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Assessing the impact of e-business on supply chain dynamics

S. M. Disney, M. M. Naim~ and A. Potter

Logistics Systems Dynamics Group, Cardiff Business School, Cardiff University,

Aberconway Building, Colum Drive, Cardiff, CF10 3EU, UK.

~ Corresponding Author

NaimMM@cardiff.ac.uk, ~ Tel +44(0)29 2087 6083, ~ Fax +44(0)29 2087 4301

Abstract

The Internet and related information and communication technologies (ICT) have recently enabled the cost-effective dissemination of information between disparate parties in the supply chain. New supply chain strategies, such as Vendor Managed Inventory (VMI), Collaborative Planning, Forecasting and Replenishment (CPFR) and Efficient Consumer Response (ECR), have begun to exploit these new communication channels, principally at the retail end of the supply chain. The impact of the e-business enabled supply chain on manufacturers and materials/component suppliers is, however, less well understood and exploited. This paper is aimed at establishing e-business enabled supply chain models for quantifying the impact of ICT, in particular its effect on dynamic behaviour. The paper concludes that simple, yet robust, models enable considerable quantitative insights into the impact of e-business on supply chain dynamic behaviour prior to their implementation.

Key words

Supply chain dynamics, e-commerce, bullwhip, EPOS, vendor managed inventory, e-shopping

Introduction

While ICT in the form of e-business is advocated as an enabler to the 1-2-1 enterprise [1] by allowing market place information to be shared by all businesses in the supply chain, there is little analytical or quantifiable evidence that it will actually improve the overall performance of the enterprise in delivering customer wants. It is usually proposed that passing information along the supply chain to all businesses in the supply chain via ICT will improve performance. In fact, recent research [2] has shown, via the supply chain "Beer Game" [3], that simply passing information on to businesses can have a detrimental effect. This is due to the fact that, as well as having more information available, schedulers need to know what to do with it.

There are many ways in which innovative information flows could be used within supply chains. Kiely [4] provides a good starting point, specifically focusing on using demand data for forecasting purposes. In this paper we analyse the impact of four ICT enabled scenarios by investigating the bullwhip effect [5 and 6] using two different approaches and comparing them to a traditional supply chain. The first approach is based on an analysis of the results of a management flight simulator, the Beer Game. The second approach is based on a quantitative z-transform analysis using the tools highlighted by Disney and Towill [7]. The aim is to compare and contrast the two approaches qualitatively to assess the implications of their evaluations of e-business scenarios on supply chain dynamics.

Bullwhip is an important measure, being symptomatic of a poorly performing supply chain [8]. It is a surrogate measure of production adaptation costs [9] and implies the inclusion of "just-in-case" stock holding to buffer against uncertainties. There is considerable empirical evidence of bullwhip including recent examples in the

- food sector where the supplier orders two tiers further upstream varied 10 times more then the electronic point of sales (EPOS) data [8].

- automotive sector where the ratio of the variance between incoming orders and order to suppliers at just a single echelon in the supply chain was 1:2 [10]).

The five supply chain strategies considered are:

- traditional – in which there are four "serially linked" echelons in the supply chain.
- e-Shopping – where the distribution network is by-passed and information and materials flow directly between the end consumer and the product suppliers.
- reduced – where an echelon in the supply chain had been removed.
- Vendor Managed Inventory (VMI) – that is simulated by developing a protocol positioned between two businesses in the supply chain that gives the necessary inventory and sales information, authority and responsibility to the supplier in order to managed the customer's inventory.
- Electronic Point of Sales (EPOS) – where information from the market place is transmitted to all enterprises in the supply chain.

Although various e-business scenarios are available the above were chosen by four groups of four Masters Programme students based on their review of commonly quoted and/or implemented strategies in both the academic and practitioner literature. It was these Masters students who implemented the scenarios in the Beer Game.

Methodology

Research on improving the dynamic behaviour of individual manufacturing businesses and supply chains is well known. Most recent research methodologies may be categorised as;

- ♦ Management games; tools such as the Beer Game that was developed at MIT at the end of the fifties [3], are useful to illustrate the benefits of different supply chain strategies. Games are limited in the sense that generally nothing can be rigorously proved from the game in itself, but they do provide a valuable source of anecdotal evidence and are a good learning device. Other authors have extended or computerised the Beer Game including van Ackere et al [11], Kaminsky and Simchi-Levi [12], Lambrecht and Dejonckheere [13 and 14].

