Disruptions in Information Flow: A Revenue Costing Supply Chain Dilemma

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Abstract

The integration of supply chains as a mechanism for value creation is largely dependent on continuous flow of real time accurate information from the customer back upstream to the manufacturer. This ideal is often unachievable when disruptions in the flow of information and materials are known to regularly occur in some manufacturing supply chains. This paper focuses on quantifying the potential lost sales revenue attributed to information and material delays in a supply chain using discrete event simulation of the Beer Distribution Game.

Results indicate a direct relationship between lost sales revenue and delay times. When exposed to several levels of delay such disruptions will cause loss of sales revenue. Interestingly, data collected suggests that information delays play a larger role than material delays as a contributor to lost sales revenue.

This study provides a solid platform to further justify the implementation of technology such as RFID in an effort to decrease the level of lost sales revenue in manufacturing supply chains. The implementation of technologies that will increase the speed of information flow throughout a supply chain as well as increasing visibility of inventory in the supply chain can assist to minimise lost sales.

Key words: Simulation, Supply Chain Management, RFID, Beer Distribution Game

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1   Introduction

Supply Chain Management (SCM) emphasizes the close coordination of the business units in the chain [41]. In most cases, even minor disruptions in a supply chain have the potential to significantly decrease a firms' performance [21]. Declines in supply chain performance can have many sources, which can be attributed to individual decision-making. Each decision can potentially create or compound a perturbation in the flow of materials and/or information in a supply chain. These situations can originate times of undesirable stock levels, tying up significant resources and lowering the efficiency and effectiveness of any member operating in a supply chain, ultimately presenting as opportunity costs at the retail end of the supply chain. Failure to commit to effectively integrating and managing a supply chain is a significant source of inefficiencies for firms [6]. In a competitive business environment, supply chains are quickly realising that increasing uncertainty in market expectations, quantum leaps in technology and globalisation of supply chains, the customer is still king [56].

This study quantifies the impact of information distortion from the perspective of the end customer; more specifically, the costs generated from inefficient operations within a supply chain to those costs associated with lost revenue from unfulfilled customer orders. As such, three research questions have been developed;

1.   What is the magnitude of the opportunity cost from incomplete or missing customer orders in a simplified supply chain simulation?

2.   How do increases in information delay times affect levels of opportunity cost?

3.   What possible solutions can be recommended to minimise losses in revenues?

The popular beer distribution game was simulated using standard ordering policies and the costs of lost sales from retailer stock outs were quantified with several customer ordering patterns. This study contends that opportunity costs at the retailer's end of a supply chain are as important as costs incurred due to inefficient SCM. In addition, the level of information delays also are seen to contribute significantly to the opportunity costs, in a similar manner as they contribute to supply chain costs. The importance of these lost sales contributes to supply chain understanding by examining the downstream impact of inadequate information sharing with the customer, in turn identifying the need for adoption of emerging information technologies such as RFID as a tool for minimising lost sales and generating customer retention through better information flow.

The article is structured as follows: Section 2 describes the relevant literature, Section 3 describes the simulation–based methodology, and Section 4 presents the results and discussion. Finally the limitations of the research are outlined, along with future areas of research.

2   Literature Review

The supply chain is often described as a process linking individual business units from the source of supply through value adding intermediaries such as manufacturing and services to the final customer; so that flow of material, information and money can be effectively managed to meet business requirements [50]. The process of integrating and managing a group of business units connected in a supply chain is a difficult task. The beer distribution game is a well recognised simulation activity used to introduce students and supply chain practitioners to the challenges of managing supply chains.

There is extensive research available on the beer distribution game and demand amplification in supply chains. Starting with the work by Forrester [16] in which a three echelon single product supply chain was designed with fixed material and information delays. From this work, the beer distribution game was developed as a role playing simulation of an industrial production and distribution system developed to introduce students of management to the concepts of system dynamics [49]. In other words, the beer game is an experimental replica of a supply chain that uses rules which are widely prevalent in business, revealing that problems originate in basic ways of thinking and interacting, more than in peculiarities of organisational structure and policy [46]. A commonly observed behaviour in simulated supply chains is the persistence of upstream demand amplification, otherwise known as the bullwhip effect. When Towill *et. al.* removed the lead times for information and material, and at the same time removed intermediaries one at a time, the bullwhip effect was significantly reduced [52]. These results have been replicated by other scholars by using the beer distribution game [1], [23].

