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ORIGINAL ARTICLE

Pioneering e-supply chain integration in semiconductor industry: a case study

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Abstract Taiwan Semiconductor Manufacturing Company (TSMC) is the largest semiconductor foundry in the world. Advanced Semiconductor Engineering Inc. (ASE) is the world's leader in semiconductor assembly and testing. From 1998 to 2004, the two companies completed electronic integration of 11 key business processes through the Internet. The result is a seamless interface between TSMC, ASE and their joint customers. They can now obtain accurate, timely information on their product status and respond appropriately when needed. While the direct economic benefits are estimated to be around US$ 10 million through productivity increase over a total investment of about US$ 2 million, the indirect benefits of this initiative could be on the order of US $100 million if the joint customers' benefits are considered. In collaboration with the RosettaNet organization, TSMC and ASE leveraged their pioneering experiences to define three data exchange standards which can then be widely adopted in the semiconductor industry. This case study is a demonstration of how two leading companies in their respective fields can join forces to make a difference in creating value for the entire semiconductor industry, which in turn benefits society at large. With the momentum continuing to build and the sphere of influence continuing to expand, it is anticipated that TSMC, ASE and the entire sector will upgrade their competitiveness in terms of cost, quality, responsiveness and customer orientation.

Keywords Supply chain · Value chain · B2B · Semiconductor industry · RosettaNet

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1 Introduction

The continuing trend of the semiconductor value chain disintegration has improved cost efficiency at each stage of the value chain. This trend has also resulted in specialized companies that are independent yet co-dependent upon one another, as shown in Fig. 1. These companies need to closely collaborate with their partners both up and down the value chain to meet the relentless end-consumer demand to achieve shorter time-to-market, lower costs, higher responsiveness, and better quality. Therefore, streamlining the business processes between partners, sharing information appropriately, and ultimately effectively "re-integrating" the value chain in a virtual manner have become the most critical issues in the semiconductor industry today.

The "virtual fab" concept is a solution that addresses the above issues. Taiwan Semiconductor Manufacturing Company (TSMC), the world's largest and most successful dedicated independent semiconductor foundry, is a service-oriented enterprise that leverages the Internet to allow customers to place orders and inquire about the status of their production orders as if they were in their very own manufacturing unit. Ever since the virtual fab concept was realized in the "TSMC eFoundry" system, customers have embraced the solution, hence increasing their reliance on TSMC as their main foundry partner.

