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The impact of cloud computing on supply chain performance
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The creation of this working paper series has been funded by an endowment established by William A. Orme, URI College of Business Administration, Class of 1949 and former head of the General Electric Foundation. This working paper series is intended to permit faculty members to obtain feedback on research activities before the research is submitted to academic and professional journals and professional associations for presentations.

An award is presented annually for the most outstanding paper submitted.
1. Introduction

Supply chains are becoming more complex (Khan and Creazza, 2009) which over time results in an increased need to coordinate and share information (Han et al., 2008). New research calls for fresh investigative efforts focusing on viable, cutting-edge information technology (IT) and IT’s impacts on communication in the supply chain, as well as problems associated with bullwhip effect. (Thomas et al., 2011).

Cloud computing, arguably one of the major advances in the history of computing (Marston et al., 2011), is a new information technology that offers more flexibility through the ability to access information from a variety of technologies (Rochwerger et al., 2010). Further, it allows users to scale services and service costs to accommodate their needs as well as their supply chain partners. Due to the benefits provided by cloud computing over electronic data interchange (EDI), we believe cloud computing technology has strong potential to improve information sharing and collaboration as well as to indirectly curtail bullwhip effect.

To fill the current cloud computing void in supply chain literature, we first provide professionals and researchers insight into how cloud computing outperforms other information technologies such as EDI in terms of dealing with information sharing and collaboration. Further we use multi-agent simulation to answer the research questions: (1) Does information sharing and collaboration (via cloud computing) alleviate the bullwhip effect? And (2) Does the resulting bullwhip effect reduction have an impact on supply chain performance?

To answer these research questions we use a multi-agent simulation. This type of simulation provides researchers the ability to capture complex structures, behaviors, communication and interactions of complex domains, including supply chain management (Sierhuis et al., 2012). After simulating a supply chain using three scenarios (e.g., base scenario without cloud computing, cloud computing with information sharing and cloud computing with both information sharing and collaboration) our simulation results show that inventory, backlogs and orders increase in the upstream levels of the supply chain when neither information sharing nor collaboration (via cloud computing) are present. Higher inventory, backlogs and orders lead to increased inventory and holding costs (Verma, 2006) which negatively impact supply chain performance (Huang et al.,
Inventory and backorder costs also decrease with greater information sharing and collaboration (via cloud computing). To further our research, we also duplicate our simulation using three sets of parameters, including a different number of agents in a four-tier supply chain. The results were the same despite changing the number of agents, thus providing validation of our results.

The main contributions of our research are four-fold. First, to the best of our knowledge, it is the first attempt to explore the impact of cloud computing on information sharing and collaboration in a supply chain context. Secondly, we endeavor to lay a foundation for future empirical research on the use of cloud computing in the supply chain management area. Third, we also increase supply chain management professionals’ awareness of SCM benefits associated with using cloud computing, including reduction of bullwhip effect, inventory and backorder costs. To increase awareness we provide background information of cloud computing and its competitive advantage in information sharing and collaboration which reduces demand uncertainty resulting in a significant reduction in bullwhip effect, inventory and backorder cost (Lee et al., 1997a; Yigitbasioglu, 2010). Finally, we provide a viable simulation tool for both SCM researchers and practitioners to evaluate information sharing and collaboration’s (via cloud computing) impact on SCM.

2. Model and theory
Drawing upon a combination of transaction cost economics, principal-agent theory and social capital theory, we develop our research framework as depicted in figure 1.

Transaction cost economics posits that transactions determine what constitutes efficient governance structures (Williamson, 1983). As seen from Table 1, cloud computing offers various benefits over traditional information technologies including the use of EDI, in its reduction of transaction costs between supply chain partners. These cost savings will be further elaborated on in the next section. While the cost saving implications provided by cloud computing do not necessarily perpetuate greater relationships between supply chain partners, it does have the potential to reduce the costly barrier often involved in information sharing and collaboration.
Principal-agent theory is concerned with the agency problem which results in imperfect goal alignment and information asymmetry, raising agency risk (Eisenhardt, 1989). Often organizations will turn to costly control mechanisms to avert opportunistic behavior (Handley and Benton, Jr., 2012; Hill, 1990; Parkhe, 1993). The main benefit that cloud computing has over other information technologies including EDI is its ability to be massively scalable in service and service cost. This flexibility in service and cost positively influence the relationship between supply chain partners, especially if the user accommodates the needs of not only themselves but their partner. This impact on relationship will reduce the opportunistic behavior resulting from principal-agent problems, ultimately building trust and relational capital. Previous research mirrors this by showing that greater relational capital can influence more information sharing (Krause et al., 2007) thereby reducing other problems associated with information asymmetry.

