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Optimizing Supplier Order Sizes to Mitigate the Bullwhip Effect in a Food Supply Chain: A Case Study Based Approach

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Abstract

The bullwhip effect (BWE) is a challenging phenomenon in supply chains that cause variability to flow from the lowest to the highest echelon which lowers efficiency. Irregular order sizes across multiple suppliers can cause bullwhip effect in a food supply chain. This study investigates the presence of the BWE and employs a Design of Experiment (DOE) approach to mitigate its impact. Focusing on a case study involving key suppliers, the research quantifies the main interaction effects of supplier and production variables on BWE. The DOE methodology highlights critical factors such as supplier-level adjustments and production configurations, identifying optimal strategies to minimize variability. Unlike conventional approaches that heavily rely on forecasting or demand information sharing, this study proposes determining the optimal level of order sizes to minimize variability in the supply chain. By isolating and testing factor interactions, the research provides a robust framework for addressing variability without the complexities of advanced forecasting methods. The minimum value of the bullwhip effect was obtained by calculating the main and interaction effects of high and low values of the supply of three major raw materials. Thus, this study provides scope for future research upon these findings by integrating forecasting and real-time analytics for a more comprehensive solution.

Keywords:
bullwhip effect, supply chain variability, design of experiment, ordering size, production optimization.

1. Introduction

The food supply chain is a complex and dynamic network that spans the procurement of raw materials to the final consumption by consumers. The food industry is vastly dependent on raw materials and any demand variation can heavily affect the quality and efficiency of the supply chain (Sunmola et al. 2024). As a result, the food supply chain faces numerous challenges such as climatic, biological, environmental, logistics, and infrastructure (Rojas-Reyes et al. 2024). Moreover, this industry plays a critical role in the global economic development of a country, involving several players in a supply chain like stakeholders, farmers, manufacturers, transporters, retailers, and consumers (Li et al. 2014; Turi et al. 2014). The food supply chain in Bangladesh is characterized by its complexity and reliance on multiple intermediaries, from farmers to consumers (Hasan & Habib 2022). In sectors like dairy and rice, the supply chain shows increasing demand for quality products and processed goods like yogurt and ghee (Minten et al. 2013).

However, challenges such as limited storage, perishable items, demand variation, inadequate transportation, and lack of capital disrupt efficiency and value addition. Demand variability is one such crucial challenging factor that affects all the parameters of a supply chain, especially the operational cost (Alaswad et al. 2019). For example, Lee & Farahmand (2008) highlighted that increasing demand variation results in an increase in the unit cost with positive interaction effects with all other factors. Three primary interconnected factors that contribute to the disruption of supply chain activities are changes in supply, fluctuations in demand, and the actions taken by governments and nations to address the prevalent issue (Magableh 2021). So, demand variation is a harmful factor that leads to the bullwhip effect and ultimately causes inefficiency in the supply chain performance.

The food supply chain in Bangladesh, like many developing countries, faces unique challenges and opportunities. The "bullwhip effect" is a significant issue where demand fluctuations increase upstream, leading to excess inventory and operational waste. This is particularly critical for perishable goods where product deterioration and service life amplify losses due to their lower expiry period (Durán Peña et al. 2021). While it is difficult to control demand variation, one way to control the bullwhip effect is to maintain a smooth order size of the raw materials from suppliers. Determining a fixed supply rate and controlling the batch sizes can better manage closed-loop supply chains where goods are produced and delivered in batches (Ponte et al. 2022).

1.1 Objectives

This study aims to investigate the presence and potential causes of the bullwhip effect in a selected food supply chain while identifying an effective method to measure its intensity. Additionally, the purpose is to analyze both individual and interaction effects of order sizes to determine the optimal combination among them for minimizing the bullwhip effect.

