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DETERMINATION OF WHEN A LITTLE BULLWHIP MAY BE HELPFUL

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Abstract

Conventional thinking suggests bullwhip should be minimised within the supply chain. One step to achieving this is producing in a batch size of one. Achieving this given capacity constraints and performance objectives is often unrealistic. Production should be based on small batches and rapid changeovers. This introduces some bullwhip into the supply chain but, managed effectively, can actually be useful. We call this useful bullwhip Maximum Reasonable Bullwhip (MRB). Variable supply and demand makes inventory management a balancing act, where a Minimum Reasonable Inventory (MRI) level is needed. This paper aims to establish relationships between batching policies, MRB and MRI in a multi-product scenario. This is applied, demonstrating how different approaches to inventory management are combined within an organisation. While some extra bullwhip is induced within one supply chain, the other sees higher inventory holding. However, overall performance objectives across the product range are satisfied.

Keywords:

Minimum Reasonable Inventory, Maximum Reasonable Bullwhip, multiproduct, batching

1 INTRODUCTION

Within supply chain management, the ability to understand and recognise bullwhip is important. There is now a wide body of literature identifying causes, consequences and remedies to the phenomenon. Two of the key themes to emerge from this literature are that bullwhip increases inventory holding (which, by implication is therefore 'bad') and that bullwhip should be reduced as much as possible. Rather than focus on minimising inventory and bullwhip, this paper considers the concepts of **M**inimum **R**easonable **I**nventory (MRI) [1] and **M**aximum **R**easonable **B**ullwhip (MRB).

If a company has rapid changeover times (so as to not require batching), zero lead times and infinite capacity, then theoretically it would be possible to have no inventory or bullwhip within the supply chain. However, this is not realistic. Supply chains are affected by the variability of demand, non-zero lead times and capacity constraints. Further, most companies have a wide product range, leading to batch production in order to make best use of shared assets and resources. At the same time, performance targets need to be achieved for all products. These factors affect both MRI and MRB.

MRI represents the lowest level of inventory appropriate for a particular supply chain in order to maintain performance targets [1]. It sets a realistic target for the supply chain to adhere to, rather than justifying the holding of excessive stocks. Actual inventory levels may be higher, the extra representing inefficiencies within the organisation.

We argue that there is the need to introduce a small amount of additional bullwhip into the supply chain, particularly given the presence of batching and a multiproduct scenario. Provided this modest bullwhip is introduced to enable performance targets (including MRI) to be met across all products, it can be considered useful and represents the MRB. Again, actual bullwhip may be higher, representing a mismatch between the ordering policy and customer requirements for that product. This is also likely to impact on other performance metrics.

It may be that within any one organisation various clusters of products may have quite different types of supply chains, depending upon either the customer or product type (such as runner, repeater or stranger [2]). Therefore each cluster may have its own values of MRI and MRB rather than a uniform value for the organisation as a whole. The aim of this paper is to establish relationships between batching policies, MRB and MRI within a multiproduct scenario and subject to the performance regime in the supply chains. To do this, we utilise a case study of a soft drinks manufacturer and consider the production planning activities for two of their customers.

2 BULLWHIP AND BATCHING POLICIES

It is generally accepted that there are at least four main causes of bullwhip within supply chains – demand signal processing (allied with non-zero lead times), order batching, rationing and gaming, and price fluctuations [3]. This paper is particularly concerned with the impact of order batching, which has also been termed the Burbidge effect [4]. In terms of the relationship between bullwhip and batch size, there have been a number of studies in the literature and considering a range of ordering policies including:

- Lot sizing – bullwhip increases in a stepped pattern, the steps being related to the ratio between lot size and average demand [5].
- (s, Q) systems – bullwhip is proportional to the square of the batch size [6].
- (s, S) systems – bullwhip is linearly proportional to the order size [7].
- (R, S) systems – the level of bullwhip adopts a wave form, with minima when the batch size is a multiple of average demand and with maxima halfway between. The sizes of the maxima are related to the square of the batch size [8].

