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QUANTIFYING THE BULLWHIP EFFECT IN THE SUPPLY CHAIN OF SMALL-SIZED COMPANIES

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ABSTRACT

This research addressed the Bullwhip Effect (BWE) in the supply chain of small companies. Identifying ways to control the BWE requires that it be understood in the context of small companies. This research analyzed quantitatively the impact of the interaction between demand management strategies and forecasting methods on BWE. Experiments were performed with four management strategies and three forecasting techniques for different levels of seasonality, lead times, and order batching. Costs and an overall BWE index were used as performance measures. Results indicate that no demand management strategy dominates under all conditions. However, the collaborative demand management strategies are best under low seasonality regardless of the forecasting method and lead time nature. Higher levels of communication do not result in the same level of improvement; it depends on the seasonality of the demand. Stochastic lead times do not exacerbate BWE when the items are batched. A quantification methodology is proposed.

Keywords: Bullwhip Effect, Small companies' supply chain, forecasting methods, demand management.

1. INTRODUCTION

The supply chain may lack stability for several reasons, including incompetence, misinformation, and doubts. A tangible and observable phenomenon that indicates the level of stability is the Bullwhip Effect (BWE) which is a metaphor that describes *demand variability* amplification based on small changes of demand at the end-user point. Several researchers have concluded that information distortion is at the center of the root causes of the BWE (Lee et al.,1997), which leads to inefficiencies all over: excessive inventory, poor customer service, lost revenues, and so forth.

Large companies, such as Walmart and Procter & Gamble, have advanced tremendously in their efforts to reduce BWE. However, globalization has affected companies of all sizes. Large corporations have decentralized and subcontracted their production needs all over the world, creating numerous opportunities for the BWE to creep in. These corporations have been able to survive the BWE because they have sufficient resources. However, small businesses do not have the same strength to withstand the BWE, yet, these firms represent 99.9 percent of the 25.8 million US businesses reported in 2005 by the Office of Advocacy estimate (SBA, 2006a). In Latin America, Pyramid Research estimates the ratio of small businesses to large corporations is 13 to 1, with more small businesses to come (Pawling (2005)). Understanding how BWE affects these small companies, and how it can be analyzed and controlled, should result in great economic benefits at the micro and macro levels.

Most of the previous research on the BWE has focused on demonstrating its existence, identifying possible causes, and providing qualitative methods for reducing its impact. In the early 2000´s, the field saw a shift to how to quantify the effect. In fact, Lee et al. (2004) states that *"although the Bullwhip Effect seems well known among practitioners, it is not clear if companies have completely succeeded in taming it."* Further, they tell us that it is necessary to conduct empirical research to estimate the ***magnitude*** of the BWE in different industry segments, and identify best practices.

This research has addressed the BWE in the supply chain of small companies and has developed a methodology to detect and quantify it, as well as to evaluate different mitigation strategies. Specific demand management strategies that enhance collaboration were considered along with some well known forecasting methods. The impact of the interaction between the demand management strategy and the forecasting method on BWE was analyzed quantitatively. This paper has been divided into eight sections. Section 2 provides a comprehensive review of the literature on the subject of this research. Section 3 provides the problem description. Section 4 describes the research goal and methodology. Section 5 describes the experimental framework including the case study used to investigate the BWE and the experimental models used to assess the BWE, along with a description of the inputs to the models. Section 6 presents the results of the various experiments and in-depth discussion. Section 7 describes a quantification methodology for BWE proposed for small company owners. Lastly, Section 8 summarizes the main contributions conclusions of this effort. It also presents possible research extensions.

2. LITERATURE REVIEW

The BWE is a phenomenon of the supply chain that has been studied for many years. The first academic description was given by Forrester (1958) who tried to demonstrate its existence through System Dynamics. As a successor to Forrester, Sterman (1989) argued that the main cause for BWE was the misperception of the feedback**.** Lee et al. (1997) modeled the operational causes of BWE analytically. They documented the effect of it in a number of specific businesses (e.g. P&G and HP), identified causes, and proposed cures. In a more recent paper, Lee et al. (2004) dealt with understanding the causes and managerial implications of the BWE. Unlike Forrester (1958) or Sterman (1989), they developed simple mathematical models of supply chains that reflect the essential aspects of the organizational structure and optimizing behaviors of the members. Previous works had suggested that the effect could be mitigated through modifications in behavioral practice (Forrester, 1958) or individual education (Sterman, 1989). However, they demonstrated that the BWE is an outcome of the strategic interactions among rational supply chain members. Their conclusion is that companies would obtain great benefits by attacking the institutional and inter-organizational infrastructure and their processes.

