

# PRACTICAL WAYS OF REDUCING BULLWHIP: The Case of the Glosuch Global Supply Chain

Peter McCullen, University of Brighton and Denis Towill, Cardiff University

## INTRODUCTION

Bullwhip costs money, wastes resources, and loses customers. So drawing on a basis of analytical, simulation and experiential techniques, the authors' present four material flow principles which can be recommended as strategies to reduce the bullwhip effect. A real-world case study from the precision mechanical engineering sector is employed to illustrate the effect of rapid response manufacturing and supply chain integration. Analyses of six years of Glosuch supply chain time-series data indicate amplification patterns damped by 36% plus a consequent 45% reduction in global inventory. The results serve to validate the four material flow principles of: selecting appropriate control systems, cycle time-compression, information transparency throughout the chain and echelon elimination wherever practicable. Interestingly, these results also suggest that manufacturing agility can improve the dynamic performance of the supply chain, mitigating variability-induced wastes including excess inventory and poor capacity utilisation. This creates a win-win scenario for both manufacturing and distribution facilities.

## THE BULLWHIPEFFECT

In this article we consider the beneficial effect of an agile manufacturing strategy on a real world Global Supply Chain (*Glosuch*). The supply chain has three echelons consisting of: overseas warehouses, a central UK finished goods warehouse and a UK factory. Each echelon procures product from its immediate upstream echelon. The original information flow from the overseas warehouses to the central warehouse consisted of a stream of purchase orders. The central warehouse communicated with the factory through demand forecasts and a jointly agreed Master Production Schedule (MPS). The poor performance of the company's original supply chain can be explained in terms of the 'bullwhip effect' which has been described as follows:

*"information transferred in the form of orders tends to be distorted and can misguide upstream members in their inventory and production decisions..... the variance of (replenishment) orders may be larger than that of sales (to end customers), and the distortion tends to increase as one moves upstream - a phenomenon termed 'the bullwhip effect'" [1].*

Readers may well recognise bullwhip (also known as 'whiplash') as being the new name for 'demand amplification' as originally described by Forrester [2]. The phenomenon is well known to operational researchers, wherein particular attention is focussed on bullwhip induced by the forecasting algorithms used within an MPS [3]. Bullwhip has also been observed in UK industries by such practitioners as the late John Burbidge. Here we are concerned with the practical principles which may be applied to real world supply chains with a reasonable guarantee of success in damping down bullwhip wherever possible. Our approach is always to eliminate the trigger at source. This means blitzing each systemic cause via the four material flow principles to be described later in the paper.

## THE PRACTICAL BULLWHIPSCENARIO – The view of Robert Schonberger

Total Quality Management (TQM) and re-engineering have made substantial contributions to manufacturing. Many final producers now practice partnering well upstream in the supply chain. Via quick-change techniques such as Single Minute

Exchange of Dies (SMED), basic materials suppliers make and deliver in smaller lots and much more often. Component makers re-engineer to create plants-within-a-plant and implement very effective work cells. JIT processing typically now extends from receipt of basic materials through to shipment and forward from one stage of manufacture to another. Each stage builds quality in, which avoids both quality-hold areas and inspection delays at customer plants. Freight hauliers reengineer as well as, operating with advance shipping notices, satellite navigation, backup vehicles, and electronic data interchange, they pick up at suppliers' docks to the hour and deliver to point-of-use at customers' plants.

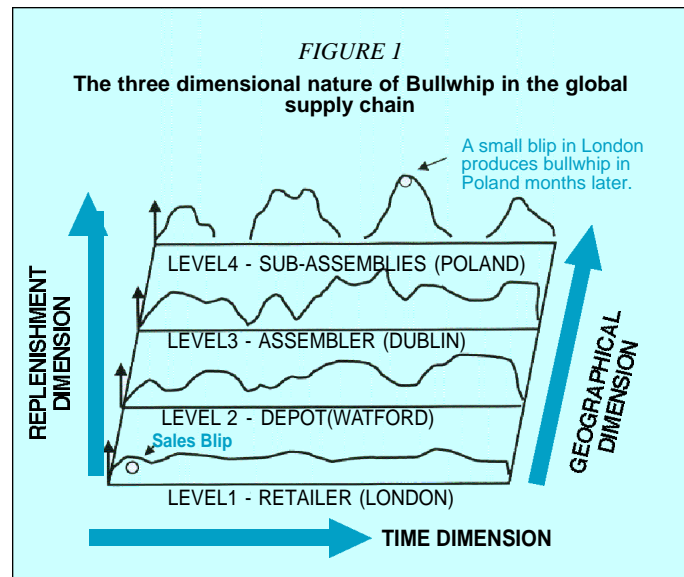
The effect is to create highly synchronised chains of customers. Timing is tight, like an Olympic-class relay team. Each stage of manufacture achieves close to 100 % on-time performance. *Unfortunately it is all too frequently on time against manufacturing's own schedules.* They, in turn, are based on off-target forecasts, orders that have been batched too many times, and with an internal fixation on capacity utilisation. Fast-changing short life cycle industries suffer the most in this scenario. Upstream production (eg., semi-conductors and fabric makers) can be 100 % on-time but 180 degrees out of phase with what final users are actually buying or want to buy. But even final producers can be well out of phase with demand, since both production and distribution fill their warehouses with made-on-a-guess finished goods – the responsibility for which is ambiguous. Consequently storage and obsolescent costs are both high. *At the same time, marketing often exacerbates these out-of-phase effects through their excessive reliance on sales promotions and end-of-period sales bonuses.* These and similar initiatives create great waves of demand as typified by the chicken soup example quoted by Fisher [4]. Where orders on suppliers are impulse-like despite actual sales being much less volatile these events always have a downswing and so the waves slosh upstream, alternately flooding and drying out the neighbouring manufacturing/supply-base warehouses. *Hence significant additional costs then result from stock-outs alternating with excess capacity.*

