The bullwhip-effect in the electricity supply

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Abstract: The bullwhip-effect is a very costly phenomenon. Recent days the length of different supply chains become longer and longer. Due to the delays in the adaptation of changes, supply chains can be dynamically unstable with respect to perturbations in the consumption rate. It can lead to stock-outs, large and expensive capacity utilisation swings, lower quality products, and considerable production/transport on-costs as deliveries are ramped up and down at the whim of the supply chain. The first part of the paper presents the bullwhip-effect in the conventional logistics systems. The main goal of different type of studies to understand the nature of this harmful effect, and to investigate the best form of modelling – and to develop the best management tools and strategies. The second part contains the specialities of production, transportation, distribution and consumption of electrical energy, including the storage opportunities. We could not imagine our everyday life without the absolute availability of electrical energy, and this is a typical „pull" system, without significant storage possibilities in an economy, like the Hungarian one. At the first sight it seems free of the bullwhip-effect, because in this system we should follow the customer demands from moment to moment – but there are extremely high inventory levels in the in-built capacities of power stations. The analogies could be profitable on the conventional fields of logistics – and from this viewpoint, we could formulate useful theories for further bullwhip-effect modelling and simulation researches.

Keywords: bullwhip-effect, infrastructure

1 The bullwhip effect

Increasing global competition in the world market today makes the supply chain management more critical. One of the most fruitful research sub-areas in the studying of supply chain management is the bullwhip-effect: a relatively new phase to describe the demand amplification phenomenon which was already well known at Procter and Gamble as long ago as 1919 [1].

Supply chain in business includes the stages, which were built to fulfill the demand of the customers. A typical supply chain usually includes raw material suppliers, manufacturers, wholesalers, retailers, and end customers. In supply chains, the variability of order quantity may considerably increase relative to the variability of the end customer demand. In practical operation of any supply chain, the downstream members of the chain will observe the demand and transmit it to the upstream members by the replenishment orders. The bullwhip effect occurs when the demand order variations in the supply chain are amplified as they move up the supply chain. It has been widely accepted that there are five major causes for the bullwhip effect: (1) forecasting, (2) non-zero lead-time, (3) order batching, (4) supply shortages, and (5) price fluctuations [2]. Although the main sources that cause bullwhip effect have been identified, quantifying the bullwhip effect still remains a challenge [3]. There are several profiles of research work, among other things the linear simulation [2], the high order autoregressive demand process [3], fuzzy [4] and chaos [5] perspectives, or the benefit of information sharing [6].

The conclusions of these studies are: (1) among the main causes of the bullwhip effect, forecasting technique may be considered as the most critical one since forecasting method has direct impact on the inventory system in the supply chain, (2) sharing customer demand information across the chain significantly reduces, but does not completely eliminate, the bullwhip effect, (3) the inventories on different levels could stabilize the supply chain, also the reaction to stock levels of other producers or suppliers has a stabilizing effect (4) lead-time management and (5) order batching policy is critical.

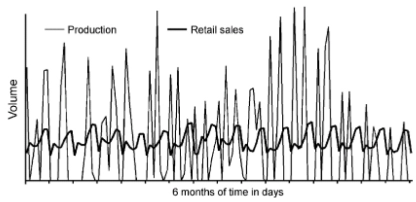


Fig. 1. Demand amplification typical of time series to be viewed through the "variance" lens. (*Source*: Potter, 2005).

1. The variance lens

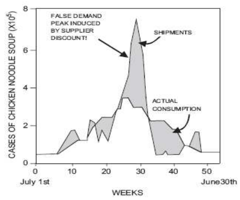


Fig. 2. Demand amplification of time series to be viewed through the "shock" lens. (*Source*: Fisher, 1997).

2. The shock lens

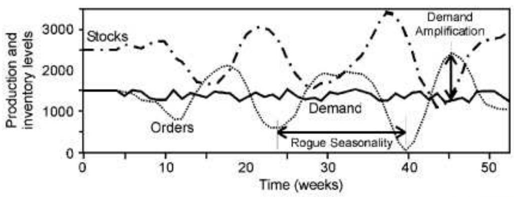


Fig. 3. Demand amplification of time series to be viewed through the "filter" lens. (*Source*: Berry and Towill, 1995).

3. The filter lens

In the detection of bullwhip, the appropriate shock, resonance and filter lens [1] demonstrated the special features of the phenomenon. Demand amplification is caused by some internal mechanism or event; it is not due to something external to the system. Furthermore, a strong business within a chain can impose a smooth order pattern for the benefit of the pipeline. In contrast a weak business can generate fluctuating orders despite relatively constant demand. Because bullwhip is a time-varying phenomenon, graphical representation of system behaviour is extremely helpful. The visualization of the outputs (the level of inventories according to the time dimension) could help to identify the type of bullwhip, and to determine the best viewpoint of the phenomenon. This is most readily achieved if a limited number of key performance indicators are used.