Recent work on the bullwhip effect, suggests that there are a number of significant sources of disruptions in the beer distribution game supply chain. By systematically changing the values of the variables corresponding to selected causes of the bullwhip effect, the relative significance of each source of the bullwhip effect was quantified, among these were the material and information delays [41]. Paik and Bagchi [41], drawing on the previous work of Towill [52] found that information lead time was a significant variable in the amplification of demand upstream. In addition, it

was found in this study that other factors had a greater level of significance as a contributor to the overall bullwhip effect.

Sterman [49] designed and used the beer game to study the individual behaviour on the generation of macrodynamics from microstructure of a simplified supply chain in a common managerial context (that is buying, selling, and inventory management). In the game, subjects manage a simulated industrial production and distribution system where their decision making is straightforward and subjects seek to minimise total costs by managing inventories appropriately in an environment with uncertain demand. Sterman [49] used a sample of 48 trials (192 players) collected over four years to derive a mathematical representation of behaviour that, while far from optimal, exhibits significant regularities, suggesting that subjects used similar heuristics to determine their orders. The pervasiveness and qualitative similarity of the oscillations is particularly interesting considering customer demand stayed nearly constant throughout each trial. A demonstration of this decision rule contains four parameters and is non linear. Other authors also used this method of gathering data to shed light on the behavioural causes of the bullwhip effect [14].

The applicability of the beer distribution game to real world supply chains is far from ideal. When complexities of real world industries are considered (product mix, variability in transport logistics, inventory capacity constraints, etc.) many causes of the bullwhip effect are amplified, mixed or even cancelled out, and may be hard to detect in the data [25]. On the other hand, many of the same conditions that exist in the beer game are present in real life supply chains.

Chatfield et al. [8] found that the level of lead time variance exacerbates, although does not initiate, the bullwhip effect. Their focus was to observe the effect of stochastic information lead times and information quality under normally distributed stochastic customer demand. This research is limited in the quantification of unfilled customer orders, instead the standard deviation of each business unit order quantities as well as the amplification of demand across the entire supply chain and across each echelon were used as the main metrics. Other examples of measuring the impacts of information delays on a supply chain can be found in [9], however these studies focused on the level of amplification of demand rather than opportunity cost from lost sales and low levels of delivery-in-full performance. Upstream focus on demand has identified the need to use technology as a mechanism to enhance visibility in the supply chain. Examples of emerging information technologies include the use of RFID tags. While recent research explores the benefits of RFID technology in the capacity of track and trace to aid inventory visibility upstream little is known about the value of such technology downstream towards the customer.

Throughout the reviewed literature on SCM and the bullwhip effect, there is the common view of using the inventory holding costs and backlog costs at each echelon as the main metric by which individual players are assessed on their performance within the supply chain. In some cases, the total costs incurred by the whole supply chain may be used to assess the performance of all the players in the game. In a supply chain, most of the research surrounding costing has been focused on defining opportunity cost as the costs associated with warehousing, capital and storage of inventory [11], [12], [18], [31], [36], [47], [51]. The use of lost sales due to unfulfilled end customer orders has yet to become a popular metric for players' performance. The end customer's view of the beer game presents a new perspective by which to assess supply chain performance.

