A Mixed QFD–ANP Approach to Mitigating Bullwhip Effect by Deploying Agility in the Supply Chain System

An-Yuan Chang, Cheng-Hsien Cho

***Abstract*—The bullwhip effect (BE) occurs when the supply chain system faces numerous uncertainties in market factors or when it fails to obtain correct information, resulting in considerable variation in order quantity and actual needs. BE significantly increases supply chain costs and decreases performance. In supply chain management, BE has long been considered a ubiquitous issue plaguing supply chain managers. However, no research work has so far been devoted to discovering how agility may be used as a tool for mitigating BE. This research attempts to employ a combined quality function deployment and analytical network process approach, considering the interrelations between supply BE and agility factors to provide agility factor ranking. The study will help managers determine the most important agility factor for deploying company resources and for managing BE encountered in the supply chain.**

Keywords: bullwhip effect, agility capability, FDM, QFD, ANP

I. Introduction

Bullwhip effect (BE) occurs when the supply chain system faces numerous uncertainties in market factors or when it fails to acquire correct information, resulting in considerable variation in order quantity and actual needs. In the supply chain system, BE is considered a prevalent issue that has long been plaguing supply chain managers because it significantly increases supply chain costs and decreases performance (Sterman, 1989; Mackelprang & Malhotra, 2015). Dominguez et al. (2015) claimed that many studies have proven that BE can cause inefficiencies in terms of total cost increase, profitability deterioration, inventory holding cost increase and high capital costs. Also, BE negatively impacts excess inventory, inaccuracies in demand forecast and insufficient or excess resource investment (Wang & Disney, 2016). According to Lee et al. (2004), BE was first documented by Forrester (1958) and characterised by Lee et al. (1997a, 1997b), who (2004) provided this definition: *bullwhip effect or whiplash effect refers to the phenomenon where orders to the supplier tend to have larger variance than sales to the buyer (i.e. demand distortion) and the distortion propagates upstream in an amplified form (i.e. variance amplification).*

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Christopher (2000) indicated that supply chain agility can reduce the negative effects of market turbulence and improve business performance. The occurrence of BE is also considered a significant factor in the turbulent market. Yusuf et al. (1999) proposed that agility is the ability to meet customer-oriented products and services in a rapidly changing market environment. Agility emphasises customer responsiveness and initiative to face an uncertain environment and is particularly important for supply chain downstream firms (Prince & Kay, 2003; Narasimhan et al., 2006; Sherehiy et al., 2007). Therefore, this study considers that supply chain agility enhancement could be used to mitigate negative BE effects. On the basis of this assumption, the study attempts to determine which agility capabilities are effective in managing BE.

II. Related Literature of Bullwhip Effect and Agility

2.1 Studies on bullwhip effect

Causes of BE have been identified in the seminal works of Forrester (1958, 1961), Sterman (1989), Lee et al. (1997a), Geary et al. (2006) and Bhattacharya and Bandyopadhyay (2011). Forrester (1961) indicated that decision makers must often repeat orders or make provisional decisions in cancelling an order because of difficulties in receiving feedback information, causing demand instability. On the basis of the beer distribution game, Sterman (1989) confirmed that information distortion and time delay are important factors causing BE. Similarly, Lee et al. (1997a) proposed four main factors causing BE: (1) demand forecast updating, (2) order batching, (3) price fluctuation and (4) rationing and shortage gaming. Many scholars then successively proposed that lead times, supply chain echelons, decision-making mechanisms and inconsistent information generation can result in BE. Consequently, scholars presented many possible solutions for BE management, such as reducing lead time and minimising the echelon of the supply chain. Following these perspectives, Wang and Disney (2016) reviewed the conventional technique in examining the elements of BE impact, including demand, delay, forecasting and ordering policy and information sharing.

This study collects from the literature relevant factors causing BE, which are summarised in Table 1.

