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Abstract: This paper evaluates a Cost of Ownership model for a piece of high-tech equipment in the semiconductor area. The paper outlines the development of COO, emphasizing desired goals, methods used, sources and manipulation of data and a practical example from ESI

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ENGINEERING ECONOMIC ANALYSIS

TERM PROJECT

Cost of Ownership Model for the Laser Memory Yield Enhancement System at Electro Scientific Industries Inc. (ESI)

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TABLE OF CONTENTS

0.) EXECUTIVE SUMMARY

Cost of ownership (COO) has become increasingly important in semiconductor decision making processes. Evaluating the Cost of Ownership (COO) of Hi-tech equipment in the Semiconductor Industry is currently a "Hot" topic. We intend to look at a COO model for a real piece of Hi-tech equipment; examine the COO model used and how it compares with other industry models (e.g. the SEMATECH COO for Semiconductor Equipment); and look at the effect of changing some of the model's parameters and their effect on the result of the model in order to find the major influences.

In our paper, the development of a cost of ownership is outlined with emphasis being placed on the desired goals, the methods used, the sources and manipulation of the data, and a practical example from Electro Scientific Industries Inc. (ESI).

1.) INTRODUCTION

Electro Scientific Industries, Inc. (ESIO/NASDAQ) designs and builds sophisticated manufacturing tools for the worldwide electronics industry. The company produces advanced laser trimming and processing systems for hybrid, multi-chip module, semiconductor and packaging manufacturers; equipment for the production, handling and testing of passive components, and machine vision products.

Founded in 1953, ESI's first products were high-precision resistance measurement instruments and reference standards. The company developed laser-based systems for hybrid circuit resistor trimming in 1970. In 1980, the company expanded its laser product line by introducing an advanced laser system, incorporating a laser of the company's own design, to be used by semiconductor manufacturers for the repair of redundant memories. In 1982, ESI acquired Palomar Systems, Inc., a successful supplier of manufacturing equipment for passive component chips. In 1991, ESI acquired Intelledex Vision Products, a manufacturer of systems that perform video pattern recognition and optical character recognition for many industries including electronics, automotive and general manufacturing. In 1994, ESI acquired Chicago Laser Systems Inc., an international supplier of hybrid laser trim systems. In 1995, ESI acquired XRL, Inc., an international supplier of laser memory yield enhancement systems.

ESI's products are designed to enable electronics manufacturers to reduce production costs, increase yields and improve the quality of their products. Currently, applications include the following five market segments:

1. Semiconductor Processing
2. Hybrid Circuit and Multi-Chip Module Production

3. Laser Micro-Via Drilling
4. Passive Component Equipment
5. Machine Vision

ESI's of laser memory yield enhancement systems utilize precise laser energy to improve the yields of memory manufacturers all over the world. The most recent systems, including those from XRL, have set new standards for speed, accuracy, throughput and user interface capability in a very demanding market segment. ESI's innovative use of robotic loading/unloading, precision X-Y motion, diode-pumped laser energy, programmable spot size, built-in link inspection, and local language support has led to substantial yield increases.

The equipment used for the model is a Laser Memory Yield Enhancement System manufactured by ESI (Electro Scientific Industries Inc.) [Appendix II]. One of the major uses of the equipment is to disable defective rows and columns (addresses) of memory on DRAMs and enable spare (redundant) rows and columns of memory on the chips in order that the full functional memory capacity of the chips is maintained. This yield enhancement (sometimes known as redundancy activation) function is performed by vaporizing fuses (links) on the memory chip by means of a laser. The Laser Memory Yield Enhancement System is positioned at the end of the processing stage, after initial functional test, while the chips are still in wafer form. After the system processes the chips, they are once more functionally tested, sawn into individual die, sorted and packaged.

3.) COST OF OWNERSHIP BACKGROUND

Equipment purchase decisions are often based on initial purchase price and installation costs and do not consider the effect of equipment reliability, calibration, and utilization. These factors may have a greater impact on cost of ownership than purchase costs. With equipment costs rising every technology generation, manufacturers became increasingly sensitive to equipment cost. Therefore, SEMATECH began developing a Cost of Ownership (COO) model for wafer fabrication equipment in 1990 . Dean Toombs brought the concept of COO to SEMATECH as an assignee from Intel. Based on his ideas, COO was developed as a sophisticated spreadsheet model that could be applied to wafer processing equipment [2].