## THE THREE PRIME DIMENSIONS OF BULLWHIP

Whilst the bullwhip literature has rightly emphasised the demand amplification phenomenon as orders are passed upstream in the supply chain, it is our experience that there are three prime dimensions to the problem. The orders we consider to be the **replenishment** dimension affecting the flow of materials and information throughout the system. But identifying and reducing bullwhip is complicated by the two other prime dimensions. These are **geographical** (since activities take place in different locations) and **temporal** (since activities take place at different times). The combined effect is shown in Figure 1 for a hypothetical but realistic European supply chain. Tracking down the true cause of unwanted variability in such a chain is a daunting task for all but the most experienced observer. Our approach is therefore based on elimination at source using the four material flow control principles to guide the re-engineering programme.

The route for transmission of orders is from the retailer (in London), via the depot (in Watford), to the assembler (in Dublin), and finally to the sub-assembler (in Poland). In a traditional supply chain this information will be transmitted sequentially and is not always acted upon immediately, particularly where time fences are out of line. In this way, as Schonberger [5] notes, orders are distorted as they move away from the market place due to guesswork and compounding of

decisions made on safety stocks and double-guessing as to what is really going on. This is made worse by adherence to a minimum batch quantity philosophy. Synchronisation of orders may be non-existent due to some companies ordering daily, some weekly and some monthly, but triggered by different dates in the calendar. The result is that a sales blip causes a major disturbance thousands of miles away and many weeks (or even months) later.



#### FOUR MATERIAL FLOW PRINCIPLES TO REDUCE BULLWHIP

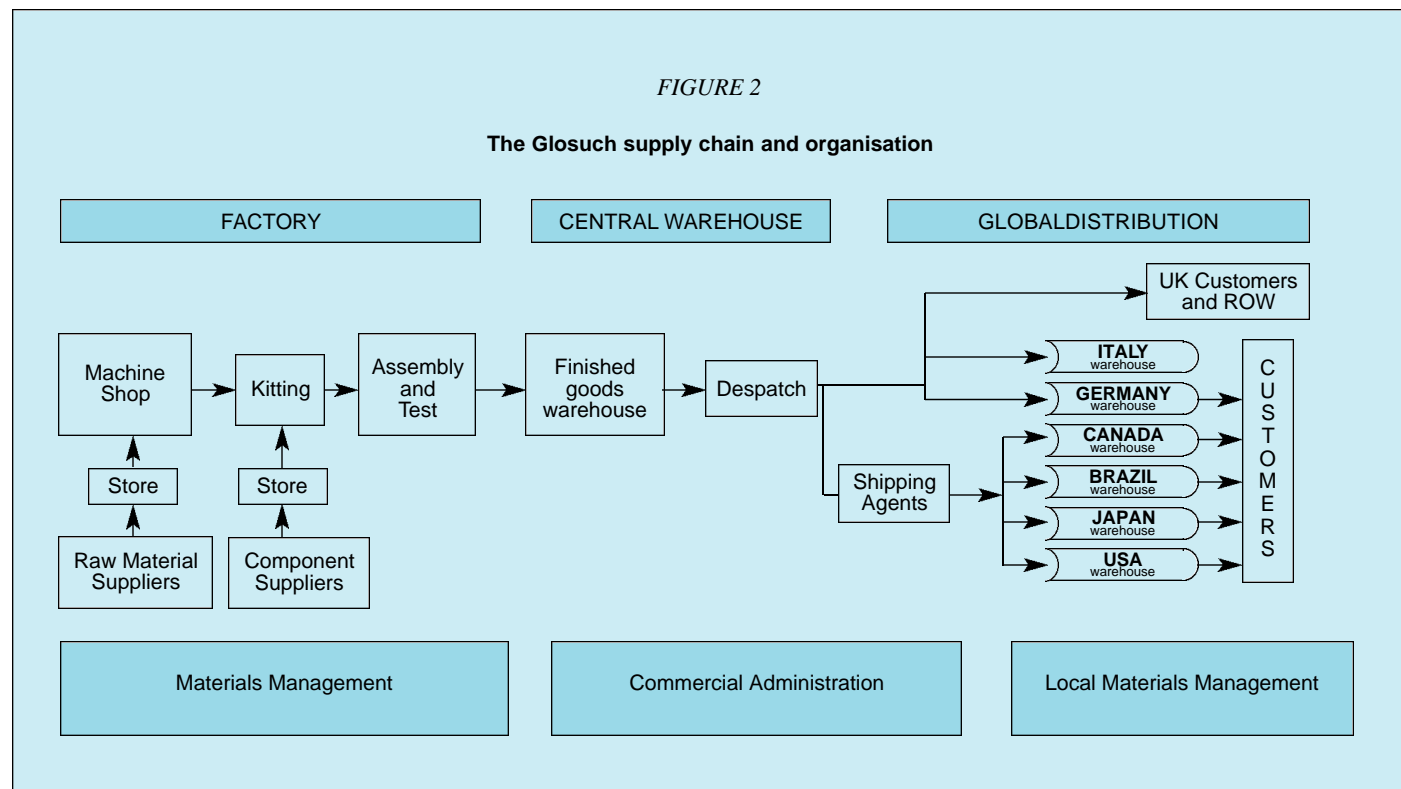
The Cardiff Logistics Systems Dynamics Group (LSDG) have been involved in a large-scale project on improving the dynamic performance of supply chains. They have concentrated on developing improvement methods based on a firm understanding of cause and effect relationships affecting supply chains in general. Consequently their proven ideas are applicable and transferable across a wide range of market sectors. As output [6] have shown that steps to providing effective damping of the bullwhip effect fall into four major categories:

