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A Web Services Based Collaborative Management Framework for Semiconductor Equipment

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***Abstract*—Web Services have afforded inter-enterprise information technologies to integrate heterogeneous systems in the e-manufacturing environment along the supply chain. In a semiconductor foundry, the equipment failure has long been recognized as a major source of unpredicted production process breakdown and excessive production loss. Equipment maintenance management is one of the important tasks in semiconductor manufacturing. Due to the prosperity of Internet and information technologies, e-diagnostics and e-maintenance through Internet have been considered as important applications in industry. Web Services can assist the data integration in heterogeneous e-manufacturing systems to support faster and remote maintenance functions. In this paper, a Web Services based Collaborative Planning, Forecasting and Replenishment (CPFR) platform, namely WS-CPFR, is developed to collaboratively manage spare parts in semiconductor equipment between equipment suppliers and semiconductor factories. The global application involving multi-factory and multi-supplier of this WS-CPFR platform can be easily achieved with Web Services technology.**

I. INTRODUCTION

IN recent years, the architecture of e-manufacturing has been continuously emerging with the substantial advancements in Internet and information technologies [1]. Through these technologies, e-manufacturing seamlessly integrates factory shop floor system, e-diagnostics, e-maintenance as well as e-collaboration. The intra- and inter-organizational information integration and visibility allow enterprises to rapidly respond customers' diversified requirements and to reduce production cost. Web Services have recently afforded an essential opportunity for inter-enterprise integration along the supply chain to realize a dynamic virtual network for enterprises [2]. In practice, however, most business applications of Web Services focus on intra-organizational integration rather than inter-organizational integration. Web Services enable the integration among heterogeneous systems in the modern e-manufacturing environment [3], [4].

Due to the high capital investment of semiconductor equipment, the equipment failure and breakdown result in an excessive production loss. Semiconductor manufacturers can improve the utilization and availability of equipment through the effective mechanisms of diagnostics and maintenance. Maintenance Management System (MMS) includes several functions such as quality management, supplier evaluation, maintenance reporting, spare part inventory control, predictive maintenance, work order dispatch, human resource management, etc [5]. Spare parts are used to replace the failed parts in order to maintain the equipment availability.

Due to the high uncertainty of spare part demands, it is very difficult to manage the inventory of spare parts. Collaborative Planning, Forecasting and Replenishment (CPFR) is a relatively new initiative proposed by Voluntary Interindustry Commerce Standards [6] to establish the collaborative mechanisms for trading partners in supply chains. For reducing uncertainty and cost, CPFR can be adopted by semiconductor manufacturers and equipment suppliers to collaborate on the spare part management. CPFR can be implemented in the environment of e-manufacturing, e-diagnostics and e-maintenance to provide a collaborative mechanisms for spare part management.

To achieve the objective of code and service reuse, the CPFR system for spare part management can be developed and integrated based on Web Services technology. This study aims at integrating remote equipment data collection and monitoring with e-diagnostics and e-maintenance systems in order to support an inter-enterprise platform based on Web Services, which allows semiconductor manufactures and equipment suppliers to collaborate on the planning, forecasting and replenishment for spare parts. The relatively new information technology, Web Services, is adopted to implement the proposed collaborative management system such that equipment engineers can effectively integrate all maintenance related tasks among semiconductor manufacturers and equipment suppliers. Semiconductor manufacturers, therefore, can significantly improve the equipment availability and utilization, and decrease the inventory level and cost of spare parts. Equipment suppliers can improve the service level of spare part provisioning to

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semiconductor manufacturers as well.

