2007 IEEE International Conference on
Robotics and Automation
Roma, Italy, 10-14 April 2007

WeE10.4

Novel Semiconductor Business Model – Engineering Chain for the Semiconductor Industry[1]

Jonathan, Chang Yung-Cheng
Member, IEEE
Institute of Manufacturing Engineering
National Cheng Kung University
Tainan, Taiwan, R.O.C.
P9893101@ccmail.ncku.edu.tw

Fan-Tien Cheng[2]
Senior Member, IEEE
Institute of Manufacturing Engineering
National Cheng Kung University
Tainan, Taiwan, R.O.C.
chengft@mail.ncku.edu.tw

Tsung-Li Wang
Student Member, IEEE
Institute of Manufacturing Engineering
National Cheng Kung University
Tainan, Taiwan, R.O.C.
peterw@super.ime.ncku.edu.tw

Abstract - **The foundry business model was first developed by TSMC in 1985. A foundry should provide customers with IC manufacturing services. Those customers include IC design houses, integrated device manufacturers (IDM), and system suppliers. However, most electronic products are consumer products, and their life cycle has been reducing with time. An IC design house needs to continuously develop ICs with new functions to meet the current market demand for consumable products. Meanwhile, to support customers for high speed and low cost end product development, foundry service providers must also continue developing new process technologies, from 0.25um down to 32nm. Unfortunately, advances in new manufacturing process technologies also create difficulties in new IC design. These advances increase the IC design failure rate. Currently, no effective working model and system exists to solve this problem. To formulate this high IC design failure problem, this work proposes a novel Engineering-Chain (EC) business model. This work also proposes an Engineering Chain Management System (ECMS) to help achieve the goals of EC, such as improving IC design success rate, reducing IC design cycle time, lowering IC design costs, and increasing revenue.**

I. INTRODUCTION – CHALLENGE IN THE SEMICONDUCTOR INDUSTRY

The overall functionality of electronic products recently has improved at unprecedented speeds. In 1970, every ten thousand persons shared one electronic product. Today, everyone can own 10 electronic products on average. The demand for electronics products increases significantly. To fulfill strong market demand, the improvements in the numbers and functions of electronic products are supported by innovations in semiconductor process technologies, which can produce the same IC cell functions in one-millionth of the space used by electronic products in 1970. The semiconductor industry currently dominates changes in electronic products.

Three trends exist in the semiconductor industry for supporting rapid functional changes in end products. First, faster IC design is required to support shorter life cycle of IC products when IC is assembled in end products and the end product life cycle is getting shorter. Therefore, rapid IC design is required to support the change in the new digital consumer era.

Second, Moore's law holds that IC function capacity doubles every 18 months [1], therefore the whole semiconductor industry is striving to sustain this trend of increasing IC function capacity. New process technologies are developed to fulfill this trend to maintain its competitiveness.

Third, owing to the considerable investment necessary to establish an IC manufacturing factory, specialization in the semiconductor industry has also become a trend. The current semiconductor industry working model functions as follows: an IC design house focuses on IC design, a foundry service provider supports IC manufacturing, and so on. Revenue growth rates in IC design houses (32%) and foundry service providers (29%) are, respectively, higher than overall semiconductor industry growth (15%) [2]. The driver of the overall increase in semiconductor industry revenue primarily comes from the new collaborative working model between IC design houses and foundries.

Figure 1 shows that, in 2004, only 34% of first IC designs can be successfully released for mass-production [3] with these new environment changes and by applying the current collaborative fabless business model. Therefore, a new business model is required, along with a framework for accomplishing it.

In the semiconductor industry new collaborative working model, a single IC design company cannot complete a new IC design task without considering manufacturing capability. An IC design is only completed and qualified when it is fully proved for manufacturability in a foundry production line.

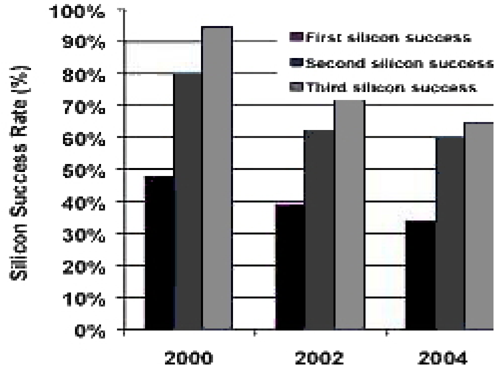

Fig. 1. IC design success rates.