- **Control Systems Principle.** This involves selection of decision support systems which contribute to the dynamic stability of the total supply chain.
- **Cycle Time Compression Principle.** This involves the re-engineering of business processes in order to slash material flow and information processing lead times.
- **Information Transparency Principle.** This involves sharing high integrity information between all the supply chain actors.
- **Echelon Elimination Principle.** This involves the elimination of echelons and functional interfaces (this reduces time delays and the information distortion which precipitates demand amplification, but can lead to a substantially different channel of distribution).

These principles have been established by studying causal relationships affecting bullwhip as identified from a variety of sources [7]. This includes mathematical modelling, simulation, time series analysis and business process re-engineering case studies. The aim has been to derive supply chain design guidelines which satisfy management theory requirements of repeatability, visibility and market sector transferability. Each of the four principles is sufficiently proven and robust that they can be recommended as the basis for individual business improvement programmes.

#### THE GLOSUCH GLOBAL SUPPLY CHAIN

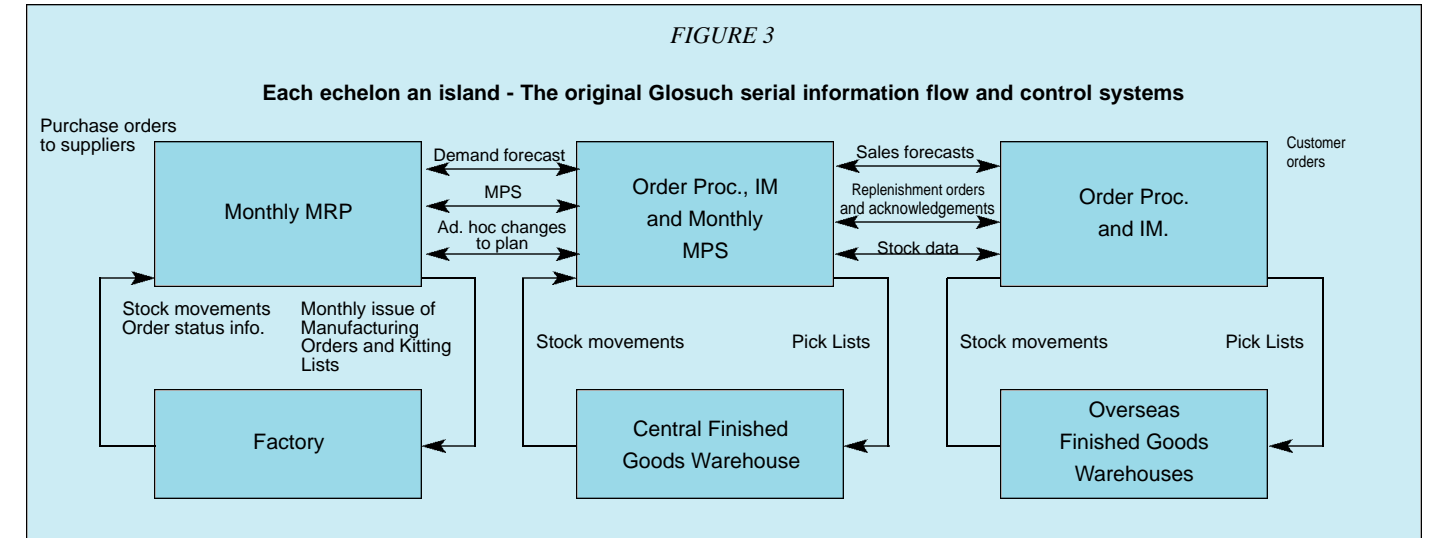
Glosuch are a UK manufacturer of precision mechanical engineering products which they distribute globally via a network of overseas subsidiaries, as shown in Figure 2 [8]. 80% of the products are exported with the largest markets in Japan and the USA. The company's internal supply chain consisted of three echelons: a UK factory, the company's head office and central finished goods warehouse, and a number of overseas subsidiary operations. Each echelon had its own control system, illustrated in Figure 3, and relied upon the serial transfer of logistics information from one echelon to the next. The entire system was forecast driven, with territory sales re-forecasts transformed into a demand plan by commercial administration, and worked into a Master Production Schedule (MPS) by factory materials management.