In recent years many authors have attempted to quantify the BWE. Metters (1997) expressed the significance of the BWE in monetary terms. He created a dynamic programming model to minimize total cost in a production-inventory system. His results showed that eliminating the seasonal BWE alone (caused by demand updating) can increase the product profitability by 10-20%. Mitigation of demand updating in particular had a greater impact in profits. Chen et al. (2000) tried to quantify the BWE for a supply chain consisting of a single retailer and a single manufacturer focusing on two causes: demand forecasting and order lead times. They concluded that centralizing the demand information can significantly reduce the BWE, but they showed that it is impossible for the BWE to be completely eliminated. Lee et al. (2000) developed a model of a two-stage supply chain and attempted to quantify the benefits of information sharing. Their results showed that a manufacturer could reduce inventory levels and costs by sharing information. More recently, Warburton (2004) developed and solved analytical models, used numerical integrations to represent inventory behavior, and derived a measure for the BWE. He also defined the total BWE from consumer to supplier as the product of the BWE of each stage in the supply chain.

Other papers have used more simulation analysis than analytical modeling to quantify the BWE. For example, Merkuryev et al. (2002) and Merkuryev et al. (2004) presented both statistical and simulation-based analysis of the BWE in supply chains. Their simulation results showed that with centralized information demand distortion upstream a supply chain is less significant than in a supply chain with decentralized demand information. However, they acknowledge that a more thorough study is needed to include other factors such as lead times, forecasting techniques, etc. Chatfield et al. (2004) used simulation to perform a series of experiments that employ factors related to lead-time variation, information quality, and information sharing. The results from the experiments were verified by comparing the observed variability amplification levels to those from the analytical work of Chen et al. (2000). These results show the impact of information sharing, lead time variation, and information quality on BWE.

Recent studies have focused on analyzing the effect of different strategies to mitigate the BWE. Towill and Disney (2003) compared traditional and Vendor Managed Inventory supply chains, and showed the benefits of VMI in reducing or eliminating some of the causes of BWE. Aviv (2001) studied the interaction between inventory and forecasting in a two stage supply chain of a single product with stochastic demand. Zhang (2004)

derived expressions for forecast and forecast error estimation for three forecasting methods and analyzed the cost impact of each method on BWE. Sun and Ren (2005) reviewed literature related to the impact of forecasting methods on the BWE. They provided management principles for the adequate use of MMSE, MA and ES.
Most of the research to date (2007) has focused on well integrated supply chains, mainly of large companies. Only recently Govindarajulu (2006) made a study on the application of demand chain initiatives to small businesses from the Indian context. He presents a review of two small businesses in India attempting to explore the potential of applying demand chain initiatives. However his study provides only a qualitative approach.
Many definitions of BWE were found in literature. In this effort, we use the definition by Chatfield et al. (2004): BWE is "*the amplification of demand (or order) variance up the supply chain from customer to factory, as demand information passes back through the supply chain*".

3. PROBLEM DESCRIPTION

The problem that this research effort has addressed is the order variability amplification, also known as Bullwhip Effect, in the supply chain of small companies. The demand amplification that occurs during the ordering process causes unnecessarily high inventory levels, which may represent high costs and low liquidity in a business. Small companies, in many cases, do not have sufficient resources and technology infrastructure to survive attacks of the BWE. Faced with this problem, these companies need to find ways to control its causes because its impact may directly affect not only their operation, but at some point, if not relieved, their bottom line.
Identifying ways to control the BWE requires that it be understood in the context of small companies. These companies have characteristics that we believe render the form and consequences of the BWE different from those of large companies: Low level cash flow buffer, little access to advanced business integration tools, and short-to-medium term relationships with many suppliers. However, as Srinivasan (2004) states, small companies have several desirable characteristics, which may act as a philosophical framework to consider a different approach to the BWE in small companies, including the following: Ability to rapidly react to market and demand changes, agile decision making due to its simple organization structures, decisions are made with awareness of their impact on the enterprise, decisions are made with everyone's input (small team), and they can be communicated quickly throughout the enterprise.
Many researchers have studied the Bullwhip and have discussed many possible causes, most of which are of behavioral (qualitative) nature. Some of these efforts have been theoretical, some have been experimental, and yet others have been of analytical nature. Most studies related to BWE make reference to large companies (e.g. Procter & Gamble, Walmart, Hewlett-Packard). So they model simple and well integrated supply chains (i.e. two-stage or three-stage supply chains with one or few retailers, manufacturers and suppliers), and their proposed mitigation solutions are affordable to large companies.