Cost of Ownership of semiconductor equipment is becoming a very important topic in the semiconductor industry. A first approximation to the projection of future semiconductor equipment prices is the extrapolation of historical price trends. Prices for semiconductor tools have been increasing at a compound rate of 13%, with individual tool types varying between 10% and 15% between 1982 to 1992 (VLSI Research). [11]

4.) COST OF OWNERSHIP IN THE LITERATURE

Cost of Ownership was developed to address the economic and productive performance of a fabrication tool by estimating the total life-cycle cost of a specific semiconductor process step. Since there are many similarities between wafer fabrications, the methods used for estimating wafer fabrication COO may be applied to estimate device and system assembly COO. COO is also useful for equipment required to support manufacturing such as inspection and repair tools. COO analysis for repair equipment is more complex than for fabrication equipment, requiring a two-part analysis. First, the cost of operating the repair tool is estimated. Second, the cost of impact of repairing on the process being measured must be estimated. [1]

Cost of ownership of capital equipment - including price, throughput, down time, maintenance cost, training and spare parts- used to be sufficient for electronics companies in evaluating their equipment purchases. But with costs in the stratosphere and investments in anew generation of technology every three or four years, corporate executives have to look elsewhere to optimize their return on investment. Many are supplementing cost-of-ownership calculations with asset management techniques, which are as follows [5]:

1. How to fund a new equipment.
2. How to determine the cost of ownership.
3. How to improve productivity of installed equipment.
4. How and when to migrate currently owned equipment to a product that does not require leading-edge technology.
5. When and how to dispose of equipment.

As mentioned above Cost-of-Ownership is an important part of asset management. In semiconductor manufacturing, the cost of ownership approach to buying equipment has been pushed by the Mountain View, CA-based Semiconductor Equipment and Material International (SEMI) Association, which has trained 2,000 people in the methodology [5].

SEMI has also developed a computer program that a company can use to figure cost of ownership. The one drawback is that the software requires a tremendous amount of information about the performance of the equipment and the processes. Most experts agree that throughput and uptime are the most important variables in determining cost of ownership. Uptime varies with the type of equipment. For process equipment, it is 100 to 300 hours; for measurement equipment, 2,000 to 3,000 hours. Mean time to repair is an important calculation for buyers of expensive equipment. [12]

5.) WHY COST OF OWNERSHIP?

As semiconductor companies invest billions of dollars they face some difficult questions. The most critical one is "How do we control the costs?". It is imperative that the equipment industry address the cost of ownership issues facing wafer fabs by creating processing equipment that delivers higher throughput and greater reliability.

Historically, the semiconductor industry has controlled its cost of ownership with continuous technology advances. In the past 10 years, increased manufacturing yields, smaller feature sizes, larger wafers and improved overall capital utilization have resulted in an incredible 72-fold increase in manufacturing productivity [4].

These gains, however, came at great cost- the highly complex tools required to achieve these productivity levels are now three times as expensive as their predecessors and operate at about 30 percent lower productivity.

A cost-of-ownership model has several benefits for end user. First, the model can provide a clear estimate of the cost-of-ownership. The program can also highlight details that might be overlooked. Cost-of-ownership provides an objective analysis method for evaluating decisions. Both suppliers and manufacturers can work from hard data to support a purchase plan. The model can also be used to evaluate process and tool design. Finally, the cost-of-ownership model provides communication between equipment suppliers and users. They are able to speak the same language-comparing similar data and costs using the same algorithms and equations [7, 13].

Industry leaders have focused on the overall cost of ownership and overall capital efficiency as possible solutions. Although those are useful concepts, they do not suffice to meet the challenge. The semiconductor industry needs to find a new source of productivity that will enable it to continue its expansion into new and increasingly global markets through the year 2000 and beyond [4].

Current trends in semiconductor manufacturing place a large emphasis on monitoring and/or controlling costs. One of the tools used in this effort is, as mentioned earlier, Cost of Ownership. COO provides a method to monitor and control costs, evaluating projects, and gain a better understanding into the manufacturing process. From the previous literature on the subject, models can range from very simple to very complex. The need for complexity in this type of model must be evaluated with respect to the actual level of accuracy required. Quality of the data obtained is very important as inaccurate information can lead to potential misuse. From past experience, data collection for modeling can range from being easily accessible to very obscure. In the search for data, various departments such as finance , engineering, facilities, production, and many others must be consulted. The value of information obtained versus the cost involved in obtaining this information must be evaluated [14].

6.) APPLICATIONS OF COST-OF-OWNERSHIP

Cost-of-Ownership models have met wide acceptance in the silicon world for helping decide which process and which tool is best suited for a particular task. In the compound semiconductor world, there are many different techniques and processes, in addition to device types, so cost-of-ownership models have typically not yet been widely used . As the production volumes increase, however, dominant techniques tend to emerge, and this helps simplify some of the decision making [16].

At a glance, using cost-of-ownership has significant benefits for end users. It is neither complex nor hard to do. With a few significant details about purchase, operation, utilization, and performance, users can determine the life-cycle cost of owning a semiconductor equipment. Over the life of the system, equipment reliability, utilization, and yield factors may have a greater impact on cost-of-ownership than initial purchase costs. Cost-of-ownership was developed for wafer fabrications tools but can easily be extended to other applications. These new applications are broadening the impact of cost modeling analysis and providing a metric for improvement for the semiconductor industry [10, 13].

With equipment costs rising every generation and manufacturers increasingly sensitive to the cost per wafer, SEMATECH began developing a cost-of-ownership model in 1990 as mentioned before. Since then, cost-of-ownership standards have been developed with Semiconductor Equipment and Materials International (SEMI), and a commercial cost-of-ownership model has been prepared through a joint development project [2].