2. Literature Review

In the 1990s, the consumer goods company Procter & Gamble (P&G) was the first to use the phrase "bullwhip effect" to characterize the phenomena of order variation amplification that occurred between P&G and its suppliers. It's interesting to note that P&G and their wholesalers saw a pattern very similar to this one back in 1910 (Wang & Disney 2016). So, the depletion of the bullwhip effect affects the profitability of the supply chain, both for pallet-level labeling costs and case-level labeling costs. In fact, most of the logistics costs of the supply chain come from having a lot of inventory in the distribution channel. Since many industries are known for making low-value goods, reducing the amount of safety stocks can be a good way to increase product margins and profits (Bottani et al. 2010). Similarly, a case study was conducted on the supply network between Asia and Europe, where three countermeasures (reorganization, process optimization, enhanced controlling) effectively reduced the problem of stock-out and costly transports (Glas 2013). Longer lead times and inaccurate selection of forecasting model parameters can result in the bullwhip effect within Supply Chain Management. For example, one study highlights various managerial strategies and optimal approaches to alleviate management challenges associated with irregular demand patterns, ultimately fostering efficient production and inventory management (Rahman et al. 2020).

Some research articles indicate that the bullwhip effect has direct or indirect implications on the operations of an industrial process like ordering, inventory and other aspects of operations management. Badar et al. (2013) showcased that integrating information on inventory levels and supply chain components into an ordering methodology can effectively mitigate the bullwhip effect. (Brauch et al. 2024) conduct a systematic literature review to identify and categorize the diverse causes of the bullwhip effect (BWE) in supply chains. They classify these causes into four primary categories: inherent system structure, uncertainty, misaligned incentives, and inadequate cognition of the situation. In 2021, (Barman et al. 2022) implemented a recovery strategy in the food industry during the COVID-19 situation by instituting a direct delivery channel. As part of this recovery plan, the manufacturer engaged multiple delivery channels, appointing vendors and facilitating direct product delivery to customers, to minimize the bullwhip effect.

3. Methods

This study was conducted to measure and provide a strategy to mitigate bullwhip effect in a food supply chain**.** A food industry was selected for this study since it is particularly vulnerable to bullwhip effect. Taking into consideration that the bullwhip effect can have a negative impact on the food industry's production cycle and supply chain management, making it especially vulnerable to this phenomenon. As the product or material flow is too high in food production, there's a high risk of bullwhip effect. During the selection process, one of the main factors that influenced the decision to focus on the food industry was the availability of previous analyses and surveys.

3.1 Data Collection

Upon reviewing the previous data and survey, there were a few surveys specifically related to the food industry, which provided valuable insights and information that could be used in research and analysis. The possibility of improvement is ample in the food industry cause It is possible to reduce food and raw material wastage, improve data quality, building resilient supply. We have selected three main suppliers in preparing the chicken meat ball and collected 12 months of varied order sizes for the 3 raw materials. The three raw materials for which supply data collected were chicken, onion and corn flours.

3. 2 Description of the Process

This intriguing case study centers on a specific product within the industry, Chicken Meatballs within a manual production system specializing in frozen food products. The production process of Chicken Meatballs in the selected food industry is a manual production system which is depicted in Figure 1. Following the sequential process, the Chicken Meatballs are ready for the final packaging phase, which adheres to strict quality and hygiene standards. Once adequately packaged, the product finds its place in the distribution warehouse, where it awaits distribution to discerning consumers. The entire production process is a testament to meticulous craftsmanship, quality control, and a commitment to delivering a premium product to the market.

