行政院國家科學委員會補助專題研究計畫成果報告

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※ **虛擬晶圓廠製造服務提供機制及其促成工具之研究(II)** ※
※ **Manufacturing Service Provisioning Mechanism and** ※
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執行期間： 90 年 8 月 1 日至 91 年 7 月 31 日

總計畫主持人：周雍強 教授
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執行單位：國立台灣大學工業工程學研究所

中 華 民 國 九 十 一 年 十 月 三 十 一 日

半導體供應網路決策品質促成技術研究-子計畫一
虛擬晶圓廠製造服務提供機制及其促成工具之研究(II)
Manufacturing Service Provisioning Mechanism and Enablers in a Virtual Fab (2/2)

計畫編號：NSC 90-2218-E-002-044
主持人：　張時中教授
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一、中文摘要

本報告總結第二年虛擬晶圓廠之研究，其研究成果包含下列兩部分。第一部份擴大第一年晶圓專製廠製造服務之研究範圍，進一步探討虛擬晶圓廠在「矽智慧財產權 (IP) 提供者—無晶圓廠 IC 設計公司—晶圓專製廠」(簡稱為 IFF) 經營模式演進過程中所扮演的角色，藉由深入訪談一些任職於無晶圓廠 IC 設計公司、IP 廠商、以及主要晶圓專製廠的管理階層或工程師，本研究進一步瞭解半導體產業中各自獨立經營的設計與製造廠商，為何以及如何能夠宛如是同一個廠商般地以伙伴關係密切合作，繼而據此建立理論模型、並預測對於服務提供機制及其促成工具的未來需求。第二部分則研究及開發一些提供智慧型製造服務的基礎元件，包括：運用軟體代理人的知識工程、以順序最佳化為基礎的排程規則選擇快速模擬器、以及在 12 吋晶圓廠中的自動化物料處理系統(AMHS)之派工。上述的研究皆有業界的配合贊助。

關鍵詞：製造服務、虛擬晶圓廠、垂直整合、演進中之模式、軟體代理人、知識工程、順序最佳化、派工、自動化物料處理系統

Abstract

This second year research of virtual fab (VF) has two parts. One part enlarges the scope from foundry manufacturing service only in the first year to the role of VF in the evolution of the Intellectual property provider-Fabless-Foundry (IFF) business models. This study performs in-depth interview with engineers/managers of fabless design houses, IP companies and leading foundry fabs. Study results lead to a better understanding of why and how virtual design-manufacturing partners successfully work together in the semiconductor industry. Future needs for service provisioning mechanism and enablers can also be forecasted. The second part investigates and develops some building blocks for intelligent manufacturing service provisioning: software agent-based knowledge engineering, ordinal optimization-based fast simulation for scheduling rule selection and dispatching of automatic material handling system (AMHS) in 300mm fabs. All these research efforts have joint sponsorship by the industry.

Keywords: manufacturing service, virtual fab (VF), vertical integration, evolutionary model, software agent, knowledge engineering, ordinal optimization, dispatching, automatic material handling system

二、緣由與目的

Fast growth of foundry fabs, fierce global competition and advancements of information technology have motivated in the semiconductor foundry industry the concept of Virtual Fab (VF) with emphasis on quality manufacturing service provisioning. The idea of VF is essentially one of the cornerstones in e-business for semiconductor manufacturing network. The principle investigators have conducted preliminary study on the subject of VF. In the study, we have identified the demands for manufacturing services under the business model of fragmented specification, given a clear definition of VF, proposed accordingly a VF framework and outlined its enabling technologies.

In view of the significance of VF for manufacturing service provisioning to the foundry, this subproject exploits the foundation established and aims at three objectives in the proposed two-year research:

1) to design for VFs a provisioning mechanism of

quality manufacturing services,
2) to develop enabling technologies or tools, and
3) to serve as a solid building block for integrated services in a semiconductor manufacturing network.

三、結果與討論

This second year research of virtual fab (VF) has two parts. One part enlarges the scope from foundry manufacturing service only in the first year to the role of VF in the evolution of the Intellectual property provider(IPP)-Fabless-Foundry (IFF) business models (Figure 1). The other part investigates and develops some building blocks for intelligent manufacturing service provisioning: software agent-based knowledge engineering, ordinal optimization-based fast simulation for scheduling rule selection and dispatching of automatic material handling system (AMHS) in 300mm fabs.

