MITIGATING THE BULLWHIP EFFECT IN THE SUPPLY CHAIN OF SEMICONDUCTOR ASSEMBLY AND TESTING THROUGH AN INTER-BUSINESS INFORMATION PLATFORM

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ABSTRACT

This paper presents a web-based inter-business information platform developed by one of the world's largest providers of semiconductor assembly and test services (denoted as A-KH) to facilitate information sharing with its suppliers. This system, called E-Hub, is among the first in semiconductor industry to seamlessly integrate supply chain members into a collaborative framework, in order to mitigate the bullwhip effect. Through E-Hub, A-KH shares demand forecasts, generated on the basis of master production schedules and material requirements planning, with its suppliers. Suppliers provide order status and shipping notices to A-KH to allow tracking of orders and goods. Furthermore, inventory levels at the suppliers are available to A-KH via E-Hub, enabling effective management of inventory and advanced preparation for supply disruptions. Based on the empirical analysis of data collected from E-Hub, we show that order variability in the supply chain can be significantly reduced after deploying E-Hub, and the amount of reduction is consistent with an analytical derivation proposed in literature. The contribution of this paper is to demonstrate that information sharing through the hub indeed alleviates the bullwhip effect in the supply chain of semiconductor assembly and testing.

Keywords: Information sharing; Bullwhip effect; Electronic business management; Supply chain management.

1. INTRODUCTION

The bullwhip effect has been observed in supply chains of different industries, and studied by many researchers [6, 7, 8, 9, 12, 13, 14]. Because of uncertain and unstable customer demands, production and inventory decisions in a supply chain are typically based on (statistical) forecasts that are seldom accurate. Since forecast errors are inevitable, firms often carry safety stocks to prevent a stock-out situation. Moving up the supply chain, from end-customers to raw material suppliers, each stage is subjected to greater order variations and hence keeps more safety stock. This phenomenon, in which demand/order variations are amplified as one moves upstream in the supply chain, is known as the bullwhip effect. Because forecast errors that lead to the bullwhip effect result mainly from the distortion of information within the supply chain, information sharing has been considered as one of the most effective ways of mitigating the bullwhip effect [1, 2, 4]. Lee [11] indicated that the bullwhip effect can be tamed by collaboration within the supply chain, using advanced information systems.

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Semiconductor firms (e.g., IC manufacturing, assembly and testing firms) are located at the upstream end of the supply chain for electronic goods (e.g., cameras, cell phones, and computers), so they are generally subjected to greater variations in demand than those seen by manufacturers of electronic products at the downstream. As a result, any change in market demand has a severe impact (e.g., huge inventory write-offs, excessive capacities, price cuts, undesirable layoffs and bankruptcies) on semiconductor firms. For example, due to the 30-percent reduction in demand, the electronics market debacle in 2001 greatly affected the semiconductor industry. More recently, because of the financial crisis in the second half of 2008, the global economy suffered a serious downturn that induced significant order volatility and amplified inventory variations in the Semiconductor supply chain. These impacts arose mainly from the drastic decline in global market demand for electronics.

Recognizing that information distortion that leads to the bullwhip effect can be remedied by sharing information with supply chain members, a few firms in the semiconductor industry have developed inter-business information systems that aim to integrate supply chain partners within a collaborative framework to enable planning, forecasting and replenishment. Hwang et al. [8] presented the e-supply chain integration between Taiwan Semiconductor Manufacturing Company (TSMC) and Advanced Semiconductor Engineering Inc. (ASE). The two companies used business-to-business (or B2B) information exchange techniques to improve the efficiency and effectiveness of their worldwide business activities. de Kok et al.[10] reported that, to alleviate the bullwhip effect, Philips Semiconductor synchronized its supply chain via an advanced planning and scheduling system that supports weekly collaborative planning of operations by Philips Semiconductors and one of its customers, Philips Optical Storage. The project brought a substantial saving of around $5 million on a $300 million yearly turnover. Although these projects demonstrate the benefits of developing advanced information systems to tame the bullwhip effect, these systems are often particular to a supplier or customer, apply closed frameworks that are not easy to maintain and may not be flexible enough to allow future expansion and upgrades. Recent advances in Internet technology have made possible the development of web-based, inter-enterprise management information systems for the management of global logistics and supply chains. For instance, Chen et al., [5] presented an example of electronic marketplace based on Formosa Technologies Marketplace. Trappey et al.[19] developed an integrated business and logistics hub (IBLH) for global logistics management in the automotive industry. Trappey et al. [18] reported the process of deriving reference models of industrial logistics hubs for manufacturing-based economics. Other examples can be found in Chen et al., [3] and Liu and Liu [15].

