Coping with Uncertainty: Reducing "Bullwhip" Behaviour in Global Supply Chains

All supply chains suffer the effects of uncertainty. One of the most documented (and painful) symptoms is upstream order magnification known as the “Bullwhip Effect”. We believe that companies which cope best with uncertainty via an effective supply chain strategy are most likely to produce internationally competitive bottom-line performance.

Although uncertainty takes many forms four key areas within a supply chain structure can represent these. These key segments are the supply side, manufacturing process, process controls and demand side. They may be combined to form the uncertainty circle. It is manifest that the uncertainty present within each of the quadrants must be reduced to maximise competitive advantage and hence market share. The paper therefore proposes a set of actions, which will reduce supply chain uncertainty caused by demand amplification (or the “bullwhip effect”) irrespective of source. The methodology is shown to apply to a wide range of realworld supply chains.

To protect market share and ensure survival companies have to meet future customer demand. A forecasting error can lead to inability to supply which not only results in a loss of sale at that moment in time but may impact future sales due to a consumer loss of confidence. Forecasting is a predictive process which by its very nature carries an element of uncertainty. However forecasting accuracy can be improved by reducing the uncertainty experienced within the supply chain especially via lead time reduction. We believe that companies who understand and cope with uncertainty can optimise their forecasting potential and are in a better position to produce internationally competitive bottom-line performance.

Much uncertainty is system induced and magnified by the “Bullwhip Effect” as opposed to being introduced by the marketplace. Hence it is our experience that the best way to cope with uncertainty is to work hard to reduce it. The ultimate goal in our approach is the Seamless Supply Chain (SSC) wherein all players “think and act as one” (1). Thus the SSC obtains a greater market share to the benefit of all the “players” within the chain.

To understand the problems posed by uncertainty, let us consider the operation of a typical company engaged in the Product Delivery Process (PDP) in which goods are supplied in response to an order from our immediate customer. But who our immediate customer actually is depends on our position within the chain. For example if we are an OEM, our immediate customer is usually a Dealer, but if we are a PCB manufacturer our customer is usually an electronic products sub-assembler. As we shall see later, in the “traditional” supply
chain, uncertainty will be a function of how far upstream we are from the ultimate marketplace. The further upstream we are, the worse will be the “Bullwhip Effect”. There are various contributing factors to supply chain uncertainty, however the source of the Bullwhip effect quoted by Lee et al (2) is that of the amplification dynamics of the order distortion as it propagates upstream.

Regardless of our position within the chain, the PDP uncertainty problem may be simplified and put into the generic format of Figure 1. Here a single echelon PDP is shown with our value added process (which may be composed of many individual tasks) is directed by the controls process. The company responds to our immediate customer (the “Demand” side). In turn our stocks are replenished with materials, components, and sub-assemblies by various vendors (the “Supply” side). Our considered view is that reducing uncertainty is achieved by understanding and tackling the root causes inherent in each of the four areas in Figure 1. The purpose of this paper is to demonstrate that an holistic approach to Supply Chain Management (SCM) based on this generic model has a great deal to offer in achieving these goals using the Uncertainty Circle as a framework for improving performance.

Shrinking the uncertainty circle

The major factors in supply chain uncertainty of Manufacturing (our value added process), Supply Side, Controls, and Demand Side may be represented by the four fundamental segments in the PDP Uncertainty circle (3). Figure 2 (a) shows a typical situation in which all four are significant and approximately equal in importance. What does then management typically do to reduce uncertainty? Two decisions are normally taken, sometimes sequentially, sometimes concurrently. Firstly, we strive to improve the performance of the value added process by reducing lead times and greatly improving quality levels via the application of Lean Thinking (4). Secondly, we work more closely with our suppliers. Preferably via a Partnership Sourcing Programme. We thereby expect to considerably improve supplier quality, reduce supplier lead times and experience much more consistent delivery patterns so that JIT production may be enabled as appropriate.

Unfortunately companies which have taken these actions (often a considerable cost in money, time, and hassle) are often perplexed to find that substantial operational uncertainty still persists. The reason is quite obvious as can be seen from Fig. 2 (b), since we have only reduced two of the sources of uncertainty, leaving the controls process and demand side problems untouched. Furthermore management is up against the law of diminishing returns here. There is thus little point in continuing to hammer our suppliers and our shop floor for even better performance particularly when there are big gains remaining to be made elsewhere in the system.