Part I: Evolutionary IPP-Fabless-Foundry Business Models

The purpose of this study is to answer the following questions: What determines the change of business models in the semiconductor industry? And how are IPP-Fabless-Foundry business models continually evolving? The semiconductor industry has gone through a process of changing from vertical integration to vertical disintegration in which the foundry-fabless model is the core structure. That is, foundry fabs and fabless design houses focus their core competency on manufacturing capability and on product innovation, respectively.

Recently, the industrial structure continues to change in two ways. First, foundry takes resources to involve some activities in IC product innovation while fabless also takes resources to involve some activities in manufacturing processes. Second, a special kind of fabless design house, IP provider (IPP), enters the design market to provide design cells with intellectual property for IC product innovation. Those changes form the IPP-Fabless-Foundry (IFF) business models which is unstable and continues to evolve. However, the way of how practitioners interact in this IPP-foundry-fabless business models and the reasons of business-modeled change is not yet well understood.

This study, therefore, focuses on IPP-Fabless-Foundry business models to explore the reasons for the evolution and to suggest a direction for next stage of evolution. Data is obtained from case study by in-depth interview with engineers/managers of fabless design houses, IP companies and foundry fabs (Figure 2). The research results lead to understand why and how virtual design-manufacturing partners successfully work together in the semiconductor industry.

This research is the first academic study to describe the phenomenon of and to theoretically explore the reasons for the evolution of business models in the semiconductor industry. The theories of Institutional Economics is applied to model the evolution of IFF and to probe the reasons for the change of IFF business models from the standpoints of individual firm level instead of industry or country level. In order to explore the reasons for the change of IFF business models and to find the conditions for further IFF development in the next stage, the IFF business models is classified into three models according the role of IPP. That is, (1) Model 1: IPP is one department of a fabless, (2) Model 2: IPP is an independent firm, and (3) IPP is one department of a foundry. In each model, the interaction of IFF is described. Then the technological and institutional conditions for the existence of each model is explored according to the relationship of business models, technology, and institution which is found based on their historical timeline. The path of IFF business-modeled change is then inferred in order to forecast the next stage of IFF evolution.

Model 3 is suggested as one of the direction for the next stage of IFF evolution. The conditions for the development of Model 3 are pointed out. As business model continue to evolve, the relationship and services demand will be dynamic in an interdependent design-manufacturing system. Therefore, the service provider in such system needs a dynamic mechanism to meet the changes in the evolutionary business model.

How does a firm provide service to its partners in such a very dynamic environment? This study first proposes a solid and clear service-oriented virtual fab (VF) concept. The concepts of virtual fab (VF) and manufacturing service have been proposed by practitioners over the past few years to face the fierce competition of the semiconductor industry. To realize the concept of VF with flexible manufacturing service provisioning in a very dynamic environment, this paper, from the standpoints of a foundry fab, clearly defines VF together with manufacturing service. Then a VF enabling framework is proposed accordingly.

The VF enabling framework consists of three layers of objects: manufacturing service, business process, and infrastructure layers. A novel scheme of dynamic manufacturing service provisioning mechanism (DMSPM) is designed to flexibly compose objects among the three layers into various manufacturing services. The skeleton of the scheme includes name mapping, business process binding, resource reservation binding, and manufacturing service management binding for flexible service composition. To assess the feasibility and potential of the framework and DMSPM, the order commitment service (OCS) provided by a foundry fab serves as a study case. A prototype system is designed and implemented to realize DMSPM in the OCS application, which demonstrates that current information technology, CASE tools, fab information infrastructure, and data/information availability make

DMSPM readily realizable and that DMSPM has a good potential for application to VF and e-business developments.