4. RESEARCH GOAL AND METHODOLOGY

The goal of this research has been to quantify and analyze the impact of different demand management strategies on the BWE experienced by the supply chains of small companies. The impact has been measured in monetary terms. From this goal the following tasks were performed:

- A small business case study was defined.
- A measure for the BWE from literature was defined.
- Models of the small business supply chain in the case study were built.
- Experiments were designed and performed to test this impact.
- Results were analyzed and conclusions were drawn on the impact of the different demand management strategies on BWE reduction and on a small business's profits.
- A general methodology was developed which can be used by small business owners.

The general research question was: *Which Demand Management Strategy is best under different conditions?*
Three demand management strategies have been considered: Independent Forecasting Management (IFM), Collaborative Demand Management (CDM), and Flexible Collaborative demand Management (FCM). To answer the research question, each strategy was compared against an unmanaged supply chain scenario, the Random Forecasting Selection (RAN) strategy.

The goal of the demand management strategies is to have a positive effect on BWE, i.e. leads to a lower BWE index than that of the unmanaged supply chain scenario.
Also, three forecasting methods (simple exponential smoothing, moving average, and exponential smoothing considering seasonality) were tested to answer the additional question: *Which forecasting method is best under different conditions?*

5. EXPERIMENTAL FRAMEWORK:

A case study was used test the research hypotheses derived from the research questions. The case study represents a small company with characteristics to resemble typical real life scenarios. Information was collected from a real life small company and was used as the basis to construct the case study. The small company of the case study is referred to as Churro Magic (CM). Churro Magic belongs to an international franchise chain, with operations in several Latin American countries as well as in the United States. For the purpose of this study, only one store was considered. The company is dedicated to the sale of gourmet churros with different flavor toppings, served in trays or in bags.

In this research, three stages of Churro Magic's supply chain have been considered with one retailer, one distributor, but multiple (three) manufacturers. The manufacturers produce the main raw materials needed for production of churros, namely: wheat flour, cardboard trays, and toppings.

This effort has used the index for BWE proposed by Chen et al. (2000):

$$B = \frac{V(q_{it})}{V(d_{it})} \qquad (1)$$

Where $V(q_{it}) =$ Variance of orders placed by stage *i* to stage *i+1* at time *t*.

$V(d_{it}) =$ Variance of demand experienced by stage *i* at time *t*.

Traditionally it has been established that BWE is present when $B > 1$. In this research BWE was measured using equation 1, but the interpretation of the numeric value has been changed. B is a random variable that follows an F distribution. Thus, BWE exists if $\sigma_Q^2 > \sigma_D^2$ at a significance level α. The decision is based on the comparison of the statistic $B_0 = \frac{s_q^2}{s_d^2}$ to a critical value of the F distribution. If $B_0 > F_{\alpha, n_1-1, n_2-1}$, then BWE exists.

EXPERIMENTAL DESIGN

Simulation was used to model the supply chain operations of the case study small company and to quantify the level of BWE using different demand management strategies.

A full factorial design was used (Table 1). The five factors considered in the experiments were: 1) demand management strategy (DMS), 2) forecasting method (FM), 3) Lead Time nature, 4) seasonality level, and 5) product ordering policy. Their combination generated four different experimental scenarios.

The response variables were the overall BWE index (equation 2) and total costs (equation 3). The total supply chain cost for a period t, $C_{Total,t}$, is the sum of the cost of placing orders, cost of materials, cost of holding inventory, and delivery costs at on all stages for period *t*.