1. We need to consider the cause of the many physical and economic systems where periodic behaviour is observed – this is the case of the “Variance Lens”. In particular, the phenomenon of „resonance” in which signals at a particular frequency are greatly magnified is well known as a characteristic of a poor automobile suspension system. If the system is linear, then these sinusoidal inputs may be decomposed, the outputs to these separately calculated via complex number theory, and the total output obtained by summing these individual contributions.

2. A typical set includes the peak deviation, the time at which it occurs, and the time then taken for the system to settle back into a quiescent state. Since the idea here is to violently disturb the model, and see what happens or observe violent behaviour in real-world supply chains, we call this perspective the „Shock” Lens.

3. In particular, the use of „message” (as a signal to be faithfully transmitted) and „noise” (an unwanted signal to be got rid of) has led to the concept of „filtering” as an action by which these goals are achieved. Hence there is an established and powerful viewpoint of bullwhip as a resonance effect when observed via the „Filter” Lens.

These three bullwhip lens are, of course, related via the system transfer function model. This will be exact if behaviour is linear, but more and more tenuous as non-linearities impact. In turn this necessitates measuring all present system states i.e. „information transparencies” and exploiting this to optimally switch between alternate control regimes. An example of this in the supply chain arena is where a company may decide to move temporarily from „rapid response” mode to „level scheduling” mode as dictated by current market conditions.

Competing bullwhip measures is thereby greatly streamlined. In the complex real world the likelihood is that supply chains will generate even greater inconsistency between alternative variance, shock, and filter lens viewpoints. However, despite the undoubted enthusiasm for bullwhip as a research topic, there is a need to exercise caution. A lot depends on the observer and the assumed (or real) operating scenario. The practical outcome is that bullwhip is in reality not a generic term meaning the same thing to all system users. Whilst it is true to say that re-engineering the supply chain to reduce any one of the foregoing bullwhip measures means the others are also improved to some extent, this may not occur in proportion. Looking through the right „lens”, which for this purpose we shall term as follows: variance, shock, filter lens, in response to random demands, „shock” demands, and recurrent peak demands, respectively. The first is essentially statistical whereas the last two are much in evidence where „rich pictures” of behaviour are available. Once it is accepted that there is a problem due to observation via different bullwhip lens, it should not be difficult to resolve it. What needs to be understood is that we are dealing with a complex dynamic system. Hence, we may well need a set of performance measures which describe target behaviour under a wide range of conditions. As with hardware systems, supply chains need to cope with many situations analogous to „locking on” (i.e. responding quickly to change), „tracking” (i.e. high availability under quiescent conditions), and „disturbance rejection” (i.e. adequately coping with disruption). It is not difficult to see that the variance lens concentrates on the tracking model, whereas the shock lens looks at locking-on and disturbance rejection. Arguably, the filter lens endeavours via empirical inferences to control all three operating requirements. The best solution is again suggested by considering how designers of hardware systems cope. Their answer is to synthesise in the domain of choice, using a „best practice” database but to cross-check via simulation studies across all possible conditions. But the good designer then learns from each successful system by feeding back generic lessons into the design process hence keeping the knowledge base growing.

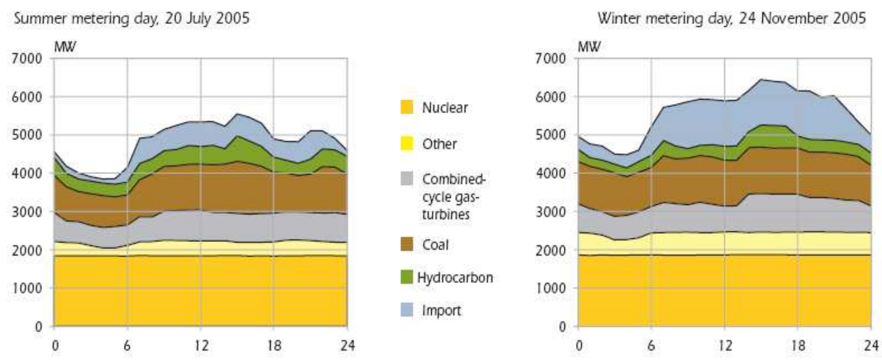
There are attractive management tools for eliminating the bullwhip-effect, like variable production speed, optimal inventory level or state-dependent lead-time – but we should pay a lot for the stability in these cases. There are favourable experiences in the analogue physical systems, like statistical physics, but in the case of supply chains the conditions are different, mainly in (1) the multi-dimensional system structure, (2) the problems of the reference fields, and (3) because of the variations in the adaptation capacity along the chain.