During the 1980s these planning processes involved spreadsheet analysis with data frequently transmitted by fax and re-keyed at the next echelon. The quarterly planning process was supplemented by a monthly cycle of re-ordering by overseas subsidiaries, and feeding into a joint process of MPS adjustment by commercial administration and materials management. Further mid-month MPS changes were negotiated with materials management reacting to order exception reports thrown out by commercial administration's 'available to promise' (ATP) system.

backorders, and found it difficult to advise materials management on priorities and optimum product mix;

- the overall supply chain was unresponsive to changes in customer demand, with a cumulative lead time of 23 weeks to react to changes in the sales forecast;
- some products, on back-order due to above-forecast demand, and, with consequently increased production, would suffer from a phenomenon whereby, just at the



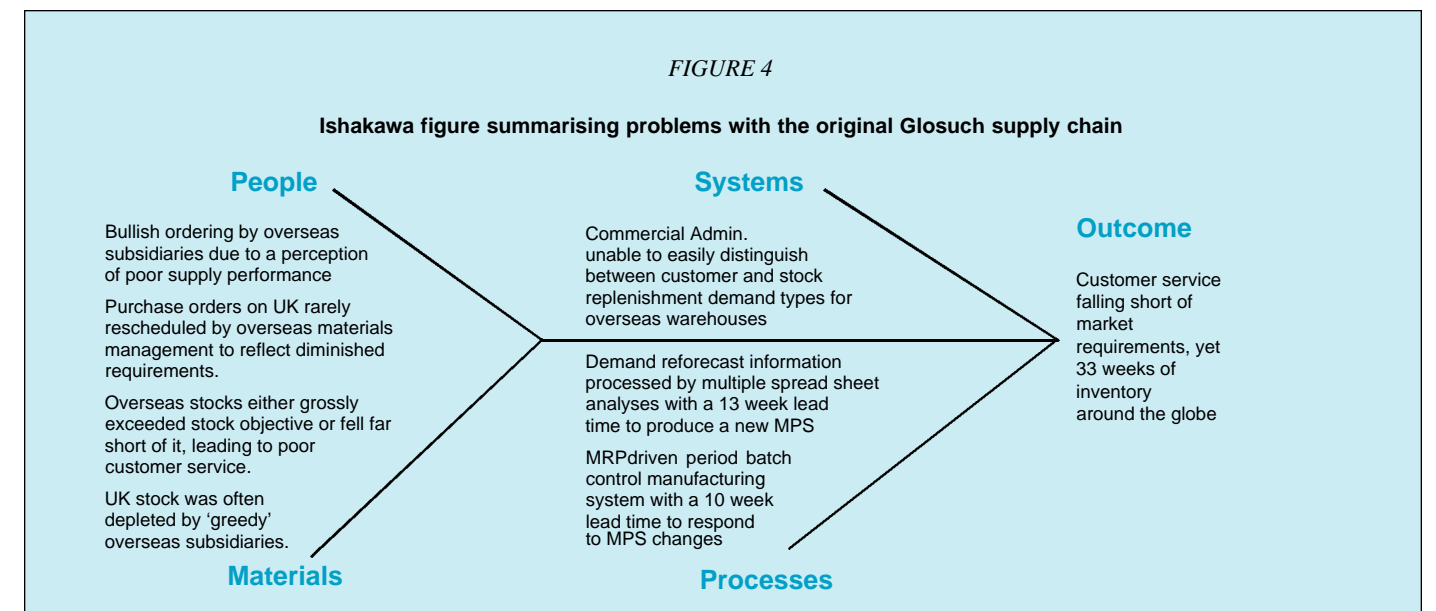
#### PROBLEMS WITH THE ORIGINAL SUPPLY CHAIN

During the mid to late 1980s the company experienced very strong sales growth and decided to increase capacity on several occasions. Behind the success story, however, supply chain actors were experiencing considerable stress, brought about by a number of problems illustrated in the Ishikawa Figure 4, [9]. The major problems were as follows:

- central warehouse safety stock was often depleted by apparently greedy overseas subsidiaries;
- overseas subsidiaries either grossly exceeded stock objective or fell far short of it;
- Commercial administration sometimes could not identify true end-customer requirements amongst a 'sea' of

point when UK stocks were recovering; overseas demand would then collapse, leading to excess stock and cuts in future production.

The bullwhip scenario at Glosuch involved many of the features described in the Schonberger literature outlined in Section 3. The Ishikawa Figure below shows how the causes may be generically grouped together under the headings of people, systems, materials, and processes. Note that in a well-documented re-engineering supply chain programme in the pharmaceutical industry, the people problem dominated [10]. This was partly due to a reluctance to accept that any change was needed for that company to remain competitive. Also the new planning and control software developed for the application was predicted by potential users to be troublesome in operation. But in fact it presented no significant problems and the company reported a smooth start-up of the new facilities.