A-KH was founded in 1984, as a member of one of the global leading semiconductor manufacturing groups. Driven by market demands for faster, smarter, portable and integrated electronic products, A-KH is increasingly moving towards more sophisticated and diversified semiconductor products. Since A-KH is at the upstream end of the supply chain, the bullwhip effect on A-KH and its suppliers is more significant than on electronics manufacturers at the downstream. Aiming to mitigate the bullwhip effect, A-KH completed a 3-year project to develop and deploy a web-based inter-business information platform, E-Hub, to facilitate information sharing with its suppliers. Hitachi Chemical and several other major suppliers of A-KH were among the first to participate in the project and provided inventory and shipping information to A-KH. The successful experience of these suppliers encouraged other suppliers to use E-Hub. At the time when the system was officially online in 2010, more than 300 suppliers (or 75%) were participating in the project and performing their daily interactions with A-KH via E-Hub.

With the centralized (demand forecast, inventory, order and delivery) information shared via E-Hub between A-KH and its suppliers, this project demonstrated the benefits of E-Hub in taming the bullwhip effect, even during its development phase. Because of the demand forecasts shared via E-Hub, A-KH and its suppliers were able to quickly notice the economic downturn at the end of 2008 (i.e., the sales of electronic products dropped sharply by 70% due to the global financial crisis in that year) and took necessary actions to resolve the impact, so as to avoid a huge disposition of inventory. The value of sharing centralized demand information with supply chain participants via E-Hub is of particular interest to this study.

The remainder of this paper is organized as follows. A-KH's supply chain is presented and its deficiencies analyzed in Section 2. The development of E-Hub and its system architecture and operations are presented in Section 3. The value of information sharing via E-Hub in reducing the bullwhip effect is investigated and demonstrated in Section 4, followed by the concluding remarks in Section 5.

2. THE SUPPLY CHAIN OF A-KH AND AN ANALYSIS OF PROBLEMS

Figure 1 depicts the three stages of the supply chain of A-KH, namely, the raw material supplier, the IC assembly (or packaging) and testing firm and the manufacturer of electronics. To fulfill customers' orders, IC foundry firms (e.g., TSMC) provide wafers to A-KH for assembly and testing. A-KH then procures raw materials from its suppliers and performs IC assembly and testing. Raw materials for IC assembly and testing include substrates, lead frames, compounds, solder balls, epoxy, chemicals, gold wire and so on, most of which are provided by Japanese suppliers, such as Hitachi Chemical (the largest compound provider to A-KH). After assembly and testing, the ICs are sent to the electronics manufacturers, such as AMD and TOSHIBA, which are customers of A-KH.

