VISUALISATION OF THE BULLWHIP EFFECT PHENOMENON APPLYING QUALITY MANAGEMENT TOOLS

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Received: June 24, 2022
Received revised: September 8, 2022
Accepted for publishing: September 13, 2022

Abstract

Bullwhip effect analysis and FMEA (Failure Mode and Effect Analysis) tools 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. Tangibility of bullwhip effect analysis is low. Adaptability of the best practices is also limited due to the number of factors that needs to be considered. In addition, limited resources are available, this further complicate the analysis. To ensure better visibility of the phenomenon application of existing resources and processes can be the solution. The lack of understanding causes significant problem in the resolution of the bullwhip effect. Visualization of the situation can support to increase the level of understanding. It can also help associates with less visibility on the topic to get an overview. FMEA frequently use the fault tree analysis and the Ishikawa chart. Both can support to visualize the problem and it also highlights the most crucial points to make the first steps. The two mentioned tools can successfully support the visualization of the practical occurrence of the bullwhip effect.

Key words: bullwhip effect, FMEA, fault tree analysis, Ishikawa

1. INTRODUCTION

Bullwhip effect (BWE) analysis has often been a focal point of scientific and practical studies in the past 30 years. Quantification of the oscillation and the impact of the phenomenon is difficult. There are case studies of the successful analysis (such as Cao et al., 2014 or Pastore et al., 2019) but due to the number of factors that need to be considered adaptability is very limited. FMEA is a quality management tool. The focus is on proactive improvement of processes to maximize the customer satisfaction. As part of this improvement, product and process related changes can happen at the same time.

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). Even if their combined research so far was not typical, we can still find improvement potentials in connecting the two areas. 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.

Due to the limited tangibility the overall understanding of bullwhip effect is low. Adequate summarisation and visual interpretation can support to increase the knowledge regarding the phenomenon. It can enable stakeholders to find the tasks they can influence and open new lines of cooperation. FMEA has multiple tools to support the visualisation and increase the transparency regarding the examined question. Applying these tools can support to make the first step of better understanding of the bullwhip effect with low level of human and financial resource investment.

The goal of this article is applying this clear structure to bullwhip effect analysis. This would broaden the circle of members understanding the phenomenon. Even if their work is not connected directly to forecasting or supply chain, they can see the impacts generated by their contribution. It can bring closer departments with conflict of interest on the topics related to bullwhip effect (such as sales department can see the impact of ad-hoc planning, or price changes).

This article consists of two parts. The literature review is the first part. It focusses on the bullwhip effect, especially the reasons of the phenomenon. The other focus is the FMEA approach, and the visualisation tools applied in it. The second part is the application of these tools. Usage of them is not typical in bullwhip effect context. This part of the article shows the possibility of using fault tree analysis and Ishikawa chart for bullwhip effect visualization purpose.

2. LITERATURE REVIEW

2.1. Bullwhip effect

The research of bullwhip effect has long history behind. First analysis of the topic was by J.W. Forrester (MIT Sloan School of Management), it is also known as the Forrester effect (Forrester, 1961). The "*bullwhip effect"* term was assigned to the phenomenon by Lee, Padmanabhan and Wang (1997). The basis of their investigation was the analysis of customer demand fluctuation. Procter and Gamble diapers showed unexplainable level of variability in sales.

The definition used in books focuses on increasing fluctuation of orders (Chopra and Meindl, 2016; Ivanov et al., 2019; Hugos, 2018). Below definition is from Hugos (2018, pp213): "*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.

2.1.1.Reasons of the bullwhip effect

The main causes behind the phenomenon have been listed by Lee et al., 1997 as below:

- Demand signal processing: this focuses on the impulses generated by the retailer. The tracking of these signals, real demand pattern is not reaching the supplier.
- Rationing game: the focus this case is on the manufacturer, but relevant at all levels of the chain. It collects cases related to limited supply availability and gambling due to the changes on the market.
- Order batching: Rules, strategies and policies may differ in the supply chain. Limitations and regulations on time and quantity related operation can lead to bullwhip effect.
- Price variation: planning of promotions, changing of prices may not be in accordance with the supply and production capabilities. Free return policy can make it even harder.