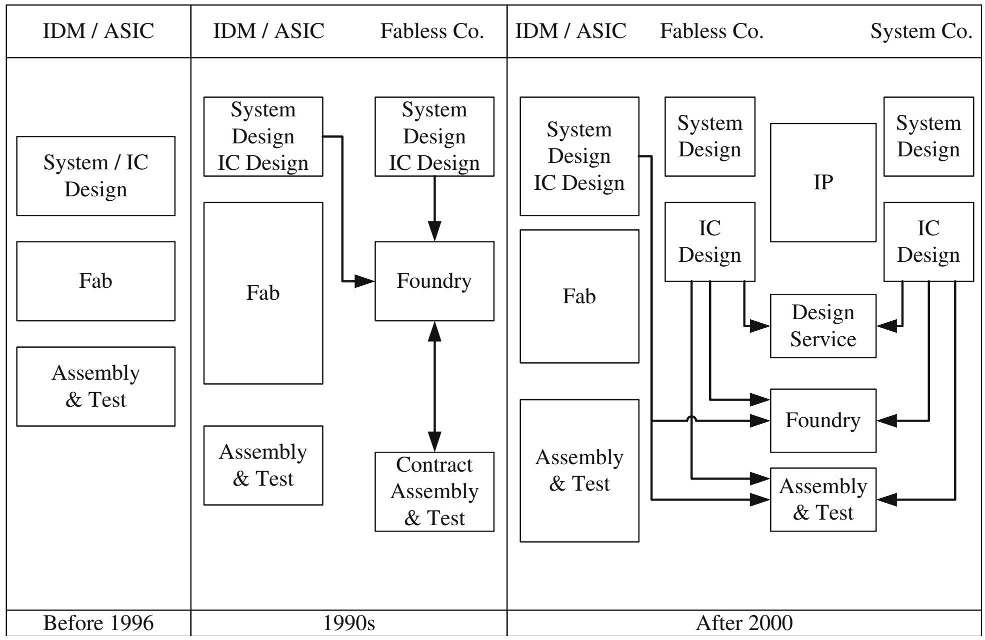

Fig. 1 Disintegration of the semiconductor industry value chain

A critical component of this virtual fab concept is integrated design, engineering, and logistical information between a fab and its downstream partners in testing and packaging. TSMC and ASE Advanced Semiconductor Engineering, Inc. (ASE), the largest independent semiconductor packaging service provider, therefore embarked on a pioneering effort to integrate the key business processes between them in 1998, covering all major business activities in the production life cycle. In that six-year period, business processes such as electronic ordering, work order entry, work-in-Pprocess (WIP) inquiry, finished goods (FG) data transfer, inventory data sharing, shipment notice, and engineering and testing data delivery were streamlined and enabled with Internet technology. This endeavor became a successful model for improving the effectiveness of the semiconductor supply chain operation and has been emulated by many players in the field.

2 Supply chain management

Facing dynamic business environments, the ability to respond quickly to market changes has been recognized as a key factor in the success and survival of enterprises nowadays. To cope with rapid changes, enterprises need to change traditional management in this intense competitive environment. Through dynamic alliance, enterprises exert themselves and cooperate with each other to meet the needs of the fluctuating market, and finally achieve the goal of win-win [1–3]. Fortunately, information technology integrates the internal and external activities of a company. This integration results in close partnership among operations and processes of the business, allowing decision-makers to obtain information more rapidly and accurately. Supply chain management (SCM) is one of the management approaches that brings about closer enterprise collaborations [4–6]. SCM is an approach that satisfies the demands of customers for products and services via integrated management in the whole business process from raw material procurement to the product or service delivery to customers [3]. With the Internet, the enterprise partners can collaborate virtually and integrate their life-cycle product development activities through seamless information exchanges [7].

Many manufacturing industries need more efficient organization because customers expect a greater response to orders. Due to this increased expectation, SCM has been widely investigated and discussed [8]. Many companies invested significant resources in developing information systems to obtain good SCM. IT investment for adapting the firm to the business environment is not only vital, but crucial to a firm's survival [9]. To solve the problem of system productivity in applying planning software packages, Kobayashi et al. [10] proposed business process integration, which fuses workflow and enterprise integration technology applications.

Reliable data and real-time data transaction are critical to the creation of a successful SCM. Organizations such as RosettaNet, formed by major companies from various industries, provide the standardized data infrastructure for integrating business processes. RosettaNet, formed in 1998, is a globally supported standards development organization for collaborative commerce, mainly in the high-tech industry. The data standards now defined are widely adopted by companies to conduct inter-company SCM. RosettaNet has six established global councils: computer and consumer electronics (CCE), electronic components (EC), logistics (LG), semiconductor manufacturing (SM), solution providers (SP), and telecommunications (TC). The organization has more than 500 world-leading organizations joining and working to create, implement and promote open e-business standards and services.

3 Research method

This case study strategy used how and why questions. We used a case study to analyze how and why a successful e-supply chain management system should be established.

This case study is appropriate for use in exploring situations in which the evaluated intervention did not have a clear, single set of outcomes [11]. This case study used a deductive design [11, 12] widely is adopted in business field [13]. It is preferred in examining contemporary events and relies on many of the same techniques as a history. Direct observation of the events and interviews of the persons involved in the events are sources of evidence not usually included in the historian's repertoire [11]. Case study research includes single-case and multiple-case studies. Case studies have been conducted about decisions, programs, the implementation process, and organizational changes [11]. This research focused on the e-supply chain management system implementation process between TSMC and ASE.

4 The e-supply chain integration project by TSMC and ASE

The goal of the TSMC/ASE e-supply chain project was to integrate key operational activities and data between TSMC and ASE, resulting in a seamless information and transaction interface for their joint customers, as if manufacturing took place in the customers' own backyard. The process integration and data exchange experiences subsequently became the foundation for three RosettaNet standards, RosettaNet 3D8 (WIP, Work in Process), 7B5/7B6 (Work Order and Work Order Acknowledge), in the semiconductor manufacturing (SM) council.