Part II: Some Building Blocks for Intelligent Manufacturing Service Provisioning

II.1 Software Agent-based Tool Dispatching

In this task, we propose a unified model for systematic representation of supervisors' lot priority determination knowledge, which serves as a foundation for knowledge-based dispatching (Figure 3). Our methodology consists of knowledge extraction via interview, building a knowledge base, implementation and inferring new facts. From our interviews with tool group dispatchers, fab dispatching coordinators, operators and MES supporting engineers, we deduce a unified model between Decision Tree and Weight Module for representing supervisors' knowledge of lot priority determination. A prototype of dispatching knowledge base system for tool supervisors (DKBS-TS) is built based on the model (Figure 4). We conduct field validation with PVD tool group supervisors. The average matching rate between the top 10 lots ranked by DKBS-TS and those by supervisors is more than 70%. Validation results support the applicability of our representation model. New pieces of knowledge are also identified and added to DKBS-TS during the validation experiment.

To learn dispatching knowledge by computers, we also propose a software agent-based approach to address these needs at the level of tool group dispatching. The learning agent (LA) consists of four functional modules: a knowledge base, a learning engine, a graphic user interface, and an inference engine, as shown in Figure 5. Deducing from interviews with veteran dispatchers, we adopt two first-order logic and tree-based representation models: decision tree and sequence tree (ST). We adopt the c4.5 algorithm for DT learning and propose a new design, ST learning algorithm, to extract the knowledge about constructing lot priority sequence in the form of ST model. We adopt object-oriented system design and the Java language for implementation of a prototype LA. Results (Figure 6) of validation with supervisors of photolithography tools lead to a high degree of matching (DOM), which indicates the LA's competence in extracting and learning knowledge from supervisors.

II.2 Design of Ordinal Optimization-based Simulation Methods for Efficient Scheduling Rule Selection for Fab Operations

In a fab with heterogeneous machine groups, the number of scheduling policies grows in a combinatorial way because each machine group has its specific dispatching rules. In this paper, we design a fast simulation methodology (Figure 7) by an innovative combination of the notions of *ordinal optimization* (OO) and *design of experiments* (DOE) to efficiently select a good scheduling policy for fab operation. Instead of finding the exact performance among scheduling policies, our approach compares their relative orders of performance to a specified level of confidence. The DOE method is exploited to largely reduce the number of scheduling policies to be evaluated by OO-based simulation. Simulation results of applications to scheduling wafer fabrications show that most of the OO-based DOE simulations require 2 to 3 orders of magnitude less computation time than those of a traditional approach, and the speedup is up to 7,000 times in certain cases (Table 1).

II.3 Dispatching of Over Head Transport Intrabay

Many heuristic dispatching rules are proposed for Automated Material Handling System (AMHS). Some of them are tested and applied in the OHT (Over Head Transport) intrabay system in the 300mm wafer fab. Most of researches believe that the Nearest Job First (NJF) dispatching rule gets the best performance out of all heuristic dispatching rules regardless the waiting time concern. In this task, we show by analysis that that the NJF dispatching rule is not the best dispatching rule and with only 66% probability on average that the optimal dispatch decision-making follows the NJF dispatching rule for ten job cases. We also bring out the knowledge-base concept by matching good rules with application situations to improve the system performance.

III. Publications

1. Y.-H. Su, R.-S. Guo, S.-C. Chang, "Virtual Fab: Enabling Framework and Dynamic Manufacturing Service Provisioning Mechanism," to appear on *Information Management.*
2. B.-W. Hsieh, C.-H. Chen, S.-C. Chang, "Scheduling Semiconductor Wafer Fabrication by Using Ordinal Optimization-based Simulation," *IEEE Trans. on Robotics and Automation,* Oct ,2001.
3. B.-W. Hsieh, S.-C. Chang, C.-H. Chen, "Efficient Selection of Scheduling Rule Combination by Combining Design of Experiment and Ordinal Optimization-based Simulation," submitted to *ICRA2003,* Oct. 2002.
4. Y.-T. Lin, S.-C. Chang, M. Chien, C.-H. Chang[3], K.-H. Hsu[3], H.-R. Chen[3], B.-W. Hsieh, "Design and Implementation of a Knowledge Representation Model for Tool Dispatching," *Proceedings of International Symposium on Semiconductor Manufacturing 2002,* Tokyo, Oct. 15-17, 2002, pp. 109-112.
5. Y.-J. Chang , S.-C. Chang, S.-K. Jeng, C. Lin, M. Chien, C. H. Chong, K. H. Hsu, "A Learning Agent for Supervisors of Semiconductor Tool

Dispatching, *Proceedings of International Symposium on Semiconductor Manufacturing 2002*, Tokyo, Oct. 15-17, 2002, pp. 101-104.