- Empirical studies; a number of authors have investigated the impact of ICT on the supply chain including Holmström [15], Fransoo and Wouters [16], Kaipia et al., [17]. However, this type of contribution looks at quantifying the improvement performance of a known strategy after its implementation; that is, there is no predictive element and the focus of the research is to identify best practices. Unfortunately, it is not always possible to compare ICT implementation strategies directly due to the varying nature of the environments they have been implemented in.

- Statistical; this type of contribution typically provides statistical insights about the impact of demand properties such as standard deviation and correlation, and supply chain properties such as lead-times and information paths on inventory costs and the bullwhip effect or demand amplification. Statistical methods are often used to quantify the performance of real situations. These methods however, fail to show how to reduce or eliminate the detrimental dynamic effects, such as "bullwhip", and insights into the causes and effects of system structure on performance are rarely obtained in depth from the technique. Recent significant contributions of this type include Lee et al., [18] and Chen et al. [19].

- Simulation and system dynamics; this approach was advocated by Forrester [20] as a method of investigating the dynamical effects in large non-linear systems without resorting to complicated mathematical control theory based models [21]. Simulation approaches alone suffer from being cumbersome, time consuming and only provide limited insight [22], but they do have the advantage of being able to model non-linearity's whilst avoiding complicated mathematics. Previous work using simulation is very prolific and includes (but is no means limited to) Forrester [20], and Coyle [23], who studied traditional supply chain structures, Cachon and Fisher [24] and Waller et al, [25] who studied VMI.

- Continuous control theory techniques; The Nobel Prize for Economics Winner in 1978 (for his work on organisational dynamics), Herbert Simon [26] was the first to describe how to use linear deterministic control theory for production and inventory control. Axsäter [27] presents a useful review paper of early work, summarising the advantages and limitations of the field. He concludes that control theory "illustrates extremely well dynamical effects and feedback", but cannot incorporate sequencing and lot-sizing issues. Much research from the Department of Production Economics at Linköping University in Sweden has been presented in the literature. They have been applying the Laplace transform and economic techniques such as Net Present Value to MRP systems, Grubbström [28]. Continuous control theory suffers from the fact that some scheduling and ordering scenarios are inherently discrete and the continuous representation of discrete time delays is mathematically complicated.

- Discrete control theory; is a very powerful way of investigating sampled data systems, that is. scheduling and ordering systems or a computer system, all of which are inherently discrete. Vassian [29], inspired by Simon's work in the continuous domain, studied a production-scheduling algorithm using discrete control theory. DeWinter [30], in possibly one of only two contributions that consider novel supply chain structures, looks at a form of centralised inventory control used in naval supply chains. Deziel and Eilon [31] describe a significant application. Burns and Sivazlian [32] consider a four level traditional supply chain using z-transforms. Bonney and Popplewell [33] have investigated MRP systems. Dejonckheere et al. [34] have been using z-transforms to investigate the bullwhip performance of common forecasting mechanisms within common control structures. Disney [35] has been using discrete control theory to investigate

Vendor Managed Inventory supply chains. The disadvantages with discrete control theory are that the mathematics often involves lengthy algebraic manipulation.

The methodology utilised in this paper is to analyse the results from the playing of the Beer Game to determine the extent of bullwhip in the various ICT scenarios described. This allows direct comparison with previous published results [2] that yielded counterintuitive results. The Beer Game results encompass both structural and human behavioural aspects. The latter characteristics may include game players' poor understanding of the game, non-deterministic decision-making and errors in transcribing orders from customers to suppliers. An analytical z-transform approach is then utilised for comparative purposes and to deduce the impact of deterministic feedback system structures on supply chain bullwhip. The analytical approach is particularly important where there is an expectation that ICT systems will handle the bulk of information transactions in the supply chain and human interference will be limited to managing exceptions.

Description of the five supply chain scenarios

The five supply chain scenarios researched are summarised by Figure 1. A short description of each scenario also follows.

Traditional

A traditional supply chain may be characterised by a four "serially linked" echelons in a supply chain. Each echelon only receives information on local stock levels and sales. Each echelon then places an order onto its supplier based on local stock, sales and previous "orders placed but not yet received" [3].

Reduced

By a reduced supply chain we mean a supply chain with a reduced number of echelons. This is representative of, say, the Amazon.com supply chain, where the retailer echelon is by-passed in the information and material flow through the use of ICT. Echelon removal has been identified by Wikner et al. [36] as an effective mechanism for improving supply chain dynamics.