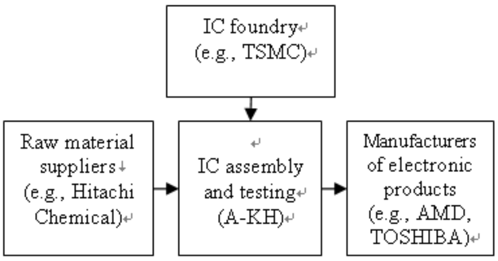

Figure 1: The supply chain of semiconductor assembly and testing

Prior to the deployment of E-Hub, information exchange (e.g., order placement and shipping notices) between A-KH and its customers and suppliers relied mainly on email or Fax, which are unreliable and inefficient methods of inter-business communication. A-KH received monthly demand forecasts from its customers, but this information was not transferred to its suppliers. At A-KH, the manager of raw materials control determined the inventory level and placed orders according to customers' forecasts/orders. The suppliers, at the far upstream end of the supply chain, determined shipping and production plans, based on the orders of A-KH. Because the suppliers did not have the demand forecast information from downstream, in order to maintain a certain level of service requirement, they were required to keep high levels of safety stock and this incurred unnecessary inventory holding costs and losses. For example, Hitachi Chemical reported a 30% write-down of inventory in 2007. Furthermore, since electronics are typically fast-moving products, the change in market demand driven by consumers' preferences is undoubtedly volatile and dramatic. This market characteristic has further highlighted the importance of sharing demand forecast information and ensuring collaborative replenishment of the upstream suppliers to tame the bullwhip effect.

In order to improve the effectiveness and efficiency of its supply chain, based on the above problem analysis, A-KH has identified a need to develop an inter-business information platform that facilitates information exchange and sharing between the supply chain participants.

3. E-HUB DEVELOPMENT AND SYSTEM ARCHITECTURE

A-KH launched a 3-year project at the end of 2007 to develop and deploy E-Hub.

3.1 E-Hub Development

A-KH has overcome a number of internal and external barriers to develop and deploy E-Hub. Particularly, in order to reach an overall consensus for the adoption of E-Hub, A-KH arranged several meetings with its suppliers. When asked to participate in the project, some of the suppliers argued that adopting the system might cause inconvenience in their daily operations and those small suppliers had very limited resources to invest in the new system. To resolve these issues, A-KH organized a series of training workshops, during the development process, to help its suppliers adopt E-Hub (e.g., Web interfaces, data entries, manipulations and exchanges and order and inventory management). Additionally, A-KH technically and financially sponsored its small suppliers in the project.

The development of E-Hub comprises the following four phases: initialization, implementation, enhancement and deployment.

Stage one – Initialization (December, 2007 ~ June, 2008): Create a collaborative consensus between A-KH and its suppliers, develop the prototype of E-Hub and complete the first pilot run of the system.

Stage two – Implementation (July, 2008 ~ December, 2008): Establish an alliance between A-KH and its suppliers and implement the fully functional E-Hub.

Stage three – Enhancement (January, 2009 ~ September, 2009): Test and enhance the functions of the hub to improve system performance and reliability and complete necessary business process reengineering for launching the hubs.

Stage four – Deployment (October, 2009 ~ December, 2010): Perform the full-scale deployment of the hub.

3.2 The Architecture of E-Hub

Figure 2 presents the system architecture of E-Hub. A-KH and its suppliers (e.g., Hitachi Chemical) can access their respective functions in the business hub via web browsers. E-Hub interfaces with A-KH's internal Enterprise Information Systems

(EISs), such as Enterprise Resource Planning (ERP) and Customer Relationship Management (CRM), through a database management system (DBMS), which ensures data format compatibility between the EISs and the E-Hub and extracts the latest data (e.g., inventory and forecasts) from the EISs. The hub regularly talks to the DBMS, to ensure information consistency between internal (at A-KH) and external databases (at E-Hub).

E-Hub also connects to the suppliers' B2Bi via a data exchange channel that allows FTP, Rosetta Net (RN) and other types of protocols for the connections. All the logistics operations can be planned and executed according to the latest information from A-KH and the suppliers, which greatly enhances the performance of logistics services. Thus, the proposed system provides much greater information transparency and efficiency of data interchange between A-KH and its suppliers, compared to previous methods that used ad-hoc and passive EDI or FTP techniques for communication between supply chain members.