四、計畫成果自評

Our second year research has gone beyond the 1st year scope of manufacturing services provisioning by virtual fabs to the role of VF in the evolution of the Intellectual property provider-Fabless-Foundry (IFF) business models. Building blocks have been developed for intelligent manufacturing service provisioning: software agent-based knowledge engineering, ordinal optimization based fast simulation for scheduling rule selection and dispatching of automatic material handling system (AMHS) in 300mm fabs. Results have been published as two journal papers and three international conference papers.

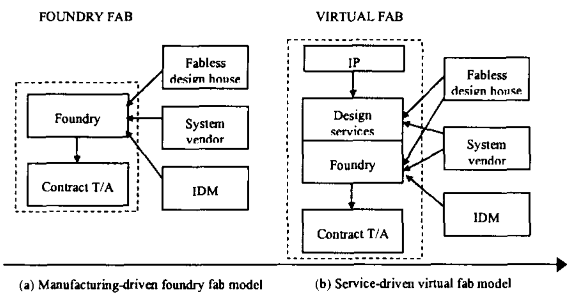

Figure 1: Evolution of foundry business model

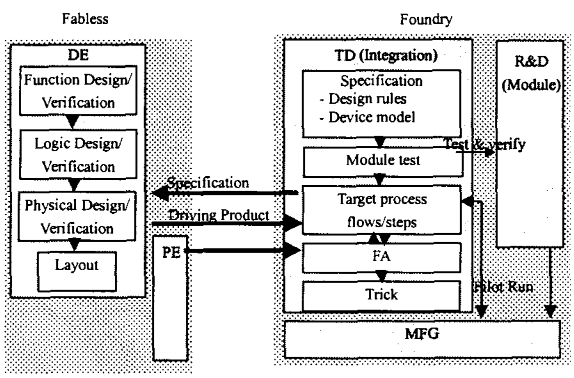

Figure 2: Interaction between Fabless and Foundry for Tuning