A cost-of-ownership program can be structured in various ways and can range from very simplistic models to those that encompass every aspect of a company's operations. For example, the earlier mentioned SEMATECH model is very popular with most companies. It is a very large and complex model that accounts for everything involved in operating a piece of manufacturing equipment. The SEMATECH model focuses mainly on equipment cost comparisons; whereas some other models focus on product cost comparisons. [6, 17]

Historically, purchase decisions have been based on initial purchase and installation costs. However, purchase costs do not consider the effect of equipment reliability, utilization, and yield. Over the life of the system, these factors have a great affect on cost of ownership than initial purchase costs. Lifetime cost of ownership per good device or wafer is generally sensitive to production throughput rates, overall tool reliability, and yield. It is relatively insensitive to initial equipment purchase price. While initial cost of ownership models were developed for wafer fabrication equipment, cost of ownership can easily be extended to other applications.[8, 15] In today's fast-paced and highly competitive marketplace, the importance of staying competitive means continually focusing on product cost and profitability. IBM's semiconductor manufacturing facility in Essex Junction, Vermont, uses a cost of ownership program to analyze every operations in its production lines. With a customized COO modeling program, it can be determined the cost for each manufacturing operation. Pareto data analyses can highlight key areas where improvements can be most beneficial; the data gives the cost of various items, listed from the highest to lowest cost and the percentage value of each item. It not only identifies the major items significantly increasing costs, but also quantifies the impact each change or improvement will have on individual operations. The methodology of this program has enabled IBM to drive down the cost of its semiconductor products while maintaining the high degree of quality and reliability. Information obtained from the COO program is being used to select future products for the IBM Microelectronics product menu [3].

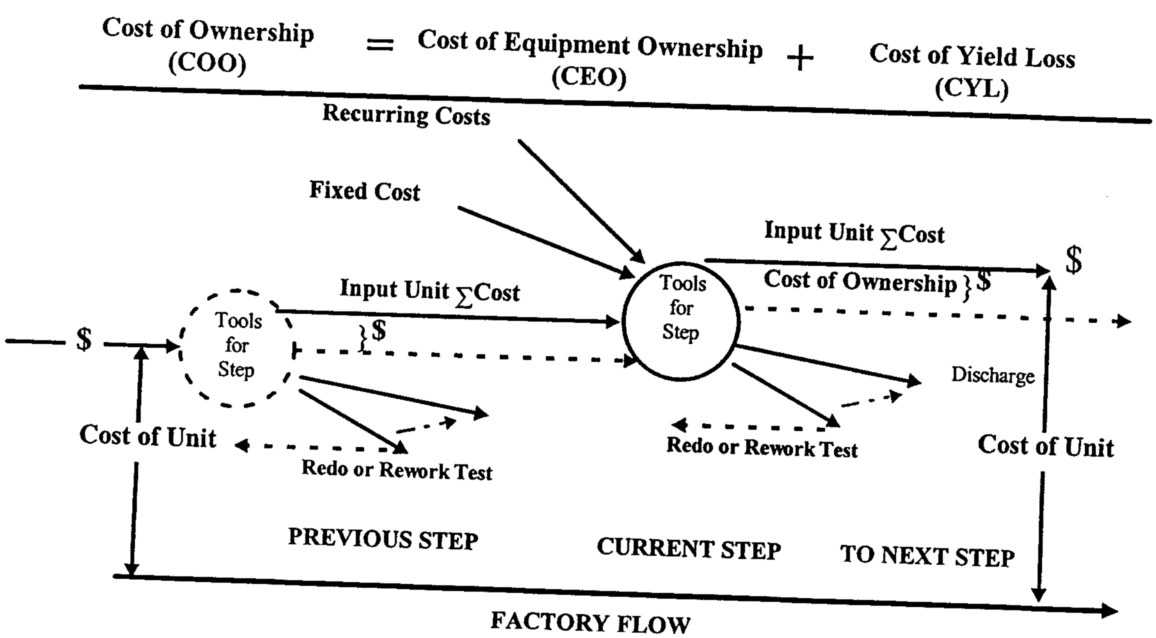
Intel Corporation, like many semiconductor manufacturing firms, has shifted its equipment procurement focus from initial cost to total cost of ownership over equipment lifetime. As a result, an increased emphasis on equipment maintenance and support has been driven back through the value chain, from the factory floor through the capital purchasing department to the supplier base. Equipment sourcing decisions are justified by total cost analysis, and suppliers who offer total cost reduction solutions are in a favorable position for contract negotiation. These forces, as well as internal emphasis on total cost reduction, has driven teams within Intel and its supplier base to pursue performance improvement projects which will ultimately improve total cost. Equipment Change Impact Model, a Microsoft Excel application used at Intel, was used to compare improvement strategies to determine the most cost effective alternative determine the potential saving, Net Present Value (NPV) and payback period of a proposed equipment change analyze the effect of data variability on decision strategies. This model is based on the SEMATECH total cost of ownership model, but has the added benefit of determining projected, best and worst case financial returns on a proposed change. A qualitative matrix section enhances the financial model by taking into account non-quantifiable data [9].