Social network theory posits that a social network not only consists of the individual actors, but also the relationships between these actors (Ibarra, 1995). Weak ties with distant contacts can facilitate information and resource exchange (Evans and Davis, 2005). Weak ties also facilitate the search for information using resources and innovation between groups (Hansen, 1999). While ties between supply chain partners can be facilitated by both EDI and cloud computing based technology, cloud computing promotes and environment of collaboration and information sharing at a higher level than EDI as evidenced by its various benefits presented in table 1. Supply chain partners then can use cloud computing to enhance information sharing and collaboration between entities, which in turn diminish the bullwhip effect and ultimately reduces inventory and backorder costs (Lee et al., 1997a,b).

Based on the combination of transaction cost economics, principal-agent theory and social network theory, we have formulated the research framework depicted in Figure 1, which will later be analyzed using agent-based simulation.

3. Literature review
Bullwhip effect is a phenomenon whereby demand order variability has oscillating demand amplification as it moves up in the supply chain (Lee et al., 1997a). Sterman (1989) was one of the first to report evidence of the bullwhip effect using the “beer distribution game”. We use the beer distribution game as a prototype to observe how the reduction of the bullwhip effect impacts costs in the supply chain.

Various studies have identified the benefits and problems associated with bullwhip effect on supply chain performance (e.g. Swaminathan and Tayur, 2003; Lee et al., 1997a,b; Chen et al., 2000). Studies suggest reducing the bullwhip effect allows companies to not only benefit from total cost reduction, but also increases service to customers, thereby improving overall supply chain performance (Leeuw and Fransoo, 2009; Emerson et al., 2009; Ouyang, 2007).

Reduction of the bullwhip effect reduces order variance, which allows every tier in the supply chain to carry less safety stock, thus reducing inventory cost (Li et al., 2006). In this simulation we will focus on the dynamics of the reduction of the bullwhip effect and its ultimate impact on inventory and backorder costs in a four-tier supply chain. Moreover, recent literature calls for an understanding of underlying information distortion behind the bullwhip effect (Niranjan et al., 2011). Thus, we also wish to provide further examination on how bullwhip effect can be mitigated by information sharing and collaboration.

3.1. Information Sharing and Collaboration on Bullwhip Effect

Overall, previous research indicates that information sharing and collaboration are key parts of a solid supply chain relationship (Li et al., 2005; Lalonde and Masters, 1994). Information sharing in the supply chain is defined as the extent to which critical information is communicated to one’s supply chain partner (Li et al., 2005). The integration provided by information sharing leads to operational performance, including, process efficiency and logistics service performance (Flynn et al., 2010; Saeed et al., 2005; Germain and Iyer, 2006; Stank et al., 2001a,b), ultimately helping eliminate the core causes of bullwhip effect. Collaboration on the other hand is the ability to simultaneously establish links with
other partners in the supply chain through joint conflict resolution and forging effective partnerships to reach benefitting relationships for both parties (Parmigiani, Klassen and Russo, 2011). Collaboration is thus a higher form of information sharing as it requires an element of trust (Ashleigh and Nandhakumar, 2007). The consistent exchange of two-way communication between supply chain partners ultimately reduces information asymmetry, thereby decreasing the chances for order variability (Lee et al., 1997a,b). The use of collaboration can also help facilitate forecasting accuracy, through consistent two way communication with a foundation of trust and common incentives. When supply chain partners consistently share information with one another, information flows freely reducing problems associated with lack of communication about shortages and trends. This leads to substantial improvement in increased responsiveness, product availability and ultimately increased revenues and earnings (McCarthy and Golicic, 2002).

The increased information flow and collaboration reduces order amplification along the supply chain thus reducing the bullwhip effect. We will further examine this in our simulation model.

3.2. Cloud Computing on Information Sharing and Collaboration

While current and previous literature examines the positive impact of the use of traditional information technologies, including EDI, in a supply chain context (e.g. Cantor and Macdonald, 2009; Machuca and Barajas, 2004; Lee et al., 1997a,b), there are new and emerging information technologies that have the potential to surpass EDI in both economic and social benefits. Cloud computing is one such state-of-the-art information technology that offers on-demand, pay-as-you-go, massivley scalable services where companies share different information with one another at any time or any place (Calheiros et al., 2011; Buyya et al., 2009; Rochwerger et al., 2009).