2 The bullwhip effect in the electricity sector

There are technical and economic specialities of production, transportation, distribution and consumption of electrical energy, including the storage opportunities. From the viewpoint of logistic, this system has special features: we should product the required electrical energy from moments to moments, otherwise the system loose the balance, and the service break off – with the high cost of missing energy, and enormous efforts of restarting. In the hungarian national grid there is no significant storage opportunity for produced and non-consumed electrical energy – and because of stability and controllability problems the in-built capacity of turbines (8558MW) is extremely higher (appr.133%) than the required daily maximum (6439MW)! [8]

At the first sight, it seems that the product of a power station is the alternating current power, but at the actual level of technology we can not store the electrical energy, so some of the power stations should be in able-to-start state, in accordance with the fluctuation of the consumers demand. The real product is not simple the electrical energy, but the availability of electrical energy, whenever the consumer need it. The main function of the electricity supply is to serve the consumer demand with solidly available (safety of supply) and satisfactory (quality of supply) electrical energy (with adequate frequency and voltage), as low full cost, as possible (thriftiness) – or recently, in accordance with the contracts obtained amongst the partners. These conditions and the contradictions amongst them form the central problem of the system operator and the management.

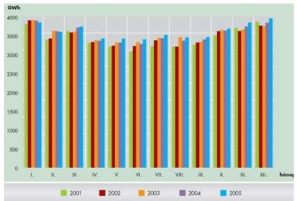
The reasons why the electricity system is growing are: (1) progressive efficiency in larger power plants (2) cooperation of plants, fewer redundancy, supply-security (3) transformation and transportation with good efficiency (4) the distribution is well soluble, easy to serve different power demands from the same grid (5) easy to use at the consumer level (6) clean and comfortable use at the final level. The consumers switch on and off theirs devices, so the requested energy is fluctuate. The daily schedule shows the production, lifestyle and meteorological conditions of a country. In normal mode the switch on and off operations counterbalance each other, and the total consumption alternate relatively slowly and with forecast-able rate. There are several methods for manipulation of demands – if we know the consumers and theirs behaviour and the whole supply chain in the function of energy and time. We could recognize the different type of consumers: household, industry (1-2-3 shift), trade, school, bureau, shop, lighting, heat-register unit, and others.



1. The daily schedule – summer and winter (2005)

2. Daily gross reserve capacity in peak (2005)

3. Weekly peak demand (2003-2005)



4. Monthly peak demand (2001-2005)

The daily peak demand and deep valley period are relatively short – but these are the critical points of control range. The standby units are the rotary (hot) and stationary (cold) turbines, the import possibilities, and at least the limitation of energy for customers (automatic frequency-dependent limitation, dispatcher operation, voltage decrease, switch off with tone-frequency and others). The inertia of a monumental inter-connected system is an advantage, the physical laws automatically solve the balancing problems – but this is a challenge to synchronize the physical events with contracts and legal rules on an opened market.

Conclusion

1. The bullwhip-effect, as we see today: In the supply chain, from the consumer to the producer (from the product to the raw material) the requests swing with high amplitude. This phenomenon is the bullwhip effect, which says that the uncertainties summing up alongside the chain, and there is a bullwhip at the end. Different type of studies agree in the causes, but they offer different solutions, from the viewpoint of the main problem: forecasting the fluctuation of demands, optimizing the orders, sharing the information, and others.

2. The role of storage: The analogy from the field of electricity production (no significant storage possibility at the level of the product, the rapid fluctuation of demands, short supply chain and lead time) shows enormous reserved production capacity level. There is no bullwhip-effect in the electricity supply – without stock the bullwhip is not possible. Even so the lesson is that the storage is reasonable as much level as possible, because in other cases we should pay a lot for the service.

3. Growing request for versatile, concerted logistics service: The example of the electricity sector shows that we could (or have to) pay higher price for the pool capacities, which are ready for start-up. In long supply chains the transportation is in intermediate role, and because of the inertia and lead time it is reasonable to construct multi-level service: for base power plant the analogy is a railway carriage, for a standby and quick reaction capable power station the analogy is a pick-up truck or a courier-service.

4. The vertical cooperation of partners: The detection of bullwhip is not self-evident for every participant of a long supply chain. In the field of the electricity production the demand fluctuation is not detectable for the nuclear power plant,

and because of physical laws it could not follow the fluctuation. We could convert this pseudo-handicap to product „half-complete electricity" (pumped hydro-electricity or/and hydrogen) in the „deep valley" period, and mobilise it at the „peak demand" period.

5. The application of transient wave management theory: Several analogies come from the electricity sector show itself promising. From the statical view of the electricity sector we could move to the upper level, to the dynamic behaviour of the system. The demand for transient wave management first appeared when the international connections were made, and the length of the wire became longer than ever. Could it be similar for long supply chains? How could we use the Bewley-pattern, the Bergeron-technique, how could we use reference-circuits? These are the interesting topics of future research.

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