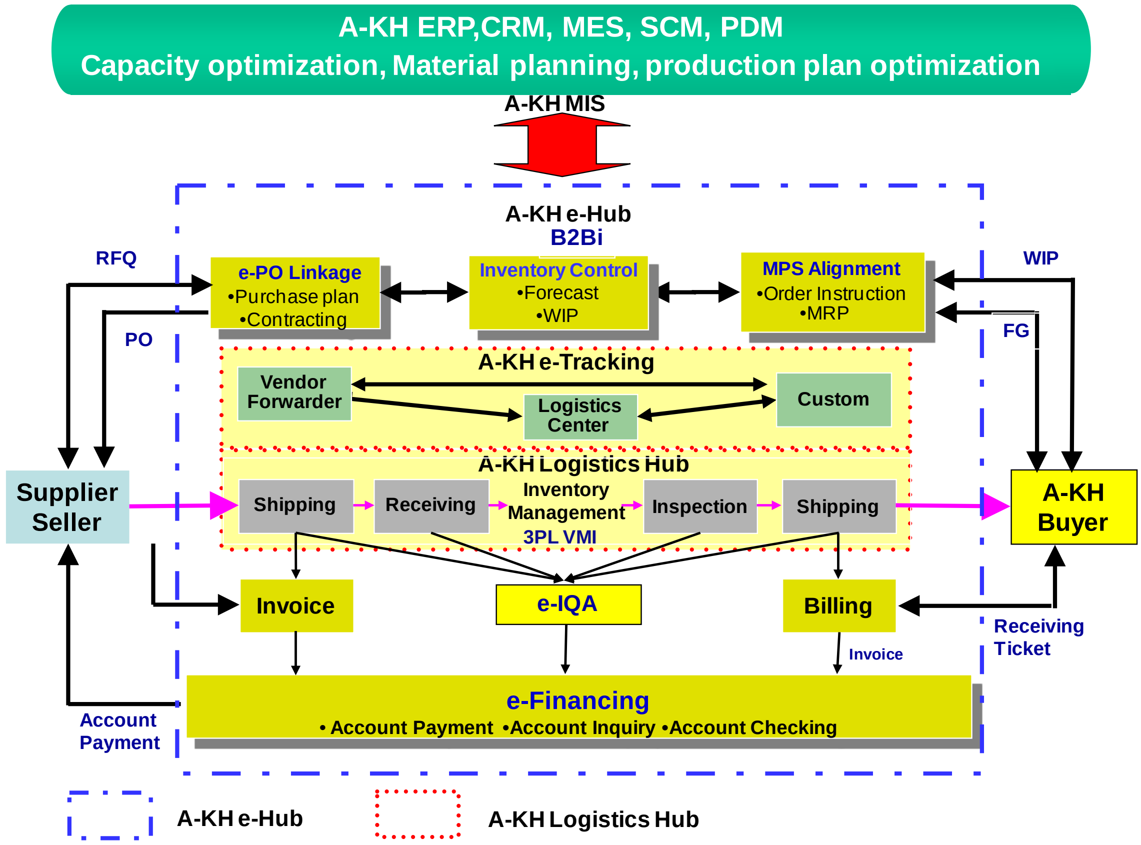

Figure 2: System architecture of the IBLH

3.3 The Information Flow

Figure 3 shows the information flow after the deployment of the hub. Downstream customers provide their monthly demand forecasts to A-KH. Based on customers' demand forecasts, A-KH generates its master production schedule (MPS) and material requirement plan (MRP), which are used to derive rolling forecasts for raw material requirements. These are shared with its suppliers via E-Hub. Additionally, A-KH places orders and its suppliers confirm purchasing orders and send shipping notices to A-KH through the web interface of the hub, which has an order-tracking function and a goods-tracking function. After orders are delivered to A-KH and confirmed by its ERP system, the account payable with the payment amount and date is created by a payment management function of the hub and sent to suppliers.