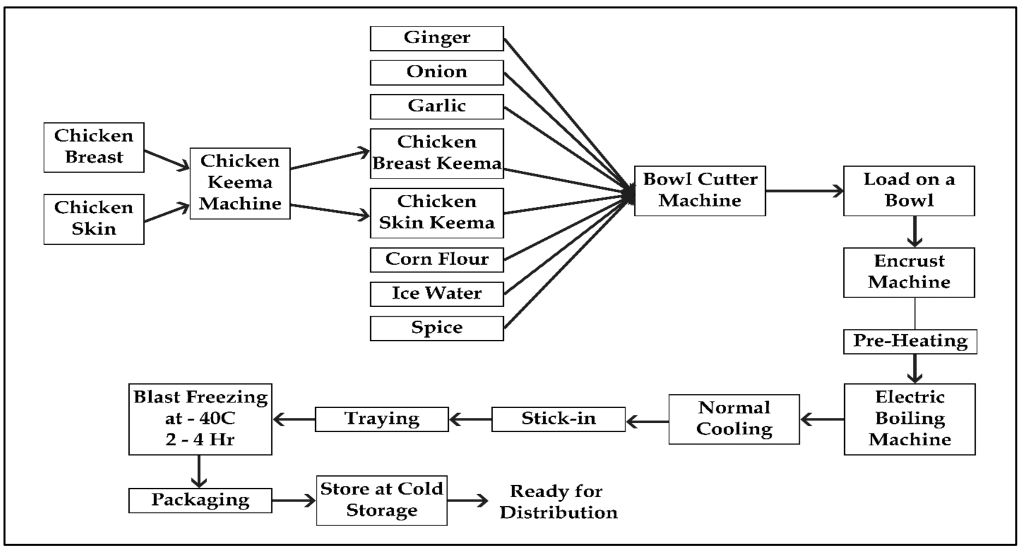


Figure 1. Flow Diagram of the chicken meatball production process

3.2 Calculation of the Bullwhip Effect:

The bullwhip effect, as suggested by Lee et al. (1997b), is measured by squaring the variance in demand upstream is σ^2 [66].Chen et al. (2000) suggested the calculation of bullwhip effect by evaluating the parameter ratio between the final demand and first stage of manufacturing with more supply chain stages as,

$$Bullwhip\ Effect\ Measure = \frac{{\sigma_o}^2/\mu_o}{{\sigma_D}^2/\mu_D} = \frac{{\sigma_o}^2}{{\sigma_D}^2}$$

Variance measures the variability in orders relative to sales, which shows fluctuations that drive the bullwhip effect (BWE). Higher variances in orders indicate overcompensation to demand changes and amplifies variability.

3.3 Design of Experiment (DOE):

Design of Experiment (DOE) is a valuable tool for evaluating the effect of multiple factors on one response variable. In this study, DOE is used to find the correct combination of ordering sizes of raw materials that minimizes the bullwhip effect. So, the factorial design is of 2^3 structure with 3 supplier with two levels for each (high and low).

4. Result

In this section, the findings of the study are presented sequentially. order/production and end stock data of the three raw materials, demand and production for each of the previous 12 periods, as summarized in Table 1.

Table 1. Customer Demand, Production and Supply Data of Three Main Raw Materials

		Manufacturer			Supplier-01 Chicken			Supplier-02 Onion			Supplier-03 Corn Flours		
Period	Customer Demand	Start Stock	Production	End Stock	Start Stock	Order	End Stock	Start Stock	Order	End Stock	Start Stock	Order	End Stock
1	15078	580	15840	220	147	10813	245	40	328	58	123	1153	84
2	14389	220	15048	122	245	10272	220	58	311	65	84	1095	105
3	12983	122	13844	243	220	9450	321	65	286	76	105	1008	131
4	11209	243	11880	243	321	8110	473	76	246	93	131	865	145
5	11319	243	12110	223	473	8267	407	93	251	84	145	882	118
6	11764	223	12480	286	407	8519	325	84	258	54	118	908	165
7	11893	286	12792	371	325	8732	243	54	265	57	165	931	163
8	12721	371	13432	313	243	9169	367	57	278	72	163	978	166
9	13129	313	13941	288	367	9516	488	72	288	61	166	1015	153
10	13840	288	14597	239	488	9964	387	61	302	74	153	1063	140
11	14616	239	15365	258	387	10489	187	74	318	60	140	1119	133
12	15044	258	15840	203	186	10813	311	60	328	69	133	1153	105

The bullwhip effect exists between customer demand, manufacturer and the suppliers because of the difference in production, also there is changing starting and ending in all periods. From the above data, the bullwhip effect is next calculated using the formula of variance between the sales and order data for each period and the cumulative variance of each preceding period. The results of the calculation are summarized in the following table 2:

Table 2. Bullwhip Effect Calculation for 12 Periods

Period	Sales	Orders	Differences	Sales Variance	Order Variance	BWE
1	15840	15078	762			0
2	15048	14389	659	156816	118680.25	0.75681
3	13844	12983	861	673432.889	760064.667	1.12864
4	11880	11209	671	2227251	2191826.19	0.98409
5	12110	11319	791	2449616.64	2456207.84	1.00269
6	12480	11764	716	2263389.89	2257511.89	0.99740
7	12792	11893	899	2007403.92	2033606.98	1.01305
8	13432	12721	711	1756480.44	1779785	1.01327
9	13941	13129	812	1587282.62	1602884.47	1.00983
10	14597	13840	757	1539798.84	1555380.05	1.01012
11	15365	14616	749	1658325.06	1676863.87	1.01118
12	15840	15044	796	1851516.35	1857950.24	1.00347

The BWE has been uneven in each period from the second to the last period. The uneven trend in the value of BWE can be seen in the following in Figure 2 too.

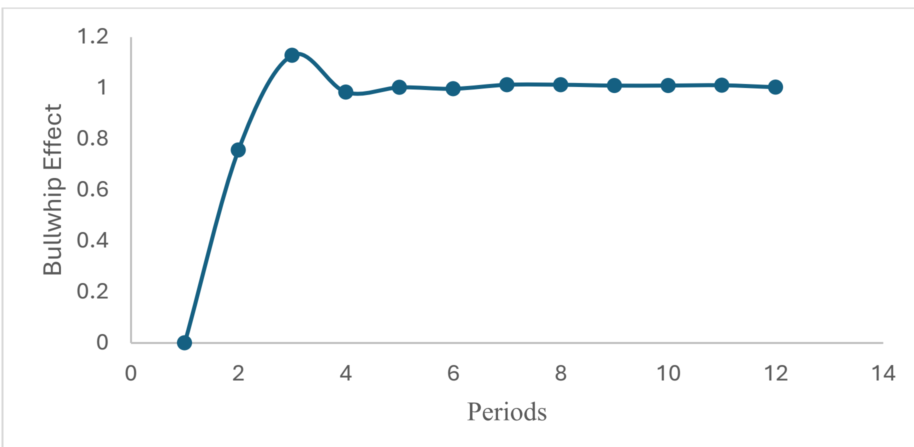


Figure 2. Trend of bullwhip effect in the food supply chain

The uneven trends in BWE across periods result from fluctuations in demand patterns, irregular order schedules, and supplier constraints. For instance, periods with higher BWE often correspond to delayed responses in supply adjustments or misaligned order sizes. Such trends impact inventory management and lead to higher costs or stockouts.

4.1 Factorial Analysis by Design of Experiment

The main effect of each supplier's high and low supply in one period (12th) was found from the start and end stock values from table 1. Then, the bullwhip effects for each combination were calculated using the equation and the results are presented in table 3.

Table 3. Bullwhip Effect Calculation for 2^3 Factorial Design

Production	Supplier-01	Supplier-02	Supplier-03	BWE
16038	10813	328	1153	1.2352
15932	10813	328	1286	1.2038
15890	10813	388	1153	1.2288
15916	10813	388	1286	1.1803
15987	10999	328	1153	1.2226
16052	10999	328	1286	1.1689
15940	10999	388	1153	1.2166
16080	10999	388	1286	1.1521
			Mean	1.2010

After that, the main effects for each factor were calculated by using the high and low value averages and the overall mean. Subsequently, the grand meaning is calculated using data from Table 2. The average Bullwhip Effect value for the low value of Supplier-01 is determined with the assistance of Table No. 3. Likewise, the average Bullwhip Effect for the high value of Supplier-01 is computed. Similar procedures are applied to calculate the average values for the low and high values of Supplier-02 and Supplier-03, and the resulting values are presented on the left side of Table 4. Following this, the Grand Mean previously calculated is subtracted from the averages of the low and high values for Supplier-01, Supplier-02, and Supplier-03, and the effect values for each supplier are displayed on the right side of Table 4.