The evolving focus of different SCM theories and perspectives can be traced back to the substitution of markets for hierarchies in the resource allocation process in the 1970s; economists and other scholars increasingly focused their attention on how organisations were incorporating external resources into their internal operations [20], [40], [57]. Over time, the network structures became more sophisticated and their centre of attention began to shift towards cost reductions. This resource based view of SCM provided little sustainable competitive advantage because management techniques such as benchmarking, business process reengineering, total quality, and best practices helped leading competitors learn how to attain maximum efficiency across their network of suppliers and allied partners. While a resource based view of the supply chain provided added capabilities and process improvements, some seemed to be moving towards improving their innovation process through knowledge sharing [40]. Assuring equitable treatment across collaborating partners requires heavy investment in trust building and the creation of organisational cultures and processes as anticipated in the collaboration literature of the 1960's and 1970's [5]. As many observers of today's business arena agree that new business and organisational models are needed if firms and economies are to fully utilise their knowledge base to continuously generate new products, services and markets (see Friedman [17]). It is expected that new entrepreneurially oriented business models will emerge, with support from new collaborative network structures, as it becomes clear that current strategies, structures and processes become obsolete. Many of those new approaches are believed to build on the experiments and experiences of the most progressive supply chain organisations [40].

Successful SCM requires planning, managing and controlling flows of material, information, ownership and payment through the integration of key processes, from original suppliers through all the echelons of the supply chain which ultimately produce values to the consumers [7], [10], [29], [41]. If there is a problem in one business unit, the problem consequently causes other problems in other areas and weakens the effectiveness of the whole supply chain. Since, a supply chain involves many players each with distinct practices and policies, those complexities result in higher degrees of uncertainty and dynamics within a supply chain [41]. Due to order processing, it is common for supply chains to experience delays in the transmission of information and materials, i.e. an order placed by one business

unit reaches an upstream supplier after an *information leadtime.* Consequently, as the product is made and the order is completed and delivered, there is a processing time, known as *material leadtime.* As demand for materials may change from the time the order is placed to the time the material is received, difficulties arise in effective management of a supply chain. Towill's results were obtained from a simulation of a serial single-product supply chain, of three and four echelons [52]-[54]. These studies indicated that the delay of information between echelons was a major contributor to the bullwhip effect. However, when Paik and Bagchi [41] tested the significance of information delays as a contributor to the bullwhip effect, it was determined that information delays were not a statistically significant contributor to demand amplification. Paik and Bagchi's results support the results of empirical studies by Croson and Donohue [14], and simulation studies by Dejonckheere and Chatfield [8], [15]

More companies are realising that in order to evolve an efficient and effective supply chain, performance assessment is essential [19]. In addition, Gunasekaran [19] states that for effective management to become a reality, measurement goals must consider the overall supply chain goals and the metrics to be used which requires a balanced approach at the strategic, tactical and operational levels complemented by financial measures as well. However, this subject of supply chain metrics must be handled with caution, as literature by Lee [31] states that many companies have the problem that there are no performance measures for the entire supply chain. Even those that do have complete sets of metrics often do not monitor them regularly or the metrics are not directly related to customer satisfaction. Lee also contended that supply chain metrics must be oriented to customer satisfaction which is a common omission in many companies' views of SCM.

In studying the behaviour of supply chains, the choice of simulation modelling over other analysis methodologies stems from its inherent flexibility; simulation is often regarded as a particularly powerful way to support decision making and supply chain design. In many cases, using a simulation to model the behaviour of a supply chain is the preferred method, as the complexity of the supply chain often obstructs analytical evaluation [24], [55]. In many cases, simulation is a natural approach in studying supply chains as their complexity obstructs more traditional analytic evaluation [24], [44], [55], and agent based simulations are often geared towards the achievement of a system goal [42].

When a system is designed through simulation, the simulation model is constructed based on either a discrete-event or continuous simulation modelling method. Although it is believed that product and information flow have continuous factors in a supply chain, most supply chain problems are solved using discrete event simulation as they often are looked at with an operational focus [35]. From a programming perspective; it is easier to look at the operational side of a supply chain system as having a beginning, then a set of rules or commands that calculate discrete changes in the system over time, finalising the simulation when the predetermined time is up. If the system dynamics of a supply chain are to be simulated from a strategic level, continuous simulations are the preferred method. Simulation has rapidly become a significant methodological approach to theory development in the literature focused on strategy and organisations [3], [30], [43], [45], [60]. Several influential research efforts have used simulation as their primary method [13], [37].