Most IC design companies believe that the greatest challenges in the IC design cycle are cost and cycle time [4]. In the next generation of process technology, mask cost will increase 100% [5]. Mask costs are doubled following each failure of the first IC design. The IC design company must pay reworking costs and the new project is left idle while waiting for second and even third rework results. The IC design cycle is extended and design costs are increased. Increasing first design success rate not only reduces design costs and IC design cycle time, but also increases revenue via earlier market entry.

High design success rate will not require IC design reworking and increase the overall product revenue. Recent studies found that applying a new process technology and embedding more functions in an IC may increase the failure rate of IC design [3]. While more functions are designed into one IC chip and a new process technology is used for wafer fabrication, the increased design complexity of process technology makes it difficult to obtain a high success rate for first IC design.

Comparing to IC design work with previous process technologies (>0.13um), more process information is required for

---

1. The authors would like to thank the National Science Council of the Republic of China for financially supporting this research under Contract No: NSC-95-2221-E006-347-MY3.
2. The corresponding author (e-mail: chengft@mail.ncku.edu.tw).

achieving a successful IC design using sub-wavelength technologies (<0.13um). Moreover, the required distributed collaborative working environment for new IC design also increases the difficulty of information communication among all design and manufacturing parties, comprising IC design houses, foundry services providers, IP/Library services providers, and test/assembly services providers. As such, a new Engineering-Chain (EC) business model is essential for integrating new process technologies into the above-mentioned collaborative working environment to achieve a higher IC design success rate. This study takes the initiative to propose a novel and effective EC business model and an EC management system (ECMS) to ensure a successful and effective IC design cycle by dealing with distributed working environment and advanced process design challenges.

II. CONCEPT OF ENGINEERING CHAIN

ITRS proposed the concept of Engineering Chain (EC) to cope with design collaboration in the semiconductor industry [9]. In a previous study by the present author, EC in the semiconductor industry was first defined as a network of facilities and distributed services that performs device design; verification of design; manufacturing pilot run; assembly and test operations; yield improvement; and final release for mass-production [11]. Figure 2 compares supply chain (SC) and EC in the semiconductor industry [9].

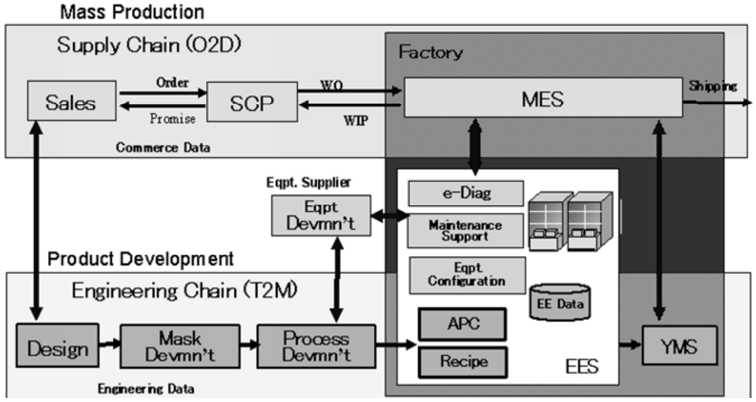

Fig. 2. Comparison of Supply Chain and Engineering Chain [9].

During the mass-production phase after successful IC design, SC manages the entire operation from order input to wafer delivery. On the other hand, during the product-development phase, EC plays the role of managing IC design operation from IC design to the release of mass production. Both SC and EC management systems should operate efficiently within the new collaborative operation model among all stakeholders to complete IC design and IC manufacturing. EC supports product development; while SC supports mass production.

The novel EC component and traditional SC component for inter-company operation were combined with the intra-company MES (manufacturing execution system) component and EES (equipment engineering system) component to create a new comprehensive e-manufacturing scope in the semiconductor industry, as illustrated in Fig. 3 [10][11]. The proposed semiconductor e-manufacturing concept focuses not only on SC "order-to-delivery" for timely and economical delivery of desired products [6][7]; but also emphases e-manufacturing support to a fast design cycle to reduce EC "time-to-market" because some IC design cycles are longer than their corresponding mass-production cycles [4][5][10].

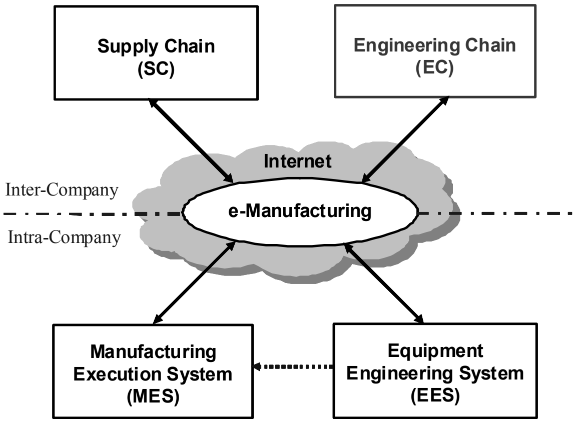

Fig. 3. e-Manufacturing scope and components.