Table 4. Main Effects of Calculation for Each Supplier

<table>
<tr><th>Level</th><th>Supplier-01 Avg.</th><th>Supplier-02 Avg.</th><th>Supplier-03 Avg.</th><th></th><th>Supplier-01 Effect</th><th>Supplier-02 Effect</th><th>Supplier-03 Effect</th></tr>
<tr><td>Low</td><td>1.2121</td><td>1.2077</td><td>1.2258</td><td rowspan="2">Subtract the mean (1.2011) from each cell</td><td>0.0110</td><td>0.0066</td><td>0.0248</td></tr>
<tr><td>High</td><td>1.1901</td><td>1.1945</td><td>1.1763</td><td>-0.0110</td><td>-0.0066</td><td>-0.0248</td></tr>
</table>

The main effects plot in figure 2 illustrates the main effect for the three supplies on bullwhip effect. The downward trend in the three lines shows that for all three supplies reduce the bullwhip effect when the order size is increased, with supplier-03 showing the highest effect. So the production planning department would no know that supplier-03 should be prioritized more during order variability considerations. Supplier-01 has a moderate effect while supplier-02 has the minimal effect on BWE. This data provides the planning department a strategy to focus more on maintaining a stable order size for the raw materials, since having variable order sizes can cause bullwhip effect.

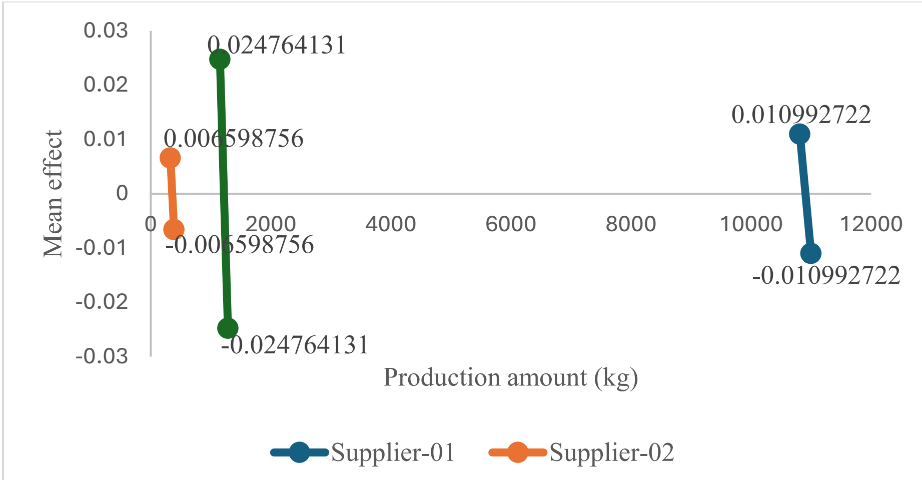


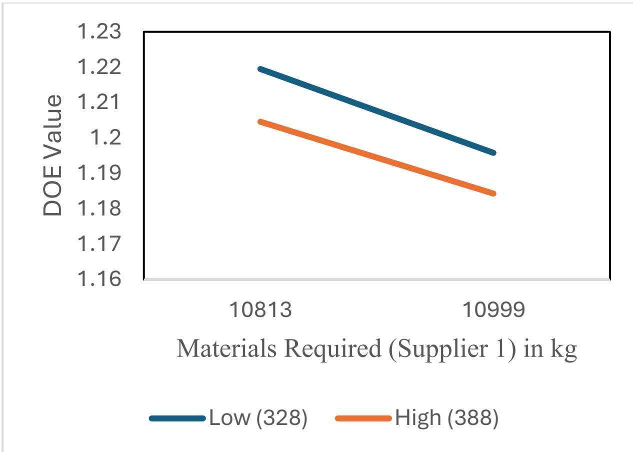
Figure 3. Main Effect Plot for Each Supplier

After identifying the main effect, the next set of analyses was conducted to observe any interaction effect between the order sizes of suppliers. The interaction effect at high and low levels of the three suppliers is presented in Table 5.