3   Methodology

Often in the literature, the focus is on reducing costs generated within the supply chain, increasing lead times and reductions in inventory. This practice has lead to important research and has been applied in many real world supply chains. In this study, the focus is shifted upon the end consumer, the final stage in a supply chain that is often not mapped due to the inherent complexity of human behaviour. By simplifying consumer behaviour in a simple supply chain to its near simplest form, the disruptions caused by changes in demand have been well documented [32], [33], [48], [49]. The use of the beer game as a representation of a supply chain for this study can be justified by its popularity as a representation of a simplified supply chain and its effectiveness as a research tool. Moreover, common practise in academia focuses on using the beer game as a tool to promote an inward focus in supply chain management. Disruptions in a supply chain often lead to poor sales from the retailer's side of the supply chain. In this case, a simulation of a simplified supply chain was used to highlight the magnitude of lost sales and the costs associated with them.

Of all the crucial elements of SCM, the collection, use and dissemination of information is one that when mismanaged, will result in adverse impacts on the supply chain. If information sharing throughout a supply chain is considered a capability of the firm, literature on the subject [39] suggests "virtually every definition of competence in the literature refers to some purpose the firm is able to achieve… preferably in a manner superior to that employed by other firms …" (p. 253). Thus capabilities represent the ability of the firm to combine efficiently a number of resources to engage in productive activities and attain a certain objective [4]. The capability of a firm to share information however, is only way to enable better coordination and planning in the supply chain, companies must develop capabilities to utilise the shared information in effective and efficient ways [34]. One example commonly used in illustrating the effects of limited sharing of information with supply chain partners is the beer distribution game.

In order to develop an empirical understanding that emphasises what is feasible; a robust simulation methodology that captures the range of options considered is required. Such a methodology should capture the importance of

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existing processes (operational and social) that may be path and context dependent. In other words, history matters, and this creates a research environment that is extremely complex. Simulation offers one of the best and most cost effective ways to determine what should be in a consideration set to capture alternative configurations in the supply chain [58]. The choice of modelling approach directly affects which problem and structure can be investigated. Understanding the advantages and limitations of these approaches can aid in the selection of an approach to study the problems faced by a supply chain [24]. Simulation has rapidly become a significant methodological approach to theory development in the literature focused on strategy and organisations [3], [30], [43], [45], [60].

A classic simulation study starts with a model of the actual system so that output for the model can be validated and verified with what is actually happening in a real life situation. Once confidence in the base model has been established different scenarios can be explored and measured against key performance indicators. Hence, simulation offers an effective way to model aggregate supply chain outcomes from heterogenous individual behaviours. This technique is particularly suitable for purposes such as prediction, training, education and discovery [38]. Several influential research efforts have used simulation as their primary method [13], [37]. From a systems dynamics point of view, an entire supply chain can be considered as a series of objects that interact to perform a given function [22]. In this case, meeting the demands of end customers (and business units' within the supply chain) demand in the most efficient way possible while minimising impacts of disruptions on other business units in the supply chain.

The choice of a simulation software package is also important, based on the requirements of the research, a simplified simulation tool may be required if the supply chain is simple. In this case, the requirement was for a flexible simulation package capable of running simultaneous continuous and discrete event flows of both information and materials while conducting mathematical or logic elements that can be used to model the more-than-trivial decision rules used in the system, generating multiple outputs and having the capability to be easily expanded for future research. The simulation software package selected for this study is ExtendTM, by Imagine That! Inc. Extend consists of multiple blocks capable of representing functions, mathematical operations, and interactions among diverse functional blocks. The simulation model generates diverse desired outputs from selected inputs through the realization of multiple arithmetic and sequential operations [28]. ExtendTM has been used in several instances where simulation models of production systems and supply chains were constructed and the system submitted to a number of 'what if' scenarios for decision support and educational purposes [2], [59].