TABLE 1
SOME OF THE FACTORS OF CAUSING THE BULLWHIP EFFECT IN THE LITERATURE

Factors causing the bullwhip effect	A	B	C	D	E	F
1. The difficulty of information feedback among the echelon of the supply chain.	✓	✓		✓		✓
2. The complicated supply chain systems is difficult to improve for managers.	✓	✓				
3. Factory capacity constraints.	✓					✓
4. Time delay.		✓	✓	✓		✓
5.Supply chain echelon.	✓	✓				
6.Decision-making mechanism.		✓			✓	
7.Inconsistent Information.	✓	✓		✓		✓
8. Cyclical demand.			✓		✓	
9.Demand forecasting.	✓	✓		✓	✓	
10. Price fluctuation				✓		
11. Order out of stock.	✓			✓		
12. Order batching	✓			✓	✓	
13. Demand variation	✓	✓	✓		✓	

A: Forrester(1961); B: Towill et al.(1992); C:Metters(1997); D: Lee et al.(1997); E: Kelle and Milne(1999); F: Sterman(1989)

2.2 Agility and its related work

First proposed by the Iacocca Institute (1991), agility incorporates rapid changes in a manufacturing environment, requires flexibility and focuses on customer–supplier relationships. Youssef (1992) indicated that agility is key to business survival. To maintain a competitive advantage, enterprises should fortify internal manufacturing technology, human resources, education, management and information among others. Gligor et al. (2013) claimed that the definition and concept of agility are evolving. Goldman et al. (1995) stressed that under a constantly changing and unpredictable competitive environment, agility is the ability to understand customers, explore opportunities and obtain profits. Yusuf et al. (1999) also proposed that agility is the ability to meet customer-oriented products and services in a rapidly changing market environment. Therefore, enterprises must enhance their capabilities in re-integrating or re-configuring their resources to build speed, flexibility, innovation, quality and productivity on a competitive basis and gain practical knowledge on the business environment (Tsourveloudis & Valavanis, 2002; Yang & Li, 2002; Bottani, 2010). Sharifi and Zhang (1999) proposed that agile organisations must have the capacity to deal with unexpected problems, survive threats from a turbulent environment and turn a situation into an opportunity to make profit. The basic requirement of agility is rapid response to market changes and adaptation to environment changes without affecting cost and quality conditions and the grasping of opportunities from such environment changes. Swafford (2006a) indicated that agility is a broad and multi-dimensional concept involving several diverse organisational aspects. Swafford et al. (2006a, 2006b, 2008) integrated related literature and proposed that an agile organisation has strong adaptability, sufficient flexibility and quick response capacity to withstand unknown challenges. Gligor et al. (2015) stated that agility is a strategic plan for competitive advantage concerning effectiveness and efficiency that involve the degree of customer satisfaction and the enhancement of effective resource utilisation, respectively. Zhang and Sharifi (2007) proposed seven agility capabilities that are intuitively related to the principles of withstanding BE: proactiveness, responsiveness, flexibility, quickness, competency, customer focus and partnership. However, no studies have been published yet on the application of supply chain agility in mitigating BE.

A traditional quality function deployment (QFD) model is a tool for translating customer requirements (BEs) into engineering characteristics from product design to production. According to Chang (2012), QFD can also be used to translate BE, allowing it to deploy its relationship with supply chain agility on the basis of the causal relationship. The present research employs a method combining QFD with analytical network process (ANP) to analyse the relationship between BE and supply chain agility and identifies the key agility factor that can effectively mitigate BE in the supply chain system.

III. RESEARCH METHODS

First, this study uses a fuzzy Delphi method to extract the important elements of agility factor and BE for the case company. Second, by considering the interactions between these two groups of factors, a QFD–ANP method is used to determine the degree of importance of the agility factor in overcoming supply chain BE.

3.1 Fuzzy Delphi method

The Delphi method is an expert prediction method proposed by Dalkey and Helmer (1963) that is used to combine opinions from different experts to obtain consensus on specific issues and produce predictive results. To solve a complicated problem, a group of experts brainstorm for solutions. The Delphi method allows experts to provide different ideas and to avoid any influence from other participants.

The shortcomings of the traditional Delphi method led Ishikawa et al. (1993) to combine it with fuzzy set theory, thus developing the max-min fuzzy Delphi method and the fuzzy integration algorithm to predict the proliferation of personal computers. Compared with the traditional Delphi method, Kuo and Chen (2008) stressed that the advantage of the fuzzy Delphi method is that it needs only a small number of samples to achieve the objective and reasonable results. The fuzzy Delphi method can save time and costs in collecting expert opinions, which will also be effectively expressed without being distorted (Hsu & Yang, 2000). Readers can refer to (Chang et al, 2013).