Tables 1 and 2 depict the benefits and risks associated with the use of EDI and cloud computing technology in facilitating collaboration and information sharing. There are several similarities in the benefits associated with both information technologies. For example, cloud
computing infrastructures notable benefit is its ability analyze terabytes of data in a period of minutes rather than hours (Marston et al., 2011; Benlian and Hess, 2011). Also cloud computing users can quickly request more computing resources with minimal service provider interaction (Marston et al., 2011; Benlian and Hess, 2011; Iyer and Henderson, 2010). While this may positively impact information flow, web-based EDI promotes similar benefits to on-demand information via the internet.

<table>
<thead>
<tr>
<th>Table 1. Benefits and Risks of Cloud Computing</th>
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<tbody>
<tr>
<td>Benefits</td>
</tr>
<tr>
<td><strong>Flexibility/Convenience</strong></td>
</tr>
<tr>
<td>Ability to choose between owned infrastructure of rented from third party vendor</td>
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<tr>
<td>Large amount of computing power in short amount of time (analyzing terabytes of data in a period of minutes)</td>
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<tr>
<td>Ability to request more computing resource in minutes with minimal service provider interaction</td>
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<tr>
<td>IT services in countries that would traditionally lack resources for deployment of IT service</td>
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<tr>
<td>Adaptive structure shared by different end users in different ways with different mediums</td>
</tr>
<tr>
<td>Offers mobile interactivity</td>
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<tr>
<td>Massively scalable services (SaaS, PaaS, IaaS)</td>
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<tr>
<td>Ability to choose between public, private or hybrid</td>
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<tr>
<td>On demand access to information</td>
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<tr>
<td>Reduced maintenance, upgrades and development with vendor (focus on core competencies)</td>
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<tr>
<td>Offers green practices</td>
</tr>
<tr>
<td>Benefits</td>
</tr>
<tr>
<td>--------------------------------------------------</td>
</tr>
<tr>
<td><strong>Cost</strong></td>
</tr>
<tr>
<td>Energy, infrastructure and maintenance cost</td>
</tr>
<tr>
<td>savings</td>
</tr>
<tr>
<td>No upfront capital investments with immediate</td>
</tr>
<tr>
<td>access to hardware resources</td>
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<tr>
<td>Low cost for switching service providers</td>
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<tr>
<td><strong>Risks</strong></td>
</tr>
<tr>
<td>Current</td>
</tr>
<tr>
<td>Reliability</td>
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<tr>
<td>Stability</td>
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<td>Security</td>
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<tr>
<td>Expected</td>
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<tr>
<td>Higher than expected cost arising from changing</td>
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<td>future requirements</td>
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**Table 2. Benefits and Risks of EDI**

<table>
<thead>
<tr>
<th>Benefits</th>
<th>Literature</th>
</tr>
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<tbody>
<tr>
<td><strong>Performance</strong></td>
<td></td>
</tr>
<tr>
<td>Business/Supply chain performance</td>
<td>Cantor &amp; Macdonald (2009); Rosenzweig &amp; Roth (2007); Sanders (2007); Zhu &amp;</td>
</tr>
<tr>
<td></td>
<td>Kraemer (2005); Lee el el. (1997a,b)</td>
</tr>
<tr>
<td><strong>Cost</strong></td>
<td></td>
</tr>
<tr>
<td>Cost reduction (transaction, paper, managerial)</td>
<td>Prahinski &amp; Benton (2004); Srinivasan et al. (1994); Handfield (1993);</td>
</tr>
<tr>
<td></td>
<td>Boyer &amp; Pagell (2000); Choudhury et al. (1998); Johnson et al. (2007);</td>
</tr>
<tr>
<td></td>
<td>Massetti &amp; Zmud (1996); Carter &amp; Frendall (1990); Olson &amp; Boyer (2003);</td>
</tr>
<tr>
<td></td>
<td>Klein (2007); Lee et al. (1997); Cantor &amp; Macdonald (2009)</td>
</tr>
<tr>
<td><strong>Flexibility/Convenience</strong></td>
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9
<table>
<thead>
<tr>
<th>Benefits</th>
<th>Literature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Faster information delivery</td>
<td>Hill &amp; Scudder (2002); Sheombar (1992); Jayaram &amp; Vickery (1998); Narasimhan &amp; Carter (1998); Boyer &amp; Pagell. (2000); Sanders (2008); Ragatz et al. (1997); Gunasekaran &amp; Ngai (2005)</td>
</tr>
<tr>
<td>Frequency of information flow</td>
<td>Hill &amp; Scudder (2002); Sheombar (1992); Jayaram &amp; Vickery (1998); Narasimhan &amp; Carter (1998); Rosenzweig et al. (2003)</td>
</tr>
<tr>
<td>Risks</td>
<td>Literature</td>
</tr>
<tr>
<td>Reliability</td>
<td>Sanders (2007); Chopra et al. (2001); Menor et al. (2002); Katsaros (1994); Hornback (1994); Lockstrom et al. (2010)</td>
</tr>
<tr>
<td>Security</td>
<td>Sanders (2007); Chopra et al. (2001); Menor et al. (2002); Katsaros (1994); Hornback (1994)</td>
</tr>
<tr>
<td>Incompatibility</td>
<td>Frohlich &amp; Westbrook (2001)</td>
</tr>
<tr>
<td>Costly</td>
<td>Narasimhan &amp; Das (2001)</td>
</tr>
<tr>
<td>Non-internet enabled EDI is difficult to implement</td>
<td>Boyer &amp; Olson (2002); Zhu et al. (2006)</td>
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</tbody>
</table>