Extend models are constructed with library-based iconic blocks. Each block represents a calculation or a step in a process. Each library represents a grouping of blocks with related characteristics such as discrete event, plotter, manufacturing and flow. Blocks are placed on the model worksheet and connected to create a model. There are two types of logical flows between the blocks in a model. The first type of flow is that of "items", which represent the objects that move through the system, these can be assigned attributes and priorities. The second type of logical flow is "values", which represent a single number and will change over time during the simulation run [28]. The reasoning behind the selection of this software tool is in its ability to run models in discrete event and continuous modes. This is particularly valuable in the integration of feedback loops that affect a supply chain, and the software's ability to do multi-run simulations where one or more variables are set to change every run.

In this case, the magnitude of individual information delays in the beer game simulation was changed and the opportunity costs measured. The opportunity costs were calculated by counting the number of cases of beer delivered minus the order size. For each case of beer not received by the customer an opportunity cost of $2 was added. In the original beer game design, the cost of backlog is double the cost of holding inventory to highlight the importance of backlogs in a supply chain. In a similar fashion, the cost of a lost sale due to an incomplete order should be double the costs of backlogging in a supply chain. In many ways, the opportunity cost calculated in this study encompasses the level of importance of lost sales. In the beer game, the customer does not abandon a particular retailer because they cannot fulfil customer requirements, and since this often occurs in real life supply chains, it was decided to double this cost. In previous studies, the heavy focus on costs incurred in the supply chain left little room for considering the level of opportunity cost, we believe this cost is of very high importance.

As the simulation used for the beer game did not involve the use of human players a set ordering policy that mimics the empirical data collected by Sterman [48], [49] in his experiments. The ordering policy rules included features such as correction of differences between desired stock and the actual stock, the evaluation of current inventory as well as expected inventory and the level of losses due to holding inventory or stock outs. This ordering policy was gathered from previous work [26], [49]. In general, orders placed by a unit, O, at time t, are given by;

$O(t) = max (0, IO(t))$

$IO(t)$ = indicated order rate, is computed based on three factors:

1. expected losses from the stock (L)

2. discrepancy between desired and actual stock (AS)

3. discrepancy between desired and actual supply line (ASL)

$IO(t) = L(t) + AS(t) + ASL(t)$

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$L(t) = x_l \bullet Lt\text{-}1 + (1\text{-}x_l) \bullet L_0$

$AS(t) = x_s \bullet (S^* - S(t))$

$ASL(t) = x_{sl} \bullet (SL^* - SL(t))$

x_l, x_s, x_{sl} = weight factors determined through regressive expectation

$S(t)$ = stock of crates

S^* = desired stock (=12 in beer game)

$SL(t)$ = supply line

SL^* = desired supply line = expected lag • desired throughput

Each time the retailer receives an order one of two things may occur, the retailer has sufficient stock to fill the order completely; conversely the order is partially filled or not filled at all. It should be noted that the ordering policies of any of the echelons in the supply chain were not altered throughout the course of the study. The customer demand used for this study was based on the default customer demand used for most commonly, the initial order of four cases of beer is maintained for the first four weeks, after which the demand is increased to eight cases of beer for the duration of the game. In addition, three stochastic ordering patterns were used. These patterns were triangular random distributions with a maximum of 12 cases and a minimum of 4 cases, mean order sizes were low (customer 1, μ=5), medium (customer 2, μ=8) and high (customer 3, μ=11). As a method of validation, the wavelength and amplitude of each echelon was compared to the model that is most widely used to demonstrate the beer game [27]. In addition, the amplification factor across the supply chain was also measured and compared to the work of Sterman [49]. The validation procedures were done through a short time horizon. The experiments conducted in this study included a larger time horizon of 150 weeks.

Upon validation of the model, simulation runs were conducted to gather data. Among the data collected were the sizes of orders issued to the retailer and of the orders received by the customer. The data generated by the simulation was then transferred to a spreadsheet program for analysis. The data was plotted to observe differences between lost sales and level of information delay for every customer demand. Cumulative lost sales for the simulation run as well as the trendline slopes were also used. Finally, the level of delivery performance for each customer demand was plotted.