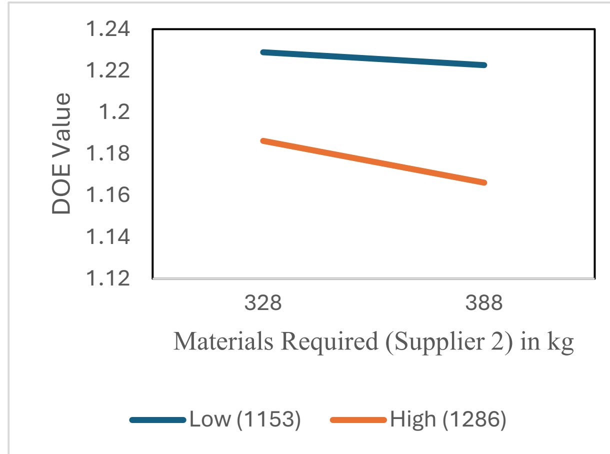
Table 5. Interaction Effect for Three Suppliers

Supplier-01 and 02		**Supplier-02 and 03**		**Supplier-03 and 01**	
Combination	**Average**	**Combination**	**Average**	**Combination**	**Average**
S1-, S2-	1.1521	S2-, S3-	1.2289	S3-, S1-	1.232
S1-, S2+	1.227	S2-, S3+	1.1863	S3-, S1+	1.2196
S1+, S2-	1.2038	S2+, S3-	1.2227	S3+, S1-	1.1921
S1+, S2+	1.2353	S2+, S3+	1.1662	S3+, S1+	1.1605

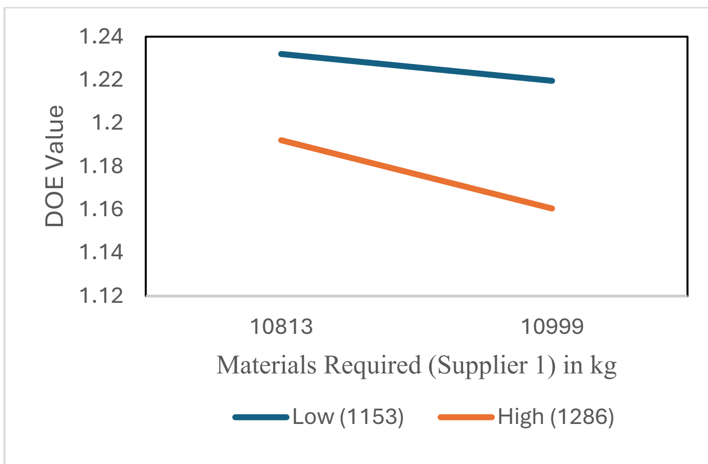
The low value of each supplier is determined based on the quantity of materials utilized during the production process, while the high value is calculated by adding the initial stock and the materials consumed. The interaction effect between the different combinations can be observed in the interaction plots in Figure 3.



(a) Interaction plot between Supplier 1 and 2



(b) Interaction plot between Supplier 2 and 3



(c) Interaction plot between Supplier 1 and 3

Figure 4. Interaction effects between (a) Supplier 1 and 2, (b) Supplier 2 and 3, (c) Supplier 1 and 3

It can be observed that when Supplier-03 is at low levels (1153), increasing supplier-01 from 10813 to 10999 reduces the BWE from 1.2320 to 1.2196. At higher levels of Supplier-03 (1286), the same increase in Supplier-01 also results in reducing BWE, from 1.1921 to 1.1605. This interaction indicates that higher levels of Supplier-03 mitigate the effect of Supplier-01 on the BWE, making Supplier-03 key in stabilizing the supply chain. Whereas, the results show that when Supplier-03 operates at high levels, increasing Supplier-01 from 10813 to 10999 results in a precise reduction of 0.0316 in BWE (from 1.1921 to 1.1605). This highlights Supplier-03's role in amplifying the stabilizing effects of Supplier-01. Similarly, when Supplier-02 is at high levels, increasing Supplier-03 results in a smaller reduction of 0.0565 (from 1.2227 to 1.1662), compared to a reduction of 0.0426 at low Supplier-02 levels. By focusing on these significant interactions, the study identifies strategies for reducing supply chain variability.