4.1 The project objectives and scopes

Objectives of the project were to streamline and integrate key business processes, improve transparency of information exchange, increase speed of information delivery, and standardize process "hand-shaking" protocols and data exchange formats. The project was comprehensive in scope, encompassing all major business activities between TSMC and ASE in the following two dimensions:

(1) Engineering Collaboration, including

- Engineering pecifications and diagram
- Engineering test data
- Yield data

(2) Logistics Collaboration, including:

- e-PO and Order Acknowledge
- WIP data
- FG tracking
- Advanced shipping notice

The inception of the TSMC/ASE e-supply chain project can be dated as early as 1998, a truly pioneering initiative ahead of other players in the industry. The early stage of this project, between 1998 and 2000, was conducted without any international standards. Hence, the two companies were truly in uncharted waters as they discussed various aspects of process streamlining, process linkage, data exchange protocols, and integrated system architecture and functionalities. After numerous mutual visits, meetings, e-mail exchanges, and telephone communications, 11 e-processes were established including yield rates, testing results, order and order acknowledgement, work-in-process, and shipment of finished products in stock; etc. Figure 2 illustrates the identified key processes between these two companies.

While defining the project architecture, these two companies intended to integrate the existing process and build a "foundation" upon which greater process integration and data exchange would be established both upstream and downstream the value chain. This model was eventually extended to more than 20 of TSMC customers (with TSMC as the interface), and to around 10 suppliers (with ASE as the interface) as shown below in Fig. 3.

This pioneering experience was significant in that it provided a practical, "down in the trenches" experience base with which the two companies were able to contribute when RosettaNet Semiconductor Manufacturing Board (SM Board) was established in 2000. Such an experience base proved instrumental in defining common e-commerce language and protocols for the semiconductor industry as more players adopted the same standards to benefit from the resulting operational efficiency and synergy.

4.2 Implementation of the project

Given the significance of this initiative's objectives and its extensive scope, substantial resources were deployed to implement the project over a six-year period. An iterative phased approach in project management was adopted to ensure solid delivery of milestones without significantly disrupting current operations. An overview of the project implementation flowchart is illustrated in Fig. 4.