II. Background of E-Diagnostics and E-Maintenance

Recently, International SEMATECH (ISMT) has proposed e-diagnostics guidelines [7] and guidebooks [8] with respect to the functional requirements of e-diagnostics. Additionally, International SEMATECH and Japan Electronics and Information Technology Association (JEITA) have started their joint research on developing the architecture of Equipment Engineering System (EES) for e-manufacturing. E-diagnostics plays an essential role in e-manufacturing to support the remote monitoring and diagnostics for equipment suppliers. Furthermore, e-diagnostics can provide the functions of data collection and fault analysis as the basis of e-maintenance to achieve the capabilities of self-diagnosis, predictive maintenance and automated notification. International SEMATECH categorizes the capabilities of e-diagnostics and predictive maintenance into four levels [9]: Level 0-access and remote collaboration, Level 1-connect and control, Level 2 - automated analysis, and Level 3 -prediction. In Level 3, e-diagnostics/maintenance can identify the negative trend of equipment health as well as notify the message to equipment engineers to perform related equipment maintenance and repair operations without delay.

There exist some remote diagnostics systems developed for various industries such as semiconductor manufacturing [3], [4], [10], [11], microscope industry [12], cement industry [13], machine fault diagnoses [14], etc. By using e-diagnostics and e-maintenance, the equipment breakdown can be substantially shrunk, and expectedly zero downtime be achieved [15]. Additionally, the smart and effective maintenance can be realized by incorporating with intelligent agents and e-business applications such as Supply Chain Management (SCM), Enterprise Resource Planning (ERP), Customer Relationship Management (CRM), etc [1]. The remote equipment evaluation in real time needs to integrate a variety of technologies involving device sensors, intelligent agents, communication, web-enabled monitoring, prognostics and diagnostics, e-business integration tools and self-maintenance. Koç *et al.* [1] proposed an e-maintenance platform in which Watchdog Agent is the kernel for degradation prediction.

The existing remote diagnostics systems have four primary drawbacks: using dedicated ISDN or telephone connections, applying proprietary information integration, providing limited functions of downloading equipment data for analysis, and manually browsing and integrating data from websites [3], [4]. To improve the existing systems, Hung et al. [4] proposed a Web Services based e-Diagnostics Framework (WSDF), which can integrate various heterogeneous data and systems on Intranet and Internet.

III. Collaborative Planning Forecasting and Replenishment

A. CPFR concepts

Collaborative Planning, Forecasting, and Replenishment (CPFR) is a recent initiative for supply chain integration and collaboration initiative. The nine-step CPFR process model is proposed by Voluntary Inter-Industry Commerce Standards [6] for supply chain collaboration.

In the beginning, most of the CPFR applications have concentrated on grocery industry [16], [17]. The primary driving forces for CPFR adoptions in the grocery industry include fierce competition, shorter product life cycle, offshore production and supply chain cost structure [16]. Supply chain collaboration has become a critical element in the complex manufacturing environment, and CPFR applications in the manufacturing field are increasing (e.g., [17]).

CPFR mainly consists of three stages: planning stage, forecasting stage, and replenishment stage [6]. Furthermore, these three stages are further divided into nine steps, which apply an iterative approach to develop the agreed collaborative business planning, forecasting and replenishment among partners. The details of steps adopted in CPFR depend on the capability of partners, role of supply chain, information source and consensus among partners.

CPFR steps and details embraced in the supply chain collaboration between partners can be decided by mutual discussions. Retailer or the vendor may play a lead role in sales forecast, order forecast, and order generation in CPFR process. Therefore, CPFR model can be divided into four scenarios of A, B, C, and D, as shown in Table I [6]. In scenario A, the

TABLE I
Key CPFR scenario leads.

	Sales forecast	Order forecast	Order generation
Scenario A	Buyer	Buyer	Buyer
Scenario B	Buyer	Seller	Seller
Scenario C	Buyer	Buyer	Seller
Scenario D	Seller	Seller	Seller

replenishment order management is led by the buyer, where the buyer leads forecast and order generation. In scenarios B, C, and D, the order generation is assigned to the seller, similar to VMI strategy.