One common theme amongst the literature is the need to reduce batch sizes as low as possible, aiming towards a 'Batch of One' [9]. However, there may be occasions where, for technical, economic or social reasons, this may not be desirable.

Another feature of the literature is that the findings are all drawn from simulation modelling with only a single product flowing through the supply chain. While this does simplify the simulation process, there are many instances in reality where different value streams within an organisation share resources and assets. Therefore, it is necessary to understand a multi-product environment. In his seminal work relating to production systems, Burbidge [10] argues that batching due to Economic Buying Quantity (EBQ) policies will result in 'interference' between value streams queuing up to utilise the shared resources. Also, incoming demand will be excessively variable due to repeated batching within the supply chain as each echelon applies their own EBQ. Therefore, Burbidge advocates the separation of value streams into independent flows.

3 MRI AND MRB

An alternative viewpoint [11] is that batching within the supply chain should occur at one level only, usually, but not necessarily, at the manufacturer. If different products can then be phased optimally, the Burbidge effects can be minimised (but not eliminated). Therefore, the 'Batch of One' concept is a reasonable but not realistic target for manufacturers. Instead, the producer should enable completion in small batches with rapid switchover times. By introducing batching, the frequency of production decreases, possibly to weekly or less often, as other products must also use the same assets. However, delivery to the customer remains daily. Hence, companies need to balance between variable, frequent customer demand and variable, infrequent supply from manufacturing while maintaining customer service levels on all products. Achieving this requires a MRI.

By contrast, MRB is the relatively small but helpful bullwhip required to enable MRI within the constraints and performance objectives pertinent to that pipeline. Throughout this paper, the characteristics for different MRI/MRB tradeoffs will be identified, thereby enabling managers to determine which products should have slightly higher bullwhip and where greater inventory holding is required. It is not the intention to try and provide unique quantification as to low and high levels of MRI and MRB. These values are unique to every organisation. The paper also complements previous work which has considered the bullwhip/inventory trade off without batching, capacity constraints or multiple products in the supply chain [12].

4 METHOD

Much of the previous research on bullwhip and batching within supply chains has used simulation as a tool for investigation. However, the focus has been on a single product as the "unit" that flows through the supply chain. Once a number of products are introduced, there are issues with simulation as the results tend to be dependent on the decision rules modelled. Further, simulation is sometimes inappropriate because of the need to understand the context behind production decisions. Therefore, we adopt a case study approach. In collecting the data, the Quick Scan Audit Methodology (QSAM) [13] was adopted. This brings together four complementary tools – process mapping, data analysis, interviews and questionnaires – with the aim of understanding and documenting the system under investigation. More details on the tools used can be found elsewhere [14].

The case study company is a manufacturer of soft drinks within the UK. The aim of the QSAM was to analyse the level of benefit being derived from the implementation of vendor managed inventory (VMI) with one of their major customers. Ideally, meeting this aim would be best satisfied through the study of the supply chain before and after implementation. However, data from the period before VMI was not available. Instead, a comparison was made between a VMI and non VMI supply chain. The non VMI supply chain was otherwise similar in terms of product range and distribution channel. Research has also been carried out separately with Retailer A, to gain a detailed understanding of this supply chain.

5 THE UK GROCERY INDUSTRY

As already noted, this paper focuses on the operations of a soft drinks manufacturer and the supply chains with two of their customers. It is important to understand the wider context of the grocery industry in the UK, as this is a driver of overall supply chain behaviour. Effectively, the market is an oligopoly [15], with four retailers currently representing around 70% of the total sales. Consequently, these organisations have a strong influence within the supply chain. Both exemplar supply chains involve one of these top four retailers.

In terms of performance measures, there are two main drivers – cost and customer service. Effectively, food is regarded as a commodity product and therefore all retailers look to reduce prices as much as possible. In the context of supply chain management, this has increased the efficiency of the retailers' distribution channels [16] as well as placing cost pressure on suppliers. For service, the key is retaining customer loyalty. Therefore, supply chains have to ensure high levels of availability on the shelf to keep customers satisfied. It has been found that up to 48% of shoppers will visit an alternative store if there is a stockout [17].