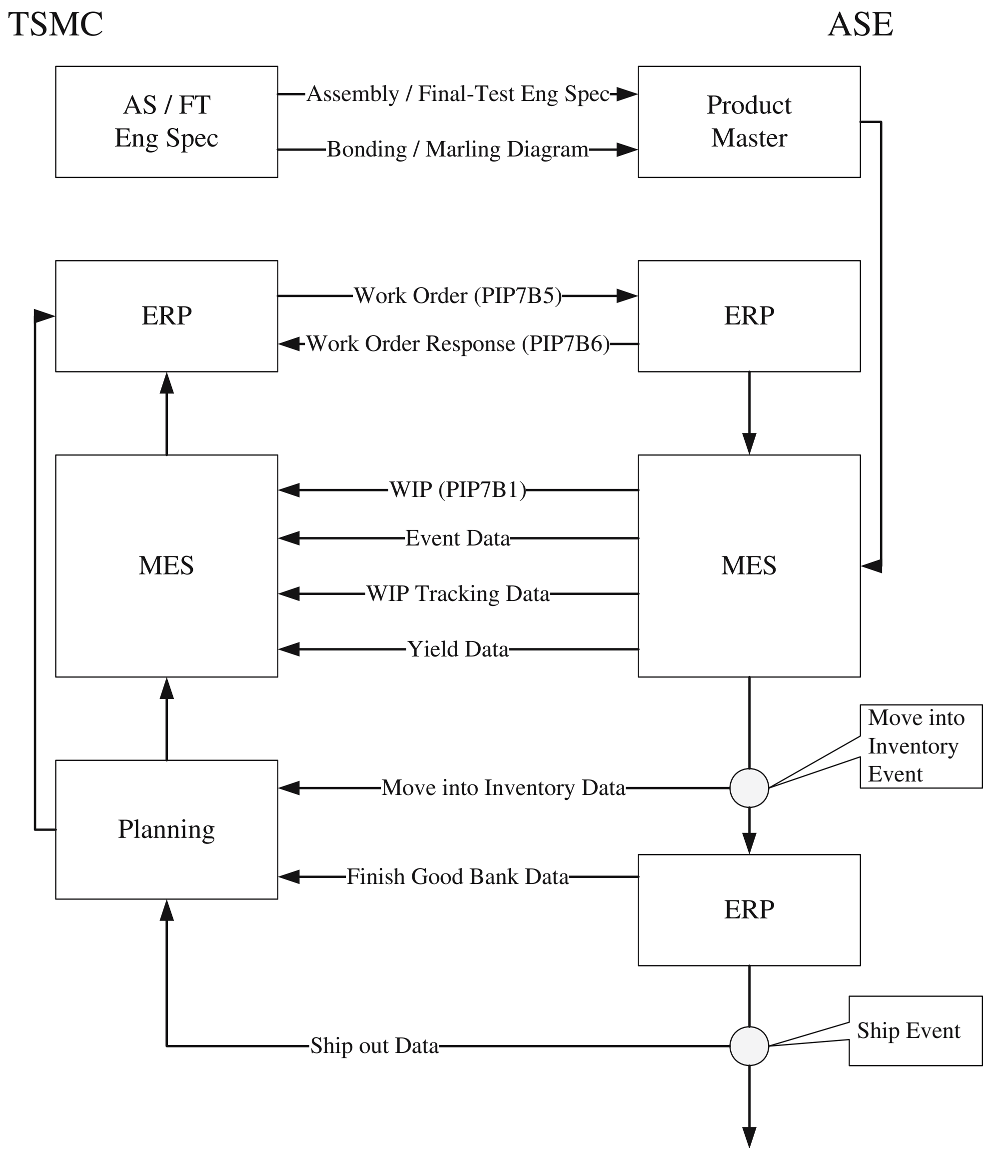

Fig. 2 TSMC/ASE's key process integration–conceptual overview * AS: Assembly, FT: Final-Test, ERP: Enterprise Resource Planning, MES: Manufacturing Execution System

This methodology emphasizes a closed-loop process, including planning, execution, result monitoring, and continuous improvement. Key performance indicators (KPI) were defined and customer satisfaction surveys were conducted to ensure that project results would meet the predefined objectives. The key activities in implementation flowchart are summarized below:

- Project initiation and planning: at the stage of project initiation, TSMC and ASE identified and prioritized business processes to be included by their degree of criticality and urgency. Then the project task force was formed, whose members were fully committed to and accountable for the project's goals.
- Requirement analysis, architecture design and system development: user interviews were conducted systematically to structure the requirements into a framework upon which to build the system. Throughout the project user requirements were monitored and controlled vigorously.
- Testing and maintenance: during the testing stage, all key processes were first "simulated" by designing and executing scenario-based scripts in a testing environment to ensure the feasibility in real-life operational environment.
- User satisfaction survey: formal user satisfaction surveys have been conducted annually with extensive questionnaires and interviews to gauge satisfaction level of TSMC/ASE joint customers. In addition, informal interactions also provide a channel for user feedback, which are carefully considered and turned into system enhancements if appropriate.
- Closed-loop monitoring: Key performance index (KPI) were defined to evaluate the project's actual results after its completion, and project benefits were continuously assessed and monitored as more functionalities were