Even though the above categories were defined some time ago, their validity is not disputed in the scientific community. However we shall note that digital technology impacted supply chain operations a lot. The change is mainly visible at information, financial and material flow (Wiedenmann & Größler, 2019). Based on the original concepts these tools recently available should support avoiding the bullwhip effect, but the practical experience does not seems to confirm it.

To the above mentioned areas the lead time parameter was added by Geary et al., (2006), due to the changes in the consumption and the lifestyles of the customers.

Nevertheless, supply chain operations also changed because of the technical and technological development. As bridging distances became easier the number of longer, international chains increased. At the same time the average lead time also grew.

The above described causes did not consider the human factors yet, the focus was on operational reasons. It is only reflected as potential improvement of the bullwhip effect (Sterman, 2006). Recently, the number of studies considering the human side of the causes increased. The focus is on information sharing, training and communication, trust in collaboration, human influence in forecasting and reactions on the impacts of the bullwhip effect (Yang et al., 2021).

The reason groups can be broken down to sub-reasons:

- Demand signal processing: Forecast is in the focus in this category. The quality of it (forecast accuracy), the applied strategy and the understanding of the market. Besides the stock out management and the way of learning out of mistakes.
- Rationing game: This group is containing factors related to the supply chain characteristics. The size of the chain (number of echelons, geographical distance); applied synchronisation and control policies are contained in this group. The level of transparent operation is also examined here. The application of chain level approaches on local level can also have impact on the bullwhip effect. Connected to this, the echelon level appearance of the fear of shortage can influence the performance of the full chain. This is also impactful from the bullwhip effect perspective.
- Order batching: Technical background is mainly in the focus regarding this category. The requested order quantities or values, lot sizes and timelines can lead to unrealistic demand signals. If the chain is missing or having low level of harmonisation this can be further aggravated. Limited availability of the needed capacity also has negative impact (Potter & Disney, 2006).
- Price variation: The bullwhip effect can also be caused by promotional activities or sales deals. If the planning is not according to the global chain level requirements it can lead to the occurrence of the phenomenon. Price changes both on finished goods or material level can also trigger oscillation.
- Lead time: Forecasting strategy need to contain an additional factor to be considered, the lead time. It has impact on the forecasting and replenishment strategy at all levels of the chain. The other related factor is the delay in information flow. Lead time is mainly due to the physical distance, but this also means distance in the communication (Geary et al., 2006).
- Human factor: The main sub-reasons here are: trust, information sharing and human influence. It can only be eliminated if the process is fully automated without human intervention. Trust and information sharing relates to the level of information shared and the time it is communicated. This can be regulated but here we may face differences at different levels of the chain. Human influence means the decisions made by the responsible person based on facts and subjective factors. It can contain for example fear of shortage or

misunderstanding of the changes on the market (Bhattacharya & Bandyopadhyay, 2010).

2.1.2. Consequences and reduction

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 & Farasyn, 2007).

Due to the characteristics of modern supply chains co-operation became more difficult. The distances in supply chains are longer and the coordination of the ever growing number of echelons is more difficult. The ideal operation would include information transparency, a global strategy at all levels of the chain and a very high level of coordination of the processes. These circumstances would decrease the probability of the occurrence of the bullwhip effect. Nonetheless, these characteristics are not likely to happen considering the real-life circumstance in the foreseeable future.

Information sharing would support better forecasting strategies and processes. It would support avoiding the highest peaks on the long run. Lead time also needs to be considered. It means a potential viewpoint to find the bottlenecks and highlight critical processes. This supports to have better control, lower uncertainty, and manageable processes. Level of information sharing, and consideration of the lead time are the first steps. This can be followed by harmonisation of strategies (forecasting, replenishment) and consideration of redesigning batch sizes and processes (Towill et al., 2007).