3.2 Quality function development

In recent years, QFD has become a widely used tool for solving MCDM problems. The QFD is used in translating customer requirements into product engineering characteristics and aims to increase customer satisfaction. This approach has been extended in transferring the connection between demands and supplies (Chang, 2012). Chang (2012) applied QFD to assess the degree of environmental uncertainty and illustrated a method for

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delivering the requirement of flexibility improvement to the manufacturing system. To improve manufacturing system flexibility, Chang (2012) claimed that an advantage of QFD is it can validate important factors of environmental uncertainty that the manufacturing system should withstand. Such validation leads to the prioritisation of manufacturing flexibility types that are required to support the system.

The main steps of the QFD-ANP method proposed by this research are as follows.

Step 1. BE factors and the agility factor (AF) are determined.

Step 2. Assuming that no interdependency exists between BEs, the pairwise comparison of relative importance between BEs is performed to obtain a matrix (W_1).

Step 3. The relational matrix (W_2) is evaluated by performing pairwise comparisons on each BE to AF.

Step 4. A pairwise comparison is performed on each BE to obtain its internal dependency matrix (W_3).

Step 5. Pairwise comparisons between AFs are performed on each AF to obtain the correlation matrix (W_4).

Step 6. The integrated importance priority matrix (W_C) of BEs is calculated, considering the inner dependence of BE, as follows.

$$W_C = W_3 \times W_1 \quad (1)$$

Step 7. Formula (2) is used to determine the relationship between BE and AF.

$$W_A = W_4 \times W_2 \quad (2)$$

Step 8. Formula (3) is used to reflect the mutual influence in QFD and determine the overall priority of AF.

$$W^{ANP} = W_A \times W_C \quad (3)$$

The research framework is shown in Figure 1.

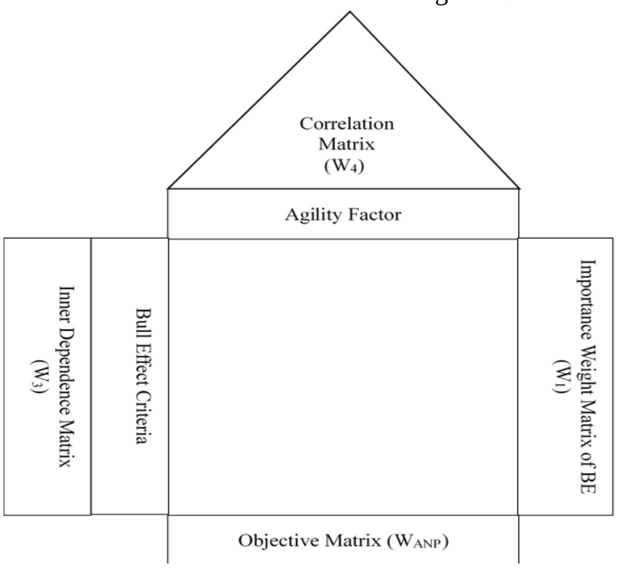

Fig. 1. The QFD-ANP approach for this study

3.3 ANP method

The ANP method is used to construct a systematic network structure of mutual relations of elements in a system to understand the influence of each element on other elements. The influence can be divided into internal and external effects. Internal effects involve mutual influences among elements within the cluster, whereas external effects involve the impact of one cluster on another.

The normal procedure for constructing a pairwise comparison matrix is to invite experts to compare the relative importance of the factors in the system. The measurement scale uses a 9-point priority measurement specification: 1-point means that the factors being compared are of equal importance; 9 points means that a comparative factor has overwhelming advantage over the compared one, and there is an overwhelming disadvantage of the comparative factor, when it is given 1/9. The diagonal is self-comparison in the matrix, so the measured value is all 1. The pairwise comparison matrix is as follows:

$$A = [a_{ij}] = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ 1/a_{12} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ 1/a_{1n} & 1/a_{2n} & \cdots & 1 \end{bmatrix}. \quad (4)$$

After each pairwise comparison matrix is established, their consistency problem must be checked, and their eigenvectors must be calculated to determine their relative priority (Saaty, 1990).

IV. Empirical Study

An electronic company in Taiwan (Company A) is taken as case study. Company A recognised that faced with a dynamic and highly fluctuating environment, its supply chain management capability was the vital foundation of its business. Thus, deploying supply chain agility to mitigate BE is necessary and urgent for the company if it were to compete in the challenging marketplace. Company A needs an accurate, appropriate and measurable method for prioritising its supply chain agility capabilities under BE situations. Therefore, Company A must find a way to improve its supply chain system performance and increase its productivity by improving agility and BE management. We asked six senior staff from Company A with qualifications of over 30 years to accomplish the questionnaire.