III. INTRODUCTION TO THE ENGINEERING CHAIN MANAGEMENT SYSTEM

Traditional electronic devices have a long product life cycle that is composed of a short design phase and a long mass-production phase. However, in the present new digital consumer era, which is characterized by short product life cycle and advanced process technologies, the current IC mass-production cycles may even be shorter than their design cycles. The SC management system can handle "order-to-delivery" cycle but cannot support the EC requirements for reducing "time-to-market".

The first challenge faced by an IC design house in initiating an IC design is to ensure that the submitted design has a high success rate. The importance of first IC design success is more crucial than before because IC design failure can easily spoil an entire project due to the market becoming unprofitable.

The fact that sub-wavelength manufacturing cannot apply image-corrected processing brings new challenges for new process technologies [8]. A new technology known as optical proximity correction (OPC) is required for IC circuit design. Without OPC operation, a circuit cannot perform as expected for delivering the plan function. In 0.13um process technologies, masks for 52% of layers must be implemented with OPC operation. In 90nm process technologies, more than 70% of photo layer designs must be completed via OPC operation.

After the adoption of OPC design technology in IC design, IC design data size has been significantly increased. Basically, OPC is applied to improve the design success rate; however excessive quantities of OPC data may increase the design difficulty in this remote collaborative design environment, which lacks a feasible system architecture and communication standards.

When IC design is completed and the designed product enters the mass-production phase, SC plays the key role to assure smooth order-to-delivery operation. However, certain IC designs might not be able to enter this mass-production phase owing to high IC design failure rates. As such, like the existing SC management system, which can increase mass-production efficiency, a novel Engineering Chain Management System (ECMS) is also required for boosting product-development efficiency.

Traditional computer-integrated-manufacturing (CIM) functions in the semiconductor industry focus on intra-factory operation support, including planning, scheduling, manufacturing execution control, SPC (statistic process control), APC (advanced process control), AEC (advanced equipment control), yield management, and so on [12]. All these CIM functions are designed based on the

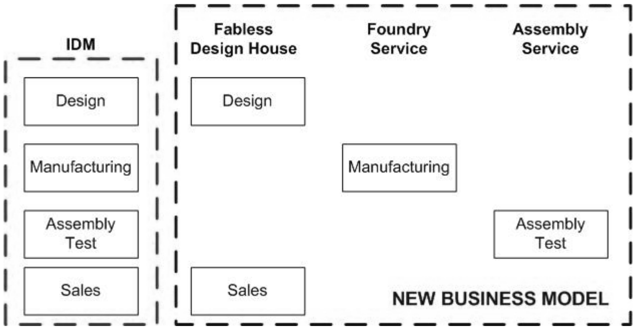

Fig. 4. New semiconductor business model.

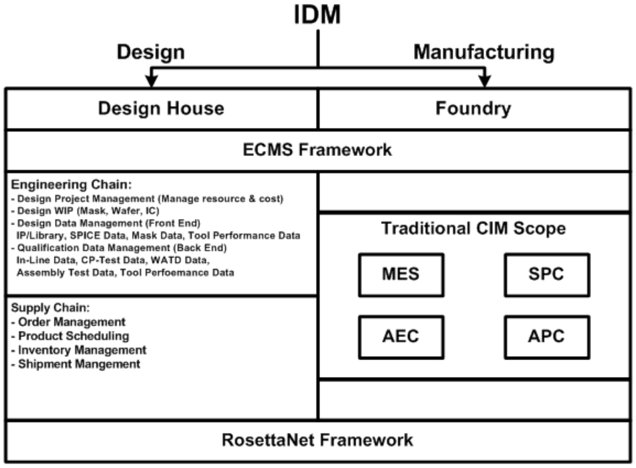

Fig. 5. New CIM scope to support Engineering Chain.

operations of a single semiconductor company.

Due to the evolution of the new business model, as depicted in Fig. 4, different from IDM's (integrated design and manufacturing) operations, current IC design, wafer manufacturing, IC assembly and test are handled by a new collaborative working team – fabless design house, foundry service provider, and assembly service provider. Consequently, the traditional CIM scope needs to be enhanced for including the supply chain management system (using RosettaNet framework for example) and the ECMS to produce a new comprehensive CIM architecture for supporting this new e-manufacturing operation [10][11]. Figure 5 shows this new CIM scope.