Information sharing has been investigated from bullwhip perspective in various research. Still, it does not always work (Haines et al, 2017). Even though, increased level of transparency and information sharing is still important. It supports detection of the bullwhip effect and resolution of the problem.

2.2. 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*" (Hu-Chen, 2016, pp 5.). 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).

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).

2.2.1. Types of FMEA

There are four types of FMEA: System, Design, Process, and Service. Stamatis (2003) describes as follows (Stamatis, 2003):

- 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.

2.2.2. Research on FMEA and BWE

Analysation has been initiated regarding the research considering both bullwhip effect and FMEA. First ScienceDirect database has been used. The result shows that bullwhip effect is part of FMEA research as risk (Wan et al., 2019; Venkatesh et at., 2015; Rostamzadeh, 2018; Giannakis & Papadopoulos, 2016; Hosseini & Ivanov, 2020). Wan et al. (2019) aims to develop a model to assess risk factors of maritime supply chains. Bullwhip effect is considered as a new risk parameter that is included in the FMEA risk assessment. Venkatesh et al. (2015) also use FMEA to mitigate supply chain risk and bullwhip effect is present as an example of the demand uncertainty. Rostamzadeh (2018) and Hosseini and Ivanov (2020) both present bullwhip effect as supply chain risk. FMEA is applied in assessment of risks. Giannakis and Papadopoulos (2016)'s focus is on rating of the risks; bullwhip effect is present as a factor leading to supply chain operational risk. On other examples the two topics are present in the same research without connecting them (Giannakis &Luis, 2011; Lyu et al., 2009). Giannakis and Luis (2011) is working with performance and complexity. Bullwhip effect is considered related agent-based technology example. Lyu et al. (2009) examines connection of bullwhip effect and the RFID technology that is considered as a reduction possibility related to the phenomenon. These two examples both presents FMEA and bullwhip effect but not connects the two areas.

Extending the research in Scopus database further articles have been checked containing also bullwhip effect and FMEA expression. The analysis led to similar result. Hsu et al. (2022) concentrates on bullwhip effect which is result of the inaccurate forecasting, FMEA is present as the applied risk assessment tool. Ghadir et al. (2022) use FMEA as the tool to identify the top supply chain risks related to COVID-19, bullwhip effect is present as one of those. Zhu et al. (2021) and Gupta et al. (2021) both present study on risk management using the FMEA approach and bullwhip effect is present among the risk factors.

These articles are considering the phenomenon from quality perspective. Detailed analysation of the bullwhip effect is not in the scope. The phenomenon means risk for quality management. The approach in this study is in opposition. The bullwhip effect is in focus and quality management is used as potential tool of analysation.

The main advantage of introducing FMEA logic and concept to measurement of bullwhip effect 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.

3. METHODOLOGY

Based on the analysis of the bullwhip effect and FMEA literature the common interest is visible. Using the learnings of the theoretical background a model fault tree and Ishikawa diagram was built up by the authors. It showed that by theory it is possible to connect the approach of FMEA and bullwhip effect.

As the next step, subject matter experts have been interviewed regarding their experiences. These interviews as part of preliminary research aimed to collect examples of experiences on the bullwhip effect. There have been ten interviews conducted on machinery industry. These interviews aimed to test if the designed approach can be applied on real life examples. The respondents are logistics experts working with forecast and or inventory. They have been asked on examples of bottlenecks they faced in the supply chain operation during their daily work. The feedback from these interviews has been formed according to the fault tree analysis.

These examples replaced the theoretical sub-reasons of the bullwhip effect. As these interviews includes feedback for multiple experts, the result cannot be used to highlight exact steps to be taken. Current approach is a simulation aims to test the applicability of the designed approach. Beside the interviews cases studies on bullwhip effect has also been presented in Ishikawa diagram format. Two example from the literature and one from the experience of the authors is visualised.