Recent evidence suggests that suppliers to UK supermarkets may be prepared to tolerate the generation of bullwhip at their level in the supply chain. The reason is the various hidden ways in which retailers impose hefty fines for incomplete deliveries [18]. For example, the Competition Commission Report into supplier-supermarket relationships produces evidence suggesting that retailers seek recompense way beyond lost profit [19]. Typically the 'fine' can be equal to the lost sales incurred by any shortfall. Because of high retailer mark-ups all the profit from a particular deal could rapidly ebb away. Under such circumstances the supplier is likely to make the strategic decision to absorb bullwhip costs internally rather than risk paying such punitive fines.

6 SUPPLY CHAIN WITH RETAILER A

Retailer A represents the largest customer of the soft drinks manufacturer, accounting for around 30% of their total sales. There are approximately 200 different product lines delivered from a single manufacturing plant to 8 distribution centres (DCs) throughout the UK. Deliveries to the store are then made from these locations. Turning to the products investigated in this supply chain, three were chosen to represent high, medium and low volume of sales. They represent 6% (high), 5% (medium) and 1.5% (low) of the total sales from the soft drinks manufacturer to Retailer A. All three carry the brand name of the supermarket and are priced according to Every Day Low Price (EDLP) principles, with no promotions.

6.1 Process overview

A simple process map of the supply chain is outlined in Figure 1. There are effectively three replenishment cycles within the supply chain. The first relates to the restocking of stores, with the store ordering system producing at least one order per day for each store. This order is then fulfilled from the DC. In terms of how orders are produced, it has been suggested that retailers take into account stock deficiency at the store, seasonal and daily factors, the weather forecast (for instance, soft drinks see a surge in orders during hot periods) and promotional activities for

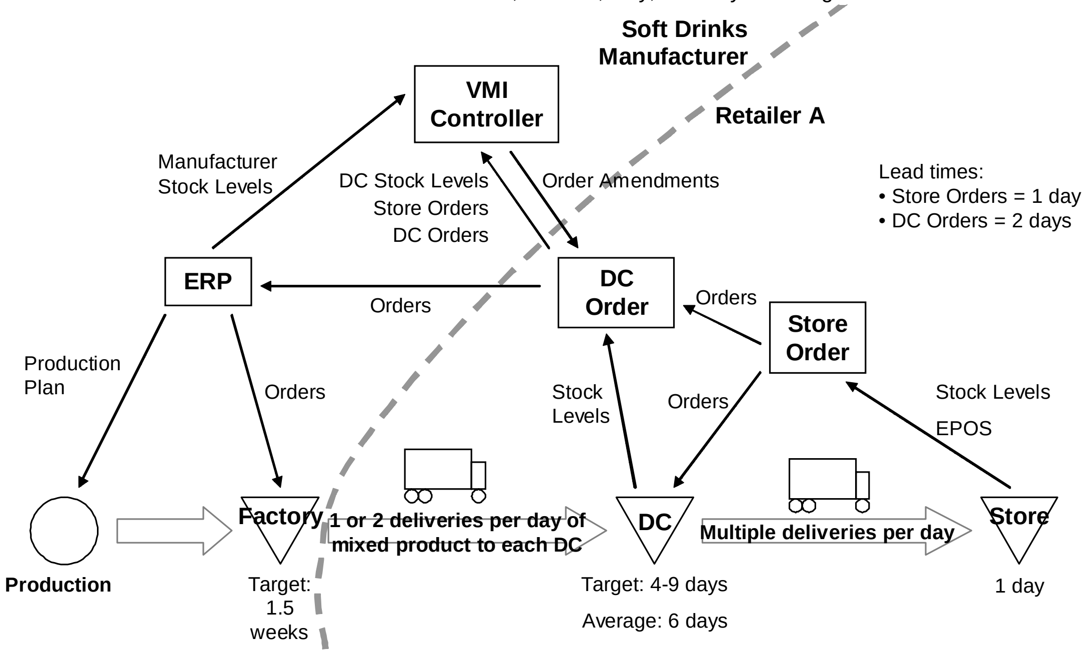


Figure 1: Process map of supply chain between case study company and Retailer A

non EDLP products [20]. Typically, deliveries will occur within 24 hours of the order being placed. Consequently, only 1 days worth of stock is held in the stores, which helps maximise their selling space.