**Table 2. Benefits and Risks of EDI**

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<thead>
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</tr>
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</tr>
<tr>
<td><strong>Flexibility/Convenience</strong></td>
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</table>
Faster information delivery

Frequency of information flow
Hill & Scudder (2002); Sheombar (1992); Jayaram & Vickery (1998); Narasimhan & Carter (1998); Rosenzweig et al. (2003)

Ease of information flow

Risks
Reliability
Sanders (2007); Chopra et al. (2001); Menor et al. (2002); Katsaros (1994); Hornback (1994); Lockstrom et al. (2010)

Security
Sanders (2007); Chopra et al. (2001); Menor et al. (2002); Katsaros (1994); Hornback (1994)

Incompatibility
Frohlich & Westbrook (2001)

Costly
Narasimhan & Das (2001)

Non-internet enabled EDI is difficult to implement
Boyer & Olson (2002); Zhu et al. (2006)

Perhaps one of the notable differences between EDI and cloud computing is the flexibility that cloud computing offers in terms of service and cost. First, unlike EDI, cloud computing offers mobile interactivity and an adaptive structure that is shared by a variety of end users with different mediums (Marston et al., 2011; Benlian and Hess, 2011; Iyer and Henderson, 2010). Whereas EDI allows for the exchange of information that is standardized and requires common platforms on either end (Frohlich and Westbrook, 2001; Monczka et al. 2011, p. 709), cloud computing allows users to choose from a variety of massively scalable services including software as a service (SaaS), infrastructure as a service (IaaS), and platform as a service (PaaS) (Mantena et al., 2012). Moreover, cloud computing users can also choose from a gamut of service cost
options including flat, pay per use and a two tier flat and pay per use system. These flexibility options in both services and cost allow users the option to choose for the benefit of not only themselves but also for their supply chain partners.

Another difference between cloud computing and EDI is cost savings. While previous research suggests EDI has substantial cost savings over traditional methods including paper transaction and telecommunications, cost savings specifically in energy infrastructure and maintenance are significantly higher in cloud computing technology (Marston et al., 2011). Moreover, there is a lower cost in terms of upfront capital investments as well as switching costs for service providers (Iyer and Henderson, 2011). These cost savings and immediate access to hardware can translate into more resources going into exchanging more accurate information on a timely basis. These resources that were once tied into maintaining a data center can be allocated to more knowledge resources that can improve the accuracy and frequency of communication flow.

As mentioned previously, collaboration, in comparison with one-way information sharing, requires both alignment of incentives and a foundation of trust (Hendricks and Singhal, 2007). Often it is difficult to achieve the level of trust and alignment of incentives necessary for adequate collaboration. Unfortunately without trust or alignment of incentives, the use of any information technology despite its advantages maybe futile. Cloud computing provides a unique opportunity for greater information flow which has been shown to impact greater relationships between supply chain partners but also uniquely aligns specific incentives as well as provides a unique way of ensuring trust among supply chain partners. Although security is a concern for both EDI (Sanders, 2007) and cloud computing (Marston et al., 2011; Benlian and Hess, 2011), cloud computing offers the option to choose between a public, private or hybrid cloud computing. Users are given the option to choose based on not only their security needs but the security needs of their partners fostering a richer relationship between the two as well as open communication. Additionally, cloud computing offers the ability to verify history of information sharing via online documentation (Iyer and Henderson, 2010). This can also enhance users and supply chain partners knowledge on past information sharing and verification of the dependability of the supply
chain partner. Ultimately, the richer relationships built from trust and alignment of incentives can promote greater collaboration among supply chain partners.