4   Results and Discussion
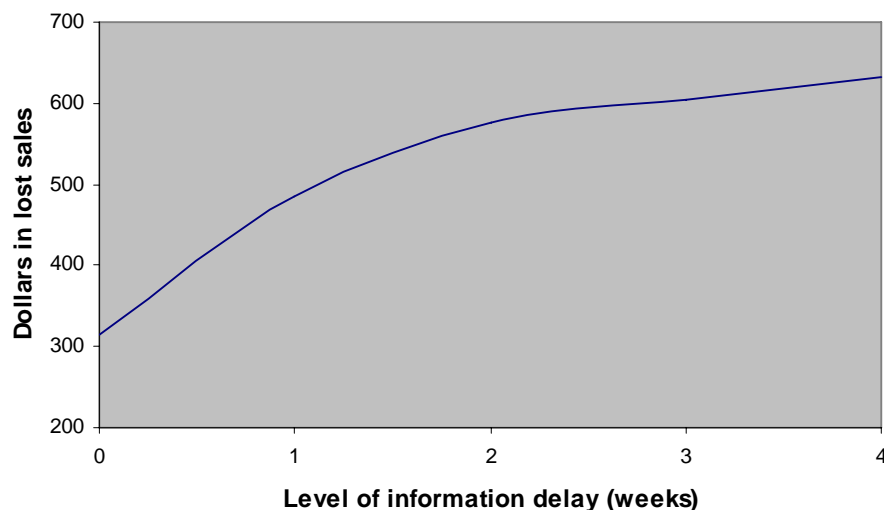

Customer lost sales v level of information delay

Figure 1: Level of customer lost sales as a function of game information delay

This section provides the findings based on the data gathered from the simulation model in the context of lost sales due to the level of information delay, and discusses the implications of the findings in relation to the research questions. The data collected from the simulation model illustrates that the magnitude of lost sales increases with time delay. Even when the level of information delay is set to zero there are still some instances when the customer

orders are not completely filled, possibly as an effect of the less than ideal conditions of the ordering policies. During the instance when the level of information delay is set to one, as in the default game settings, there are some customer orders that go completely unfilled. This was observed as a function of retailer stock outs generated during the simulation run as shown in figure 1 using stepped customer demand.

It was found that not only do more orders get unfilled as the time delay is increased, but the concept of increases in lost revenue is more related to information delays rather than material delays, this finding presents a compelling argument for the investment of emerging technologies such RFID as a tool to increase the speed at which information flows throughout the supply chain, which will impact the manner in which stock levels are maintained at every echelon of a supply chain when all supply chain partners are aware of the long lead time in information flow. In investigating the importance of each level of time delays contribution to total lost sales, a cumulative losses graph was generated (Figure 2).
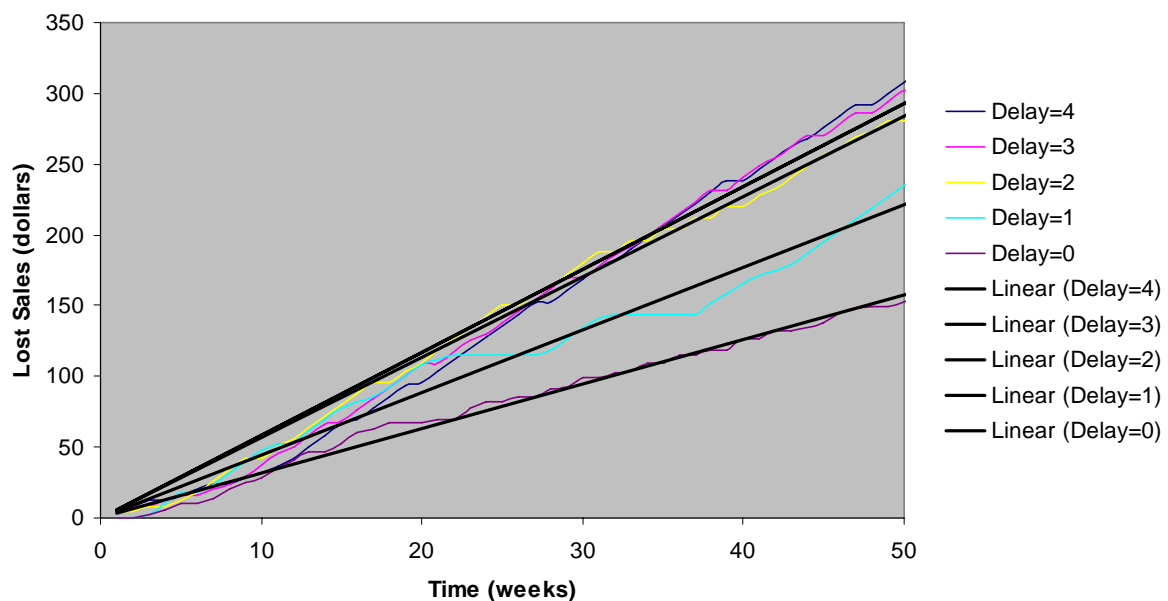
Cumulative Lost Sales for Each Time Delay