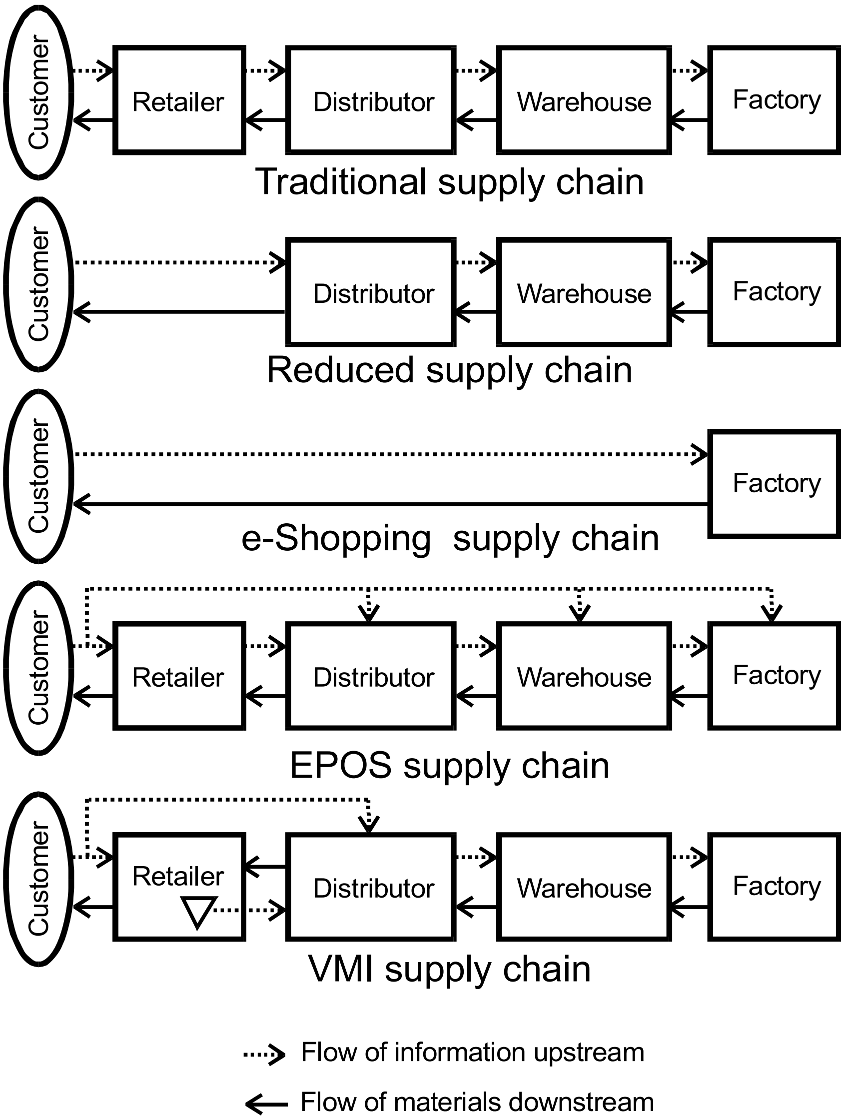

Figure 1. The five different e-business scenarios

e-Shopping

By the term e-Shopping we refer to the scenario where the manufacturer receives an order directly from the end consumer (possibly via the Internet like Dell) and ships the product directly to him after the production and distribution lead-time. Thus this supply chain strategy has exactly the same fundamental structure as a single echelon traditional supply chain.

EPOS enabled

In the EPOS enabled scenario, the end consumer sales are made visible to all members of the supply chain. This is equivalent to the situation in many grocery supply chains, where the EPOS (Electronic Point Of Sales) data is available electronically via the Internet, either directly from the retailer or via a third party, and can be used by supply chain members to generate their own forecasts. Specifically, in this strategy, the end consumer sales may be used by each echelon for their own planning proposes, but each echelon still has to deliver (if possible) what was ordered by his customer. A full-scale investigation of this strategy has been conducted using z-transforms by Dejonckheere et al. [37], inspired by the simulation approach of Mason-Jones [38].