## OUTLINE OF THE GLOSUCH RAPID RESPONSE MANUFACTURING PROGRAMME

Glosuch recognised that its problems were fundamentally due to the company's forecast-driven supply chain, and the implicit assumption that everything would be fine if forecast accuracy could be improved. The Operations Director believed that the solution was therefore to reduce manufacturing's dependence on forecasts by slashing lead times. The company's objectives were Rapid Response Manufacturing and Information Systems (IS) integration for material control activities throughout the supply chain, [11]. This approach, it was hoped, would buffer both customers and manufacturing from the effects of poor sales forecasts.

Agility and rapid response are related, as Kidd [12] explains: 'Agile manufacturing enterprises will be capable of responding rapidly to changes in customer demand'. The objectives of the company's rapid response project were identified as follows:

- Slash manufacturing lead times;
- Directly link UK factories to international customer demand;
- Plan more frequently and rapidly throughout the supply chain;
- Streamline Physical Distribution Management (PDM) in relation to global needs to achieve a more balanced distribution of finished goods inventory.

The company's original manufacturing system was based on a period batch control system. Products were built in batches by skilled fitters on benches (a fixed position layout). Manufacturing planning and control was achieved through a monthly release of manufacturing orders for machining and assembly. Assembly orders were kitted prior to final assembly, with shortages progress chased in prior to building the batch. In summary, the company's rapid response manufacturing strategy involved the following improvements:

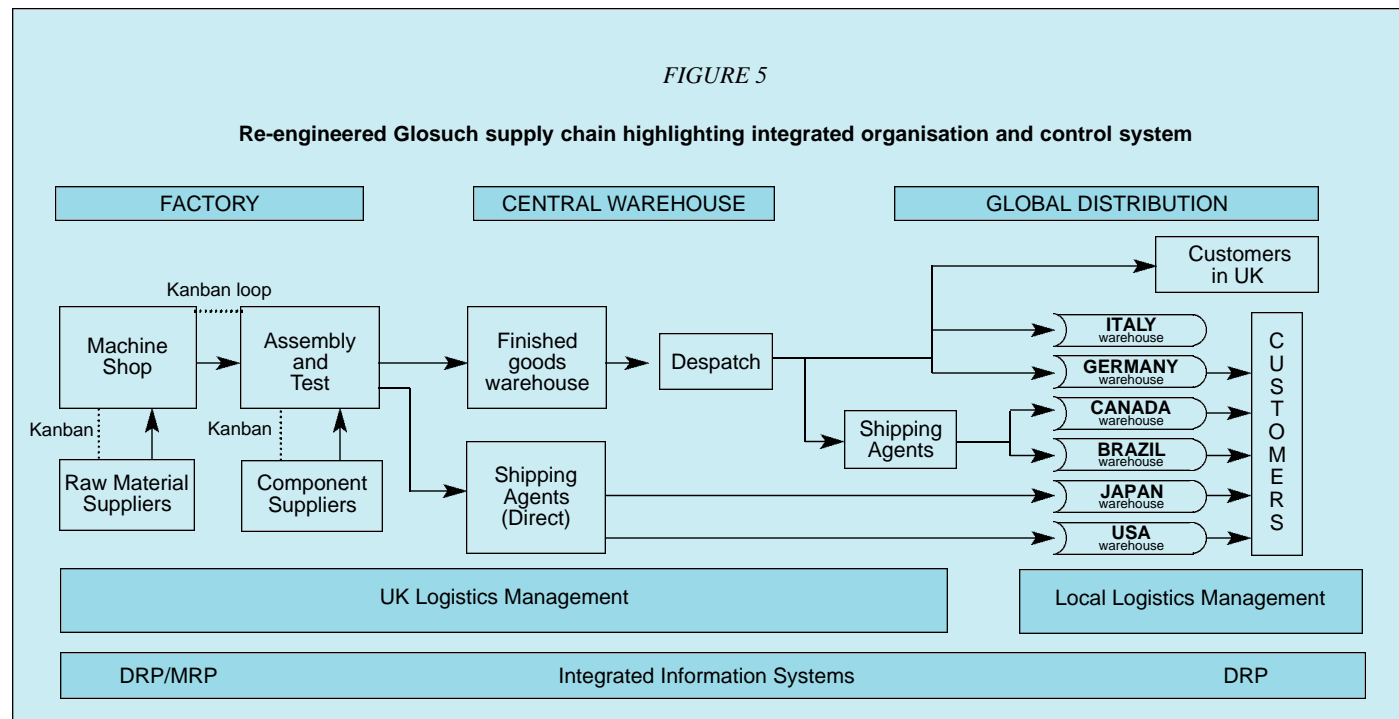
- assembly flow lines were developed which could handle single piece unit flow, ie. any mix of products in any sequence, with a batch size of 1;

- manufacturing control of the machine shop was switched from a 'push' to a 'pull' system, driven by Kanban signals from final assembly;
- partnership arrangements were developed with component suppliers to achieve direct line feed in final assembly, also driven by Kanban signals;
- similar arrangements were developed with raw material suppliers;
- 'backflushing' was employed to update stock records;
- the planning cycle was initially changed from monthly to weekly, and finally from weekly to daily.