But of course we have so far concentrated on the easy actions. It is manifestly much simpler to re-engineer the shop floor and chase/change our suppliers than attempt to persuade all players in the chain to seriously practice SCM! It is thus obvious that to deliver the further improvements shown via the Seamless Supply Chain in Fig. 2 (c) that we must be able to amply demonstrate the benefits accruing from successful SCM. This we shall do using both simulation and real-world supply chain results.

The Bullwhip Effect in Traditional Supply Chains

Forrester (5) first simulated the demand amplification characteristic exhibited by real-world supply chains over thirty years ago. More recently this phenomenon has become known as “Bullwhip Effect” due to the characteristic increasingly magnified and hence worsening behaviour observed upstream from the source disturbance. Burbidge (6) offered an explanation for this behaviour and called it “Law of Industrial Dynamics”. Hence the Bullwhip effect can be seen as a resultant of the following law:

As we approach the seamless supply chain
the Key to Enhanced Performance.
"If demand for products is transmitted along a series of inventories using stock control ordering, then the demand variation will increase with each transfer".

So the demand amplification inherent in supply chains is systemic and is directly affected by both information and material delays in the chain and the feedback loops in the decision making process. A real world example of the effect this has on the dynamic behaviour of a supply chain is shown in Figure 3. The retail supply chain example used was initially presented by Stalk and Hout (7) and it clearly shows the increasing magnification of order fluctuations as they proceed further upstream.

At each company within a supply chain, order information is subject to delay, bias, and noise before transferring it onto their subsequent supplier. Far from canceling each other out, these various sources of distortion of true marketplace demand is at best additive and at worst multiplicative in their effect. Hence any genuine marketplace uncertainty is greatly magnified as orders are transmitted upstream in the supply chain. Frequently this is compounded by players at all levels "double guessing" the true order pattern. Unfortunately their actions are usually out-of-phase with what is actually required to damp down excess magnification of the order waveform. The result is typified by the demand amplification pattern exhibited in Figure 3 where the upstream yarn manufacturer is having to cope with order fluctuations in excess of 40% greater than the downstream retailer.

The Bullwhip Effect has been widely observed and researched to discover opportunities for good supply chain design. The practical real-world consensus is that if the demand can find a way to multiply then it will, (8). So, the further away from the end consumer a "player" is in the supply chain, the less he is aware of the true consumer demand and the more misled he is likely to be especially since there is usually geographical as well as time separation. In a traditional supply chain the raw materials supply will respond to an increase in consumer demand maybe weeks, months or even years after the buying practice first showed itself in the marketplace. By this time the product may well be obsolete with vast quantities of stock written off at various points throughout the chain.

Simulation models capable of answering "what if" questions are a valuable tool in engineering the supply chain (9). But despite the fact Forrester made his observations in the early 1960's the problems identified then still hold true in the majority of today's chains (10). The problem of demand amplification and its subsequent dynamic effects have not gone away despite the enormous amount of research and the flurry of supply chain improvement programs.

Uncertainty still persists, but learning to constrain the effects by developing strategies that deal effectively with it are crucial supply chains activities to ensure they can actively compete in the marketplace. Before a supply chain can achieve this goal it needs to accept that uncertainty is a problem and target the root causes in each of the four quadrants of the Uncertainty Circle.

**Tackling Uncertainty in both Pipelines Reduces the Bullwhip Effect**

Jay Forrester first coined the phrase "pipeline management" to describe the continuing controlled flow of goods on demand using the analogy with the behaviour of a hydraulic system. This embraced the view that there is a continuous flow of materials through the supply chain rather than via a series of unconnected operations. Effective Supply Chain Management requires the development of seamless strategies which smooth the flow by removing barriers between companies. All supply chains have two distinct lead-time pipelines, the order information transfer pipeline moving upstream from point of sale to raw material supplier and secondly the product transfer downstream from raw material to customer. The information and material pipelines are clearly in figure 3.

The uncertainty Circle (previously show in Figure 2) illustrates the four key areas within a supply chain where uncertainty is present. Each of the four segments suffer from uncertainty in both the information and material pipelines. As previously stated many supply chains have targeted their material pipelines and achieved reduced uncertainty via, for example, optimised manufacturing processes. However the information pipeline still has much potential in providing a great opportunity for uncertainty reduction. Even if a supply chain achieves maximum benefit from streamlined material flow its overall dynamic behaviour in comparison to the actual marketplace will still be subjected to demand amplification if the information pipeline is not similarly improved. Companies must understand that optimisation of material flow alone is not enough to achieve...
a sustained competitive advantage and the key differentiator may well be how effectively the order data is transferred upstream.