4. APPLICATION OF FMEA TOOLS

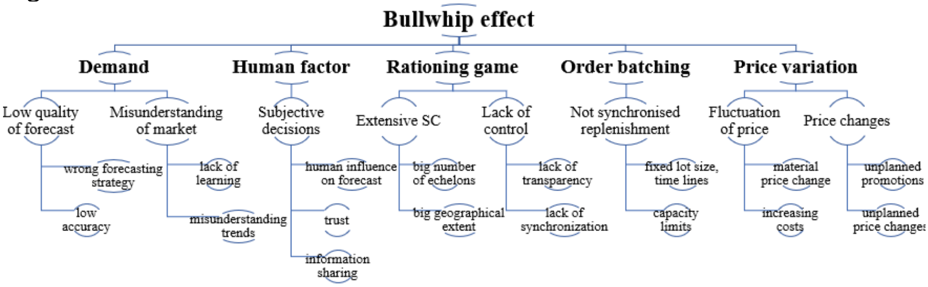
There are several quality management tools that are frequently used during the FMEA process. As example fault tree analysis, Ishikawa diagram, Pareto chart, risk matrix, and paired comparison are among the numerous different methods (Lim, 2020; Luthra et al., 2021). In this article the goal is to implement visualization tools to have better overall understanding. In Chapter 4.1. two widely used tools of FMEA is presented: fault tree analysis and Ishikawa diagram.

4.1. 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 1 shows the theoretic version of it. It visualizes reasons which are in the literature part of the article also collected in Chapter 2.1.1. 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.

Figure 1. FTA – BWE reasons



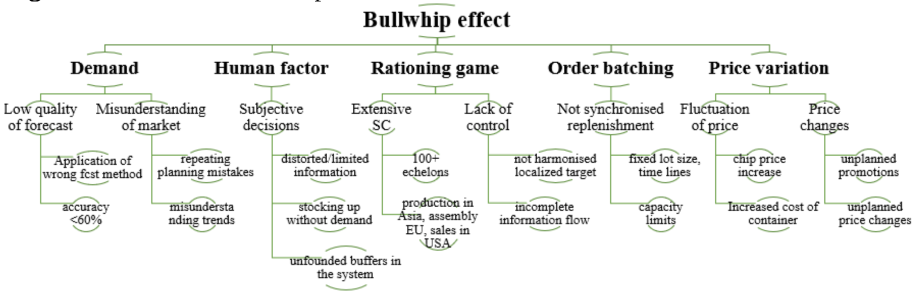
Source: Authors' edition

This structure can be further specified by real life examples, which is visible on Figure 2. 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.

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.

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 2. 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.

Figure 2. FTA – BWE example



Source: Authors' edition

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.

Price variation reasons are also presented in Figure 2. 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.

Figure 2. 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 area.

4.2. 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).

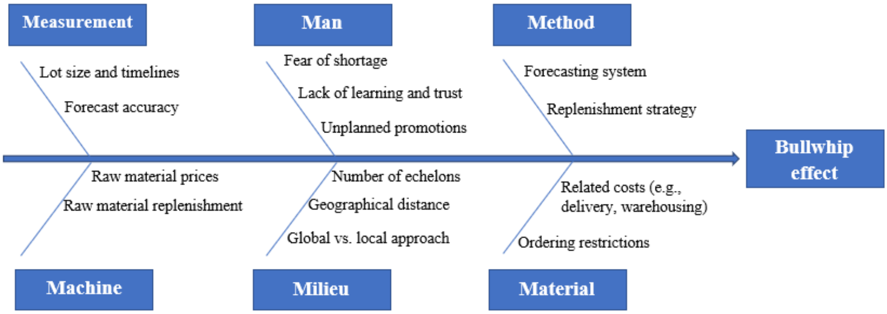
The 6M approach is typically used with Ishikawa, this article is using this approach to categorise issues during visualisation. The Ishikawa diagram beside summarisation and visualisation, also breaking down main issues to manageable elements. This method can also be used for visualising the bullwhip effect. As the diagram has its' own grouping methodology, it leads to a new perspective for categorizing reasons. Figure 3. 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.

