöm a segítségét. A kitöltés 10 percet vesz igénybe.

Dear Respondent,

My name is Diana Strommer. I am a PhD student of Széchenyi István University. In my research I am analysing the supply chain performance and the bullwhip effect. Completing this survey would mean a great support for me. Please respond to below questions if you are a professionel from the field of planning, procurement, or inventory (production planning, supply planning, demand planning, purchasing). Thank you very much in advance for filling it in. It takes 10 minutes.

Tapasztalta Ön a készletszint (alapanyag, késztermék, félkész termék) ingadozását a munkája során? (Igen/Nem)

Do you experience fluctuation of the stock level (raw material, semi-finished or finished goods)? (yes/no)

Mennyire tartja ezt az ingadozást indokoltnak? Kérem jelezze az alábbi skálán! (1-legkevésbé/nem indokolt; 5-nagyon indokolt)

Do you consider the fluctuation of the stock level reasonable? Please rate in a 1 to 5 scale (1- not reasonable; 5-very reasonable)

Mi az az időpont, amitől már hosszúnak tekinti az átfutási időt? (pl. 35 nap, 2 hónap)

What is the point in time from when you consider the lead time long? (e.g., 35 days, 2 months)

Kérem válaszoljon igennel vagy nemmel az alábbi kérdésekre aszerint, hogy jellemző-e az ellátási láncra, amelyben dolgozik.

Please respond with yes or no on below questions based on your experience, whether it is true for the supply chain you work in.

Magyar	English	yes/no
A termék gyártása és értékesítése között hosszú idő telik el?	Do you consider the lead time between the production and the sales long?	
Sok szereplő van jelen az ellátási láncban, amelyben dolgozik?	Do you think the number of supply chain members is high at the chain you work for?	
Megjelenik nagy, kontinenseket átívelő földrajzi távolság a gyártás és az értékesítés között?	Is the long (crossing continents) geographical distance typical for your supply chain?	
Ön szerint/számára az ellátási lánc folyamatai átláthatóak? (feladatkörök határai, áruáramlás folyamata, felelősségi körök, allokációs folyamatok, változások (pl. ár) stb.)	Do you think that the supply chain you work in operates with transparent processes? (roles, responsibilities, flow of goods, allocation process, changes (eg. price), etc.)	
Jellemző-e munkája során, hogy a hiányos információ miatt nehézségbe ütközik?	Do you typically face difficulties in your role due to incomplete information flow?	
Az alkalmazott előrejelzési stratégia (forecasting strategy) kellően pontos eredményt ad?	Is the applied forecasting strategy leading to accurate enough result?	
Jellemzők-e a nem az ellátási lánc adottságainak megfelelően (kellő időben) tervezett ár változások/promóciós események az ellátási láncában?	Do you experience promotions or price changes that are not planned according to the needs of the supply chain (well in advance)?	
Ön szerint a rendelések során alkalmazandó rendelési tételnagyságok csökkentik a készletezés rugalmasságát??	Do you think that the defined lot sizes are decreasing the flexibility of the inventory management?	

Please mark on the scale of 1-5 the level of impact of the stated factors on your daily work (1- not important, 5- very serious, 0- not relevant for me)

Kérem jelölje 1-5 skálán, hogy munkájának eredményességét milyen mértékben befolyásolja az adott tényező (1 nem befolyásolja, 5 nagyon erős hatással van rá, 0 – nem találkoztam munkám során ezzel)

Magyar	English	1-5
hosszú átfutási idő	long lead time	
sok szereplős ellátási lánc	high number of echelons	
nagy földrészeket átívelő földrajzi távolság az ellátási lánc szereplői között	long (crossing continents) geographical distance in the supply chain	
folyamatok átláthatóságának hiánya (feladatkörök határai, áruáramlás folyamata, felelősségi körök, allokációs folyamatok, változások (pl. ár) stb.)	**lack of transparency (roles, responsibilities, flow of goods, allocation process, changes (eg. price), etc.)**	
információ megosztás hiánya	**lack of information sharing**	
Az alkalmazott tervezési stratégia (forecasting strategy)	the applied forecasting strategy	
nem megfelelően tervezett ár változások, promóciók	not properly planned price changes, promotions	
alkalmazandó minimális rendelési mennyiségek	defined minimum order quantity	

Ön szerint az alábbi tényezőből fakadó esetleges nehézség kiküszöbölhető az ellátási lánc hatékonyságára gyakorolt negatív hatás nélkül?