4. Methodology

Simulation models are used when certain characteristics of the supply chain cannot easily be modeled with analytical tools such as regression, queuing and optimization, or when stochastic variables are present (Riddalls et al., 2000). Using multi-agent simulation, we simulate the effect of collaboration and information sharing (via cloud computing) on a four-tier supply chain. This follows the beer distribution game, developed by the System Dynamics Group at the Massachusetts Institute of Technology in the 1960s (Sterman, 1984).

Agent-based is an approach to understanding complex adaptive systems (Tesfatsion, 2003). Shalizi (2006) defines an agent as a persistent and relevant entity which interacts with other agents in a mutually modifying context. An agent-based model is a collection of agents, their states, the rules governing interaction and the environment in which they live (Shalizi, 2006). In agent-based simulation low level entities with relatively simple attributes and behaviors can collectively generate a complex and realistic system of behaviors. A multi-agent system (MAS) is composed of multiple interacting agents, which can be used to solve problems that are difficult for an individual agent (Yoav et al., 2008).

We identify different agents in the supply chain and provide each agent with an ability to utilize a subset of an internal mechanism. The internal mechanism helps in decision making at the agent level by utilizing basic rules or polices (e.g., inventory polices, shipping rules and replenishment algorithms) for demand, supply, information and material control within the supply chain. Furthermore, we apply discrete event simulation to represent individual events and incorporate uncertainties in this paper. With discrete event simulation, a supply chain system is modeled by defining the events that occur, processing in a chronological order, and describing the logic. Thus, all of the actions in a supply chain system, such as inventory queuing and manufacturing are addressed (Kleijnen et al., 2003).
5. Simulation implementation

5.1 Model description and base assumptions

The beer distribution game is a commonly used and effective tool to simulate the bullwhip effect in a supply chain (Jacobs, 2000). A frequently accepted beer distribution game supply chain design borrowed from Sterman (1984) consists of four agents: retailers, wholesalers, distributors and factories. In order to effectively simulate the impact of information sharing and collaboration on the bullwhip effect we use this four-tier supply chain design. Moreover we use the Any Logic\(^1\) simulation tool, to adjust the initial parameters such as initial inventory, replenishment rules and storage or backlog cost.

5.1.1. Uncertainty in supply chain

Previous supply chain literature has often ignored uncertainty in order processing, production and transportation time (Viswanathan et al., 2006). In our simulation model we consider all three factors, which are highly related to both information sharing and collaboration.

Uncertainties are usually reported as stochastic processes using probability distributions. The triangular distribution is useful in representing these approximate qualifiers, due to their conceptual and computational simplicity. Generally, when only a small amount of the distribution of an outcome is known, for example the smallest and largest values, it is possible to use the uniform distribution. However, if the most likely outcome is known, then the distribution is best simulated by a triangular distribution (Johnson, 1997).

\(^1\) AnyLogic (http://www.xjtek.com) is a multi-method simulation modeling tool developed by XJ Technologies.
5.1.2. Agents

Using the beer distribution game as a prototype for our agent-based supply chain model, we setup four groups of agents: retailers, wholesalers, distributors and factories. Each agent makes dependent inventory decisions without any information from other members in the supply chain.

5.1.2.1. Retailer

Demand begins at the consumer level. Demand at the consumer level is satisfied if the inventory level \( I \) at the retailer level is as large as or greater than the demand. If the demand exceeds the inventory level, the customer takes the currently available items, and the excess of demand over supply is backlogged and decreased by future deliveries from the wholesaler.

A retailer reviews its inventory level and decides how many items to order from the wholesaler. An \((S, s)\) inventory policy was imported as the retailer's decision rule (Arrow et al., 1951). To pursue an \((S, s)\) inventory policy, the retailer establishes a lower stock point \( s \) and an upper stock point \( S \). No order is placed until inventories fall to \( s \) or below, whereupon they are restored to the maximum of \( S \). The retailer \( i \) calculates its inventory backlog \( IB_i \) as formula 1:

\[
IB_i = (I_i + S_i - B_i)
\]  

Where \( S_i \) denotes the expected shipments of retailer, \( i \), and \( B_i \) represents the backlogged orders. The retailer will send an order message to wholesaler if \( I_i < s \). When a shipment arrives from the wholesaler, we assume for simplicity that it is used immediately to satisfy any backlogged customers.
5.1.2.2. Wholesaler

When a wholesaler receives an order from the retailer, it ships products following a first in, first out (FIFO) method, if it has enough inventory. In this simulation, partial orders are not shipped. We refer to processing time and shipping time as uncertainty and further assume they follow triangular distributions.