The second cycle relates to the replenishment of the DCs by the supplier. In this particular instance, the relationship incorporates vendor managed inventory (VMI). However, the initial orders are still generated by the DC Order system. This system uses information on forecast store orders, DC inventory levels and the order pipeline to generate a new order. The DC Order system also ensures that a full vehicle load has been achieved across all of the products from the manufacturer [21]. Once this has occurred, there is then the scope for the VMI controller (a human) to adjust the orders, while considering inventory levels both within the DCs and at the manufacturer. When the controller is satisfied that the orders can be met, they are confirmed and sent via EDI to the ERP system of the manufacturer. Typically, orders placed on day 1 are delivered on day 3, giving a two day lead time. Transport for the delivery is arranged by the retailer. More stock is held at the DC, with between 4 and 9 days cover.

The final cycle relates to production at the soft drinks manufacturer. The planning process is driven by the ERP system. Further, production is planned around a batch size of 7,500 cases, although sometimes 'half batches' of 3,750 cases are made. Ultimately, however, production is determined by the production manager depending upon inventory levels for finished goods and raw materials, as well as constraints relating to cleaning of the production line and the sequence in which products can be made. Typically, the target is to hold 1.5 weeks of stock, although much of this stock holding exists in order to maintain customer service. In terms of production, there is no dedication of the assets to either a particular product or customer. Potter et al. [14] provide more details on this supply chain.

6.2 Production behaviour

The above provides an overview of the supply chain and the factors that affect orders and deliveries. Within the context of this paper, it is necessary to carry out data analysis to identify both the variability in inventory levels and the amplification induced into the system. To do this, data for a period of 12 months (aggregated weekly) was collected for each product. Values obtained included customer purchases in Retailer A's stores, orders placed by Retailer A on the manufacturer and the amount produced each week. From these values, it was possible to calculate the net stock position as historical inventory holding data was not available.

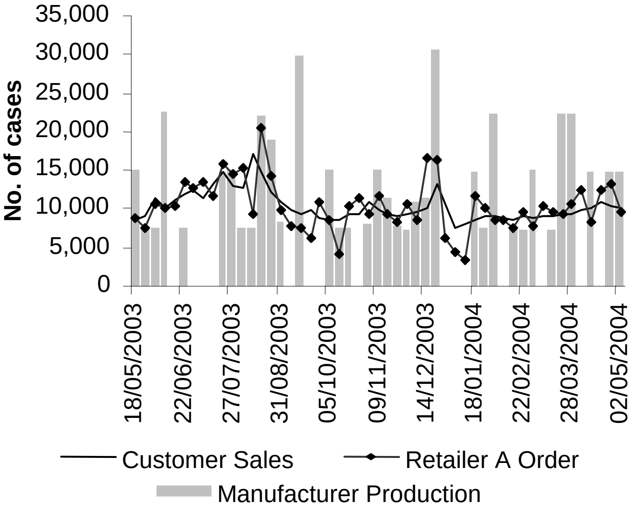
Bullwhip was calculated by dividing the coefficient of variation (CoV) for production by the CoV for orders received. Because this measure considers the variation relative to the average demand level, it enables comparisons to be made between the different products, not only for Retailer A but also with Retailer B. The results were:

- High volume – bullwhip value of 2.78.
- Medium volume – bullwhip value of 2.40.
- Low volume – bullwhip value of 3.17.

These values indicate that the soft drinks manufacturer is increasing the variability of demand from Retailer A by at least a factor of 2.