5. Discussion

This study investigates the bullwhip effect (BWE) in a selected food supply chain and identifies mitigation strategies through a Design of Experiment (DOE) approach. The findings reveal the significant role of order sizes from multiple suppliers and production levels in controlling demand variation. Interaction effects, particularly between one supplier and the other suppliers, were identified as critical determinants of the BWE. These results demonstrate that optimizing production strategies and carefully managing supplier interactions are essential for reducing the BWE. Many studies, such as those by Lee & Farahmand (2008) and Pastore et al. (2020) emphasize the importance of supplier interactions and demand parameter uncertainty in reducing variability within supply chains. Similarly, this study highlights the critical role of supplier-level combinations in mitigating the BWE

The implications of these findings extend to supply chain management practices since controlling the supplies at a fixed value minimizes the need and cost of inventory. Furthermore, encouraging collaboration among suppliers can help address variability at the earliest stage of production by aligning production and supply strategies. For example, the results from the 2^3 Factorial DOE showed that the order size to supplier-3 has the maximum effect on reducing the bullwhip effect. Furthermore, the interaction effect between the order sizes from three suppliers also shows that, it is possible to fix the order size from one supplier and dictate the others to further control the bullwhip effect. To mitigate the bullwhip effect, planning departments should focus on stabilizing order sizes for Supplier-03, as it plays a pivotal role in reducing variability. Aligning production schedules with Supplier-03's capacities and employing buffer inventory during periods of high variability can enhance supply chain stability. Furthermore, prioritizing Supplier-03 when designing order strategies and leveraging Supplier-01's stabilizing effects can minimize disruptions and improve efficiency In terms of production levels, prior research by Dai et al. (2017) focus on inventory management strategies like Vendor-Managed Inventory (VMI) and third-party logistics to optimize stock levels and reduce variability, the design of experiment (DOE) approach in this study includes specific supplier-level order sizes and production variables to quantitatively determine their effect on the BWE.

The application of DOE turned out to be a significant decision-support tool for identifying factors and interactions that contribute to the BWE. Furthermore, the proposed approach of prioritizing the order sizes from suppliers can lead to more effective mitigation strategies. This study highlights the potential of DOE to support supply chain optimization and provide solutions in multi-supplier based supply chains that are seeking to reduce operational inefficiencies.Despite its contributions, this study has certain limitations. The analysis focuses on a specific food supply chain and the findings may require modifications for broader application across different industries. The proposal of this research outcome demands a level of co-ordination across the three suppliers which will incur some initial cost. So, implementing the research outcomes will incur an initial cost but the long-term benefits will overcome this initial investment by reducing inventory cost and overproduction. The application of the DOE method of utilizing multiple factors can be applied for future research. Using more than three raw materials will further reduce the bullwhip effect. A further complex model can be generated and that might lead to even more improved outcomes. This study was focused on reducing the bullwhip effect in a food processing industry. The research methodology and tools used in this research can be applied in other industries for further research in other supply chains. Overall, this study highlights the importance of addressing supplier interactions and production levels in reducing the BWE, offering a statistical approach for enhancing supply chain performance.

6. Conclusion

This study investigates the bullwhip effect (BWE) in a food supply chain and provides strategies to mitigate its effect through a Design of Experiment (DOE) methodology. Global and national businesses are continuously looking for newer ways to have leaner, lighter, and more flexible supply chain management systems in order to serve their consumers better and remain competitive. To stay relevant in the growingly competitive market, companies need to evolve continuously and adopt systems that offer improved efficiency. Obstacles like bullwhip effect reduce the efficiency and increase waste and cost in the supply chain system. So, it is essential to find ways to mitigate the ill effects of the bullwhip effect. Hence, this research proposes a model that will provide an efficient method to keep track of the bullwhip effect that may occur in the upcoming periods. The findings further propose ways to level the production and supply of the raw materials so the bullwhip effect can be minimized. Thus, the findings suggest that the adoption of the DOE method can explore the effects of different order sizes on the reduction of the bullwhip effect in any supply chain system.