Readers are referred to [6] for the further details of CPFR. The nine steps of CPFR are briefly discussed as below:

Step 1. Develop Collaboration Arrangement
Step 2. Create Joint Business Plan
Step 3. Create Sales Forecast
Step 4. Identify Exceptions for Sales Forecast
Step 5. Resolve/Collaborate on Exception Items for Sales

Forecast
Step 6. Create Order Forecast
Step 7. Identify Exceptions for Order Forecast
Step 8. Resolve/Collaborate on Exception Items for Order Forecast
Step 9. Generate Order

IV. Development of WS-CPFR

A. Foundation of WS-CPFR

The equipment maintenance cost contributes a major portion of the production costs in semiconductor manufacturing firms. The primary objective of the spare part inventory management is to ensure that the failed equipment items can be replaced right away to maintain satisfactory productivity. The characteristics of spare parts significantly differ from that of production items on criticality, specificity, demand pattern and part value [18]. Additionally, the proposed Web Services based CPFR system, namely WS-CPFR, considers the diagnostics and maintenance requirements such as work order release and auditing, failure resolution, preventive maintenance, predictive maintenance and corrective maintenance, etc. With this collaborative management system, Mean Time Between Failure (MTBF) can be lengthened as well as Mean Time to Repair (MTTR) can be shortened.

The WSDF developed by Hung et al. [3] and Hung et al. [4] can automatically integrating diagnostics information with Web Services technologies. With WSDF, the functions of e-diagnostics and e-maintenance such as automatically collecting equipment data, remotely diagnosing, fixing, and monitoring equipment, and analyzing and predicting the equipment performance can be achieved over the Intranet and Internet. The proposed WS-CPFR is constructed on the basis of WSDF. Similar to WSDF, WS-CPFR can collect, integrate and exchange data and information among cross-network, cross-platform, and heterogeneous systems. In WS-CPFR, not only the diagnostics and maintenance related data, information and systems are integrated, but also those of the spare part logistics management are integrated to support the maintenance management objective of near-zero downtime.

According to WSDF, in WS-CPFR, Simple Object Access Protocol (SOAP) is adopted as the messaging protocol to realize the inter-operation of cross-platform and distributed heterogeneous systems [19]. As well, Universal Description Discovery and Integration (UDDI) performs the directory function for locating the services on Web [20]. Web Services are programmable business application components expressed by Web Services Description Language (WSDL), and they are published on Web [21]. The heterogeneous information can be integrated and exchanged among cross-network and cross-platform by expressing data with eXtensible Markup Language (XML) [22].

In WSDF, the sub-systems in manufacturing factory side mainly include Equipment with Embedded Agents (EEA), On-site Diagnostics/Maintenance Server (ODMS), Local Diagnostics/Maintenance Database (LDMD), APC/OEE Server (AOS), and On-site Diagnosability/Maintainability Evaluator (ODME). In equipment supplier side, the sub-systems include Remote Diagnostics/Maintenance Server (RDMS), Global Diagnostics/Maintenance Database (GDMD), and Remote Diagnosability/Maintainability Evaluator (RDME) [3], [4].

The On-site Logistics Management Server (OLMS) in semiconductor factory side and Remote Logistics Management Server (RLMS) in equipment supplier side are two primary sub-systems added into the WS-CPFR for collaboratively managing spare parts. In WS-CPFR, Equipment Engineering System (EES) connects equipment with plant, enterprise and equipment suppliers. By Data Access Control (DAC), EES can store and retrieve equipment engineering data. These data can be transferred via Internet to the related equipment engineering applications developed by semiconductor manufacturers and equipment suppliers. In general, the equipment engineering applications include e-Diagnostics, Equipment Health Monitoring (EHM), Advanced Process Control (APC), Fault Detect and Classification (FDC), Overall Equipment Effectiveness (OEE), etc. For ensuring the security of information access, the integrated system incorporates an Authentication Service (AS) mechanism developed by Hung et al. [3].

In WS-CPFR, OLMS and RLMS incorporate with the e-diagnostics/maintenance system for semiconductor equipment in WSDF. Therefore, WS-CPFR mainly includes six sub-systems: (1) Equipment with Embedded Agents (EEA), (2) On-site Diagnostics/Maintenance Server (ODMS) and Database, (3) Advanced Process Control (APC) and Overall Equipment Effectiveness (OEE), (4) On-site Diagnosability/Maintainability Evaluator (ODME), (5) On-site Logistics Management Server (OLMS), and (6) Remote Logistics Management Server (RLMS). The first four sub-systems were developed in WSDF [3], [4]. OLMS is developed according to the requirements of e-diagnostics/maintenance to build the logistics network of spare parts. OLMS and Remote Logistics Management Server (RLMS) are linked by WS-CPFR, which can allow both sides to collaborate on the planning, forecasting and replenishment of spare parts.