4.1 Phase 1: fuzzy Delphi method

After reviewing related literature, we confirmed all assessment items and designed a fuzzy Delphi expert questionnaire for the first survey phase. Each expert provided a range of values for the importance of the assessed item. The questionnaire was excluded from extreme values other than the 'two standard deviations'. The fuzzy theory was then used to calculate the minimum value (C_L^i), the geometric mean value (C_M^i) and the maximum value (C_U^i) of the 'most conservative cognition value (C^i)', the minimum value (O_L^i), the geometric mean (O_M^i) and the maximum value (O_U^i) of the 'most optimistic cognition value (O^i)'.

The researcher and the manager established the threshold value setting in accordance with the research needs. In this

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study, the BE factor and AF thresholds are set to 6.40 and 7.340, respectively. Tables 2 and 3 show the results after screening. According to the setting of the threshold value, BE and agility factor each have seven important items.

TABLE 2.
FUZZY DELPHI METHOD TO COMPUTING THE BULLWHIP EFFECT CONSENSUS VALUE GI

	Factor	G_i
1	Decision mechanism	7.36
2	Demand forecasting	7.30
3	Replenishment strategy	7.24
4	Demand variation	7.23
5	The periodicity of demand	7.19
6	Inconsistent information	6.89
7	Inventory strategy	6.46

TABLE 3.
FUZZY DELPHI METHOD TO COMPUTING AGILITY FACTOR CONSENSUS VALUE G_i

	Factor	G_i
1	Fast customer response	8.205
2	Provide customers with high value-added products	7.447
3	Improve quality	7.399
4	Select partners with better performance and basic capability	7.372
5	Employees' trust and support for senior managers.	7.364
6	Improve delivery reliability.	7.363
7	Senior management support and management commitment	7.340

4.2 Phase 2: QFD–ANP method application

In accordance with steps in 3.3, the following matrices were obtained. The analysis steps are as follows.

Step 1: A pairwise comparison on the importance of BEs is performed, and their weighted priority matrix (W_1) is obtained. The results are shown in Table 4.

TABLE 4.
PAIRWISE COMPARISON OF IMPORTANCE MATRIX OF BE (W_1)

	BE1	BE2	BE3	BE4	BE5	BE6	BE7
BE1	1.000	0.333	1.000	0.200	0.500	0.500	1.000
BE2	3.000	1.000	2.000	1.000	1.000	1.000	2.000
BE3	1.000	0.500	1.000	0.333	0.500	0.500	1.000
BE4	5.000	1.000	3.000	1.000	3.000	3.000	3.000
BE5	2.000	1.000	2.000	0.333	1.000	0.333	1.000
BE6	2.000	1.000	2.000	0.333	3.000	1.000	3.000
BE7	1.000	0.500	1.000	0.333	1.000	0.333	1.000

Step 2: A pairwise relational comparison on BE and AF are performed to obtain the relational matrix (W_2). The results are shown in Table 5.

TABLE 5.
PAIRWISE COMPARISON OF AF WITH RESPECT TO BE1

	AF1	AF2	AF3	AF4	AF5	AF6	AF7	W_{21}
AF1	1.000	0.200	2.000	1.000	2.000	1.000	2.000	0.135
AF2	5.000	1.000	3.000	2.000	4.000	1.000	3.000	0.290
AF3	0.500	0.333	1.000	0.500	0.500	0.500	0.333	0.062
AF4	1.000	0.500	2.000	1.000	0.500	0.333	0.500	0.089
AF5	0.500	0.250	2.000	2.000	1.000	1.000	1.000	0.116
AF6	1.000	1.000	2.000	3.000	1.000	1.000	4.000	0.202
AF7	0.500	0.333	3.000	2.000	1.000	0.250	1.000	0.107

With respect to each BE factor and considering the degree of its relationship with AF, we can obtain the eigenvector for each BE factor. The relational matrix obtained is (W_2). The results are shown in Table 6.

TABLE 6.
THE RELATIONAL EIGENVECTOR MATRIX BETWEEN BE AND AF (W2)

	BE1	BE2	BE3	BE4	BE5	BE6	BE7
AF1	0.135	0.180	0.122	0.229	0.136	0.153	0.191
AF2	0.290	0.075	0.072	0.102	0.181	0.072	0.066
AF3	0.062	0.061	0.058	0.051	0.049	0.067	0.081
AF4	0.089	0.196	0.201	0.206	0.215	0.297	0.248
AF5	0.116	0.096	0.138	0.059	0.057	0.077	0.076
AF6	0.202	0.272	0.266	0.265	0.278	0.126	0.185
AF7	0.107	0.120	0.144	0.087	0.085	0.208	0.153

Step 3: The correlation matrix (W_3) of BE is computed. The results are shown in Table 7.