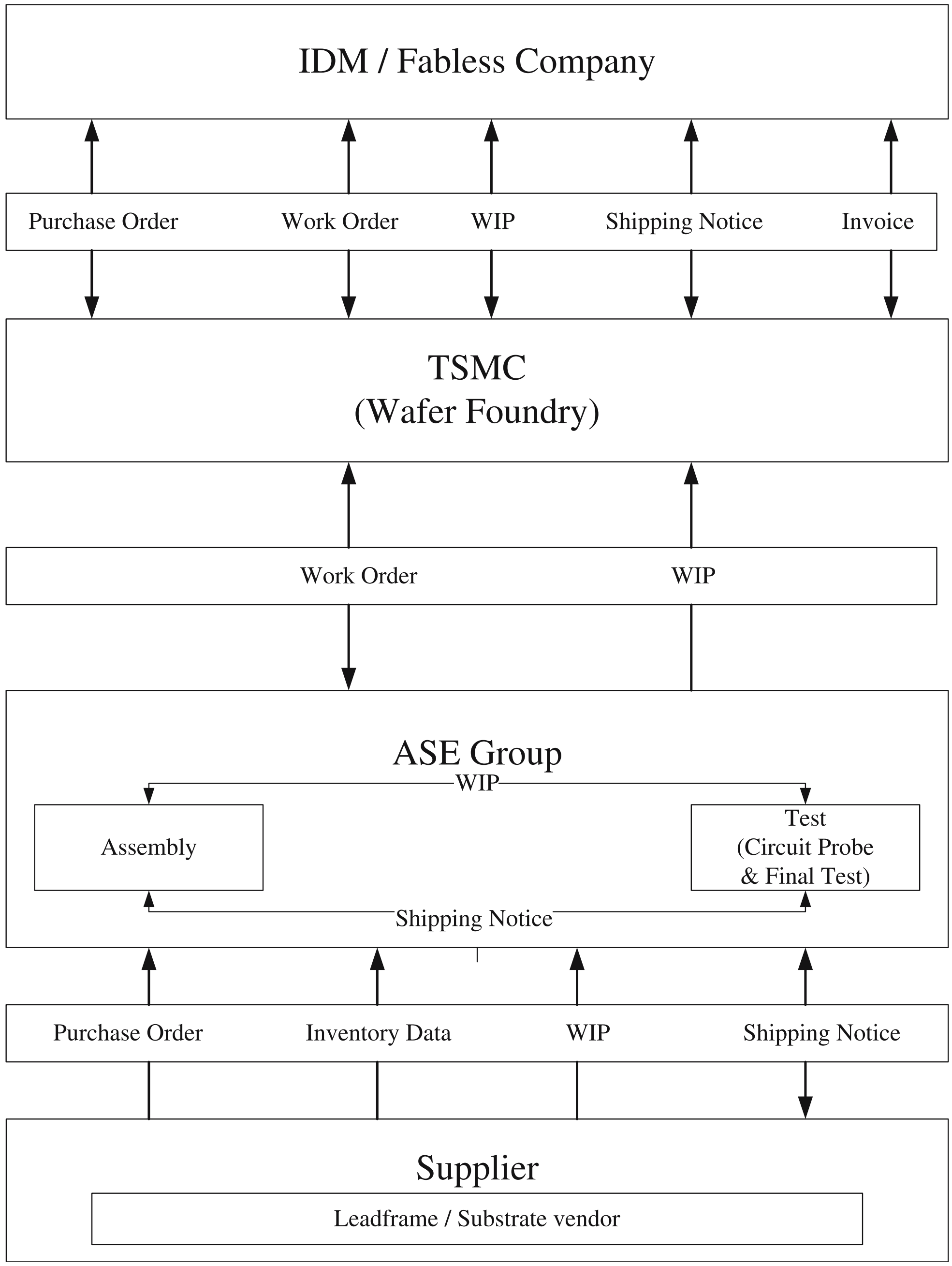

Fig. 3 Extending integration up and down the value chain

added to the system. Both TSMC and ASE executives review these results on a regular basis and they are used as the benchmark when planning future similar projects.

5 The cost/benefit analysis

5.1 Costs

The TSMC/ASE e-Supply Chain project represented the starting point for the two companies' collaborative e-commerce services for their joint clients. During the six-year period from 1998 through 2004, the two companies invested substantial amounts of human and monetary resources on the project, including US$ 1.1 million for TSMC and US$ 1.0 million for ASE. The following figure shows the cost percentage breakdown by investment items (Fig. 5).

5.2 Benefits

The benefits were realized through shorter data transmission time, timely information delivery, and increased data transparency and accuracy due to standardization of data