B. WS-CPFR architecture

The CPFR guidelines proposed by VICS mainly aim at reducing the uncertainties of demand, process and supply through effective information sharing and collaboration between trading partners. In the WS-CPFR for spare parts of semiconductor equipment, the semiconductor manufacturing firm act as buyer and the equipment supplier as seller. With respect to the requirements of e-diagnostics/maintenance, the manufacturing firms share the information involving preventive maintenance, predictive maintenance, corrective maintenance, demand forecast, part degradation prediction, maintenance schedule, OEE to equipment suppliers.

With the shared information of preventive maintenance, equipment suppliers can prepare the required spare parts for manufacturing firms in advanced. With the information of predictive maintenance, equipment suppliers also can more accurately predict the required spare parts for failed items. With the information of corrective maintenance, equipment suppliers can more quickly respond the required spare parts to the manufacturing firms, which results in the reduction of production loss due to machine breakdowns. The demand forecast and OEE information allow both sides to make more accurate replenishment decisions through CPFR. The uncertainty of spare parts of semiconductor equipment and replenishment lead times can be reduced by implementing CPFR, and the spare part inventory cost, equipment cost and production loss can thus be decreased.

The proposed WS-CPFR system is developed by Web services architecture (refer to Fig. 1). WS-CPFR mainly integrates OLMS in the manufacturing firm (factory side) and RLMS in the equipment supplier (supplier side). Due to the transmission flexibility of Web services, OLMS and RLMS can easily incorporate with WS-CPFR and use the applications provided by Web services. Since the transmission between OLMS and RLMS is via SOAP protocol, WS-CPFR can be easily extended to the vision of globalization (refer to Fig. 2). Multi-supplier and multi-factory can be included in the global architecture as in WSDF.

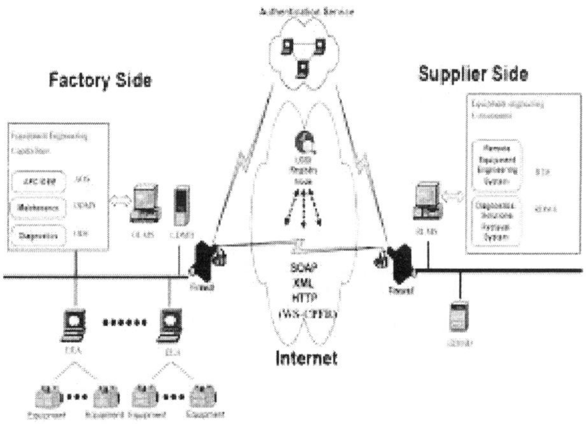

Fig. 1. The framework of WS-CPFR.

C. *System analysis for WS-CPFR*

The proposed WS-CPFR system for semiconductor equipment is developed according to the requirements of diagnostics and maintenance, and the CPFR guidelines by VICS. The service components are developed for the CPFR steps, which can support the functions and operations of OLMS and RLMS. The nine steps of WS-CPFR for spare parts of semiconductor equipment are briefly discussed as below:

Step 1. Develop Collaboration Arrangement for spare parts of semiconductor equipment: Semiconductor manufacturing firm (buyer side) and equipment supplier (supplier side) agree on implementation principles and related guidelines to establish a collaborative relationship, and thus enter into a collaboration agreement for planning, forecasting and replenishment for spare parts. Collaboration agreement defines the objectives, resource requirements, shared data and confidentiality conditions for the WS-CPFR initiative on managing the spare parts of semiconductor equipment.