But what are the underlying reasons for this? The fact that there is batching within the production decision would appear to be the major cause. However, to gain a deeper understanding, the data was plotted in both time series and cusum graphs. The latter technique is a well known tool for scatter reduction and trend detection [22]. The graphs for the high volume product are shown in Figure 2, although comparable results were obtained for the other products. EPOS data is also included to show the amplification induced by Retailer A. On the cusum graph, there is a sharp divergence between production and orders at the manufacturer in June 2003. No manufacturing of this product occurred due to technical issues with the production equipment and orders were satisfied from stock.

a) Time series



b) Cusum

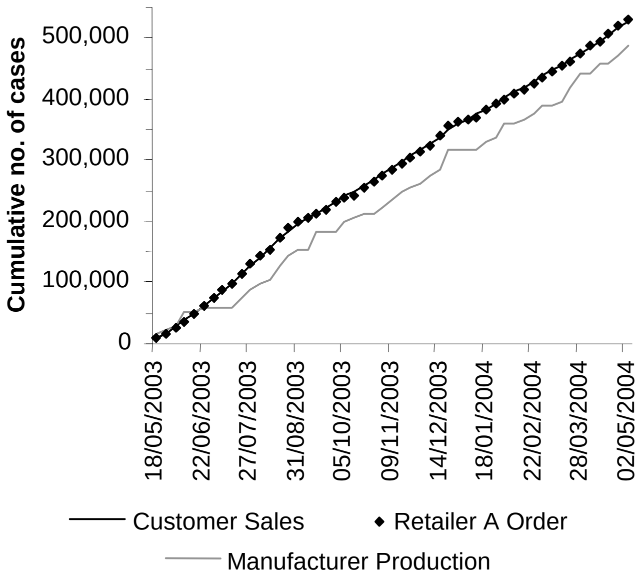


Figure 2: Time series and cusum graphs for sales to Retailer A

The cusum graph proved particularly useful in analysing behaviour within the supply chain. Looking firstly at the orders received from Retailer A, it can be seen that demand is fairly constant, given the steady gradient of the cusum line. This is much less evident in the raw time series graph. What is also clear is that there is an increase in the rate of sales during the summer period (July and August). This is not unexpected as the UK experienced its hottest summer on record, leading to a surge in demand for soft drinks.

Another trend that could be seen in the cusum graph was the way in which production closely tracked the retailer's orders. This trend was again evident for both medium and low volume products. Often where batch production is concerned, there is the implication that a large amount of inventory (not including safety stock) is also generated. However, this does not occur in this supply chain and reference to the time series graph illustrates why.

Average sales require 4 batches to be produced every 3 weeks. Given that a batch size is 7,500 cases, this procedure is evident. However, some weeks see 3 or 4 batches produced. These are then compensated for by not producing in subsequent weeks, effectively freeing up capacity for other products. In the context of the medium volume product, the tracking of orders is even closer as the batch size is broadly equivalent to average demand.

The issue with this approach to managing production is that is does introduce bullwhip into the supply chain. The consistency of demand could result in the manufacturer producing the same amount every week – effectively level scheduling. However, capacity and technical constraints mean variability has to be introduced and the variation of production is greater than that of orders received.

7 SUPPLY CHAIN WITH RETAILER B

By contrast, Retailer B represents around 10% of all sales of the soft drinks manufacturer, with around 130 product lines. Of the products chosen for analysis, they represent around 8% (high volume), 3.5% (medium volume) and 1.6% (low volume) of this volume. Again, they are produced in packaging bearing the retailer's brand name. The significant difference when compared to Retailer A is that the products are subject to promotions which create surges in demand.

7.1 Process overview

In terms of the supply chain with Retailer B, there is a broad similarity to that for Retailer A. There are again three replenishment cycles relating to the store, the DC and manufacturing. In terms of DC replenishment, there is no VMI relationship in this supply chain. Instead, the manufacturer just receives orders from Retailer B which it is then expected to satisfy accurately. These orders are delivered on a similar lead time to Retailer A, but with transport organised by the manufacturer. Deliveries are made to 7 DCs throughout the UK. Because of the lack of a VMI relationship, there are only simple information flows between Retailer B and the manufacturer. Production planning within the manufacturer follows the same process as for Retailer A, although as the products have a lower volume, they are more suited to production in 'half batches'.