Vendor Managed Inventory

The specific VMI scenario that we consider is as follows. The vendor (the distributor) in a two echelon VMI relationship manages the consumers stock in the VMI relationship (the retailer) stock. The distributor is given information on the retailer's sales and stock levels. In this scenario the retailer does not place orders on the distributor, but rather the retailer trusts the distributor the dispatch adequate amounts of stock to ensure that there is enough (but too much) stock at the retailer. We use the VMI strategy highlighted by Disney et al. [39] for the VMI echelons in the supply chain. The other echelons in this scenario (the Warehouse and Factory) were run in traditional mode.

Impact of ICT on supply chain dynamics

Beer Game Results

Hong-Minh et al. [2] analysed the results from four different teams playing different supply chain management strategies, one of which was the EPOS scenario previously described. Even though the research literature implies great benefits for information sharing [40], surprisingly the EPOS strategy yielded the worst result. Whilst the EPOS strategy limited the degree of bullwhip in the supply chain, this was at the expense of long periods of backlogs (negative net stock). It was concluded that, although market information was shared with all echelons without any delays, each player of the supply chain had their own ordering rule. That is, there was no collaboration between the different players.

To test the hypothesis that although sharing market information is potentially a good thing it will only yield benefits as part of an agreed overall supply chain decision making strategy [38], the EPOS strategy was re-run but with the added characteristic that all players were involved in collaborative planning, forecasting and replenishment; in other words, CPFR.

The Beer Game was also run twice by the current authors as part of a Masters Programme in International Transport involving 16 students. The first time the game was played it was run in traditional mode. That is, the Beer Game was played exactly as described by Sterman [3]. It was then played for a second time in with the students working in syndicates. Different syndicates re-enacted the four different ICT supply chain strategies. The demand pattern (which all syndicates responded to) was randomly drawn from an 8-sided dice for the first four order periods. From time period 5 (to 25 in both games) demand was generated by a 20-sided dice. The game was subsequently run with an independent group using the same demand pattern and the traditional supply chain structure, therefore enabling comparative results to be generated for all five scenarios.

For the purposes of this paper the second set of results are analysed. While different measures of performance were collected from the game they have been summarised according to Equation 1 [19].

$$Bullwhip^i = \frac{\sigma^2_{ORATE^i} / \mu_{ORATE^i}}{\sigma^2_{CONS} / \mu_{CONS}} = \frac{\sigma^2_{ORATE^i}}{\sigma^2_{CONS}} \quad \text{.....Equation 1}$$

which gives; the bullwhip measure, the co-efficient of variation, at echelon *i*, where σ^2 is the variance and μ is the mean of the end consumer sales (CONS) or the order rate (ORATE) at echelon *i*.

As well as the bullwhip measure we also adopted the classic performance index utilised in the Beer Game, that is the inventory cost. Stock holding is penalised at £0.50 per item and a stock out incurring a cost of £1.00. The inventory cost is an important measure as it ultimately determines the extent to which we satisfy the customer as well as determining the risk of stock obsolescence. The severity of backlog cost is justified because, no matter how well we control the degree of volatility in the supply chain, if we do not satisfy the end consumer then we will eventually go out of business.

Summary results from the game are shown in Table 1. The inventory costs are shown as a relative ranking achieved, normalised so as to be independent of the number of actual echelons in a particular supply chain strategy. We are therefore penalising those supply chains with fewer echelons. Also, two EPOS results are shown. The first is that played in the research described in this paper and has been defined as EPOS-CPFR. The second (named EPOS – no CPFR) is based on the actual results recorded by Hong-Minh et al. [2].

Supply chain	**Inventory cost ranking**	**Bullwhip**			
		Retailer	**Distributor**	**Warehouse**	**Factory**
e-Shopping	**1st**				1.50
Reduced	**2nd**	1.00		0.99	0.93
EPOS – CPFR	**3rd**	1.92	1.37	0.99	0.49
VMI	**4th**		3.42	4.68	4.44
EPOS – no CPFR	**4th**	1.85	0.83	0.55	0.69

Table 1. Sample Beer Game results

EPOS – CPFR again does well at minimising, and in fact is reducing, bullwhip in the supply chain. But, as with EPOS – no CPFR, a price is paid in inventory costs, which is primarily attributable to the supply chain having long periods of stock out. Despite the normalisation of the inventory costs it is evident that a strategy that eliminates an echelon, or a number of echelons, still outperforms alternatives. As has been previously reported (see for example, Wikner et al. [36], eliminating an echelon removes a decision point and reduces total lead-times in one simple to implement and understand step.