7.) SEMATECH MODEL

In 1995, SEMATECH has established a model for calculating the cost of ownership for factory equipment subsystems in the semiconductor industry. Before then, companies have been developing COO models based on their assumptions (i.e. cost components) and been using their company standard terms. However, SEMATECH model was intended to standardize the calculation of COO, or at least give an insight about an improved way of calculating COO to semiconductor industry audience, and the terminology used in the model.

Cost of ownership metric in SEMATECH model is defined to be the incremental cost added to a unit of good product material flowing through a volume-sized process system embedded in a factory environment for a specified lifetime plus the cost of yield loss. In other words, it is the full cost of embedding, operating and decommissioning in a factory environment a process system to accommodate the required volume of product material. COO is calculated on an annualized basis. The metric is expressed as cost per good wafer equivalents (GWE) for one pass through the system. Most semiconductor companies are currently using the guidelines in the SEMATECH model and customizing the model based on company needs by taking SEMATECH model as a basis.

The following figure depicts the accumulation of cost which can be factored into two components, which are the components of Cost of Ownership (COO): Cost of Yield Loss (CYL) and Cost of Equipment Ownership (CEO) [6].



Therefore, we can define COO by the following equation:

COO = CEO + CYL (Equation 1)

Equation 2 and 3 shows the components of CYL and CEO, respectively.

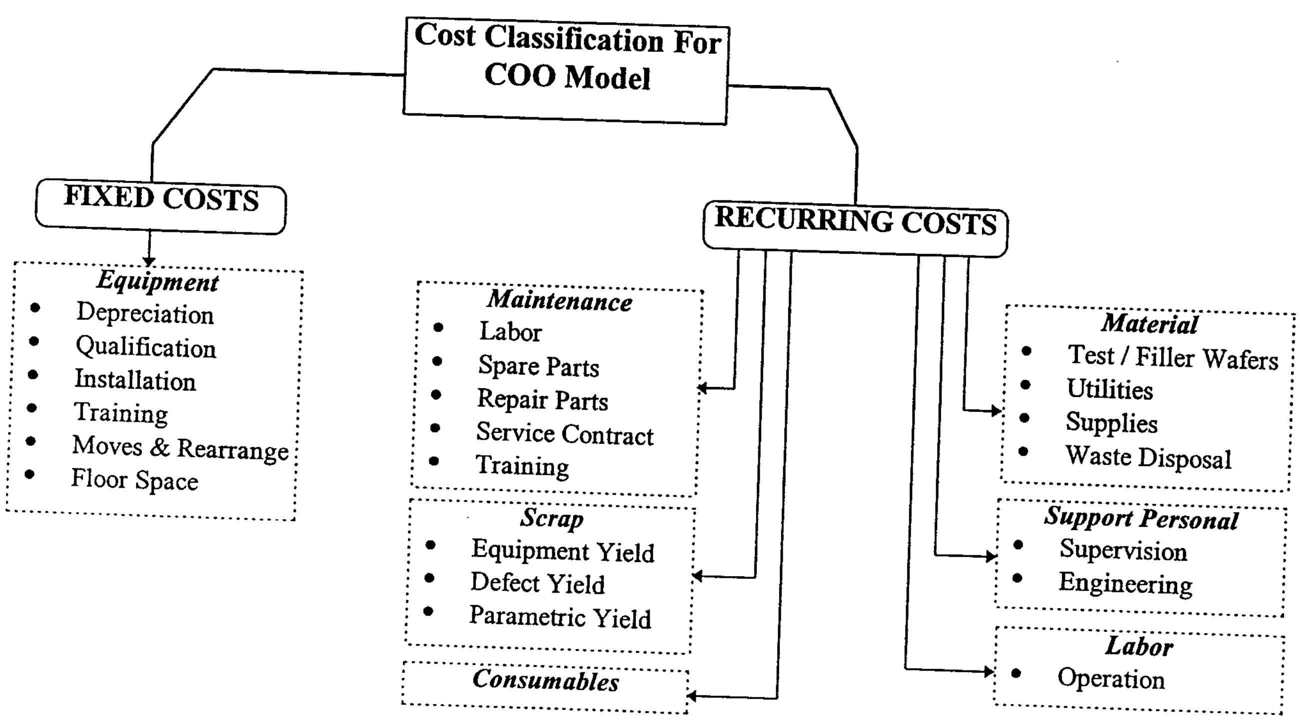
Cost of Yield Loss (CYL) (Equation 2):

$$CYL = \begin{Bmatrix} annualized\_cost\_of\_wafers\_lost\_to\_equipment\_yield \\ + annualized\_attributed\_cost\_of\_wafers\_lost\_to\_die\&parametric\_yield \end{Bmatrix} * \frac{1}{good\_units\ per\_year}$$