## ACHIEVING INFORMATION SYSTEMS INTEGRATION

The re-engineered Glosuch supply chain is represented in block diagram format in Figure 5, [9]. The new Distribution Requirements Planning (DRP) based information system allowed manufacturing logistics to distinguish between customer orders, forecast demand and safety stock replenishment needs. The new information system also facilitated an organisational change whereby manufacturing logistics became responsible for its own finished goods stock, effectively eliminating commercial administration as a logistics information processing echelon. Initially DRP was re-run on a weekly basis, but the company soon realised that a daily re-run could provide manufacturing with virtual real-time information on market demand. Whereas PDM had previously been driven by purchase orders placed by overseas subsidiaries, the new system employed a simple re-ordering algorithm, with transfer batches directly related to usage over the transit time.

This new 'pull' distribution system effectively retained stock in the central warehouse until the last possible moment, thus avoiding the global stock imbalances which characterised the original supply chain. Direct shipment from the factory to the port of departure was also implemented for volume products destined for the USA and Japan. *The combined effect of rapid response manufacturing and IS integration was to dramatically reduce the combined information and material processing lead time from 23 weeks to 2 weeks, thereby achieving time compression of 91%.*



## RELATING THE FOUR MATERIAL FLOW PRINCIPLES TO THE BULLWHIP EFFECT OBSERVED IN THE GLOSUCH SUPPLY CHAIN

It is readily apparent that the Glosuch rapid response manufacturing and IS integration strategy corresponds very closely with LSDG's four material flow principles, as indicated in Table 1 [8].

In the light of the correspondence between these four principles and observed practice we would expect Glosuch to experience significant demand smoothing and a reduction in the bullwhip effect. A detailed investigation was therefore conducted in order to investigate the following questions:

- Q1. Did Glosuch experience the bullwhip effect in its original supply chain?
- Q2. If so, was demand amplification attenuated as a result of its strategy of rapid response manufacturing and IS integration?
- Q3. Does rapid response manufacturing and IS integration help to reduce variability, thus simultaneously facilitating inventory reduction and a leaner supply chain?

Rapid response manufacturing implies time compression which, according to findings from Industrial Dynamics theory and practice [13], tends to substantially improve the dynamic performance of the supply chain. Thus in the re-engineered supply chain we might expect smaller variations in demand and inventory, and less inventory to buffer those fluctuations. These considerations lead to the third, more general question concerning the relationship between rapid response (or agile) manufacturing and lean supply.

## INDUSTRIAL INVESTIGATION OF BULLWHIP

The industrial investigation at Glosuch involved interviews, participant observation and the collection of six years of monthly time-series data on: sales, replenishment demand, production and inventory levels. Demand and production time-series were smoothed using three point moving averages to reduce random variation, and the existence of a bullwhip effect was ascertained (Q1) by inspecting these time-series. Bullwhip, or amplification, was measured using the average unsigned difference between the time-series for Replenishment Demand on the central warehouse and Actual Production. The implementation of DRP followed initial trials of rapid response manufacturing for products 1-6 in month 36, the 'supply chain improvement watershed'.

The degree of attenuation was evaluated (Q2) by comparing amplification before and after that date. The effect on variability (Q3) was evaluated by measuring the extent of inventory swings using a new time-series for stock. These time-series calculated the coefficient of stock variation (in order to allow for the non-stationary nature of the series) over the previous five months. Again, values were compared before and after the supply chain improvement watershed. The leanness of the supply chain was evaluated by measuring global inventory in 'weeks cover' for the years following implementation.