7.2 Production behaviour

In terms of the behaviour of production at the manufacturer, reference was again made to the time series and cusum graphs of orders received and actual production. These are not included in this paper due to space limitations. Data on sales in the stores of Retailer B could not be obtained. Again, the first stage was to calculate the level of bullwhip introduced into the supply chain by the manufacturer. Using the ratio of CoVs again, the results were:

- High volume – bullwhip value of 1.99.
- Medium volume – bullwhip value of 1.83.
- Low volume – bullwhip value of 1.49.

For all of these products, the level of amplification is less than a factor of 2, which contrasts sharply with the findings for Retailer A. Therefore, it appears that the retailer may be adopting a different production control strategy for Retailer B.

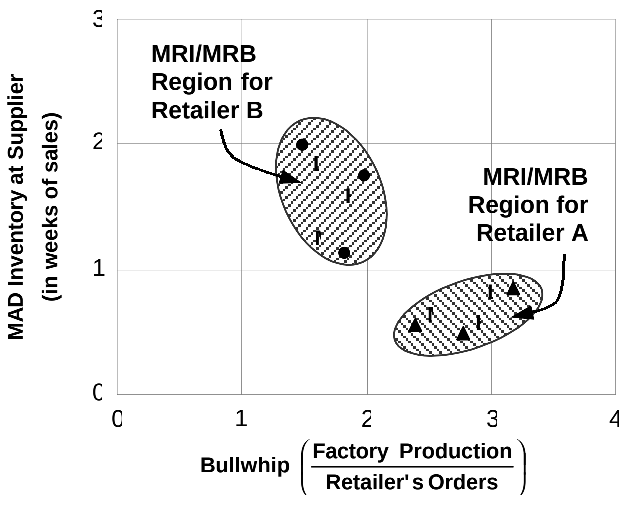
By studying the time series it was found that each of the products were subjected to promotions during the year (contrasting with Retailer A), resulting in large surges in demand, with peak orders 5 times the average weekly sales. This large peak existed because the product was promoted at the end of an aisle (known as a 'Gondola end' and recognised to sharply increase sales and make forecasting difficult [23]). Even outside these periods, there was slightly greater variability in orders placed, as evidenced through the cusum graphs. In addition, the fit between average sales and batch size was not as good as for Retailer A. Coupled with the variable demand, this resulted in production being erratic in nature, with clear steps being introduced into the cusum curve. This effectively represents an increased inventory variation when compared to Retailer A.

8 SO CAN A LITTLE BULLWHIP BE HELPFUL?

The above examples have illustrated that, within a single manufacturer, different strategies may be adopted in planning production for different customers. However, in both instances delivery performance is comparable, with average values of 99.1% and 99.2% for Retailers A and B respectively over a six month period. In the case of Retailer A, some extra bullwhip appears to be accepted in order to keep inventory as low as possible. By contrast, for Retailer B the manufacturer appears to be more content to hold inventory than to introduce bullwhip into the supply chain. To illustrate this more clearly, the bullwhip and mean absolute deviation (MAD) of inventory values have been plotted in Figure 3. The MAD values have excluded the period of no production in June 2003 (referred to earlier) as this only affected Retailer A. In making the comparison, we have assumed that none of the variability is due to inefficiencies within the organisation. Given the products are manufactured through the same production lines, this is reasonable.

There are a number of factors that combine to result in more bullwhip for Retailer A. Firstly, there is EDLP. This means that the sales are visible. Therefore, variability within the orders received is relatively low. This increases the confidence of the manufacturer in respect of likely production requirements every week and can effectively facilitate level scheduling for products. With Retailer B, the potential for promotions creates uncertainty. The variability in demand can be further adjusted by the VMI controller if he perceives that the system is ordering stock unnecessarily, thereby reducing peaks.