One industrial example of the performance benefits that can be achieved by ensuring both information and material flows are optimised is shown below in figure 4. Figure 4 was originally presented by Towill (11) based on data from Goldman (12).

As an example to show the type of opportunities available in the information pipeline Figure 4, originally presented by Fine (13) compares the actual marketplace sales and the order pattern imposed on the upstream machine tool manufacturer. At first sight the dynamics shown could be from two separate non-related companies as opposed to the reality of being part of the same supply chain. The dynamics of the information pipeline shown in Figure 5 clearly illustrate the Bullwhip effect and hence the uncertainty that builds up within the supply chain resulting in wild swings in capacity requirements.

The way to attenuate the Bullwhip effect is to reduce uncertainty caused by distorted data and hence effectively damp down the demand amplification behaviour. Replacement of a product is initiated by a consumer buy therefore PDP is activated by the marketplace sales information (3). Thus speed of information transference is crucial to an effective supply chain. Unlike production delays, which are reliant on improving hardware technological processes, the order information pipeline can in theory be literally at the speed of light. Not surprisingly, EDI has become essential to ensure a competitive market position for many industries.

The importance of information has long been recognised in the change process, and is described by Hammer and Champy (14) as a key-enabler for BPR. Speed of information transfer has therefore been recognised as a key commodity that can, if handled properly, become a competitive advantage. However it is the quality of the information not the quantity of data which is the key enabler. Many companies have discovered this the hard way having implemented IT they have received none of the expected payback (15). The danger is that blindly bolting IT on to existing information systems without ensuring an optimised will only transfer bad data faster - it will not improve the quality of the information. To ensure improved a dynamic behaviour and hence reduced uncertainty, information needs to be treated as a commodity whose pipeline strategy can be re-designed. To ensure competitive advantage and maximised bottom line performance supply chains should seek strategies that limit the effect of uncertainty in both the material and information pipeline across all four segments of the Uncertainty Circle.

**Targeting Material and Information flow shrinks the circle**

There are a variety of tools which can be utilised to improve supply chain performance across all four quadrants of the Uncertainty circle. Some key ones are summarised in Figure 6. As can be seen the sources of uncertainty are in both the material and the information pipelines.

![Fig 5. - The Supply Chain Bullwhip Effect in the Machine Tool Industry(12)](image-url)
Uncertainty reduction strategies within the material flow pipeline are well developed and have been applied in many industries, one of the most notable techniques is via Lean Thinking (4). The best way to reduce uncertainty within the order information pipeline is to ensure everyone in the supply chain gets the most up-to-date and useful information. As market sales data is the catalyst information for the whole supply chain it is the source of the undistorted data. Therefore by directly feeding each level of the supply chain with the market sales data actively tackles the order uncertainty from the point of source. This enrichment is achievable with a point of sales link at each level in the supply chain. So rather than each link making an order decision based purely on the internal chain sales data it can now make an informed judgement based on what the end consumer is actually buying. A standard way of establishing benchmarks for judging the effectiveness of competitive supply chain redesigns is via the use of simulation models (16). We use a generic model for this purpose, which is a tried and tested representation of good industrial practice. Each echelon is represented by a Decision Support System (DSS) which takes account of orders received, Work In Progress (WIP), stock policy, and any forecasts available. The echelons are then coupled together in the way which best describes current supply chain strategy. One example of such a generic model depicting the behaviour of an electronic products supply chain is described by Berry et al. (17), which was used to benchmark various real-world strategies against the baseline case.

We find that for synthesis purposes it is realistic to use a step demand to simulate a shock event at the marketplace. The Bullwhip wave-form propagation upstream is then observed. The reason for this is that the step response provides an extremely “rich picture” of the supply chain dynamics. Hence the approach adopted is to make a preliminary selection of the best strategy on the basis of the step response, and then verify the choice by simulating random and seasonal disturbances (18). One benchmarked output from such a simulation study is shown in Table 1 in which the scenarios have been selected to demonstrate the impact of lead-time reduction and information enrichment on the Bullwhip Effect. Four strategies were simulated to illustrate the effect of adopting improvement programmes. The first was a datum design, which simulated a supply chain before any improvement. The second simulated design adopting a strategy, which targeted the information pipeline alone by enabling all players sight of the actual marketplace sales. The third design simulates an improved material pipeline by speeding the flow so the chain can be more responsive. The fourth strategy simulates a total Uncertainty Circle approach where both the material and information pipelines are optimised.