TABLE 7.
CORRELATION EIGENVECTOR MATRIX OF BE (W_3)

	BE1	BE2	BE3	BE4	BE5	BE6	BE7
BE1	0.130	0.103	0.140	0.166	0.110	0.244	0.229
BE2	0.204	0.206	0.216	0.083	0.279	0.100	0.154
BE3	0.112	0.085	0.065	0.178	0.059	0.107	0.223
BE4	0.263	0.293	0.263	0.253	0.167	0.085	0.125
BE5	0.044	0.101	0.131	0.086	0.229	0.095	0.116
BE6	0.174	0.160	0.122	0.156	0.095	0.284	0.065
BE7	0.072	0.053	0.063	0.078	0.061	0.084	0.088

Step 4: The internal dependence matrix of AF is calculated, and a procedure the same as in Step 4 is used. A pairwise comparison is also used to determine the impact of each AF on other AFs. The eigenvectors of each AF are shown in Table 8.

TABLE 8.
THE INTERNAL DEPENDENCE EIGENVECTOR MATRIX OF AF (W_4)

	AF1	AF2	AF3	AF4	AF5	AF6	AF7
AF1	0.190	0.059	0.000	0.000	0.000	0.202	0.000
AF2	0.041	0.142	0.079	0.141	0.000	0.000	0.267
AF3	0.083	0.116	0.119	0.061	0.000	0.056	0.102
AF4	0.000	0.285	0.275	0.294	0.000	0.169	0.000
AF5	0.075	0.000	0.000	0.000	0.048	0.000	0.000
AF6	0.230	0.052	0.041	0.046	0.000	0.144	0.000
AF7	0.238	0.203	0.200	0.173	0.238	0.000	0.59

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Step 5: Formula (1) is applied to obtain the interdependent importance matrix (W_C).
Step 6: Formula (2) is applied to calculate the integrated relationships of BE and AF, as shown in Table 9.

TABLE 9.
RELATIONSHIP BETWEEN BE AND AF PRIORITY(W_A)

	BE1	BE2	BE3	BE4	BE5	BE6	BE7
AF1	0.083	0.093	0.081	0.103	0.093	0.059	0.078
AF2	0.093	0.082	0.087	0.080	0.088	0.119	0.099
AF3	0.080	0.070	0.067	0.073	0.075	0.075	0.074
AF4	0.160	0.142	0.140	0.149	0.175	0.148	0.145
AF5	0.016	0.018	0.016	0.020	0.013	0.015	0.018
AF6	0.082	0.096	0.082	0.108	0.093	0.074	0.089
AF7	0.152	0.134	0.131	0.140	0.134	0.146	0.145

Step 7: Finally, Formula (3) is used to calculate the overall priority of AF (W_{ANP}), as shown in Table 10.

TABLE 10.
OVERALL PRIORITY VALUE OF W_{ANP}

AF	W_{ANP}	Ranking
AF1 Quick customer response capability.	0.056	**5**
AF2 Provide customers with high value-added products.	0.082	**3**
AF3 Quality improvement	0.043	**7**
AF4 Select partners with superior performance and basic ability	0.145	**1**
AF5 Employees' trust and support for senior executives	0.051	**6**
AF6 Improve delivery reliability	0.101	**2**
AF7 Senior management support and commitment	0.072	**4**

The case results show that the highest AF priority in overcoming BE is AF4, which is the cooperative partner with excellent performance and basic ability. The second and third important factors are AF7 that involves the support and management commitment of senior management and AF2 that provides customers high value-added products, respectively.

V. CONCLUSIONS

Literature reviews show that few studies have focused on the application of supply chain agility in mitigating BE. Firstly, the fuzzy Delphi method is used to segregate the important factors. Secondly, the QFD model is used as a tool for translating the BE and AF of a supply chain system. Then, a combined QFD and ANP approach is used to analyse the relationship between BE and supply chain agility and to determine key agility criteria that can effectively mitigate BE in the supply chain system. The results of this study will enable supply chain managers to understand how agility factors may be used to reduce BE impact on a supply chain and to formulate strategies to prevent negative BE effects.

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