Table 1: Factors and levels considered in experimental designs

Factor	Levels	
Demand Management Strategy (DMS)	RAN =	Random selection of forecasting method at each stage of the SC
	IFM =	Independent Forecasting Management
	CDM =	Collaborative Demand Management
	FCM =	Flexible Collaborative Management
Forecasting Method (FM)	ESS =	Exponential Smoothing Adjusted with Seasonality
	SES =	Simple Exponential Smoothing
	MA =	Moving Average
Seasonality Level	L =	Low H = High
Lead Time Nature	D =	Deterministic S = Stochastic
Product Ordering Policy	B =	Batched N = Non batched

$$B_{overall} = \frac{\sum_{i=1}^{n} B_i}{n} \quad \textbf{(2)}$$

$$C_{Total,t} = \sum_{k=1}^{s} C_{P,t,k} + \sum_{k=1}^{s} C_{M,t,k} + \sum_{k=1}^{s} C_{H,t,k} + \sum_{k=1}^{s} C_{D,t,k} \quad \textbf{(3)}$$

Where:

$C_{Total,t}$ = Total supply chain cost for period t. $C_{P,t,k}$ = Total cost of placing orders in t at stage k.

$C_{M,t,k}$ = Total cost of materials in period t at stage k $C_{H,t,k}$ = Total holding cost in period t at stage k.

$C_{D,t,k}$ = Total delivery cost in period t at stage k.

EXPERIMENTAL MODELS

Experiments required an operational model and a planning model (Figure 1). Four simulation models were built (Table 2) under the assumptions in Table 3. The operational model was built using ARENA, and it represents the flow of order information and products in the supply chain. The planning model was built using Excel and helps managers at each stage decide how much and when to order using different forecasting, demand planning, and scheduling techniques. The period of analysis is one quarter of a year (16 weeks). Initial inventory levels were assumed. All companies in the supply chain use an (r, S) inventory policy.

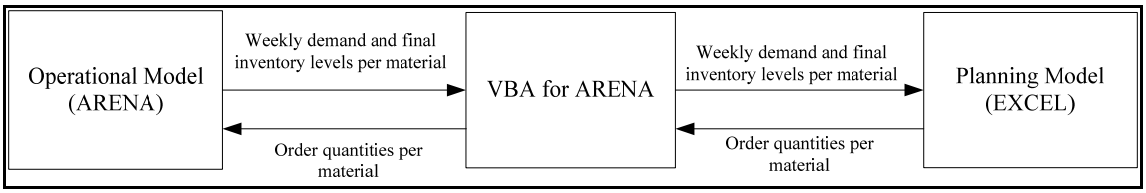

Figure 1: Interaction between experimental sub-models

Table 2: Description of four experimental models

Model	Description
RAN	It represents the unmanaged supply chain. Retailer uses exponential smoothing with trend and seasonality (ESTS), simple exponential smoothing (SES), or moving average (MA). The other stages use either (ESS), SES, or MA.
IFM	IFM strategy. Each stage makes its own forecast of demand but use the same forecasting method (ESS, SES, or MA). For the retailer ESS extends to ESTS. Low level of communication.
CDM	CDM strategy. Retailer uses a forecasts independent demand. Demand planning is used to determine order quantities. Medium level of communication.
FCM	FCM strategy. Retailer uses a forecasting method to predict independent demand while demand planning is used to determine order quantities. Flexibility is incorporated by allowing order quantities to change. Highest level of communication.

Table 3: Assumptions of experimental models

1. Demand patterns show seasonality and trend.
2. There are four seasons (quarters) present in the yearly sales.
3. Within each season, seasonality is also present.
4. Physical Inventory inspection is made at the end of each week.
5. CM orders to DC are made at the beginning of every week.
6. All companies in the Supply Chain use an (r,S) inventory policy.
7. Backordering is not allowed.
8. Materials travel from one stage to the other using the original packaging units.
9. Each stage *j* starts week one with an initial inventory level (I_{0j}).
10. Used an arbitrary additional 10% in the forecasted value at the retail level, a 7% for DC, and a 5% for all manufacturers.
Assumption 1) lead to using Exponential Smoothing with trend and seasonality as the forecasting method. Assumptions 2) and 3) are based on empirical observations (data) and experiences with the real company on which the case study is based.