Even more surprising than the EPOS – CPFR result is that, of the four e-business strategies, the VMI scenario had both the worst inventory holding costs and the worst bullwhip. It was evident in the game de-briefing that, despite the provision of well-documented protocols, the players had problems in implementing the concept.

z-transform evaluation

Again we use Equation 1 to determine the bullwhip factor at level *i*, because it allows closed form expressions for bullwhip to be determined via a z-transform approach [7], and is commonly used by academics to quantify bullwhip [19].

We determined the amount of bullwhip generated by each supply chain strategy using the sum of the squared impulse response method described in Disney and Towill [7]. In general, the supply chain models considered may be summarized as follows.

- Unless necessary to model specific strategies, the production decision has an ordering rule based on the sum of average demand, a fraction of the difference between a target finished goods stock and actual stock, and a fraction of the difference between target pipeline stock and actual pipeline stock [41] structure. This is appropriate because Naim and Towill [42] have shown this to be equivalent to Sterman's [3] anchoring and adjustment heuristic that in known to replicate human behaviour when playing the Beer Game.
- The complexity of the mathematical manipulation was reduced by using the Deziel and Eilon settings [43 and 7] within the ordering rule. This is appropriate as Disney and Towill [7] have shown that this is a subset of the general APIOBPCS model that has some important desirable dynamic properties.
- The mathematical task was also further simplified by setting the average age of the exponential forecast (Ta) in the ordering rule equal to the inverse of the gain (1/Ti) in the

two feedback loops minus one and setting the production/distribution lead-time equal to two order periods. This was required to avoid extremely high order polynomials in the bullwhip expressions.

- The specific VMI scenario modelled was one in which the vendor manages the stock levels at his customer, and endeavours to keep the stock level between a mutually agreed upon minimum and maximum level. In particular, the minimum and maximum levels do not change over time. This situation results in a two-echelon supply chain that behaves exactly as a single echelon supply chain [35]. For more information on VMI and its variants (especially when the minimum and maximum levels change over time) we refer to Disney [35].

Our results are summarised in Figure 2. There are two fundamental bullwhip closed forms: one for the traditional, reduced, e-shopping and VMI supply chains and another for the EPOS supply chains. We can conclude from Figure 2 that bullwhip will generally increase as the order pattern is transmitted along a supply chain with the traditional structure. However we note from close inspection near Ti>4 that bullwhip can actually reduce as is flows up the supply chain.

Eliminating one echelon obviously removes a source of bullwhip, as one set of order modifications are simply not carried out, whilst eliminating the whole distribution network effectively makes the factory order rate the same as the first echelon in the traditional supply chain. Although, a "low-tech" use of ICT, the two strategies involving echelon removal are conceptually simple to understand. As these strategies require no new behaviour from the scheduler, this may explain why they generated favourable results in the Beer Game. However, they suffer from a serious drawback; removing retailers, distribution centres and wholesalers in real supply chains, removes a point of presence near customers. So unless customers are prepared to accept the disadvantages of the lack of presence (as they may do with books or computers), it is unlikely that this strategy could be used.

In VMI supply chains, we may get two echelons to behave as a single echelon. In fact there is no reason why we cannot have a four echelon VMI strategy and make the four echelons behave as a single echelon. Therefore, VMI may be used to get good order dynamics and provide a local point of presence for customers. This may explain why the strategy is often found in grocery supply chains. The EPOS strategy however has a fundamentally different order structure and we need a new set of closed forms. However we can see that we can get nearly the same performance from EPOS as we can from VMI. The EPOS strategy also allows a local point of presence and thus will be of more general use.