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Biographies

Md. Shakil Ahamed is a recent graduate with a Bachelor of Science in Industrial and Production Engineering from the National Institute of Textile Engineering and Research (NITER), affiliated with the University of Dhaka. He has demonstrated a strong academic record and a keen interest in research areas such as the Bullwhip Effect and Supply Chain Management. Shakil's undergraduate thesis, titled "*Minimization of the Bullwhip Effect of a Food Supply Chain by Balancing the Supply of Multiple Raw Materials Using Design of Experiment (DOE)*", focuses on enhancing supply chain efficiency in the food industry. By leveraging DOE techniques, his research addresses critical issues like supply chain disruptions that lead to food spoilage, expiry, and unnecessary financial losses, all of which contribute to the global food crisis. In addition to his academic accomplishments, Shakil has practical experience in the manufacturing industry. He served as a Management Trainee Officer (Operations) at Croydon Kowloon Design Limited, where he developed hands-on expertise in operations such as Cutting, Sewing, Quilting, and Finishing, while driving process innovations in high-demand production environments. He further enriched his industry knowledge through an internship at Kazi Food Industries, focusing on quality control and workforce optimization strategies within the FMCG sector. Shakil is eager to leverage his academic background, research expertise, and practical experiences to contribute effectively to dynamic and innovative industries in Bangladesh and beyond.

Sadiatul Farin is a recent graduate with a B.Sc. degree in Industrial and Production Engineering from the National Institute of Textile Engineering & Research (NITER), University of Dhaka, Her research interests lie in process optimization and production efficiency, with a focus on the fields of operations management and supply chain management. During her undergraduation, she showed excellence in academic and research work which was showcased in her thesis, titled "Minimization of the Bullwhip Effect in a Food Supply Chain by Balancing the Supply of Multiple Raw Materials Using the Design of Experiment (DOE)." She gained practical experience through an industrial attachment at Akij Food & Beverage Limited, where she gained hands-on experience in production systems, lean manufacturing principles, data analysis and reporting, supply chain insights, problem identification, manpower study, and team collaboration. She is focused on engaging herself more in future research work and pursue higher education in the field of Industrial and Production Engineering.

Kazi Sadia Suriya graduated with a Bachelor of Science in Industrial and Production Engineering from the National Institute of Textile Engineering and Research (NITER), University of Dhaka. Her undergraduate thesis, "Minimization of the Bullwhip Effect of a Food Supply Chain by Balancing Supply of Multiple Raw Materials using Design Of Experiment", utilizes methods to lessen bullwhip effect in manufacturing by balancing of raw materials. She has gained industry insights from her internship at "HATIL Complex Ltd." where she concentrated on Production & Supply Chain system. Sadia's work as a business analyst at ITL BD has reinforced her abilities to model business processes and evaluate data ensuring technology solutions align with corporate goals, making strategic planning and decision-making easier.

Tasmia Tabassum holds a Bachelor of Science in Industrial and Production Engineering from the National Institute of Textile Engineering & Research (NITER), University of Dhaka, where she has demonstrated strong academic performance. Her research interests are centered on minimizing the bullwhip effect. For her undergraduate thesis, she conducted a study titled "Minimization of the Bullwhip Effect in a Food Supply Chain by Balancing the Supply of Multiple Raw Materials Using the Design of Experiment (DOE)." During her internship at Kazi Farms Kitchen, she gained valuable industry knowledge, with a focus on supply chain management aimed at optimizing the bullwhip effect. Tasmia Tabassum earned her Bachelor of Science in Industrial and Production Engineering from the prestigious National Institute of Textile Engineering & Research (NITER), affiliated with the University of Dhaka. Throughout her academic journey, she has consistently maintained a strong academic record, showcasing her dedication and commitment to her field of study. Her primary research interests are centered on the phenomenon known as the bullwhip effect, particularly in supply chain dynamics. This research involved using statistical methodologies to explore how variations in raw material supply can lead to amplified effects as they travel along the supply chain, ultimately proposing solutions to enhance efficiency.

Corresponding Author: Nurul Ahad Choudhury
Nurul Ahad Choudhury is currently working as a lecturer in Industrial and Production Engineering at the National Institute of Textile Engineering and Research. His research interests lie in the optimization and improvement of logistics and supply chain processes, and human factors engineering. Currently, he is pursuing his Ph.D. in Industrial Engineering and Management at Oklahoma State University. His present research work focuses on improving

decision-making through cognitive engineering in the field of firefighter decision-making. This research paper represents their dedication to advancing knowledge in the field of productivity improvement and assembly line balancing. He supervised the whole research being a thesis advisor in a project and would be positioned as a Corresponding Author. Email: nachoudhury@niter.edu.bd