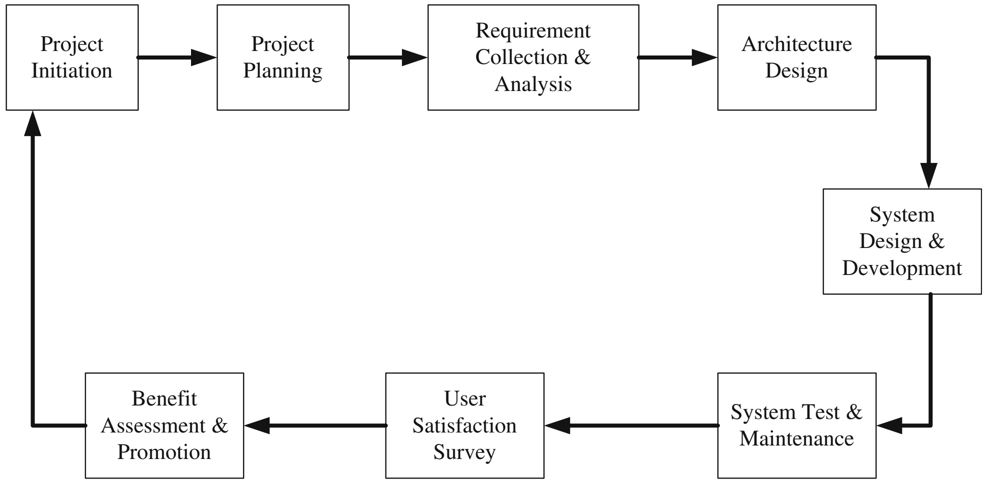

Fig. 4 Implementation flowchart

exchange protocols and formats. Time was saved with less data collection, verification and correction, which shortened the time to market and improved employee productivity, and lowered the entire supply chain operational cost.

Customers can now take part in various operational processes via the Internet, including real-time order placement, inquiry on production progress and testing results, forecast of product delivery, and so on. All this information, when received timely and accurately, greatly expedites the R&D, design, or other operational activities of the clients, and thereby contributes to increased customer satisfaction and the overall competitiveness of the industry. Over the past 6 years, it is estimated that more than US$10 Million has been jointly realized by the two companies, compared with the US$ 2 million total investment. The overall benefits and investments included all the major e-business processes integrated, such as e-order, work-in-process, inventory entry, inventory of finished products, shipment, engineering data, and testing results. Table 1, taking an e-order as an example, illustrates the key factors for quantitative benefit calculation. The overall benefits for the 11 e-processes in the two collaboration group are shown in Table 2.

It is worthwhile to note that the above figure is only the "direct" benefits achieved by TSMC and ASE internally. As mentioned in previous sections, more than 30 companies in

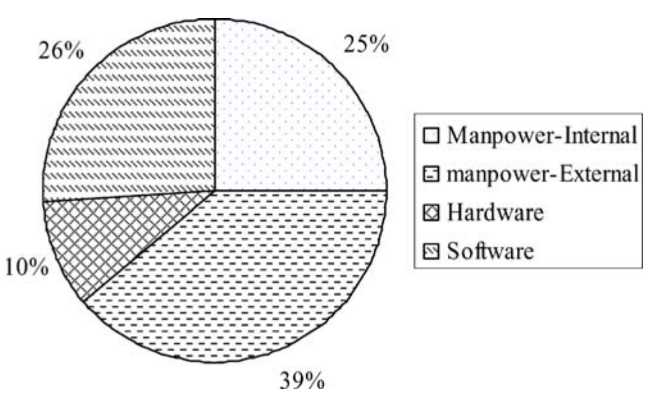

Fig. 5 Cost Breakdown

semiconductor industry have joined the e-Supply chain network ever since. More companies in the high-tech industry adopted the WIP, work order/work order acknowledgement data exchange format after these three standards were verified and published by RosettaNet. The "indirect" benefit brought to the whole industry value chain could be in the order of 10X.

6 Lesson learned

An initiative at such a grand scale will inevitably have abundant challenges and lessons to be learned. The most difficult challenges encountered over the six-year period of project implementation were related to business process re-engineering, process/system integration, data exchange standardization.

6.1 Challenges

6.1.1 Incompatible business process

Like any major IT projects, the process rationalization is always the first step of process automation. In the first stage of the e-supply chain project, both companies present and examine the current inter-company business process related to the defined project scope. There were some misalignments being identified and significant effort was then invested to re-think how to engage the business transaction more effectively. For example, one-to-many relationship of customer's product name to vendor's internal manufacturing device name often caused confusion when both sites handled order taking, WIP, and invoicing. Consequently, a great amount of manual effort was placed to prevent and/or correct operation errors. To fundamentally solve this problem, a process-reengineering project was conducted to re-define the product naming scheme and generate a mapping table to maintain a one-to-one relationship.

Table 1 Before and after operation cost comparison for e-order

Items	Before	After	Remarks
Data transmission time	120 minutes/order	20 minutes/order	1. Around 20,000 e-orders per year. 2. The average error recovery time is 40 hours 3. 32 man-year cost reduction, equivalent to US$ 1M savings per year
Order processing time	100 minutes/order	20 minutes/order	
Order Errors (e.g., incorrect order line items, mis-matched product ID, wrong billing amount	12 orders/month	1.5 order/month	

6.1.2 Disconnection between business process and system

After reviewing and refining high-level business processes, the detailed process activities, execution flow and algorithm were created for system implementation. Disconnections were found during the system development stage because some key activities were not comprehensively defined. For example, a "purchase order" process is defined as a sequence of activities: a customer sends a PO to vendor, a vendor receives the PO and sends an acknowledgement to the customer, a customer receives the acknowledgement and completes the purchase order.