The new inventory level at the wholesaler $j$ is calculated as:

$$I_{j,t+1} = I_{j,t} - S_t$$  \hspace{1cm} (2)

Where $I_{j,t+1}$ denotes new inventory level of wholesaler $j$, $I_{j,t}$ represents the previous inventory level, and $S_t$ is the unit number of shipped products.

Any order that is not shipped is counted into backlog. After any orders are shipped to the retailer, the wholesaler reviews its current inventory level and decides how many items to order from the distributor. Similar to the retailer level, a stationary policy $(S, s)$ is used to help the wholesaler decide how much to order. When a shipment arrives from the distributor, the items in the shipment are added to the wholesaler's inventory.

5.1.2.3. Distributor

When the distributor receives a message from the wholesaler, it will also follow a FIFO method of shipping, if there is enough inventory. We assume that the processing time and shipping time follows a triangular distribution. The new inventory level is calculated and any order that is not shipped is backlogged.
After the orders are shipped to the wholesaler, the distributor reviews its current inventory level and decides how many items to order from the factory. Similar to the wholesaler, a stationary policy \((S, s)\) is used to help the distributor decide how much to order.

5.1.2.4. Factory

The factory uses a FIFO method to ship orders. The processing and lead time distributions are the same as the wholesalers’ and distributors’.

After orders are shipped to the distributor, the factory reviews its current inventory level and decides how many items to manufacture. In this simulation we assume that raw materials are always available. The time required to manufacture \(T\) is given as:

\[
T = e + k \times M
\]  

(3)

Where \(e\) is the time to setup the manufacturing line, \(k\) is the time to manufacture each item and \(M\) is the number of products. When a batch of items has been manufactured, the items are added to the factory's inventory.

5.1.3. Internal mechanism

Internal mechanism is defined as the process used to facilitate production and transportation of products within the supply chain. Design of an appropriate internal mechanism is the objective of problems related to supply chain contracts and supply chain coordination (Swaminathan et al., 1998). To simulate the essence of agents in a four-tier supply chain, we design two internal mechanisms for each agent in this model: order processing and routing control (Min and Zhou, 2002; Lancioni et al., 2000). The first mechanism reflects the operation process inside each agent, and the latter decides the communication among agents.
5.1.3.1. Order processing

Each agent in our model has a workflow of its own (see Figure 2).
Figure 2. Agent workflow

At the beginning of a time cycle, each agent checks the order waiting list, tries to satisfy the last backorder first, and then considers replenishment of new orders based on inventory level. If inventory is lower than the safety stock level, it will send an order message to the upstream agent (see Figure 3).

The upstream agents will then receive the order information and process that order at the beginning of its next time cycle. Based on this there are two kinds of delays we simulate: shipment delay (time required to ship the item), and information delay (time to send, receive and process information). Delivery cost will be aggregated after every shipment event happens. Delivery cost \( D \) is calculated by (4):

\[
D_{t+1} = D_t + S_f + S_v \times N
\]

(4)

Where \( D_{t+1} \) and \( D_t \) denotes the current and previous delivery costs respectively, \( S_f \) is the fixed cost for each shipment, \( S_v \) is the shipping cost per unit and \( N \) is the delivery size.
5.1.4 Performance measures

In this study we consider system level quantitative performance measures which include inventory cost and backorder cost. We also consider the cost of cloud computing usage. Inventory cost is calculated as:

\[ IC_{t+1} = IC_t + S_{t+1} \times VC_I \] (5)

Where \( IC_{t+1} \) and \( IC_t \) denote the current and previous inventory costs, respectively, \( S_{t+1} \) represent the product number in stock at \( t+1 \), and \( VC_I \) is the stock cost per unit per day.