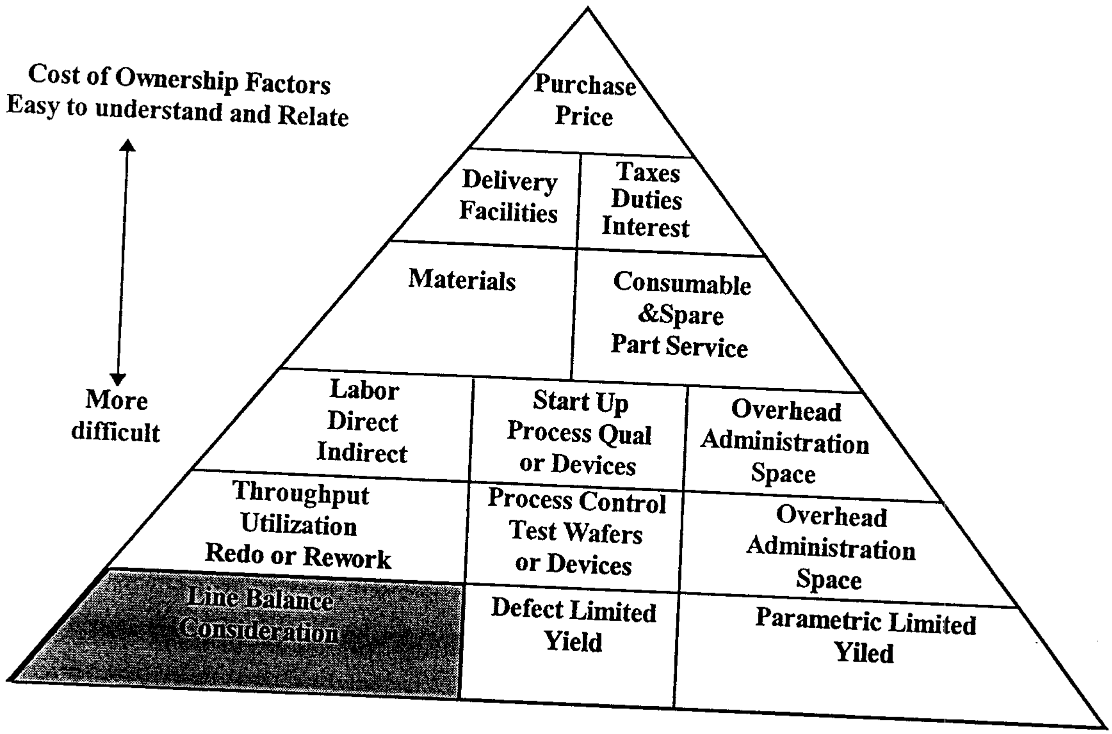
Cost of Equipment Ownership (CEO) (Equation 3):

$$CEO = \begin{Bmatrix} annualized\_fixed\_cost\_per\_system \\ + annualized\_recurring\_cost\_per\_system \end{Bmatrix} * \frac{volume\_required\_no\_of\_systems}{good\_units\_per\_year}$$

A sample classification structure for fixed and recurring cost categories are shown on the following figure:



The following figure depicts some of the elements in terms of difficulty in establishing various costs [6]:



8.) OVERVIEW OF THE YIELD ENHANCEMENT PROCESS IN ESI

Defects on a memory chip are usually caused by small particles which fall onto the wafer during the various manufacturing steps, causing breaks in the conducting lines of the memory matrix and therefore loss of particular rows and columns (addresses) in the memory.

The memory chips are functionally tested on networked test systems prior to processing by the Laser Memory Yield Enhancement System. The results of the functional tests are stored in Tester Data Files on a file server accessible to both the testers and the Laser Memory Yield Enhancement Systems. These files contain the position of each failed die on each tested wafer, together with the addresses which have failed on each die.

When the wafers arrive at the Laser Memory Yield Enhancement System, the appropriate Tester Data File of each wafer is downloaded from the network file server to the system. As each wafer is processed, the failed addresses for each of its chips are converted into sets of x and y coordinates of fuses which will de-activate the failed rows and columns (failed addresses) and activate the spare rows and columns.

The Laser Memory Yield Enhancement System uses a laser beam positioning system to place each link which is to be opened (vaporized) underneath a laser focusing system and pulses the laser to remove the link material. It does this for each die on the wafer and each wafer in the lot.

9.) THE COST OF OWNERSHIP MODEL AT ESI

The Cost of Ownership model attempts to determine the costs involved in the purchase, installation, maintenance, processing etc. during its full useful life. It has been developed to primarily produce information allowing the total cost of using the machine in production to be calculated for product pricing purposes, as well as a means of evaluating competing equipment bids during the purchasing process.

The model used in this project is based on the SEMI standard E35-95A "Cost of Ownership for Semiconductor Manufacturing Equipment Metrics" [Appendix III].

9.1.) Parameters Used In The Cost Of Ownership Model

The parameters used in the cost of ownership model were taken from the existing model, from the default values of the Sematech COO model. Number of die per wafer, throughput times, yield data, Fix-to-Attempts data and utilization figures have been taken from actual customers. A table at the end of this discussion summarizes the values and their sources.

The four production scenarios used were chosen to attempt to produce comparisons between US and Asian production facilities, as well as comparisons between a mature product and one which is in the initial phase of production. They were also chosen in pairs because of the design of the existing cost of ownership model.