To perform effective inventory management (such as vendor managed inventory, or VMI), A-KH also shares its inventory status with its suppliers. If a supplier observes that the inventory level at A-KH's warehouse is below a pre-determined threshold, then it will replenish the inventory position to a base-stock level. By sharing the inventory information, VMI suppliers can periodically review the inventory level and make production and replenishment decisions accordingly. For local suppliers who implement just-in-time (JIT) delivery, shipping and replenishment notices are provided to A-KH via the hub, before delivering orders to A-KH's production sites. A-KH can also access the information about inventory levels at suppliers to enable preparation for supply disruptions.

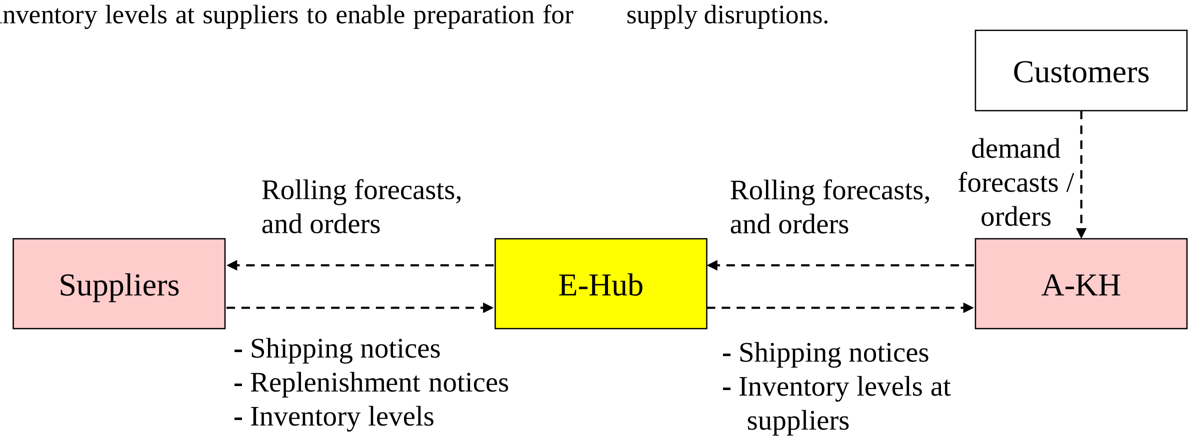

Figure 3: Information flow after the deployment of E-Hub

4. THE VALUE OF INFORMATION SHARING

Sharing rolling forecast information with its suppliers is one of the main reasons that A-KH developed and deployed E-Hub. Information sharing typically refers to centralized demand information within a supply chain. E-Hub plays the role of a data center, from which suppliers can access A-KH's rolling forecasts and inventory level information. The benefits of information sharing have been analyzed in literature [16]. A-KH was particularly interested in the reduction of the bullwhip effect substantiated by sharing demand and inventory information with its suppliers through the proposed system (i.e., the value of information sharing in reducing the order variability in the supply chain). To analyze the benefit of information sharing for reducing the bullwhip effect, this study adopts the approach, proposed by Chen et al.[1], to quantify the bullwhip effect in the supply chain and to compare the bullwhip effect under provision of centralized and decentralized information (i.e., before and after the deployment of E-Hub).

Consider A-KH's three-stage supply chain (Figure 1). Customers (i.e., manufacturers of electronics) are at stage 1, A-KH is at stage 2 and suppliers (e.g., Hitachi-Chemical) are at stage 3. Each stage k (k = 1, 2, 3) in the supply chain faces a fixed lead time, L_k (days). Customers at stage 1 adopt a moving average technique to estimate the mean and standard deviation of weekly demand, using the past p observations; that is,

$$AVG = \sum_{i=t-p}^{t-1} D_i / p \quad \text{and}$$

$$STD = \sqrt{\sum_{i=t-p}^{t-1} (D_i - AVG)^2 / (p-1)} \tag{1}$$

where D_i denotes the demand observation in period i. In every period (or week), the mean and standard deviation are updated, based on the p most recent observations. According to the estimated mean and standard deviation of these observations, customers apply the base-stock level inventory management policy, which is a periodic review policy that reviews its inventory position every period and places an order to bring its inventory position to a pre-determined level.