Backorder costs are calculated as:

\[ BC_{t+1} = BC_t + B_{t+1} \times VC_B \] (6)

Where \( BC_{t+1} \) and \( BC_t \) denote the current and previous backorder costs, respectively, \( B_{t+1} \) represents the product number in backorder at \( t+1 \), and \( VC_B \) is the backorder cost per unit per day. In this study we calculated a common form of service cost for cloud computing service (i.e. two-tier pay as you go and flat fee service). Cloud computing cost is calculated as:

\[ CC_t = a + b \times Z \] (7)

Where \( a \) is a constant that denotes the set up cost of cloud computing, \( b \) is the service cost per day and \( Z \) is the total days of use.

5.2. Scenarios design and simulation results

5.2.1. Base scenario: No cloud computing
In the base scenario, we assume that there is no cloud computing used to facilitate information sharing and collaboration. Without cloud computing’s ability to quickly process large amount of data process time is slowed. When an order is sent by a downstream agent, the information will take some time to get to its destination, and the upstream agent will not begin to process the order until the next working day.

5.2.2. Cloud computing scenario I: Full information sharing

In the second scenario, we assume all of the agents can gain access to real time information from cloud computing. Compared to the base scenario, there is no information delay in this scenario. Furthermore, compared to one-way communication, in the base scenario, the information flow with cloud computing is considered to be two-way communication between supply chain partners. For example, retailers will be able to send their demand information to wholesalers and in return wholesalers can respond with inventory information to the retailers.

5.2.3. Cloud computing scenario II: full information sharing and full collaboration

In the third scenario, we take collaboration into consideration, where each agent has full access to real-time information. Collaboration is different from simple information sharing, because it involves all supply chain partners interacting and working toward the same goal in mind (Angerhofer and Angelides, 2000). Collaboration in this model represents full disclosure of information. An element of trust is also vital for facilitating cohesive collaboration (Ashleigh and Nandhakumar, 2007). In scenario II, partners share operations data and make forecasting, promotion plan, maintenance schedule decisions based on demand and inventory information shared collectively. Since disclosure of information and trust between supply chain partners has been tied to greater accuracy of demand (Akkermans et al., 2004), in this scenario, the downstream and upstream members have greater demand forecast accuracy.

6. Simulation results: a numerical example
As shown in Table 1, there are fifteen basic parameters defined by us before running the model. We designed our parameters based on a typical supply chain, where the number of retailers exceeds wholesalers, the number of wholesalers exceeds distributors and the number of distributors exceeds suppliers. We also set up three different sets of numbers of agents in order to examine inter-group stability.

We evaluate the performance of the entire supply chain by performance measures after the system fulfills 10,000 products for the customers. Customers randomly choose a retailer and we assume a triangular distribution (2, 10, 5) to describe the customer demand. This distribution is chosen, because it is representative of a typical four-tier supply chain customer demand. To simplify the model and focus on efficiency comparison among scenarios, we assume all the agents use the same (S, s) policy, or (80, 20). All of the other parameters are assumed to be fixed.

<table>
<thead>
<tr>
<th>Simulation repeat times</th>
<th>Retailer</th>
<th>Wholesaler</th>
<th>Distributor</th>
<th>Factory</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of Agents (1)</td>
<td>20</td>
<td>10</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Number of Agents (2)</td>
<td>30</td>
<td>10</td>
<td>7</td>
<td>3</td>
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<tr>
<td>Number of Agents (3)</td>
<td>10</td>
<td>5</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 3. Parameters configuration
Under each scenario, the inventory level and order information are recorded for each respective agent. The inventory, backorder and cloud computing costs are also updated in real-time. The simulation will stop when the retailers have sold 10,000 products to make the performance measures comparable.

As shown in Figure 4, both inventory and backlog increase from downstream to upstream in the supply chain. The bullwhip effect occurs when information sharing and collaboration are not present.
The resulting bullwhip effect causes a considerable increase in inventory and backorder costs. In scenario I, where cloud computing is used to initiate full information sharing, cloud computing cost increases to $579.42, yet inventory and backorder costs significantly decrease with a resulting total cost of $20,666.01. In scenario II cloud computing usage cost increases to $784.52. However, inventory and backorder costs reduce to a total of $15,895.29, resulting in a savings of $18,286.68. Both scenarios I and II reduced total costs by 65% and 105%, consecutively in comparison with the base scenario.

After conducting the same simulation with a four-tier supply chain using three different sets of parameters, the results show the same pattern.