Using the Sematech Cost of Ownership model as a base and the cost center classification structure, the following parameters and assumptions were used :

9.1.1.) Fixed Costs :

CF1.0 Equipment

The equipment price has been chosen at full list price to allow the inclusion of most of the fixed costs associated with the purchase and itemized below. As the cost of the system is usually discounted, these costs have been assumed as part of the equipment purchase price. The items which have been separated out are depreciation, cost of floor space and training.

CF1.1 Depreciation :

The Sematech default was used - 5 year straight line depreciation

CF1.2 Qualification

Due to the nature of the equipment, qualification is performed on several lots of production wafers which continue in normal production after evaluation. The cost of qualification is not loss of product, but extra time for monitoring and analysis by Engineers.

CF1.3 Installation

Installation from the supplier side is included in the system cost. Installation costs from the buyer side is assumed included in the purchase price.

CF1.4 Training

Initial training requirements have been categorized with the recurring costs of maintenance training and separately itemized in the model as two people for two weeks per system per 5 years as an average. This assumption has been made as most sites have multiple systems do not require separate initial training for each machine installed. Costs of training are an annualized value for the course itself at $1500 per week, the actual cost of the time for the attendee and the travel and living expenses.

CF1.5 Moves and Re-arrange

Assumed included in the purchase price of the machine

CF1.6 Floor Space

The machines are usually installed in a class 1000 or less so the Sematech value of $100 per square foot was used with the actual footprint of the machine.

9.1.2.) Recurring Costs :

CR1.0 Material

The material costs associated with the machine have been separately itemized in the model.

CR1.1 Test / Filler wafers

Tests on the machine are usually performed using known scrap (zero yield for cosmetic or other parametric reasons) so it has been assumed that there is no associated cost.

CR1.2 Utilities

The utilities required are electricity, vacuum and compressed air. Vacuum and compressed air are supplied from central sources and their associated cost has been grouped with the cost of electricity in the model.

CR1.3 Supplies

There are no special specialty gases etc required for the machine, so no cost has been included.

CR1.4 Waste Disposal

As there are no special supplies required by the machine and no waste requiring special handling, no cost has been included.

CR2.0 Consumables

The consumable costs associated with the machine have been separately itemized in the model

CR3.0 Maintenance

Each of the maintenance costs associated with the machine have been separately itemized :

CR3.1 Labor

The labor costs associated with the machine have been separately itemized in each case as the total working hours per year divided by the number of machines the category of personnel supports times the appropriate labor rate.

CR3.2 Spare Parts

The Spare Part costs associated with the machine have been separately itemized.

CR3.4 Service Contracts

No service contract has been included as most of the problems associated with the machine would be covered under a one-year warranty program.

CR3.5 Training

Costs of training are an annualized value for the course itself at $1500 per week, the actual cost of the time for the attendee and the travel and living expenses.

CR4.0 Labor : Operation

The labor costs associated with the machine have been separately itemized.

CR4.1 Labor : Operation

The labor costs associated with the machine have been separately itemized in each case as the total working hours per year divided by the number of machines the category of personnel supports times the appropriate labor rate.

CR5.0 Support Personnel

The labor costs associated with the machine for each category of support personnel have been separately itemized.

CR5.1 Supervision

The labor costs associated with the machine for each category of support personnel have been separately itemized.

CR5.2 Engineering

The labor costs associated with the machine for each category of support personnel have been separately itemized.

CR6.0 Scrap

Values for the scrap values of the wafer have been taken from actual average costs.

CR6.1 Equipment Yield

Values for the equipment yield of the wafer have been taken from actual average costs. The value is very high due to the prior testing process which detects the scrap prior to processing by the machine.

CR6.2 Defect Yield

No value associated with this due to the nature of the machine.

CR6.3 Parametric Yield

No value associated with this due to the nature of the machine.

CR7.0 Support Services

The labor costs associated with the machine for each category of support personnel have been separately itemized.

Total Operational Time :

	16Meg USA	64Meg USA	16Meg Asia	64Meg Asia	Units	Comments :
Working Hours	24	24	24	24	Hours Per Day	Customer
Working Days	7	7	7	7	Days per week	Customer
Working Weeks	52	52	52	52	Weeks per year	Customer

Downtime :

Unscheduled :

	16Meg USA	64Meg USA	16Meg Asia	64Meg Asia	Units	Comments :
MTBF (Mean Time Between Failures)	1000	1000	1000	1000	Hours	Time between equipment failures - existing model
MTTR (Mean Time To Repair)	120	120	120	120	Minutes	Time to repair system - existing model
MTBA (Mean Time Between Assists)	240	240	240	240	Hours	Time between Operator Interventions - existing model
MTTA (Mean Time To Assist)	10	10	10	10	Minutes	Time for Operator to Intervene - existing model

Scheduled :

	16Meg USA	64Meg USA	16Meg Asia	64Meg Asia	Units	Comments :
Preventive Maintenance Time	120	120	120	120	Minutes	Time to complete maintenance - existing model
Preventive Maintenance Events	0.3	0.3	0.3	0.3	Maintenance	Maintenance interval = 3 months - existing model
Calibration Time	0	0	0	0	Minutes	Calibration not required
Calibration Events	0	0	0	0	Cals per month	Calibration not required
Product Changeover Time	3	3	3	3	Minutes	Time to change from one product to another - existing model
Product Changeover Events	0.5	0.5	0.5	0.5	Per 8hrs Operation	# of product changes per 8 hours
Cassette Load Time	0	0	0	0	Minutes	Time to exchange processed cassettes for unprocessed cassettes -existing model
Cassette Load Events	1	1	1	1	Per 8hrs Operation	Existing model