Can the potential difficulty resulted by below factors be eliminated without any negative impact on the supply chain performance?

Magyar	English	yes/no
hosszú átfutási idő	long lead time	
sok szereplős ellátási lánc	high number of echelons	
nagy földrészeket átívelő földrajzi távolság az ellátási lánc szereplői között	long (crossing continents) geographical distance in the supply chain	
folyamatok átláthatósága hiánya (feladatkörök határai, áruáramlás folyamata, felelősségi körök, allokációs folyamatok, változások (pl. ár) stb.)	lack of transparency (roles, responsibilities, flow of goods, allocation process, changes (eg. price), etc.)	
információ megosztás hiánya	lack of information sharing	
Az alkalmazott tervezési stratégia (forecasting strategy)	the applied forecasting strategy	
nem megfelelően tervezett ár változások, promóciók	not properly planned price changes, promotions	
alkalmazandó minimális rendelési mennyiségek	defined minimum order quantity	

Kérem, jelölje meg, az alábbi két ok közül véleménye szerint melyik van nagyobb befolyással az Önök ellátási lánca esetében a készletszintek indokolatlan ingadozására!

Based on your experience which factor is resulting in unintended fluctuation of the stock level in your supply chain?

The forming of pairs is based on the Ross's series.

1. a forecastok (előrejelzések) bizonytalansága
2. hosszú átfutási idő (sok szereplős ellátási lánc, a nagy földrajzi kiterjedtség okozta szállítási bizonytalanság)
3. információ megosztás, átláthatóság hiánya
4. a rendelési tételnagyságok adottságai (túlkészletezés a nagy tételek miatt)
5. alkalmazott készletezési stratégia
6. az árak ingadozása
7. a piaci igények és változások félreértelmezése

a forecastok (előrejelzések) bizonytalansága	hosszú átfutási idő (sok szereplős ellátási lánc, a nagy földrajzi kiterjedtség okozta szállítási bizonytalanság)
a piaci igények és változások félreértelmezése	alkalmazott készletezési stratégia
az árak ingadozása	a forecastok (előrejelzések) bizonytalansága
információ megosztás, átláthatóság hiánya	hosszú átfutási idő (sok szereplős ellátási lánc, a nagy földrajzi kiterjedtség okozta szállítási bizonytalanság)
az árak ingadozása	a piaci igények és változások félreértelmezése
a forecastok (előrejelzések) bizonytalansága	információ megosztás, átláthatóság hiánya
hosszú átfutási idő (sok szereplős ellátási lánc, a nagy földrajzi kiterjedtség okozta szállítási bizonytalanság)	a rendelési tételnagyságok adottságai (túlkészletezés a nagy tételek miatt)
a piaci igények és változások félreértelmezése	a forecastok (előrejelzések) bizonytalansága
a rendelési tételnagyságok adottságai (túlkészletezés a nagy tételek miatt)	információ megosztás, átláthatóság hiánya
alkalmazott készletezési stratégia	hosszú átfutási idő (sok szereplős ellátási lánc, a nagy földrajzi kiterjedtség okozta szállítási bizonytalanság)
a forecastok (előrejelzések) bizonytalansága	a rendelési tételnagyságok adottságai (túlkészletezés a nagy tételek miatt)
információ megosztás, átláthatóság hiánya	alkalmazott készletezési stratégia
hosszú átfutási idő (sok szereplős ellátási lánc, a nagy földrajzi kiterjedtség okozta szállítási bizonytalanság)	az árak ingadozása
alkalmazott készletezési stratégia	a rendelési tételnagyságok adottságai (túlkészletezés a nagy tételek miatt)
az árak ingadozása	információ megosztás, átláthatóság hiánya
a piaci igények és változások félreértelmezése	hosszú átfutási idő (sok szereplős ellátási lánc, a nagy földrajzi kiterjedtség okozta szállítási bizonytalanság)
a forecastok (előrejelzések) bizonytalansága	alkalmazott készletezési stratégia
a rendelési tételnagyságok adottságai (túlkészletezés a nagy tételek miatt)	az árak ingadozása
információ megosztás, átláthatóság hiánya	a piaci igények és változások félreértelmezése
alkalmazott készletezési stratégia	az árak ingadozása
a rendelési tételnagyságok adottságai (túlkészletezés a nagy tételek miatt)	a piaci igények és változások félreértelmezése