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.

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).

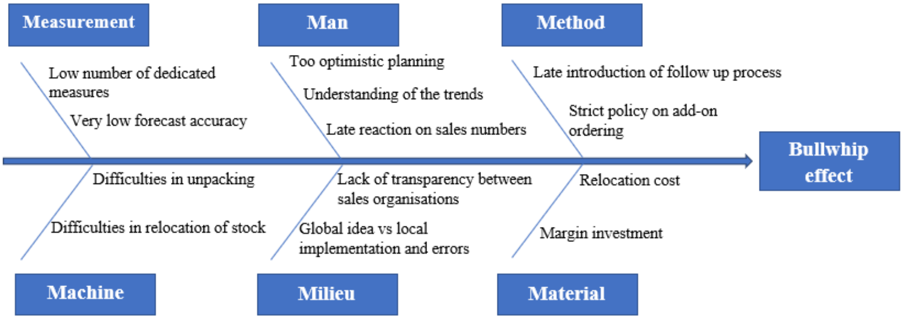
Figure 3. Ishikawa – BWE reasons



Source: Authors' edition

This visualization and structure of reasons can support analysis of the bullwhip effect. Figure 4. shows the fishbone diagram of a real-life example based on the experience of the authors. The visualized example is a poorly planned promotional activity. A well rotating product sold with a gift (add-on) free of charge. The market was not interested in the added product, it led to significant overstock of the gift after the promotion. As it is not sold individually cost is realized on multiple angle such as warehousing or margin.

Figure 4. Ishikawa – BWE example



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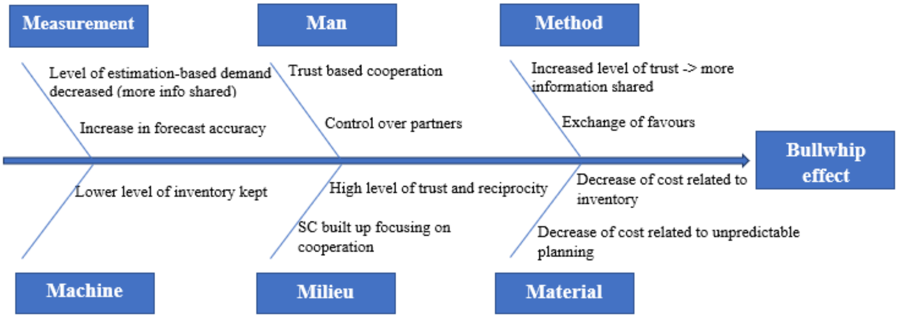
This example resulted in high level of overstock. As the event is not that special, similar promotions are planned on trimester base improvement potential is high. Measurements here are crucial from long term perspective. Issue faced are partially due to low number of dedicated measures that supports the activity from the beginning. Measured low forecast accuracy is also indicating the occurrence of the bullwhip effect. From man perspective the reason is mainly too optimistic expectations which are combined with misunderstanding of the market trends (the gift was not interesting at all for the targeted group). The other problem was the late reaction. Forecast change has not happened even after first sales numbers showed that the interest is very low. Beside the change in number the action to improve the performance of the promotion was also missing. From method perspective missing sales follow up process was deepening the issue. Here also the gift ordering process' difficulty and inflexibility need to be mentioned.