Performance Assumptions and Results:

	16Meg USA	64Meg USA	16Meg Asia	64Meg Asia	Units	Comments
Repair time per die	0.9	3.0	0.9	3.0	Seconds per die	Current average times
Wafer overhead	13.0	13.0	13.0	13.0	Seconds per die	Current average times
No. of die per wafer	450	200	450	200		Current average numbers
Percent wafer repairable	80%	60%	80%	60%		16Meg : 10% perfect, 10% scrap 64Meg : 0% perfect, 40% scrap due to immature process
Repairable die per wafer	360	120	360	120	Die per wafer	Current average numbers
FIRST PASS YIELD	**99.8%**	**99.8%**	**99.8%**	**99.8%**	PERCENT FTA (Fix-to-attempts)	Repair rate extremely high due to testers detecting scrap.

Financial Input :

Selling Price :

	16Meg USA	64Meg USA	16Meg Asia	64Meg Asia	Units	Comments
Base System	$1,300,000	$1,300,000	$1,300,000	$1,300000		Full selling price of machine
Cost of Consumables per year	$12,500	$12,500	$12,500	$12,500		From existing model
One year of Training and Support	$2,553.85	$1,620.28	$2,553.85	$1,620.28		2 technicians, 2 weeks training in 5 years, annualized.
One year's spares	$6,000	$6,000	$6,000	$6,000		From existing model
Annual Cost of Capital	10.0%	10.0%	10.0%	10.0%	% Per Year	From existing model
Salvage Value	$50,000	$50,000	$50,000	$50,000		From existing model

Variable Costs :

	16Meg USA	64Meg USA	16Meg Asia	64Meg Asia	Units	Comments
Direct Labor (Operator)	$25.24	$25.24	$5.14	$5.14	$'S per hour	Fully burdened, USA costs from Sematech model, Asia costs from existing model
Indirect labor (Technician)	$36.06	$36.06	$6.88	$6.88	$'S per hour	Adjusted relative to the Asia costs from existing model
Indirect labor (All other)	$48.08	$48.08	$9.62	$9.62	$'S per hour	Adjusted relative to the Asia costs from existing model
Electricity per system	$0.40	$0.40	$0.40	$0.40	$'S per hour	From existing model
Other utility costs per system	$0.00	$0.00	$0.00	$0.00	$'S per hour	
Optional cost input per system	$0.00	$0.00	$0.00	$0.00	$'S per hour	

Other Costs :

	16Meg USA	64Meg USA	16Meg Asia	64Meg Asia	Units	Comments
Die cost for scrap	$5.00	$25.00	$5.00	$25.00	$'S per die	Current average numbers
System life for depreciation	5	5	5	5	Years	5 Year Straight Line Depreciation - from existing and Sematech model
Floor space cost	$100.00	$100.00	$100.00	$100.00	$'S per square ft	Class 100 Cleanroom, from Sematech model
System floor space required	28.88	28.88	28.88	28.88	Square feet	From existing model
Systems per operator	4	4	4	4		From existing model
Systems per other indirect labor	8	8	8	8		From existing model

9.2.) Cost of various parameters as a percentage of the overall Cost of Ownership

Breakdown of Expenses for 16 Meg devices at baseline values - 100% throughput, 85% Utilization, 80% repairable die per wafer, 99.8% yield :

Expense	Cost	Proportion of Total Cost
Depreciation expense per year	$250,000	33.1%
Interest expense /yr	$82,937	11.0%
Direct labor (operator) / year	$55,125	7.5%
Indirect labor (technician) / year	$2,089	0.3%
Indirect labor (all other) / year	$52,500	6.9%
Spare part expense per year	$6,000	0.8%
Total cost of rework per year	$0	0.0%
Training	$2,554	0.3%
Scrap product exp in $/year	$427,156	37.6%
Utilities & floor space exp/yr	$6,382	0.8%
Consumables expense per year	$12,500	1.7%
TOTAL EXPENSE / YEAR	$897,243	100.0%

Breakdown of Expenses for 64 Meg devices at baseline values - 100% throughput, 85% Utilization, 60% repairable die per wafer, 99.8% yield :

Expense	Cost	Proportion of Total Cost
Depreciation expense per year	$250,000	27.9%
Interest expense /yr	$82,937	9.2%
Direct labor (operator) / year	$55,125	6.1%
Indirect labor (technician) / year	$2,089	0.2%
Indirect labor (all other) / year	$52,500	5.9%
Spare part expense per year	$6,000	0.7%
Total cost of rework per year	$0	0.0%
Training	$2554	0.3%
Scrap product exp in $/year	$427,156	47.6%
Utilities & floor space exp/yr	$6,382	0.7%
Consumables expense per year	$12,500	1.4%
TOTAL EXPENSE / YEAR	$897,243	100.0%

9.3.) Results of Scenarios

The results of the four scenarios run on the model as the basis for all the following comparisons are summarized below :

Baseline Values (Yield 99.8% Throughput 100%)	Total Annual Cost to Repair Die ($)	Cost per die ($)
16 Meg USA	755,418	0.0267
16 Meg Asia	665,227	0.0235
64 Meg USA	894689	0.1049
64 Meg Asia	807,090	0.0947

The differences between the USA and Asian manufacturing facilities lies in the cost of labor. The other significant cost sources of values in the model have been kept the same for the following reasons :

Depreciation : Inflation rates are similar and capital would be raised on international markets, plus some countries link their currencies to the value of the dollar.