Figure 2 shows the inputs needed by the models. Raw data were analyzed to establish probabilistic models for these inputs of the simulation models.

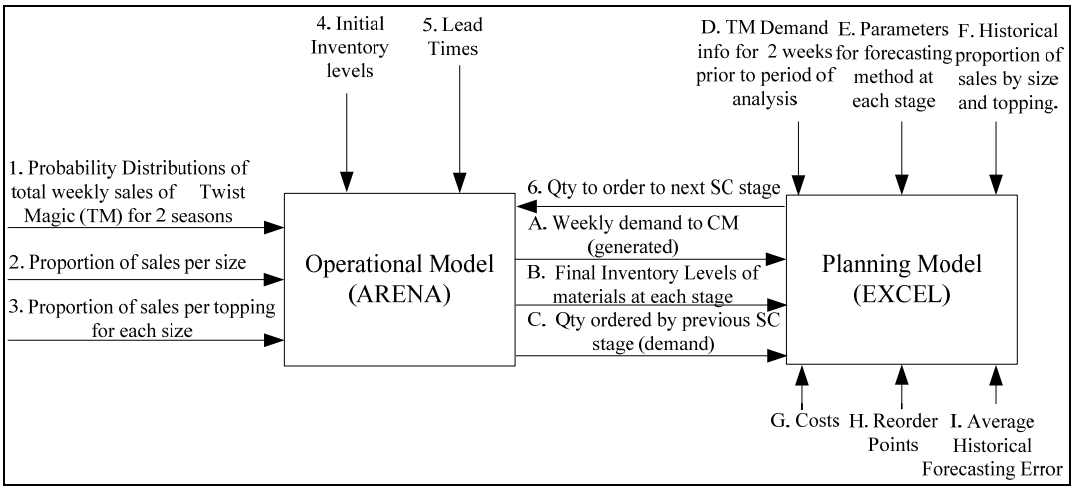

Figure 2: Inputs needed for the models

SELECTION OF FORECASTING METHOD

Demand patterns were analyzed to choose an appropriate forecasting method. The regression analysis performed suggested that there could be some seasonality embedded in the data. This was confirmed by the experience of the manager of the case study company who stated that *"sales vary depending on the week of the month. For the last and middle week of each month sales increase, usually coinciding with the pay days of most people who visit our store"*. According to management, from experience of previous years there is also a tendency of sales to decrease from the beginning weeks of the third quarter to the last weeks. Based on the seasonality analysis, exponential smoothing with adjustment for seasonality and trend was selected as the forecasting method for the first part of experimentation. However, since both trend and seasonality were not very strong, simple exponential smoothing and moving average were also considered.

6. EXPERIMENTATION AND DISCUSSION

Recall that the general research questions were 1) Which demand management strategy is better under different conditions?, and 2) Which forecasting method works better for the best demand management strategy?

The experimental models were built to reduce the number of scenarios to four, while still have the full factorial experiment: 1) Low Seasonality – Deterministic Lead Times, 2) Low Seasonality – Stochastic Lead Times, 3) High Seasonality – Deterministic Lead Times, and 4) High Seasonality – Stochastic Lead Times.

All experiments used a significance level of 0.05, and when needed, the confidence intervals were built at 95% confidence level.

The most relevant results were shown in the interaction of the demand management strategy and the forecasting method. Table 4 summarizes the rankings for this interaction according to the BWE analysis, whereas Table 5 summarizes the rankings according to costs.

Table 4: Rankings for Interaction between DMS and FM (BWE analysis)

		Conditions							
		Low Seasonality				High Seasonality			
DMS	FM	Deterministic LT		Stochastic LT		Deterministic LT		Stochastic LT	
		Batched	Non-Batched	Batched	Non-Batched	Batched	Non-Batched	Batched	Non-Batched
FCM	ESS	3	9	3	9	9	10	9	9
	MA	**1**	2	**1**	2	**1**	5	**1**	2
	SES	2	3	2	3	2	6	2	3
CDM	ESS	12	10	12	12	10	11	10	10
	MA	5	**1**	5	**1**	7	**1**	7	**1**
	SES	8	4	9	4	8	8	8	6
IFM	ESS	10	12	10	10	12	4	12	12
	MA	6	5	6	5	3	2	3	4
	SES	7	8	7	8	6	3	6	8
RAN	ESS	11	11	11	11	11	12	11	11
	MA	4	6	4	6	4	7	4	5
	SES	9	7	8	7	5	9	5	7