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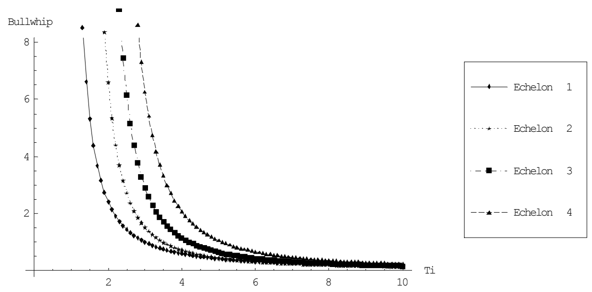
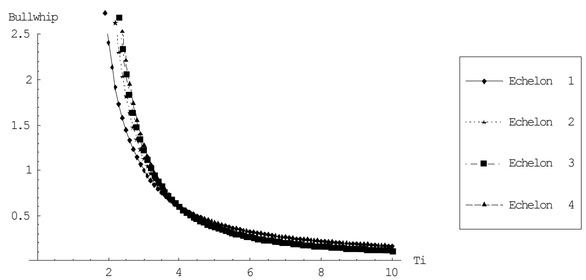
S C	Bullwhip graph	Bullwhip closed form (BW^i=Bullwhip at echelon *i*)	Focus: Traditional	Focus: Reduced	Focus: eShopping	Focus: VMI
Traditional, Reduced, e-Shooping and VMI		$BW^1 = \frac{5(1+2Ti(1+Ti))}{(-1+2Ti)^3}$	Ret.	Dist.	Fac.	Dist.
		$BW^2 = \frac{33+2Ti(65+Ti(128+Ti(76+Ti(87+26Ti+58Ti^2))))}{(-1+2Ti)^7}$	Dist.	Ware.	…	Ware.
		$BW^3 = \frac{\left(\begin{array}{l}245+1546Ti+4670Ti^2+7120Ti^3+8570Ti^4+3964Ti^5\\+6688Ti^6-1600Ti^7+4270Ti^8-180Ti^9+1932Ti^{10}\end{array}\right)}{(-1+2Ti)^{11}}$	Ware.	Fact.	…	Fact.
		$BW^4 = \frac{\left(\begin{array}{l}1921+16898Ti+70556Ti^2+169640Ti^3+279652Ti^4+287320Ti^5\\+293384Ti^6+73984Ti^7+256798Ti^8-120148Ti^9+270016Ti^{10}\\-143120Ti^{11}+124108Ti^{12}-21016Ti^{13}+35048Ti^{14}\end{array}\right)}{(-1+2Ti)^{15}}$	Fact.	…	…	…
EPOS		$BW^1 = \frac{5(1+2Ti(1+Ti))}{(-1+2Ti)^3}$	Retailer			
		$BW^2 = \frac{9+2Ti(-17+Ti(21+Ti(21+13Ti)))}{(-1+2Ti)^5}$	Distributor			
		$BW^3 = \frac{9+2Ti(-34+Ti(121+Ti(-155+2Ti(22+Ti(34+21Ti)))))}{(-1+2Ti)^7}$	Warehouse			
		$BW^4 = \frac{\left(\begin{array}{l}9-98Ti+534Ti^2-1480Ti^3+2298Ti^4\\-1542Ti^5-72Ti^6+366Ti^7+298Ti^8\end{array}\right)}{(-1+2Ti)^9}$	Factory			

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Figure 2. Bullwhip in different supply chains

Conclusions

There are important managerial implications for the research presented in this paper. We have taken two different approaches to understand the impact of ICT on supply chain dynamics. The z-transform analysis indicates that there is an expectation that the innovative ICT will outperform the alternative strategies. But the Beer Game results have indicated that ICT adds a degree of complexity to human decision-making that is difficult to cope with even if well-defined protocols are provided. There is just too much information and too many calculations to manage. The Beer Game also indicates that poor management of the ICT protocols leads to increased inventory costs. We conclude that although the Beer Game is a simulated and simplified environment, much like the real-world people have to make decisions the consequences of which are not immediately known. As Sterman [3] has indicated people are not good at making decisions in such an environment. While ICT offers the opportunity for greater supply chain transparency, it creates an even more complex environment so that when people do have to intervene, the decision-making is even more difficult.

Between playing the Beer Game in traditional mode and implementing the e-business scenarios there may be a learning curve that the players go through. The results of the e-business scenarios suggest that if the learning curve did exist for the results indicated then the simpler the scenario the faster up the learning curve the players progress.

There is also the possibility that the players in implementing the e-business scenarios were far too ambitious in their strategies. Again, this is not unlike the real world. Companies may often over stretch their capabilities and resources in implementing new technologies that are either too advanced for their needs or are inherently too resource intensive to implement and operate.

As it is difficult to ensure that everybody is appropriately trained to manage new ICT protocols, there is a need to design robust systems that minimise human interaction. Alternatively when human interaction is required it should be intuitively obvious what particular decisions have to be made and with which specific sources of information. At the same time, with current technology, it is difficult for ICT systems to handle exceptions, such as absenteeism or factory shut downs. Appropriate simplified procedures are therefore required to enable simple human interaction to manage the exceptions.

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