The next factor is the behaviour of the factory scheduler. Because demand is fairly constant for Retailer A, he can be confident as to likely demand in forthcoming periods. Therefore, if there is pressure on production capacity due to a surge in demand for other retailer's products (as evidenced with the promotions involving Retailer B), he can review finished goods levels and decide whether production will actually be required of Retailer A's



H = High Volume, M = Medium Volume, L = Low

Figure 3: Bullwhip and inventory variance for the soft drinks manufacturer

products. If not, he can then either bring forward or push back production so as to compensate for the missed week. This introduces bullwhip into the supply chain of these products and effectively counteracts the reduction in bullwhip through level scheduling. However, the process is controlled and provides the opportunity to maintain service levels for other customers. What was not evidenced through the case study was whether information about this approach was passed on to suppliers, as otherwise the variation may have an adverse effect on the supply chain upstream. The uncertainty in likely orders for Retailer B means that the scheduler needs to ensure inventory is replenished at the same rate as it diminishes.

Finally, there is the visibility afforded through VMI. Not only can the manufacturer observe their own operations, but inventory levels and store orders can also be monitored. When making production decisions which affect Retailer A, consideration can also be given to the amount of inventory at the DCs. In contrast, the manufacturer can only respond to orders placed by Retailer B.

Turning to the lower inventory position for Retailer A, this can be explained by several factors. As with bullwhip, the low level of demand variability means that the level of safety stock required in achieving a given service level is much less than for Retailer B. Also, the visibility from VMI effectively provides extra buffer stock as inventory at DCs can be observed. The VMI process permits the VMI controller to redistribute orders, so as to balance inventory better and minimise stockouts at the DCs.

Additionally, there is the close relationship between the batch sizes and average demand which accounts for the low inventory level. As already noted, these are quite closely aligned. With demand being predictable, it is possible for the manufacturer to pace production against demand and therefore minimise the amount of inventory required to be held. The alignment for Retailer B is not as good, leading to increased variability in stock holding.

This case study demonstrates that there appears to be circumstances where introducing a little bit of bullwhip into the supply chain can bring benefits to all products sharing particular assets and resources. The manufacturer is effectively customising his supply chain strategies according to the customer, adopting an approach very similar to the base and surge demand method suggested by Christopher and Towill [24]. The low order variability products from Retailer A are planned using a level scheduling approach (although this then is adjusted according to capacity constraints) while higher variability products from Retailer B are planned around forecast demand, using inventory to provide a buffer. One of the key factors in enabling this differentiation is the presence of VMI. This gives both visibility and control to the manufacturer, enabling them to reduce the uncertainty within their supply chain.

9 CONCLUSIONS AND MANAGERIAL IMPLICATIONS

This paper has investigated the trade off between bullwhip and inventory in a multiproduct environment with batching in production. The aim was to demonstrate that, in meeting performance objectives of the complete pipeline, there may be the need to introduce additional bullwhip and/or extra inventory into the supply chain. Future research will look to develop the Bullwhip-Inventory matrix further so as to enable the trade offs and their implications to be fully understood.

Through a case study of a soft drinks manufacturer, an attempt has been made to validate this proposition. By studying the supply chains with two different customers, distinct clusters of results were found, representing situations with a high MRB/low MRI and low MRB/high MRI. However, performance levels were consistent across both supply chains, indicating that a small amount of bullwhip can be helpful. Characteristics of the high MRB/low MRI situation included low demand variability, good information visibility and proactive production management. These are effectively the opposite characteristics of the low MRB/high MRI scenario.

Where this paper contributes to the literature is through challenging the contention that bullwhip and inventory holding is always bad for the supply chain. In satisfying performance objectives for all products, it may be that a controlled amount of one or the other is required. The term 'controlled' is important in this context as excessive inventory holding or rampant bullwhip will still be destructive to the supply chain.

In terms of managerial implications, this paper highlights the benefits that can be obtained from different inventory management control strategies and how, when combined, they enable performance objectives for all products to be maintained.

10 ACKNOWLEDGMENTS

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