A-KH at stage 2 and suppliers at stage 3 also use the moving average technique and the base-stock level inventory management policy. In the supply chain with decentralized demand information (i.e., before the deployment of the hub), A-KH had to estimate the mean and standard deviation of weekly demand and determine the base-stock level according to the previous p orders placed by customers, rather than actual (or observed) demand data, because customers did not share the demand information with the upstream end of the supply chain. In accordance with Theorem 3.2 in Chen et al.[1], the ratio of the variance of the orders placed by the customers, $Var(Q_1)$, to the variance of the demand observations seen by customers, $Var(D)$, satisfies:

$$\frac{Var(Q_1)}{Var(D)} \geq 1 + 2\frac{L_1}{p} + 2\frac{L_1^2}{p^2} \tag{2}$$

In addition, the variance of the orders placed by A-KH, Var(Q_2), relative to the variance of the demand observations, $Var(D)$, satisfies:

$$\frac{Var(Q_2)}{Var(D)}_{Decentralized} \geq (1 + 2\frac{L_1}{p} + 2\frac{L_1^2}{p^2}) \times (1 + 2\frac{L_2}{p} + 2\frac{L_2^2}{p^2}) \tag{3}$$

Conversely, in the supply chain with centralized demand information (i.e., after the deployment of the hub), the downstream members share their demand forecasts with the upstream end of the supply chain, through E-Hub. Thus, A-KH uses its customers' demand forecasts to determine its target (base-stock) inventory level and suppliers set their base-stock level according to A-KH's rolling forecasts for raw materials. In accordance with Theorem 3.1 in Chen et al.[1], the variance of the orders placed by A-KH, $Var(Q_2)$, relative to the variance of the actual demand, $Var(D)$, satisfies:

$$\frac{Var(Q_2)}{Var(D)}_{Centralized} \geq 1 + 2\frac{L_1 + L_2}{p} + 2\frac{(L_1 + L_2)^2}{p^2} \quad (4)$$

The ratios of the variance of the orders placed by Hitachi-Chemical, $Var(Q_3)$, to the variance of the actual demand, $Var(D)$, under decentralized and centralized demand information can also be derived, using Eq.(3) and Eq.(4), respectively.

Eqs.(3) and (4) indicate that while the variance of orders increases multiplicatively with the total lead time under the provision of decentralized demand information, the increase is additive for the case of centralized demand information. Thus, centralizing demand information can significantly reduce the bullwhip effect, although it does not completely eliminate it. Moreover, according to Eqs.(3) and (4), the variance of orders placed by an upstream stage of the supply chain is an increasing function of the total lead time (L) between that stage and the farthest downstream stage and a decreasing function of the number of order observations (p) in the moving average forecast. Hence, reducing L and/or increasing p also helps to mitigate the impact of the bullwhip effect.

The above theoretical analysis of order variability under decentralized and centralized demand information is consistent with actual order variability, before and after deploying E-Hub. Figure 4 shows the order data of A-KH and one of its major customers (denoted as T), from February, 2008 to September, 2010. Since the implementation of the IBLH in December, 2008, A-KH's order variability has been significantly reduced, except for the period of the global financial crisis between September, 2008 and April, 2009. This real data demonstrates that information sharing through the E-Hub indeed alleviates the bullwhip effect for A-KH. Moreover, it can be seen that, after December, 2008, the gap between A-KH's order and T's order has decreased and the pattern of A-KH's order is essentially in line with that of T's order, even in the period of the financial crisis. Thus, information sharing via E-Hub helps A-KH to make better forecasts and to account for market changes, which in turn enables A-KH to better serve its customers.

