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**Comprehensive and practice-oriented analysis of the  
supply chain instability**

Doctoral Theses

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## **Motivation and goals**

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 analysis 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.

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.

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.

## **Methodology**

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.

## **Theses**

**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 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 below 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.

**BSc perspectives, BWE reasons and potential 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	<ul style="list-style-type: none"> <li>number of supply chain echelons</li> <li>number of harmonized local KPIs</li> <li>number of occurrence of shortages</li> </ul>
Internal business	existing processes operational metrics	Order batching	replenishment policy time frame	<ul style="list-style-type: none"> <li>Safety stock level,</li> <li>Lot size</li> </ul>
Financial	costs related measures	Price variation	promotional impact price changes	<ul style="list-style-type: none"> <li>Bias</li> <li>Price level fluctuation,</li> <li>Number of promotions</li> </ul>
Customer	customer satisfaction loyalty	Demand signal processing	forecasting uncertainty estimation based planning	<ul style="list-style-type: none"> <li>Forecast Accuracy</li> <li>Service level</li> </ul>

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.

#### Publications:

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

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

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

#### **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 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.

Publications:

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

**Thesis 3 – Quality management approach can support the detection of the instability of the supply chain. FMEA tools can be applied in analysis of it.**

Bullwhip effect analysis and FMEA 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. 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. 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. 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. 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, and 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 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.

Publication:

*Diana Strommer, Norina Szander, Péter Földesi (2022): 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.*

**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. 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%). 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. 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 mechanical, 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.

Publication:

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

## **Conclusion**

The aim of my dissertation was supporting to bridge the gap between theory and practice. Limited adaptability of current approaches led to need for new perspective to be used. My dissertation is not looking for new theoretical solutions but try to use the potential of the partner areas. Performance measurement and quality management are the areas that had been analysed.

Performance measurement can support by targeted usage of given measures and frameworks to investigate the bullwhip effect phenomenon. The used tools are well known and widely used in practical and present on research side. Introduction to the practical usage has low human and financial resource requirement.

Quality management is a new area to connect with SC instability. However, the purpose and direction of the applied tools has much in common. FMEA model and frequently used tools of it has been analysed and defined as a learning potential. These tools can ensure a fresh viewpoint and it can support increasing the understanding of the topic in the organisation.

## **Publications of the author**

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

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

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

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

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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

**Publication not cited**

Norina Szander, Diana Strommer, Peter Bajor (2014): Beer game: demonstration and performance evaluation of supply chains, European Conference on Games-based Learning,