The CIM framework of SEMATECH has become the automation standard for semiconductors [12]-[14]. This study follows the same methodology to establish the CIM framework to develop the ECMS framework. Therefore, the ECMS framework presented in this work is designed to provide a modular, component-based application architecture that satisfies several objectives, including interoperability, substitutability, extendibility, and reuse of applications [16][17]. The ECMS requirements used to define functional components and operating scenarios are summarized in the following section. This work further develops the ECMS framework to produce better leveraging distributed computing standards and details application integration among components.

IV. REQUIREMENTS OF THE ENGINEERING CHAIN MANAGEMENT SYSTEM

An EC environment involves numerous design partners allocated among different locations working together to produce advanced IC design and engaged in considerable engineering data exchange. Each professional partner of the EC focuses on his professional work. As a coherent operation platform, the ECMS supports the realization of the competitive advantage of each member in the design cycle achieved via collaboration through transparent information exchange. The ECMS can support the operating efficiency of the collaborative team – including first design success rate enhancement, design cycle time subtraction, and finally design cost reduction. The ECMS supports EC operation and engineering data exchange by providing a new system framework and comprehensive operating scenarios.

To fulfill the expected performance of the ECMS, the key requirements are as follows [11][15]:

1) *Distributed Operation*
2) *Integration Capability*
3) *Security Control*
4) *Efficient Data Exchange Mechanism*
5) *Reliable Data Exchange Mechanism*
6) *Real-time Co-work Capability*
7) *Interoperability*
8) *Product Life Cycle Management and Project Management Capability*

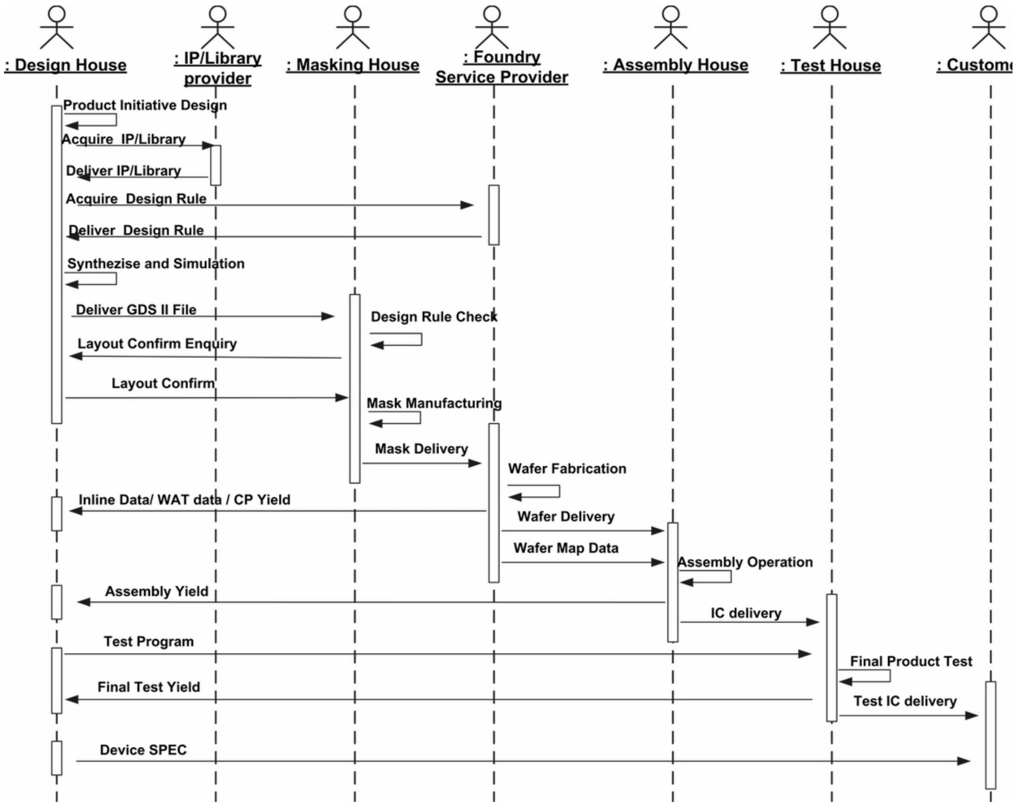

Fig. 6. Engineering Chain's operating scenarios.

9) Cross-boundary Knowledge Management

10) Design Performance Evaluation

Based upon the above-mentioned requirements, ECMS is proposed for supporting comprehensive EC operation. Each member of the EC possesses an EC agent and a local database. The EC agent is responsible for secure, accurate, and efficient engineering-data exchange among all of the EC members. Besides, the design house, IP/library house, masking house, foundry, and assembly/test house own the design management server, IP/library management server, masking service server, foundry service server, and assembly/test service server, respectively.