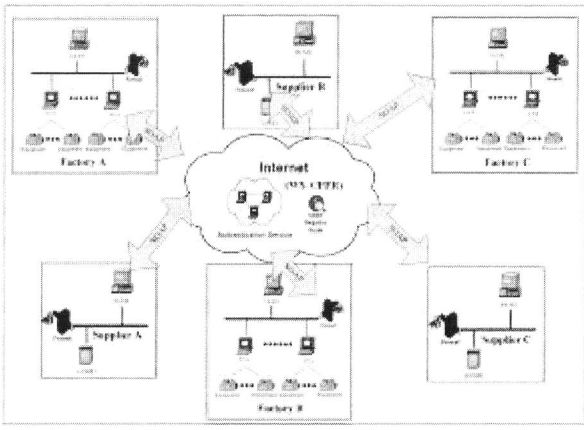

Fig. 2. The global WS-CPFR architecture.

Step 2. Create Joint Maintenance Plan: Both sides identify partnership strategies, communication and operational plan, exception criteria for managing variation. The management profiles of spare item such as order commitment, lead times and order intervals are established in this step. This step mainly identifies the items for collaboration management, and the shared information of maintenance policy and data.

Step 3. Create Demand Forecast for Spare Parts: In general, the maintenance types of semiconductor equipment consist of preventive maintenance, predictive maintenance and corrective maintenance. In this step, the actual spare part demands from the semiconductor manufacturing firm are shared to generate the more accurately demand forecast. OLMS integrates the OEE data supported by AOS, ODE and ODMS to generate the schedule and prediction of preventive maintenance and predictive maintenance. With such information, the WS-CPFR can generate the spare part demand forecast of spare parts. After coordination, the generated demand forecast becomes the common guidance for mutual subsequent order forecasting of spare parts.

Step 4. Identify Exceptions for Demand Forecast for Spare Parts: This step focuses on identifying the exception items that do not satisfy the agreed criteria defined by both sides in demand forecast.

Step 5. Resolve/Collaborate on Exception Items for Demand Forecast: This step involves resolving demand forecast exceptions by querying shared data, email, telephone conversations, meetings, and so on and submitting any resulting changes to demand forecast. The increased real-time collaboration enabled by WS-CPFR fosters effective joint decision-making between both sides, which is expected to gradually increase confidence in the eventual committed order.

Step 6 Create Order Forecast for Spare Parts: Demand forecasts of spare parts from Step 3 is incorporated with maintenance information, casual information and inventory policies from OLMS to support the order forecast in this step. The short-term use of order forecast is to generate orders while the long-term application exists in maintenance planning and partnership strategies of spare parts. In scenarios A and C, the semiconductor manufacturing firm is responsible for this step. In scenarios B, and D, the equipment supplier is responsible for this task.

Step 7 Identify Exceptions for Order Forecast of Spare Parts: This step is similar to the step (Step 4) of identifying exceptions for demand forecast. Exception items for order forecast are explored based on pre-determined exception criteria.

Step 8 Resolve/Collaborate on Exception Items for Order Forecast of Spare Parts: Similar to the step (Step 5) of resolving/collaborating on exception items for demand forecast, this step involves the process of investigating order forecast exceptions through querying shared data, email, telephone conversations, meetings, and so on and submitting any resulting changes to order forecast.

Step 9 Generate Order of Spare Parts: Once the order forecasts are agreed, they can be changed into committed orders. No matter which side generates orders for replenishment, the focus is on meeting the replenishment procedure. In Scenario A, the semiconductor manufacturing firm is responsible for this step. In Scenarios B, C, and D, the equipment supplier is responsible for this task.

V. System Implementation

A. System architecture

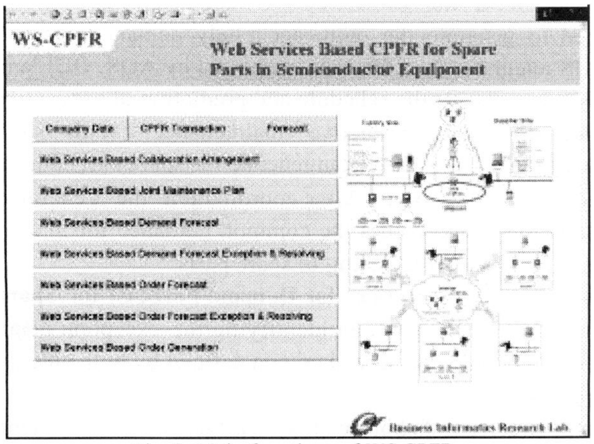

Fig. 3. Main functions of WS-CPFR.