Table 5: Rankings for Interaction between DMS and FM (Cost analysis)

		Conditions			
DMS	FM	Low Seasonality		High Seasonality	
		Deterministic LT	Stochastic LT	Deterministic LT	Stochastic LT
FCM	ESS	3	3	2	3
	MA	2	2	8	6
	SES	**1**	**1**	6	5
CDM	ESS	12	11	4	2
	MA	4	4	5	8
	SES	5	5	7	7
IFM	ESS	11	7	3	4
	MA	6	6	11	12
	SES	10	9	10	9
RAN	ESS	8	10	**1**	**1**
	MA	7	8	12	11
	SES	9	12	9	10

From the BWE perspective the following conclusions can be made:

1. For batched products, the best demand management strategy under all scenarios is FCM combined with MA as the forecasting method.
2. For non batched products, there was a greater interaction between the demand management strategy and forecasting method used. CDM is best for non batched products under all conditions only when MA is used. But if there are stochastic lead times, then FCM combined with either SES or ESS is better. Further, if there is high seasonality with constant lead times, then IFM.
3. As expected, the strategies that correspond to the highest levels of communication and collaboration between companies yield the lowest BWE levels. We know two new things:
   3.1. These strategies interact better with MA, as together they adjust better to changes in demand and variations in lead times.
   3.2. The level of the improvement as communication increases is less when dealing with batched products.

From a cost perspective, the following conclusions can be made:

1. For low seasonality demand, the choice of an appropriate demand management strategy is more important than the forecasting method. FCM combined with SES or MA offers the best BWE and costs.
2. For high seasonality demand, the situation is reversed: the choice of forecasting method is more critical than the demand management strategy. ESS showed the lowest costs regardless of the demand management strategy, with RAN combined with ESS yielding the lowest, followed by FCM-ESS.

In regards to lead time nature (stochastic vs. deterministic) and product ordering nature (batched vs. non-batched), the following may be concluded:

1. The rankings of the combinations are not affected by the nature of lead times.
2. The BWE is statistically the same under both stochastic lead times and deterministic lead times.
3. As previous research has asserted, batched products have a significantly higher BWE than non-batched products.
4. The BWE level is less sensitive to the random behavior of stochastic lead times when the item under consideration is ordered in batches.

The results of this effort are consistent with the findings of other researchers, especially in regards to the level of communication and collaboration in the supply chain. Higher levels of communications lead to lower overall BWE levels; hence, supply chain costs are reduced (Lee et al. (2000) and Chatfield et al. (2004)). However, these works consider only two levels of information sharing (with and without information sharing), whereas we considered three levels. Further, they were not specific with respect to the type of strategy used to share information, whereas we considered four specific strategies. None of the previous studies looked into what would happen to the forecasting method performance when combined with a specific demand management strategy as it was done in this effort.

Results also support and *expand* the idea that using commonly known time series forecasting methods, such as SES and MA, may result in significant reductions in BWE levels, as the works by Chen et al. (2000) and Zhang (2004) have asserted. Our results expand this idea by showing that for relatively constant (low seasonality) demand, the forecasting method is overshadowed by the demand management strategy for batched products. In such cases, an effective demand management strategy renders the forecasting method irrelevant. On the other hand, for high seasonality demand, the choice of an appropriate forecasting method is more critical and may overshadow the effect of the demand management strategy.

From a cost perspective, flexible collaborative strategies that apply Lean Thinking and TOC principles, as the FCM strategy, would significantly reduce the total supply chain costs. Flexible collaborative strategies for demand management enable small companies to react to their dynamic markets, and it gives them a competitive advantage.

7. BWE QUANTIFICATION METHODOLOGY

A BWE Quantification Methodology (BQM) has been developed to serve small company managers as a means of 1) quantifying the BWE, and 2) evaluating different demand management strategies to mitigate BWE. It is intended as a guideline.