1. uncertainty of the forecast
2. excessive lead time (due to number of echelons, and/or geographical distance)
3. lack of information sharing, transparency
4. defined order quantities (overstock due to the high MOQs)
5. applied replenishment strategy
6. fluctuation of prices
7. misunderstanding of the market (changes, demand)

uncertainty of the forecast	excessive lead time (due to number of echelons, and/or geographical distance)
misunderstanding of the market (changes, demand)	applied replenishment strategy
fluctuation of prices	uncertainty of the forecast
lack of information sharing, transparency	excessive lead time (due to number of echelons, and/or geographical distance)
fluctuation of prices	misunderstanding of the market (changes, demand)
uncertainty of the forecast	lack of information sharing, transparency
excessive lead time (due to number of echelons, and/or geographical distance)	defined order quantities (overstock due to the high MOQs)
misunderstanding of the market (changes, demand)	uncertainty of the forecast
defined order quantities (overstock due to the high MOQs)	lack of information sharing, transparency
applied replenishment strategy	excessive lead time (due to number of echelons, and/or geographical distance)
uncertainty of the forecast	defined order quantities (overstock due to the high MOQs)
lack of information sharing, transparency	applied replenishment strategy
excessive lead time (due to number of echelons, and/or geographical distance)	fluctuation of prices
applied replenishment strategy	defined order quantities (overstock due to the high MOQs)
fluctuation of prices	lack of information sharing, transparency
misunderstanding of the market (changes, demand)	excessive lead time (due to number of echelons, and/or geographical distance)
uncertainty of the forecast	applied replenishment strategy
defined order quantities (overstock due to the high MOQs)	fluctuation of prices
lack of information sharing, transparency	misunderstanding of the market (changes, demand)
applied replenishment strategy	fluctuation of prices
defined order quantities (overstock due to the high MOQs)	misunderstanding of the market (changes, demand)

Mely iparágban dolgozik?

Which industry you work for?

- Agrár/Agriculture
- Élelmiszer/ Food industry
- Gyógyszer ipar/Healthcare
- Autóipar/Automtive industry
- Építőipar/Construction industry
- Gépgyártás/Machinery industry
- Egyéb/Other

Melyik országban dolgozik?

In which country are you working?

Milyen méretű cégnél dolgozik?

What is the size of the enterprise you are working for?

- <250 (250 főnél kevesebb, less than 250 employee)
- 250-5000 (250-5000 fő foglalkoztatott közötti, 250-5000 employee)
- 5000< (több mint 5000 foglalkoztatott, more than 5000 employee)

Milyen munkakörben dolgozik?

In what position are you working?

Milyen szerepkört tölt be az ellátási láncban? (közvetlen értékesítő, viszonteladó, elosztó, gyártó)

In which part of the supply chain are you working?

- közvetlen értékesíő/retailer
- viszonteladó/wholesaler
- elosztó/distributor
- gyártó/manufacturer

Kérem jelölje mely időtávok tervezése valósul meg tervezési munkája (forecasting) során. (több válasz is megjelölhető)

Please mark the periods below you are considering during the forecasting. (you can chose more than one option

- rövidtáv (6 hónap vagy rövidebb) /short-term (6 months or less)
- Középtáv (6-12 hónap) / mid-term (6-12 months
- hosszútáv (12hó+) / long-term (12 months+)

Appendix 2.: Connection of the bullwhip effect reasons and the survey

BWE reason group	BWE reason	Question connected in the survey	Pairwise comparison
Demand signal processing	inaccurate forecast	Is the applied forecasting strategy leading to accurate enough result?	x
	forecasting strategy		
	handling stockout		
	lack of learning		
	misunderstanding of the market	Do you typically face difficulties in your role due to incomplete information flow?	x
Rationing game	number of echelons	Do you think the number of supply chain members is high at the chain you work for?	
	lack of transparency	Do you think that the supply chain you work in operates with transparent processes?	x
	lack of control		
	fear of shortage		
Order batching	lot size	Do you think that the defined lot sizes are decreasing the flexibility of the inventory management?	x
	replenishment policy		x
	capacity limitations		
	ordering timelines		
Price variation	fluctuation of ordering price		x
	fluctuation of the finished goods prices	Do you experience promotions or price changes that are not planned according to the needs of the supply chain?	x
	changes of other costs		
	planned and unplanned promotions	Do you experience promotions or price changes that are not planned according to the needs of the supply chain?	
Lead time	due to geographical distance	What is the point in time from when you consider the lead time long?	x
	due to process's time requirement		

Source: Author's edition