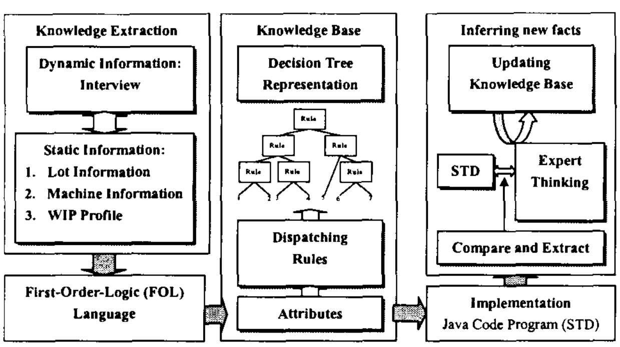

Figure 3: Dispatching Knowledge Engineering

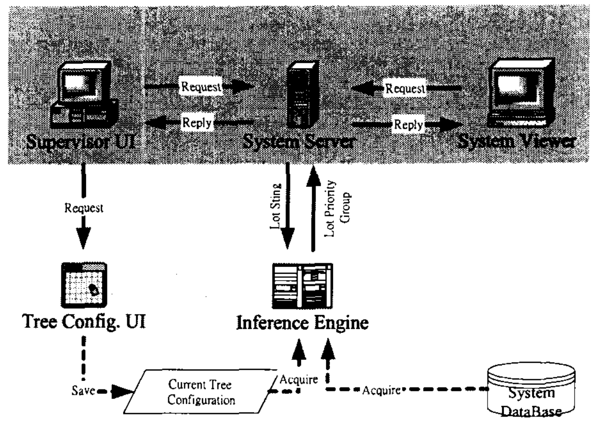

Figure 4: System Architecture of DKBS-TS

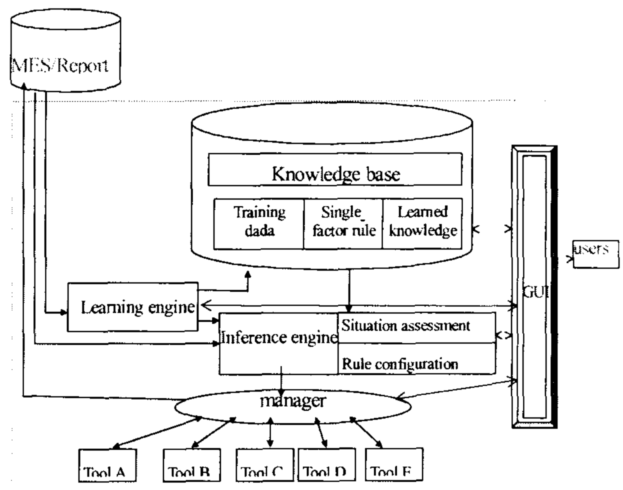

Fig 5: Architecture of the dispatching learning agent

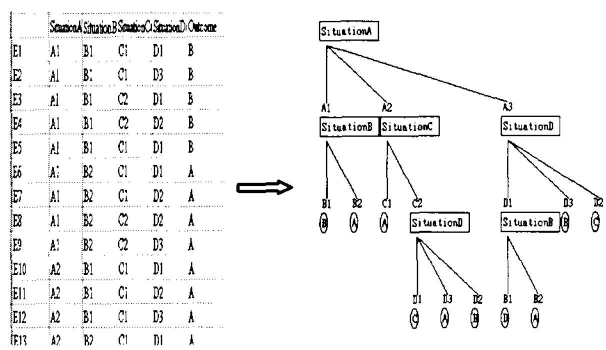

Fig 6: Decision tree learning for fab-level policy selection

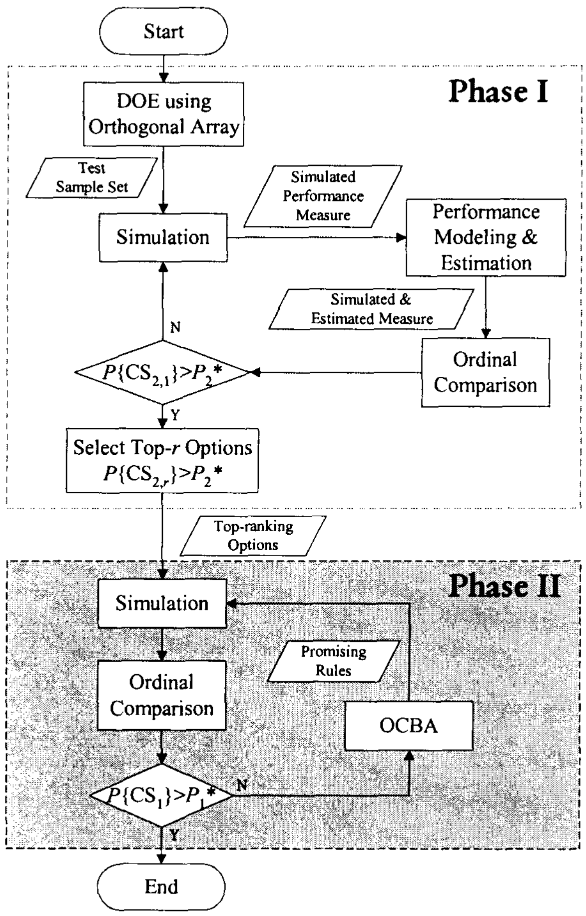

Figure 7: Flowchart of the OO-based DOE algorithm

Table 1: Computational efficiency of the OO-based DOE simulation

Exp. ID	Performance Index	Simulation Replications		Time Saving Factor
		Traditional (approximated)	OO-based DOE	
1	VCT	7,023,865	972	7,226
2	VCT	5,520,734	783	7,051
3	SM	1,099,417	576	1,909
4	SM	1,994,606	435	4,585
5	MCT	22,524	858	26
6	MCT	20,583	1,053	20
7	SM	381,547	546	699
8	SM	476,888	417	1,144