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Information sharing configuration (information delay distribution)</th>
<th>Collaboration configuration (shipment delay distribution)</th>
<th>Performance measure item</th>
<th>Mean1</th>
<th>Standard Deviation 1</th>
<th>Mean2</th>
<th>Standard Deviation2</th>
<th>Mean3</th>
<th>Standard Deviation3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base scenario</td>
<td>Triangular [0.5, 2, 1]</td>
<td>Triangular [0.5, 2, 1]</td>
<td>Inventory cost</td>
<td>$24,734.71</td>
<td>$6,415.37</td>
<td>$23,916.17</td>
<td>$6,328.47</td>
<td>$26,193.21</td>
<td>$6,648.54</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Backorder cost</td>
<td>$9,547.26</td>
<td>$2,049.49</td>
<td>$9,846.15</td>
<td>$1,914.86</td>
<td>$10,148.36</td>
<td>$2,021.53</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cloud computing cost</td>
<td>$0.00</td>
<td>$0.00</td>
<td>$0.00</td>
<td>$0.00</td>
<td>$0.00</td>
<td>$0.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Sum</td>
<td>$34,281.97</td>
<td>$33,762.32</td>
<td>$36,341.57</td>
<td>$36,341.57</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cloud computing scenario I</td>
<td>0</td>
<td>Triangular [0.5, 2, 1]</td>
<td>Inventory cost</td>
<td>$14,347.45</td>
<td>$1,618.49</td>
<td>$12,756.39</td>
<td>$1,347.85</td>
<td>$16,742.19</td>
<td>$1,662.01</td>
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<tr>
<td></td>
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<td>Backorder cost</td>
<td>$5,739.14</td>
<td>$984.12</td>
<td>$6,334.58</td>
<td>$1,006.61</td>
<td>$7,016.27</td>
<td>$994.82</td>
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<td>Cloud computing cost</td>
<td>$579.42</td>
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<td>$410.33</td>
<td>$36.47</td>
<td>$896.17</td>
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<td></td>
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<td></td>
<td>Sum</td>
<td>$20,666.01</td>
<td>$19,501.30</td>
<td>$24,654.63</td>
<td>$24,654.63</td>
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<td></td>
</tr>
<tr>
<td>Cloud computing scenario II</td>
<td>0</td>
<td>Triangular [0.2, 0.5, 0.3]</td>
<td>Inventory cost</td>
<td>$12,078.50</td>
<td>$1,014.82</td>
<td>$10,149.52</td>
<td>$985.17</td>
<td>$13,186.32</td>
<td>$1,151.27</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Backorder cost</td>
<td>$3,816.79</td>
<td>$678.24</td>
<td>$3,418.94</td>
<td>$628.64</td>
<td>$4,011.25</td>
<td>$704.50</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Cloud computing cost</td>
<td>$784.52</td>
<td>$38.46</td>
<td>$536.71</td>
<td>$30.43</td>
<td>$1,017.32</td>
<td>$74.31</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Sum</td>
<td>$16,679.81</td>
<td>$14,105.17</td>
<td>$18,214.89</td>
<td>$18,214.89</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
7. Discussion and Conclusion

Despite the array of benefits provided by cloud computing in information sharing and collaboration, very little research has assessed the impact of cloud computing on information sharing and collaboration in the supply chain management area.

In order to fill this gap in literature and provide SCM professionals a viable tool to optimize supply chain performance, we used a multi-agent simulation to simulate a more realistic view of information sharing and collaboration (via cloud computing) and their impact on bullwhip effect.
effect and supply chain performance in a four-tier supply chain. Overall, our results reveal cloud computing has the potential to increase collaboration and information sharing (at a higher level than traditional EDI methods) thereby reducing the bullwhip effect and enhancing supply chain performance. Further, we have duplicated our simulation results using three sets of parameters reflecting a four-tier supply chain with different numbers of agents in order to validate our results.

While this simulation provides a foundation for future research in cloud computing, it is not without certain limitations that should be further discussed. First, in order to simplify the simulation, there were three specific assumptions that were made: (1) Cloud computing impacts information sharing and collaboration (2) The market was stable, and there was no price volatility taken into account in our simulation. (3) We assumed a triangular distribution in customer demand, and the same replenishment policy was used for each agent. And (4) we assumed no information delay and a small mean triangular distribution for shipment delay. Although the first assumption has yet to be empirically validated, we feel given its similarities and benefits over EDI, that it is likely cloud computing will impact information sharing and collaboration assuming all other variables are controlled. Future research should examine this further empirically and look into different moderator or mediating variables. Further, while these assumptions were made and may present bias, simplification was unavoidable. Estimates remained conservative and were based on a typical four-tier supply chain.
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