Coherent IC design operations among many heterogeneous companies are the operating model of the EC. Enormous quantities of data, including design files, mask data, process specifications, and yield data, need to be exchanged among all the members of the EC. Therefore, transparent information sharing is essential to significantly improve design efficiency and assure the first-pass tape out of an IC design.

Figure 6 [11][15] illustrates the operating scenarios and functional groups of EC. These operating scenarios are fundamental for completing IC design. Each operating scenario should be designed in the ECMS to optimize operating efficiency to support an effective IC design. The design house serves as the central coordinator to complete this whole IC design cycle from layout design, masking preparation, manufacturing qualification, assembly and testing to mass-production release.

Figure 6 addresses key operations for an IC design cycle. The figure includes several key considerations for reaching higher IC design success rate and fast IC design cycle. However, several issues may be still encountered and result in IC design failure.

The objectives of the EC operation include “First Tape Out Success”, “Design Cost Reduction”, “Design Cycle-Time Reduction”, “Empowerment Agility”, “WIP Visibility”, “Asset Utilization” and “Time to Market”. With the generic protocol, common system architecture and operation standards, the ECMS can provide an effective design environment for all design partners to improve IC design success rate for minimizing time-to-market and design cost.

V. IMPLEMENTATION OF THE ENGINEERING CHAIN MANAGEMENT SYSTEM

Supporting the above EC operating scenarios in the ECMS architecture requires exchanging considerable engineering data. Currently, there is no industrial standard (as what the semiconductor industry did for logistics data) for EC engineering-data exchange in the semiconductor industry. This work adopts the new generation distributed objected-oriented technology with web services [18] as the enabling technology of the ECMS framework.

A. Applying the Concept of Framework to Design the ECMS

The ECMS enhances the first-pass (passing the qualification at the first design) possibility in the IC design cycle through coherent operation by efficient and effective design information sharing. Without the ECMS, several fragmental system applications exist for partial implementation of EC operations. Notably, no standard exists for implementing applications to support the EC operations.

Existing EC applications that are not based on the framework concept eventually become legacy systems, which cannot be easily integrated with other applications in each service partner of the EC. Even worse, various applications for the same function may be established owing to the adoption of different information exchange mechanisms among service partners. For example, a single design house must maintain different yield information exchange platforms with all engaged foundry service suppliers that do not use the same platform. Consequently, when a single design project is initiated in a design house with numerous possible service providers, separate interfaces must be established with various IP/library service providers, mask houses, foundry service providers and assembly/test houses owing to the lack of a framework design and standard protocols.

A framework design in the ECMS provides several benefits for all CIM managers in an EC environment [13]. With the advance of the application of Internet and information technologies to e-manufacturing, a framework design based on these two technologies can enhance IC design productivity in EC operations. Therefore, the ECMS framework, which fulfills the key requirements of the EC, can remarkably improve the efficiency of design collaboration in EC.

B. Implementation of the ECMS Framework

To support the ECMS requirements, the ECMS framework should possess four key functionalities:

1) EC Operating Capability: The ECMS should be equipped with five levels of EC operating capabilities:

i Remote access and remote collaboration
ii Data collection and debugging
iii Data analysis
iv IC design operating- scenario-management capability
v Project and product management.

2) Data Security: Data transfer via the Internet in the ECMS is critical, and may even be a determinant of the success of a new device design. Data security thus is the main consideration of the ECMS implementation.

3) EC Application Service Registration and Publication: Overall, the EC is constructed by many applications located in various member companies for completing a specified design project. A service registration mechanism should be constructed to enable various members to register available applications and services corresponding to specific design projects.

4) Communication Protocol: The ECMS is built on top of the Internet with a firewall constructed in each company. The ECMS should adopt mainstream network protocols, which can directly pass through the firewall. Consequently, the new-generation distributed object technology, known as web services, is adopted to construct the communication infrastructure of the ECMS.

Figure 7 reveals that the ECMS framework comprises five main servers, including the IC design management server, IP/library management server, masking service server, foundry service server, and assembly/test service server, the functions of which are described below.

The design management server of an IC design house is responsible for IC design product life cycle management, IP/library data request and management, design rule file request and management, process specification request and management, process parameter request and management, GDS II file and mask management, and yield data request and management.