Figure 2: Level of information delay as a contribution to total lost sales revenue

As expected the cumulative values of the opportunity cost increase with level of delay. Of note, the slopes of the cumulative opportunity cost seem to be much greater once the delay is increased from the standard 1 week per delay. This relationship suggests that the value of information sharing between partners in a supply chain is equivalent to at least 16% of the opportunity cost (percentage difference between delay =2 and delay =1). In other words, opportunity cost by way of lost sales is a directly related to the level of information delay across a supply chain.

In other studies where the beer game was used to describe the behaviour of a supply chain, as well as in the initial design of the beer game, the focus was on viewing the dynamics of a supply chain and how easy disruptions may occur. The bullwhip effect literature often focuses on the inventory levels and upstream effects of changes in customer demand. Both views are can be considered important contributions to knowledge. This study contributes by extending the beer game simulation scenario to focus on how significantly the customer would be affected by information delays that occur downstream.

Another metric used in this study is the level of orders that are delivered in full by the retailer to the customer with both stepped demand and stochastic demand. As expected the levels of delivery performance decreased with increases in information delays. As shown in Figure 3 all customers experienced reduced levels of delivery-in-full performance from increases in information delay. Interestingly, it was the lower order size customers that suffered the highest decrease in delivery-in-full with increases in information delay.

More importantly, the results of this study indicate that the level of opportunity cost generated through lost sales is a very important variable in supply chain performance. It was noted that the customer demand remains constant, in real world supply chain terms this is seldom true presenting a scenario that could potentially lead to a much greater level of lost revenues for the retail end of any supply chain. These findings highlight the importance of embracing emerging technologies such as RFID as a means of enhancing information transference in an effort to increase

inventory visibility and reduce damaging information distortion both up and downstream towards the customer. While existing technology provides channels for information sharing and traceability (Bar-coding), such systems often operate in isolation from each other and remain dependent on accuracy of input. The potential of smart RFID is in reducing input accuracy through reduced scanning, in turn providing much needed responsiveness for downstream service providers, and ultimately providing a better service experience for the end user.
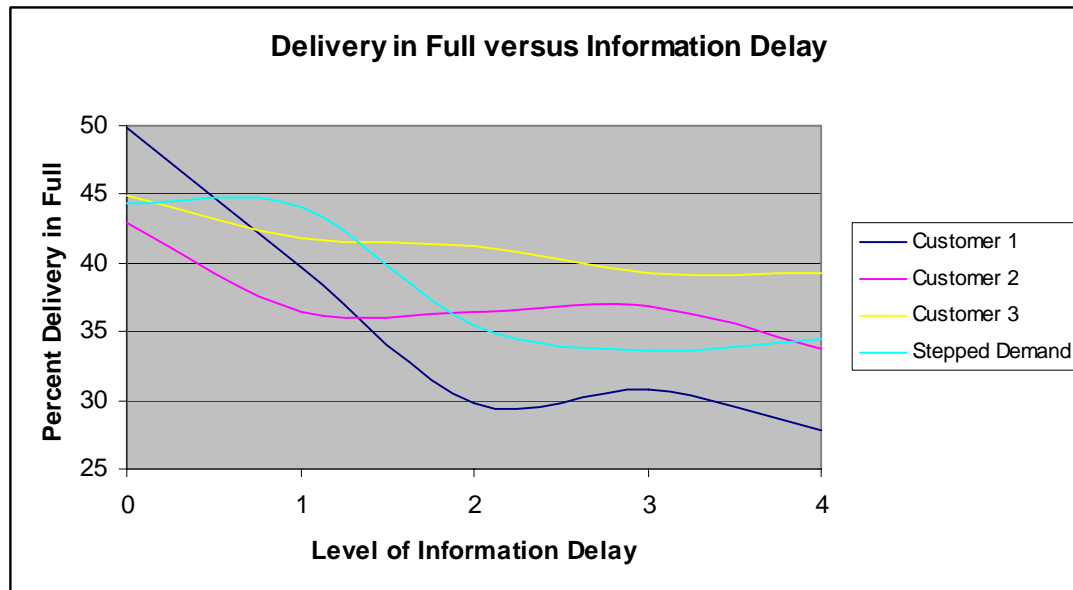