Figure 5 depicts the value of $Var(Q_2)/Var(D)$, computed using the actual demand data and order data of A-KH. As seen in the figure, the value of $Var(Q_2)/Var(D)$ is greater than 1.4, before the deployment of E-Hub, while it is less than 1.05, afterwards. Note that, in addition to the reduction of order variability for A-KH, $Var(Q_2)$, A-KH's lead time (L_2) also decreases, because of the efficient order-processing function that is supported by E-Hub. Figure 6 shows that L_2 decreased from 8 days to 3 days, after A-KH used the hub.

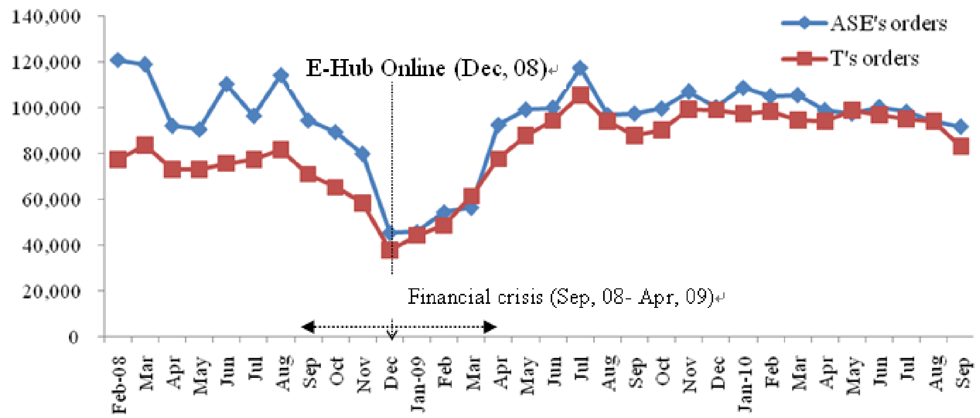

Figure 4: Actual order data, before and after the deployment of IBLH

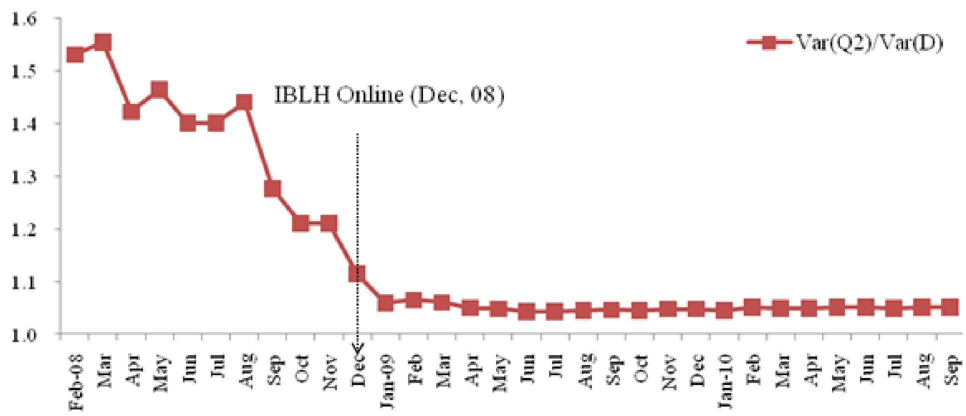

Figure 5: The values of Var(Q_2)/Var(D) computed using actual data

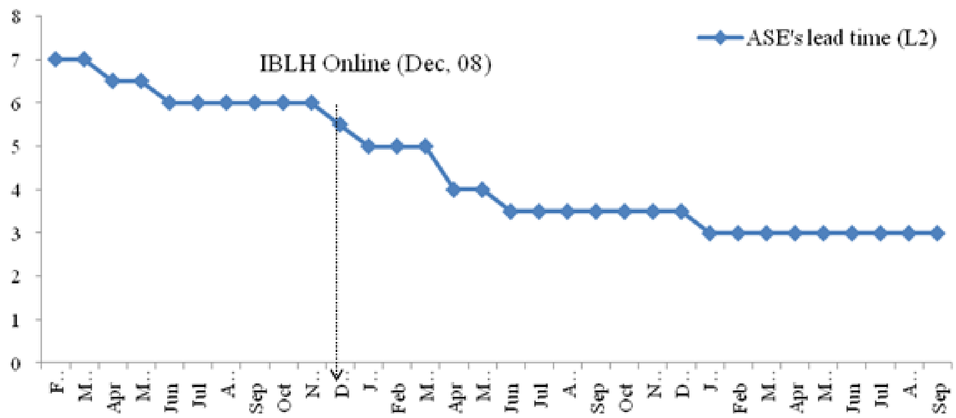

Figure 6: A-KH's lead time

5. CONCLUDING REMARKS

This paper presents the inter-business information platform, E-Hub, developed by A-KH to facilitate information sharing with its suppliers and the integration of information flow. An analysis of the problems associated with A-KH's supply chain revealed its ineffectiveness and inefficiency and resulted in the development of E-Hub for A-KH and its suppliers. With a particular emphasis on taming the bullwhip effect in its supply chain, A-KH spent three years in completing the development and deployment of E-Hub, which was partially sponsored by ITRI, Taiwan. This hub gathers demand and order data into a central data warehouse and generates supply chain collaborative planning and forecasting information, which is shared with A-KH's suppliers.

The hub has been on-line for more than two years and substantial benefits have been realized. In particular, A-KH's order variability has been significantly reduced since deploying the hub, which demonstrates that information sharing via E-Hub indeed alleviates the bullwhip effect in the supply chain. This study's empirical observations are consistent with the theoretical analysis conducted using the approach proposed in literature [1]. Additionally, A-KH's lead-time has greatly decreased, because of the improved order processing function supported by the hub.