The IP/library management server includes an IP/library management application, a patent version management application, and a customer management application. Meanwhile, the masking service server in a masking service house includes a design-rule-checking management system, optical process correction application, work-in-progress application, shop floor management application, and yield management application. A foundry service server installed in a fab incorporates a shop floor control system, WIP management application, scheduling application, equipment management application, and yield management application.

Most assembly/test operation service providers provide both

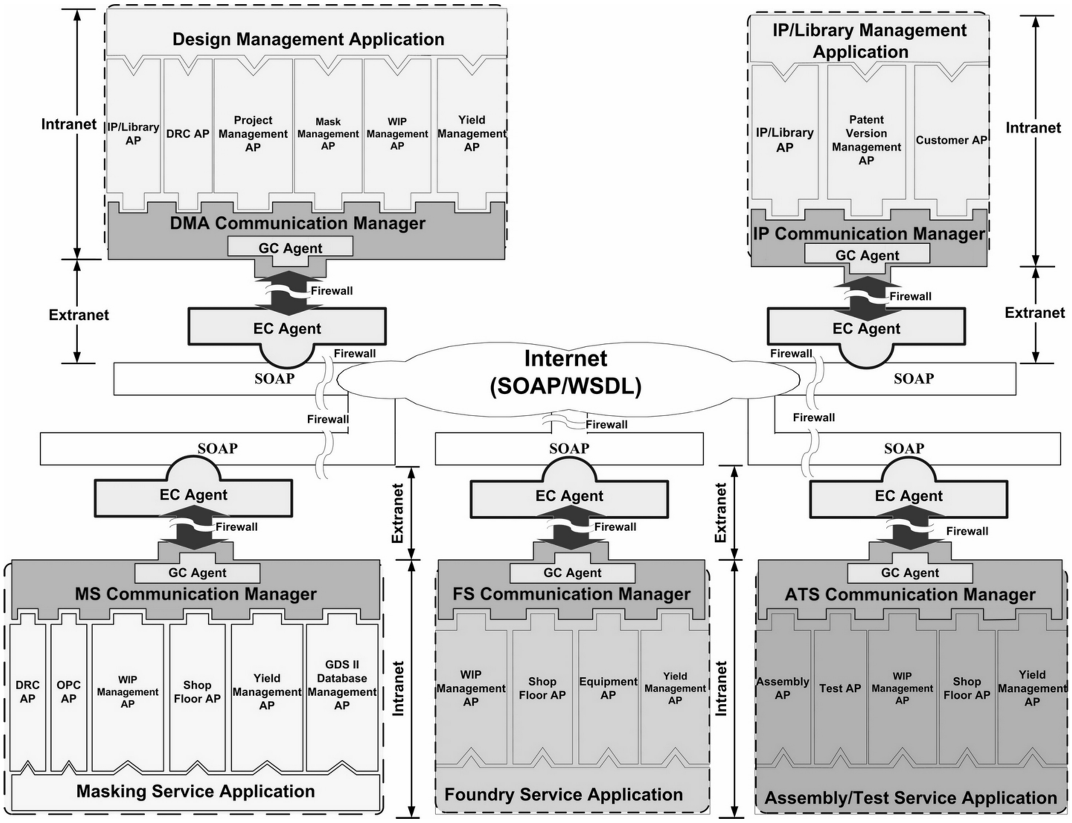

Fig. 7. ECMS framework.

services in the same factory. Their assembly/test service management server includes a WIP management application, a shop floor management application, an assembly operation management application and a test operation application.

As depicted in Fig. 7, each of the ECMS servers possesses a communication manager responsible for engineering data management operations – including data request, data classification and XLST (XML Stylesheets) data format conversion. These common functions can then be identified and designed in a generic communication component, called the generic communication agent (GC agent). Afterwards, each communication manager (of all the ECMS servers) can be constructed by inheriting the GC agent and adding specific functions for this communication manager.

Figure 8 illustrates the functional blocks of the GC agent. The GC agent is basically designed to support several common functions of the ECMS: GC communication kernel, SOAP (Simple Object Access Protocol) communication interface, UDDI (Universal Description, Discovery, and Integration) registry mechanism, data classification mechanism, XSLT mechanism, and local database.

Another common function in each ECMS server for data exchange is identified and developed via an EC agent. Notably, the GC agent is mainly responsible for common data management operation, while the EC agent is in charge of data exchange operation.

Figure 9 illustrates the functional blocks of the EC agent that possesses the generic functions of data exchange. These generic functions include a SOAP communication module for establishing the communication backbone; a security logging module to maintain all connection and data transfer records; a certificate management module for managing certification dispatch and registration; an authentication and authorization module as well as a user policies and profile management module to manage data security functionality; an XML signature and XML encryption module to manage data exchange via defined standards; a large-data transfer module to handle exchange of large amounts of data; a data quality module to ensure data quality and error recovery; and a data communication and integration services module to provide the network services jointly agreed upon by collaborative partners. Finally, the EC communication kernel manages and applies the above-mentioned modules to achieve secure, robust, and efficient data exchange to support an IC design project in an EC environment.