The proposed WS-CPFR is implemented by Microsoft Visual Studio .net, and the system is operated on Windows 2000 Server. Additionally, the database management system is SQL Server 2000. The WS-CPFR system provides a collaborative management platform based on Web Services for semiconductor spare parts. This platform connects OLMS in semiconductor factory side and equipment supplier side. The main functions of WS-CPFR are illustrated in Fig. 3. The architectures of OLMS and RLMS are shown in Fig. 4 and 5, respectively.

With Web Services, the proposed collaborative management platform, WS-CPFR, can easily integrate

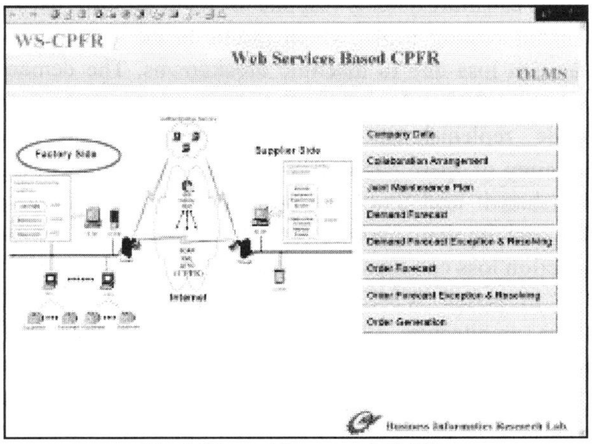

Fig. 4. The architecture of OLMS.

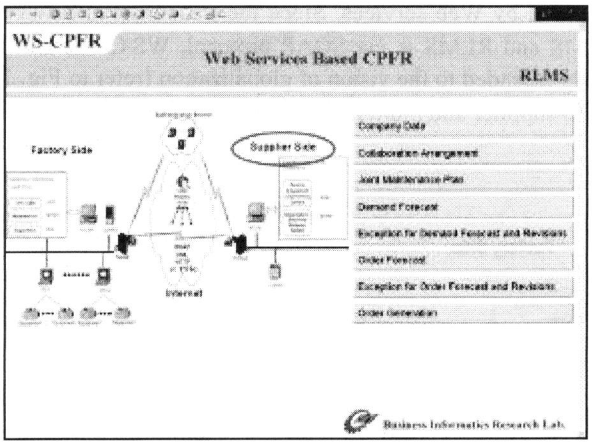

Fig. 5. The architecture of RLMS.

maintenance management system and CPFR as well as synchronize with other e-business applications. In semiconductor manufacturing, the vision of Device-to-Business (D2B) can be achieved through the proposed system.

VI. Conclusions

With the rapid advancement of Internet and information technologies, the e-business applications have been broadened to e-diagnostics and e-maintenance in semiconductor industry. Through these advanced technologies, semiconductor manufacturers can remotely collect and monitor the real-time equipment data. Therefore, they can more accurately predict the failure pattern and failure time of equipment. This remote data collection and monitoring mechanisms can be incorporated with e-manufacturing in order to provide the inter-enterprise integration and information visibility for equipment status.

The nine steps and primary four scenarios of CPFR proposed by VICS only provide guidelines for implementation, and these guidelines can be further designated for various industries by considering their characteristics. With respect to the requirements of spare parts in semiconductor equipment, this study develops a Web Services based CPFR system, WS-CPFR, for collaboratively planning, forecasting and replenishing spare parts between fabs and suppliers. The developed WS-CPFR system assist maintenance engineers to make right decisions on replenishment of spare parts to reduce equipment downtime, maintenance cost and production loss.

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