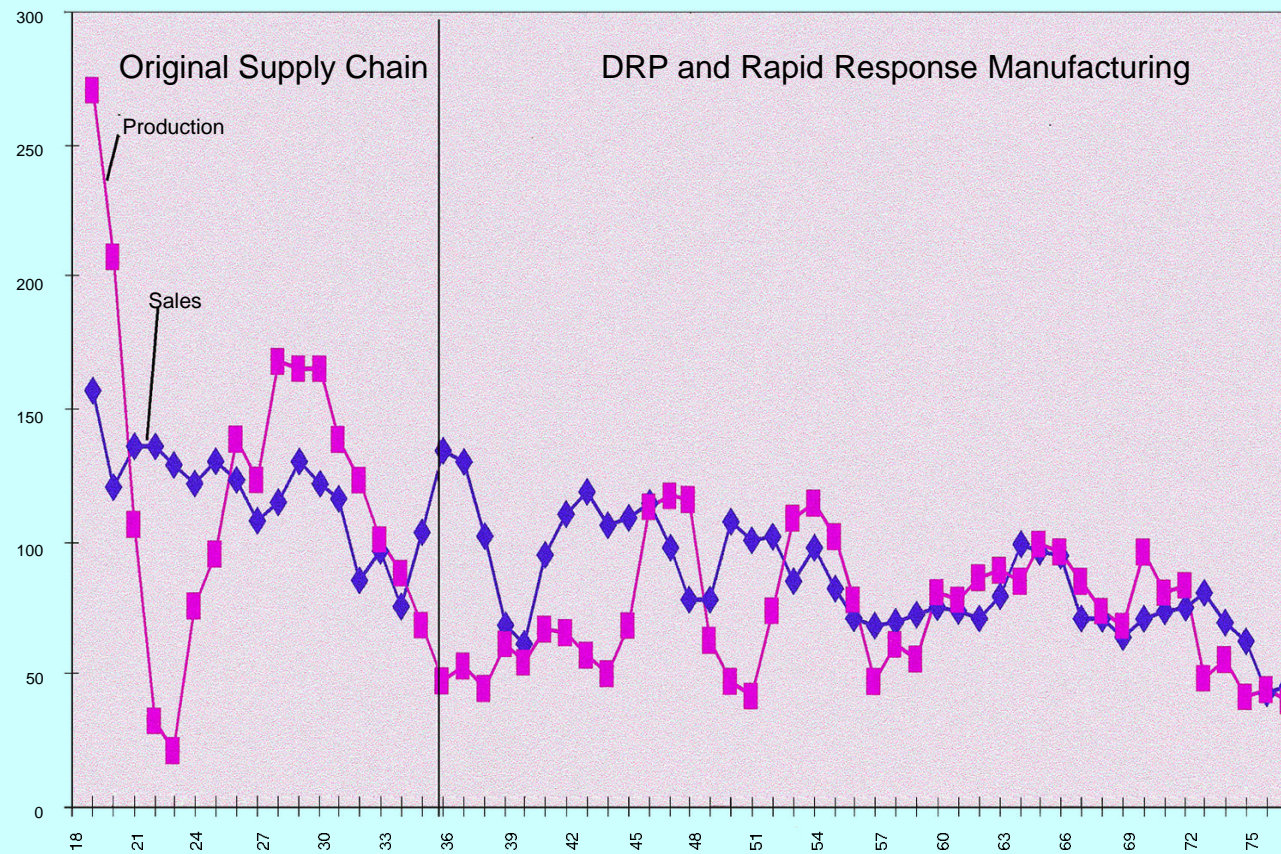
The degree of bullwhip experienced across the overseas warehouse, central warehouse and factory echelons before and after month 36, the 'supply chain improvement watershed' is clearly visible in Figure 6. It can be seen that bullwhip has been dramatically reduced after implementation of the rapid response programme. Note that although there is an immediate improvement in bullwhip amplitude as orders are brought into alignment with sales, there is a phase lag which persists for about two years. This is due to the organisational learning curve associated with the new manufacturing system and re-engineered supply chain coupled with the implementation of planned stock reduction.

TABLE 1  
Correspondence between the company's supply chain improvement strategy and LSDG'S four material flow principles

SC IMPROVEMENT	RE-ENGINEERING DETAIL	CONTROL SYSTEMS	TIME COMP.	TRANS-PARENCY	ECH ELIM.
SLASH MANUF. LT	SINGLE PIECE UNIT FLOW		●		
	PULLSCHEDULING ELIMINATING COMPONENT LEAD TIMES.	●	●		
	MANUF. PLANNING CYCLE CHANGED FROM MONTHLY TO DAILY		●		
LINK FACTORY DIRECTLY TO DEMAND	DRP PROVIDES FACTORY WITH VIRTUALLY REALTIME INFORMATION ON INTERNATIONAL CUSTOMER DEMAND	●		●	
MORE FREQUENT AND RAPID PLANNING	DRP IS RUN FIRST WEEKLY AND THEN DAILY		●		
	DEMAND FORECASTS ARE AUTOMATICALLY GENERATED BY DRP INSTEAD OF COMMERCIAL ADMINISTRATION			●	●
STREAMLINED PDM.	TRANSFER QUANTITIES SELECTED TO COVER DISTRIBUTION LEAD TIME	●			
	KANBAN SYSTEM RETAINS INVENTORY CENTRALLY UNTIL THE LAST POSSIBLE MOMENT TO MINIMISE GLOBAL STOCK IMBALANCES	●			

FIGURE 6

Bullwhip reduction estimated across three echelons of the Glosuch supply chain: USA sales and actual UK production of product code 01



**GLOSUCH BULLWHIP REDUCTION**

TABLE 2

Glosuch Bullwhip across two observed echelons before and after the supply chain improvement watershed						
Products	1	2	3	4	5	6
Products	1	2	3	4	5	6
Months 1-35	62	84	59	84	35	37
Months 36-84	34	62	48	63	30	20
Change	-45%	-26%	-18%	-25%	-14%	-46%

product 4 may be explained by a change in the pattern of demand. Some customers order this product in large numbers for single consignment letter of credit orders, and there had been an increase in this particular type of demand since month 36.

TABLE 3

Glosuch central warehouse stock variability before and after the supply chain improvement watershed						
Products	1	2	3	4	5	6
Products	1	2	3	4	5	6
Months 1-35	56%	72%	57%	39%	62%	53%
Months 36-84	37%	49%	37%	45%	45%	34%
Change	-34%	-31%	-35%	+15%	-27%	-36%

The general reduction in variability has allowed the company to substantially reduce its global inventory, as shown in Table 4. Simultaneously customer service has also been improved. At the USA warehouse, for example, the company measured

the average number of days late against customer due date, and the standard deviation of delivery variation. Between months 32 and 43 the first measure improved from an average of 10 days to only 1 day late, and the second from 15 days to 4 days [14]. Note that Table 4 also indicates the extended time scale over which supply chain improvements may be observed. There has been a continuing and significant reduction of global inventory for four successive years, with the trend line indicating that more benefits are still to come.