From machine perspective the physical difficulties of relocation appeared. Langue and differences in regulations needed to be bridged. Cost impact was also significant as the product with add-on needed to be repacked (separated). Regarding the milieu the global idea versus the local implementation need to be mentioned. Even if local needs were considered during planning implementation and global aims had significant gap in-between. Furthermore, communication of sales organisation was incomplete, best practices, good approaches or even mistakes had not been shared. Due to the lack of flexibility regarding material background the chart should also consider the impacts of this. It led to additional costs as the generated overstock needed to be sold with margin investment. This is connected to the bullwhip effect due to increasing distance of real market demand and planning.

In a literature example 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 which 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 5. Ishikawa - Guanxi approach to decrease bullwhip effect



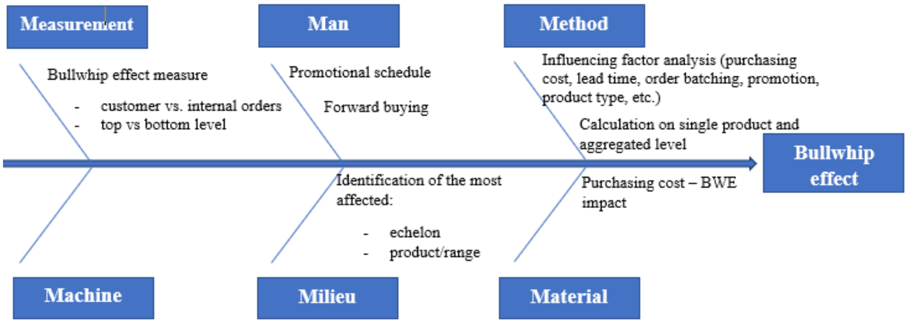
Source: Authour's edition based on Cao et al, 2014

Figure 5. 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.

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 6., 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 6.: Ishikawa – data analysis approach – spare parts industry



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

5. CONCLUSION

Competition is getting fiercer, and circumstances are becoming more difficult. Extraordinary cases such as COVID-19 or crucial availability issues (such as microchip shortage) test the resilience and the operation of supply chains. Due to the competition, it is not enough to get through the difficulties, continuous improvement is needed. As bullwhip effect has key role in the supply chain operational performance it needs a high level of attention and understanding. Visualization of the phenomenon aims to extend the circle of people who understand the issues and work on the solution.

Fault tree analysis and Ishikawa approach can be used as adequate tool to present the reasons of the bullwhip effect. This supports in increasing the understanding of the phenomenon. It gives also high-level overview and summary where focus needs to be placed. As these tools are well-known and likely used by another department introduction is not resource intensive. It can be a first step toward the understanding of the phenomenon and determination of the main reasons of the bullwhip effect in the examined cases.

FMEA is applied in mainly in the most bullwhip relevant supply chains. These are complex networks that have multiple echelons. The cooperation needs to be kept under control. This is also true from a quality perspective. FMEA aims to maximize the customer satisfaction through reaching the highest potential of the product or service. FMEA approach applies multiple tools to visualize problems, processes, or hierarchical connections. These tools can support the bullwhip effect analysis as well. Application of the fault tree analysis and Ishikawa diagram is possible in connection with bullwhip effect. This visual approach has two main advantages:

- *It increases 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.

- *It highlights the main reasons of bullwhip effect in the analysed chain*: The reasons behind the phenomenon are available in the literature but still it differs chain by chain. Visual interpretation of the actual, experienced reasons can show the weighted overview of the phenomenon, highlighting the most critical factor.

The main limitation of the research is the industrial representation. The examples are only covering one segment. Extension of the analysis is needed for further industries. The number of interviews also limits the potential to generalise the results, but it still supports testing application of quality tools in bullwhip effect extent.

As the potential extension of the scope of this research, a survey can be conducted. It can broaden the examination by checking other industries. The survey can also have additional questions that can show the perception of the bullwhip effect in the supply chains. As a result, industry level and overall consequences can be conducted. It can highlight the most critical reasons of the bullwhip effect, that would help in improving the performance of the supply chain.

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