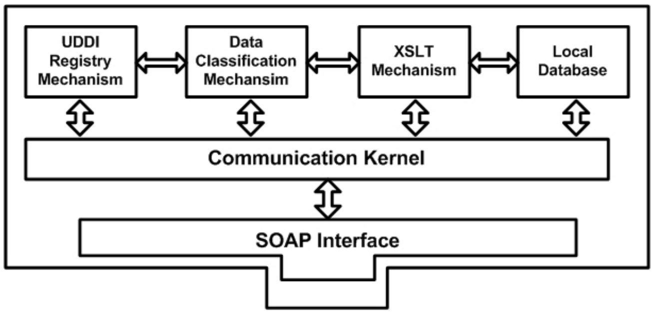

Fig. 8. Functional blocks of the GC agent.

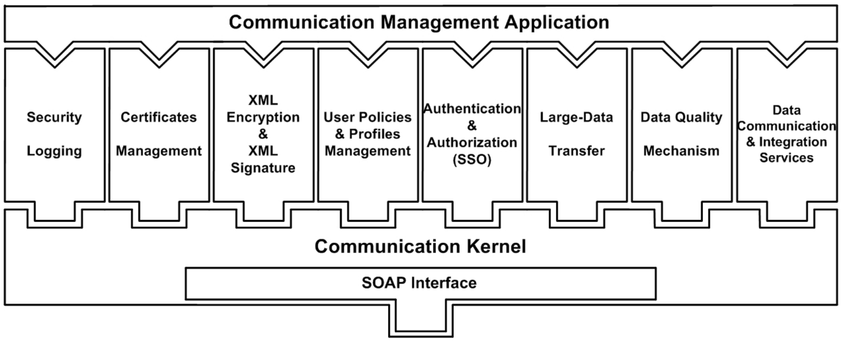

Fig. 9. Functional blocks of the EC agent.

C. *ECMS Framework Messages*

After completing the design of all of the ECMS functional servers, it is necessary to define the associated framework messages among and in-between all of the functional servers to enable interoperability and collaboration. Owing to lack of space, only the framework messages of yield data exchange between the design house and foundry service are illustrated. Figure 10 shows a

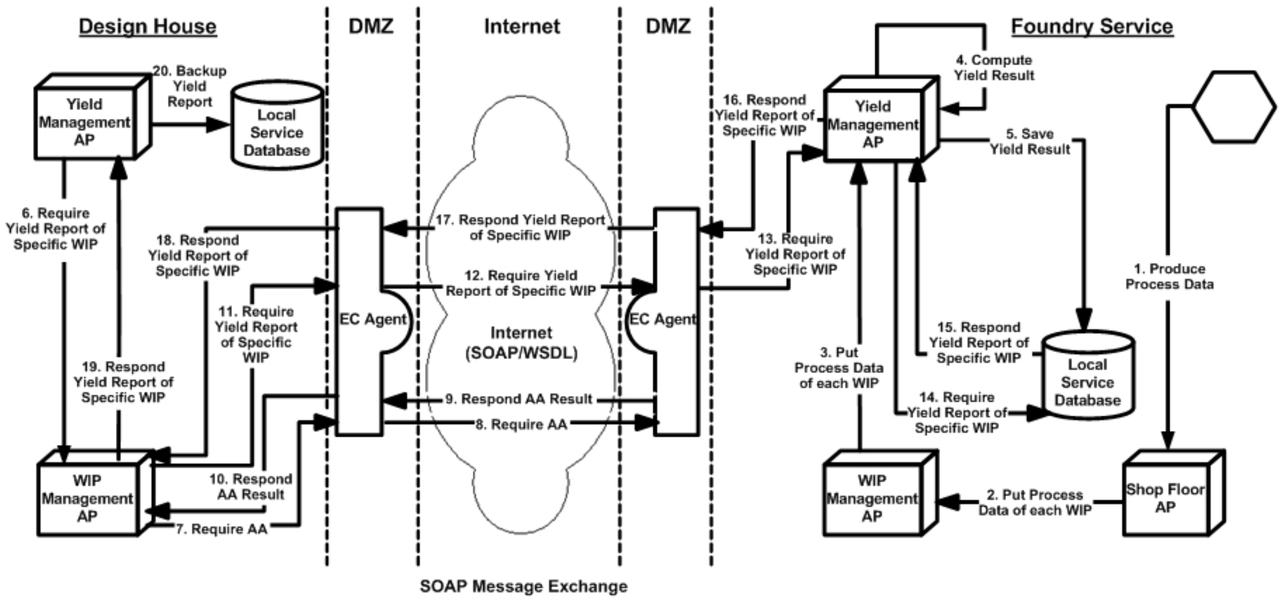

Fig. 10. Framework messages for design house requesting yield reports from foundry service.

framework-message example for a design house requesting yield reports from its engaged foundry service provider.