At the heart of the methodology is data collection. The methodology calls for the small business manager to be organized and keep records of customer demand and materials consumption. It also calls for having material decomposition diagrams for all products under consideration. It also calls for the retailer to strategically establish a long term relationship with the distribution center, and for the DC to do so with its suppliers.

The methodology consists of four phases (**Error! Reference source not found.**): 1) Set up, 2) Data collection, 3) Analysis framework, and 4) Analysis.

1. The *set up phase* is basically focused on establishing the framework for the long term and continuous tracking of BWE.
2. The *data collection phase* focuses on tracking the behavior of demand and consumption and representing such behavior via a probabilistic model.
3. The *analysis framework phase* focuses on deciding which forecasting method to us and which demand management strategies to consider.
4. The *analysis phase* is the evaluation for the various forecasting-demand management strategy combinations, both from BWE and costs perspectives. The last step in it is to choose the best combination for the company.

If data is collected for more than one period, then use following performance measure: *the average of the average overall BWE indices and average total supply chain costs for all periods considered*. Compare the performance measures of all alternative strategies against the performance measures of the current strategy using pair-wise

comparisons. Consolidate data for each alternative strategy to perform paired-t tests (analysis Tool-Pack in Excel) and determine the best alternative.
For the purpose of implementing the methodology, it suffices that the small business keeps track of the collected data either in a spreadsheet (e.g. Excel) or in a database (e.g. Access). The tracking and decision making calculations should be programmed by someone knowledgeable on basic spreadsheet formulas.

8 CONTRIBUTIONS AND FURTHER RESEARCH

The following are the main contributions of this research:

1) Specific demand management strategies that enhance collaboration have been considered. This study has specifically analyzed the performance of three demand management strategies (DMS) on the BWE. Particularly the impact of *flexible* collaborative strategies on BWE has being considered.
2) More importantly, the impact of the interaction of these strategies and specific forecasting methods on BWE has been analyzed quantitatively.
3) Analysis was made in the context of small companies and the impact of the strategies was measured under different levels of demand seasonality, nature of lead times, and product ordering policies, making our analysis more robust.
4) This effort has expanded the conceptual state of the art by providing new knowledge about the BWE behavior:
    a) Although demand management has a significant effect in reducing BWE beyond just the forecasting methods, and the one with higher collaboration in general tends to reduce BWE, no strategy is dominant.
    b) From a cost perspective, for low seasonality demand, the choice of demand management strategy is more significant, regardless of the forecasting method used.
    c) For mitigating BWE of batched products, FCM is best under all conditions regardless of the forecasting method used. However, the best performance is achieved with MA.
    d) For mitigating BWE of non-batched products, CDM along with MA is the best strategy under all conditions. The flexibility in the ordering policy is not as significant as in batched products.
    e) The interaction between the demand management strategy and the forecasting method is significant in the case of non batched products and under high seasonality demand patterns.
    f) The improvements of having a higher level of communication by applying FCM or CDM are higher under low seasonality than under high seasonality demand patterns.
5) A methodology has been provided to detect, quantify, and mitigate BWE. The BWE Quantification Methodology (BQM) was designed as set of guidelines to assist small company managers in detecting and quantifying BWE in the supply chains of their companies as well as in evaluating different mitigation strategies.
6) The BQM provides a more accurate way of detecting the existence of BWE and a means of measuring how critical it is, if it is present. It also provides a way of testing different demand management strategies to help mitigate its effect and measuring their performance in monetary terms. This way, managers would be able to justify investments made to implement such strategies in their companies. According to Metters (1997) “if the impact of inefficiencies can be measured and shown to be significant they are far more likely to be recipients of managerial attention”.

The following research questions provide lines of thought for possible extensions:

- How could small company managers continuously assess BWE while operating?
- What other diagnostic tools could be used to assess the severity of BWE impact in small companies?
- What other measures could be used to properly assess overall BWE in supply chains?
- What would happen if each stage uses different inventory policies?
- If prices varied, what further impact, if any, would this variability have on BWE?
- What is the correlation of applying demand management strategies and strategies related to the other causes of BWE?
- What alternative flexible collaborative strategies could help mitigate BWE?

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