Future research will analyze and evaluate the performance of the proposed hub, using other techniques, such as simulation and supply chain operation reference (SCOP) models. To further enhance the performance, A-KH will also conduct a survey to learn suppliers' experiences and satisfactions with the hub. Survey results will be used in an importance-performance analysis (IPA), to investigate the gap between the information needs of suppliers and the utility provided by E-Hub and to identify further upgrades to the hub.

Sustaining the initiative value of E-Hub, A-KH formed a supply management alliance (SMA) with hundreds of local suppliers in a bid to better control inventory to cope with demand volatility in the industry. A-KH's leadership and innovation are visible and measurable in the development of E-Hub and the formation of SMA. The move came after the industry rebounded from a severe industrial slump amid improving global economies and recovering demand for electronics in 2009. Through leading the SMA, A-KH has set the standards for leading corporations, while serving as an operational model in the industry. A-KH has committed to its broader community of suppliers and partners to bring new ideas, take actions, and derive best practices for the semiconductor industry.

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摘要

本文描述世界最大半導體封裝測試廠(簡稱A-KH)為了促進與供應商之間的資訊共享(Information Sharing)，建構網際網路企業資訊平台。此資訊平台稱為E-Hub (Electronic Business Hub)，是半導體封裝測試產業中第一個無縫整合供應鏈夥伴的協同合作平台，其主要目的在於減輕長鞭效應(Bullwhip Effect)對於供需雙方的影響。通過E-Hub的功能運作，A-KH與供應商分享基於主生產計畫(master production schedules)和物料需求計畫(material requirements planning)所產生的需求預測；另一方面，供應商則提供訂單狀態和發貨通知到A-KH，以進行訂單和貨況追蹤。此外，A-KH亦能即時掌握供應商的庫存水準，能夠有效管理庫存和做好避免供應中斷的準備。經過A-KH E-Hub收集到的數據進行實證分析，本研究發現在推動E-Hub平台後，A-KH供應鏈中的訂單變異有明顯的下降，且下降的程度與文獻中經由分析模式推導的結果一致。本研究的主要貢獻在於證實透過E-Hub進行供應商資訊分享，確實能夠減輕長鞭效應對於半導體封測產業供應鏈所帶來的影響。

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