The above framework messages only demonstrate the scenarios for yield-report request operations. Similarly, the framework messages of other operations, such as remote job view for masking data preparation, design pattern debugging, and so on, can also be defined.

To ensure the successful development of the ECMS for supporting the IC design challenge in the semiconductor industry, overall ECMS simulation and performance evaluation are also performed as part of this project. Future research will examine ECMS simulation and performance assessment.

VI. SUMMARY AND CONCLUSIONS

This study proposes effective EC operation scenarios for improving the design productivity, through faster design cycle and higher product yield. This study also develops a collaborative platform – the ECMS. The framework of this platform is designed to support the coherent collaboration of the EC. It is believed that the ECMS framework can be applied to develop any information communication platform involving all EC design partners, and to enhance the design productivity for the semiconductor and other industries.

REFERENCES

[1] G. E. Moore, “Cramming More Components onto Integrated Circuits, Electronics”, April 19, 1965. [Online]. Available: ftp://download.intel.com/research/silicon/moorespaper.pdf

[2] D. Decker, “Outlook on the Global Fabless Semiconductor Industry”, Fabless Semiconductor Association (FSA), 2004. [Online]. Available: http://www.fsa.org/

[3] “What Are the Challenges and Opportunities in Semiconductor IP?”, FSA, Semiconductor Venture Fair III, May 12, 2004. [Online]. Available: http://fsa.org/resources/presentations/SVF_III_051304.pdf

[4] K. Jou, “IC Design House Survey 2004”, EE Times. [Online]. Available: http://www.eetasia.com/SURVEYS/EETT_ICD_TW04.PPT

[5] R. Madhavan, “Changing Economics of Chip Design”, FSA Presentation, 2004.

[6] R. Ganeshan and T. P. Harrison, “An Introduction to Supply Chain Management”, Penn State University, [Online]. Available: http://silmaril.smeal.psu.edu/misc/supply_chain_intro.html

[7] Performance Indicators in Logistics, IFS Publications / Springer-Verlag, NEVEM-workgroup, 1989.

[8] Web site of the Synopsys. [Online]. Available: http://www.synopsys.com/

[9] International Technology Roadmap for Semiconductor 2005 Edition, ITRS, Dec. 2005. [Online]. Available: http://public.itrs.net/

[10] F.-T. Cheng, “Researching Strategy and Development Proposal,” *Automation Division of National Science Council*, Taiwan, R.O.C, October 2004.

[11] J. Y.-C and Chang, F.-T. Cheng, “Engineering Chain Requirement for Semiconductor Industry,” *2005 IEEE International Conference on Automation Science and Engineering*, Edmonton, Canada, August 2005.

[12] SEMI E81, Provisional Specification for CIM Framework Domain Knowledge, June 1999.

[13] SEMI E93, Guide for CIM Framework Technical Architecture, 2003.

[14] SEMI, E102, Provisional Specification for CIM Framework Material Transport and Storage Component, March 2000.

[15] J. Y.-C. Chang and F.-T. Cheng, “Framework Development of an Engineering-Chain-Management-System for the Semiconductor Industry,” 3rd *International IEEE Conference on Industrial Informatics*, Perth, Western Australia, August 2005.

[16] F.-T. Cheng, C.-F. Chang, and S.-L. Wu, "Development of Holonic Manufacturing Execution Systems," *Journal of Intelligent Manufacturing*, Vol. 15, No. 2, pp. 253-267, April 2004.

[17] F.-T. Cheng, H.-C. Yang, and J.-Y. Lin, "Development of Holonic Information Coordination Systems with Failure-Recovery Considerations," *IEEE Transactions on Automation Science and Engineering*, Vol. 1, No. 1, pp. 58-72, July 2004.

[18] M.-H. Hung, F.-T. Cheng, and S.-C. Yeh, "Development of a Web-Services-based e-Diagnostics Framework for the Semiconductor Manufacturing Industry," *IEEE Transactions on Semiconductor Manufacturing*, vol. 18, no. 1, pp. 122-135, February 2005.