A design flaw was found that when a transaction failed, the system could not tell if the failure was caused by inconsistent data content, application server malfunction, or a network problem. To cope with this disconnection, an additional error-handling process had to be implemented.

6.1.3 Lack of Data Exchange Standard

Collaboration supply chain requires partners to agree with a standard protocol for information exchange. The significance of such protocol multiplies when the number of supply chain partners increases. To allow the data exchange protocol supporting business transaction between TSMC and ASE and also for our joint customers located in upper stream of the semiconductor value chain, the standard needs to be comprehensive and universal enough without sacrificing the system performance. Take WIP as an example, there were more than 300 data elements being defined. Each was marked as mediatory or optional in order to fulfill different needs. One of the key data elements, "Stage Name", had a resolution that could be very detailed, down to hundreds of process routes, or aggregated up to less than ten key stages. The data spectrum and granularity of adopting such a protocol is often a compromise between business needs and the sophistication of the installed ERP or MES system.

6.2 Critical successful factors

6.2.1 Business process re-engineering

The key to implement a successful, value-added e-commerce initiative is to fundamentally change the paradigm of how business is done with Internet technology, not just to automate existing processes [7]. Such business process re-engineering ranged from individual operational procedure changes to large-scale organizational re-structuring. Needless to say, change of this magnitude required unwavering project task force determination, and strong top management commitment.

6.2.2 Business Process and System Integration

Re-engineering serves to streamline and rationalize the individual business processes of two companies, and also ultimately integrate their operational activities to achieve a seamless interface [5, 6]. The value of automating the re-engineered processes through IT is to minimize the manual effort and, more importantly, to provide real time visibility to order processing, manufacturing status, and shipment between the two trading partners.

6.2.3 Process and data exchange standardization

Standardization of industry supply-chain processes and protocols is an inevitable, irreversible trend [3]. However, the entry barrier for most companies, especially for those small to medium-size ones, is high. RosettaNet organization's effort to define the industry standard and investigate ways to simplify the implementation standard has been widely recognized by the high tech electronic industry. The successful application of RosettaNet standard depends on the completeness of inter and intra processes as well as the maturity of their internal ERP and MES systems of trading partners.

Table 2 Collective benefits summary

e-operational processes	1998	1999	2000	2001	2002	2003	Total (US$, K.)
Logistics collaboration	7	515	1,481	1,836	1,852	1,955	7,645
Engineering collaboration	0	250	463	535	617	576	2,442
Total	7	765	1,944	2,371	2,468	2,531	10,087

6.2.4 Change Management

As described above, process re-engineering and integration resulted in significant behavioral and even organizational changes. Executives' fully support and guidance to the necessary transformation is definitely a key for project success [9].

7 Conclusions

Pioneering industry-shaping initiatives are always challenging and richly rewarding. The TSMC/ASE e-supply chain project, initiated in 1998 and still continuing in 2004, has evolved from a simple two-company project into a paradigm-shifting force to upgrade the entire semiconductor industry competitiveness through process and data standardization via RosettaNet. Vision, innovation, strong determination and relentless execution are all key success factors to make the success of this project possible [4, 10].

This case study can become a successful model on how to re-integrate the industry value chain virtually through the Internet, so other players in the semiconductor industry and even players in other industries can all learn, benefit from the experience, and follow to create value in their own fields.

The e-supply chain project covered the scope of engineering and logistic collaboration respectively between TSMC and ASE. It concentrated more on the mid-to-down stream of the semiconductor value chain due to the nature of these two companies. For future extensibility to the overall semiconductor value chain, a comprehensive engineering-related data exchange standard will be a focus. Compared with logistics, variances of inter-process and data exchange content of engineering for trading partners in the semiconductor value chain are large. The engineering data content for up-stream companies (IC design and foundry) and down-stream (foundry and assembly & final test) are quite different in complexity and volume. To define a comprehensive engineering data exchange standard would be beneficial to all companies in the semiconductor value chain. Future researchers could adopt the multiple-case research design for comparison.

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