TABLE 4

Glosuch global inventory following the supply chain improvement watershed

	Year 0	Year 1	Year 2	Year 3	Year 4
Weeks	31	26	22	20	17
Difference	-	-5	-4	-2	-3
Total Change	-	-17%	-29%	-35%	-45%

Overall the company's strategy of rapid response manufacturing and IS integration has led to improved dynamic performance, as predicted by independent research from LSDG. It has also led to a leaner supply chain, as discussed in detail in Reference 9. Importantly, Glosuch has amply demonstrated that improved pipeline control simultaneously reduces order variability (thereby reducing ramp-up ramp-down on costs), and increasing stock turns (thereby reducing stock holding, obsolescence, and wastage costs). So the re-engineering programme based on rapid response and encapsulating the four material flow control principles has produced a win-win situation for both production and distribution facilities [11].

**CONCLUSIONS**

The empirical results drawn from the case study serve to validate the four material flow principles as these were embedded in the Glosuch strategy of rapid response manufacturing and IS integration, leading to an average bullwhip reduction of 36%. Of course, unlike using a simulation model wherein ideas and theories may be tested in isolation by keeping other conditions constant, industry is driven to action along many parallel paths. Thus while it is possible to conclude that all four material flow principles contributed to the success of the rapid response programme, it is not possible to allocate exact percentage benefits to each specific cause. However, we do not consider this imperfect linking with causation to be particularly important. What industry wants are reliable guidelines which, given good re-engineering skills, really will deliver the expected improvements, as has been amply demonstrated at Glosuch. We therefore strongly recommend blitzing each source of bullwhip via thorough application of the four material flow principles.

**REFERENCES**

1. Lee, Hau L., Padmanabhan, V. and Whang, S. "Information Distortion in a Supply Chain: The Bullwhip Effect", *Management Science*, Vol. 43, No. 4, pp. 546-558 1997.
2. Forrester, J.W. *Industrial Dynamics*, MIT Press, Cambridge MA, 1961.
3. Adelson, R.M. "The Dynamic Behaviour of Linear Forecasting and Scheduling Rules", *OR Quarterly*, Vol. 17, No. 4, pp 447-462, 1966.

4. Fisher, M.L., "The Right Supply Chain for Your Products", *Harvard Business Review*, March-April, pp 105-116, 1977.
5. Schonberger, R.J. "World Class Manufacturing : The Next Decade", Free Press, NY, 1966.
6. Towill, D.R., Naim, M.M. and Wikner, J. "Industrial Dynamics Simulation Models in the Design of Supply Chains", *International Journal of Physical Distribution and Logistics Management*, Vol.22, No.5, pp. 3-13, 1992.
7. Towill, D.R. "Industrial Dynamics Modelling of Supply Chains", *Int. Jnl. Phys. Dist. and Mat. Man*, Vol. 26, pp 23-42, 1996.
8. Towill, D.R. and McCullen, P.L. "The Impact of Agile Manufacturing on Supply Chain Dynamics", *The International Journal of Logistics Management*, Vol.10, No.1, pp. 83-96, 1999.
9. McCullen, P., and Towill, D.R., Manufacturing Agility and the Lean Supply Chain", *Proc. MIM 2000 Conf, Aston*, pp 429, 2000.
10. Belk, K., and Steels, W., "Case Study ATS BERK : from Arbitration to Agility", *Log. Int. Man.* Vol. 11, No. 2, pp 128-133, 1998.
11. McCullen, P., and Towill, D.R., "Manufacturing Agility and the Lean Supply Chain", *Proc. MIM 2000 Conf, Aston*, pp 431, 2000.
12. Kidd, P.T. *Agile Manufacturing: Forging New Frontiers*, Addison-Wesley, 1994.
13. Wikner, J., Towill, D.R., and Naim, M.M. "Smoothing Supply Chain Dynamics", *International Journal of Production Economics*, Vol. 22, pp. 231-248, 1991.
14. McCullen, P., Cope D., and Silano, M., "Industrial Dynamics and Supply Chain Integration", *Proceedings of the 2nd International Symposium of Logistics*, Nottingham, pp. 367-375, 1995.

**About the authors**

**Professor Denis Towill** is presently Co-director of the Logistics Systems Dynamics Group (LSDG) at the University of Cardiff Business School. He is a Fellow of the Royal Academy of Engineering and served on the RAcadEng Management of Technology & Construction Sector Inquiry Panels. More recently he was a member of the Technology Foresight Systems Engineering Panel.

He served his apprenticeship in heavy electro-mechanical engineering. Since then he has worked with the aerospace, automotive, electronics, steel and construction sectors. His present major interest is in providing industry with a proven methodology for achieving the seamless supply chain.

**Peter McCullen** is a Senior Lecturer in Supply Chain Management at the University of Brighton Business School. He graduated from the University of Nottingham in Production Engineering and Production Management in 1982, and worked for Lucas Diesel Systems in both production engineering and business planning. He has also worked for SHM gear manufacturers on the implementation of Kewill's MICROSS software, and in Logistics Management within the precision mechanical engineering sector.