Table 1 - Benchmarking Supply Chain Bullwhip Performance. Performance Improvement Benchmarking: Shrinking the Uncertainty Circle

<table>
<thead>
<tr>
<th>Supply Chain Design Strategy</th>
<th>Bullwhip Performance Measures</th>
<th>Overall Bullwhip Performance Benchmark</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Peak Value</td>
<td>Peak Time</td>
</tr>
<tr>
<td>Datum Design</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>Information pipeline redesign only</td>
<td>****</td>
<td>**</td>
</tr>
<tr>
<td>Material pipeline redesign only</td>
<td>*</td>
<td>****</td>
</tr>
<tr>
<td>Both pipelines redesigned</td>
<td>****</td>
<td>****</td>
</tr>
</tbody>
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Industrial Examples of Shrinking the Uncertainty Circle

One good example of market sales information being used within the consumer market is the business link between Wal-Mart Stores (USA) and Procter & Gamble, one of its main suppliers. Basically Wal-Mart dismantled the barriers to information sharing and opened its consumer information to its suppliers for their tactical and strategic usage. This was a revolutionary step resulting from the new Wal-Mart ideology that it did not matter what competitors might thereby learn.
about the business so long as the Wal-Mart relationship with their suppliers grew stronger thus resulting in a better service for customers (19). Procter & Gamble now take the consumer information from Wal-Mart at point of sale and decide how much stock to deliver to the stores so as to ensure consumer demands are satisfied. It is Procter & Gamble responsibility to keep Wal-Mart shelves full through a Vendor Managed Inventory (VMI) strategy. This strategy has a double benefit in terms of shrinking the size of the Uncertainty Circle. Firstly it reduces uncertainty by eliminating both material and information flow delays; secondly it reduces uncertainty yet further by eliminating a decision point within the chain.

Another real-world supply chain application of the principles of shrinking the Uncertainty Circle has been reported by Towill and McCullen (20). It concerns the re-engineering achieved in a mechanical precision product global supply chain via their rapid response and IT integration programmes. Actions taken and implemented include manufacturing lead time reduction (manufacturing process quadrant); linking factories direct to customer demands (demand quadrant); more frequent and more rapid planning (planning and control quadrant); streamlined acquisition and distribution (supply quadrant); and a new Decision Support System (again the control quadrant) to exploit reduced time delays.

Table II summaries the performance improvements achieved by the company through reducing uncertainty in each of the four quadrants of the Uncertainty Circle.

Table II - Improved Supply Chain Dynamic Performance Observed Following Implementation of Agile Manufacturing Programme (Towill and McCullen (11))

<table>
<thead>
<tr>
<th>PRODUCT CODE</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduce in production demand amplification variability</td>
<td>45%</td>
<td>24%</td>
<td>38%</td>
<td>25%</td>
<td>14%</td>
<td>46%</td>
</tr>
<tr>
<td>Reduce in central warehouse stock variability</td>
<td>34%</td>
<td>31%</td>
<td>35%</td>
<td>45%</td>
<td>27%</td>
<td>36%</td>
</tr>
</tbody>
</table>

The recorded results presented in Table II include the downward trend in (reducing by 45% over a five year period), and up to 46% reduction in the Bullwhip effect across the sampled products. Unfortunately the data does not enable the credit to be apportioned between "rapid response" elements and "IT integration" elements of these concurrent re-engineering programmes but the combined benefits are indeed impressive. They also confirm the effectiveness of our approach to shrinking the Uncertainty Circle as a means of reducing the Bullwhip Effect.

CONCLUSION

The Uncertainty Circle is a useful concept in greatly improving the performance of real-world supply chains to the benefit of all players therein. Whereas the Supply Side and Manufacturing Process segments are essentially under the direct control of the business and may be tackled using principles such as Lean Thinking, the Process Planning and Control and Demand Side require action to be taken externally if significant improvements are to be achieved. Both the Process Controls and Demand side uncertainties in product delivery may be substantially shrunk via the ready transparent availability of undistorted marketplace data. To obtain the necessary collaboration business may find the Partnership Agreements are good enabling mechanisms. Our particular approach to shrinking the Uncertainty Circle has been demonstrated via simulation modelling and real-world BPR experiences. Only if strategies, which tackle the uncertainty present in both the information and material pipelines in all four segments of the Uncertainty Circle, are adopted can maximum opportunity be realised.

REFERENCES