Figure 3: Delivery-in-full performance for all customers

This study highlights several key issues which support the implementation of RFID technology. Firstly, the unpredictability of end user customers and their potential erratic purchasing patterns presents challenges to supply chains which differ from standard B2B exchanges. RFID provides organisations the ability to be responsive to unpredictable demand. This is a necessary capability of supply chains who want to compete in customised mass markets. Secondly, while information sharing is identified as necessary, it is so in the context of delivering customer satisfaction, by avoiding stock-outs and responding to demand. After all, in an effort to reduce costs associated with inventory (efficiency), organisations are required to become more effective in their use of limited resources. In this instance RFID provides a mechanism for real time communication of information. Thirdly, this simulation presents downstream variability in the supply chain. While this presents ongoing challenges for supply chain professionals, it is realistic in it's portrayal of an ever-changing dynamic environment which exists within many supply chains. Competitive organisations are continuously reacting to change from both the customer and the market, RFID technology provides organisations the ability to react and be responsive to ongoing changing demands in the marketplace.

4.1   Limitations

Generally, a simulation is a simplification of an existing process generated to gain a better understanding of some features of the real world. In this case there are several limitations that should be highlighted. The simulation of the beer game was constructed using examples of different studies that have interpreted the results of the beer game in their own way. Therefore the validation of the resulting baseline model became very difficult. An educated assessment of the goodness-of-representation was conducted on the outputs as a method of validation.

It is recognised that customers often react to a less-than perfect order size delivered, however it was decided that customer reactions to partially filled or unfilled orders was outside the scope of this study. Future studies will explore customer reactions to inefficient supply chains and supply chain reactions to varying demand signals from the customer.

5   Conclusion

This study builds upon previous SCM literature by providing a different perspective on the costs associated with running an inefficient supply chain. The quantification of lost revenue due to incomplete or missing orders to end customers is a significant source of losses to the supply chain which is often overlooked. Using a computer simulation of the popular beer distribution game powered by popular ordering policies; the opportunity costs from the end customer quickly became a significant cost to the overall supply chain. In addition, the level of information delay to which the supply chain was operating under was increased and as the level of information delay increased so did

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the level of lost sales. Often supply chains pay more attention to the flow of materials than the flow of information, in this case material flow was held constant throughout the experiments, proving that costs associated with poor information flow are indeed very real. The requirement of improved visibility and speedier information flow throughout the supply chain is paramount in the reduction of these costs. In many cases, the use of technologies such as RFID to increase visibility throughout the supply chain presents an attractive solution to the problem.

5.1 Future Research

The quantity of literature on the beer game is extensive, leaving limited scope for further research using the beer game as a tool for supply chain simulation. However, the inherent flexibility of simulation can be used to highlight the levels of opportunity costs from lost sales in complex supply chains. By examining the levels of lost sales under different supply chain structures, researchers will gain a better idea of the level of importance of lost sales on total supply chain costs. Other supply chain 'what if' scenarios will be simulated from a lost sales perspective.

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