Consumables : Machine consumables are bought from the same source

Scrap product : Prices of scrap would be much the same as DRAMS are commodities

As the only differences are in the labor costs, we will consider the USA manufacturing model for the scenario analyses, but discuss the effects of the scenarios on the Asian manufacturing model in the discussion of results.

10.) SENSITIVITY ANALYSIS

10.1.) Scenario 1 - Changing the Yield

a. 16 Meg devices

Baseline = 99.8% Yield 100% Throughput	Yield	Cost per die ($)	Total Annual Cost to Repair Die ($)	Change in baseline parameter (%)	Change in cost (%)
Baseline	99.8%	0.0267	755,418	0%	0%
	99.7%	0.0317	897,254	0.1%	18.8%
	99.5%	0.0418	1,180,926	0.3%	56.3%
	99.0%	0.0673	1,890,108	0.81%	150%
	98.0%	0.1190	3,308,470	1.84%	338%

b. 64 Meg devices

Baseline = 99.8% Yield 100% Throughput	Yield	Cost per die ($)	Total Annual Cost to Repair Die ($)	Change in baseline parameter (%)	Change in cost (%)
Baseline	99.8%	0.1052	897,243	0%	0%
	99.7%	0.1304	1,110,821	0.1%	23.9%
	99.5%	0.1809	1,537,977	0.3%	72.0%
	99.0%	0.3081	2,605,869	0.8%	192.9%
	98.0%	0.5664	4,741,651	1.8%	438.4%

10.2.) Scenario 2 - Changing the Throughput

a. 16 Meg devices

Baseline = 99.8% Yield 100% Throughput	Throughput	Cost per die ($)	Total Annual Cost to Repair Die ($)	Change in baseline parameter (%)	Change in cost (%)
Baseline	100%	0.0267	755,418	0%	0%
	90%	0.0285	727,051	10%	6.7%
	80%	0.0308	698,684	20%	15.4%

b. 64 Meg devices

Baseline = 99.8% Yield 100% Throughput	Throughput	Cost per die ($)	Total Annual Cost to Repair Die ($)	Change in baseline parameter (%)	Change in cost (%)
Baseline	100%	0.1052	897,243	0%	0%
	90%	0.1114	854,527	10%	5.9%
	80%	0.1190	811,811	20%	13.1%

10.3.) Scenario 3 - Changing the Cost of Capital

a. 16 Meg devices

Baseline = 99.8% Yield 100% Throughput	Annual Cost of Capital	Cost per die ($)	Total Annual Cost to Repair Die ($)	Change in baseline parameter (%)	Change in cost (%)
Baseline	Rate 10%	0.0267	755,418	0%	0%
	Rate 12%	0.0273	773,114	20%	2.34%
	Rate 15%	0.0282	800,291	50%	5.94%

b. 64 Meg devices

Baseline = 99.8% Yield 100% Throughput	Annual Cost of Capital	Cost per die ($)	Total Annual Cost to Repair Die ($)	Change in baseline parameter (%)	Change in cost (%)
Baseline	Rate 10%	0.1052	897,243	0%	0%
	Rate 12%	0.1073	914,939	20%	2.0
	Rate 15%	0.1105	942,116	50%	5.04%

10.4.) Scenario 4 - Changing the Utilization

a. 16 Meg devices

Baseline = 99.8% Yield 100% Throughput	Utilization	Cost per die ($)	Total Annual Cost to Repair Die ($)	Change in baseline parameter (%)	Change in cost (%)
Baseline	Rate 85%	0.0267	755,418	0%	0%
	Rate 75%	0.0289	722,045	11.8%	8.2%
	Rate 65%	0.0318	688,672	23.5%	19.1%

b. 64 Meg devices

Baseline = 99.8% Yield 100% Throughput	Utilization	Cost per die ($)	Total Annual Cost to Repair Die ($)	Change in baseline parameter (%)	Change in cost (%)
Baseline	Rate 85%	0.1052	897,243	0%	0%
	Rate 75%	0.1126	846,989	11.8%	7.03%
	Rate 65%	0.1222	796,735	23.5%	16.16%

10.5.) Scenario 5 - Changing the Number of Repairable Die per Wafer

a. 16 Meg devices

Baseline = 99.8% Yield 100% Throughput	Repairable Die per Wafer(%)	Cost per die ($)	Total Annual Cost to Repair Die ($)	Change in baseline parameter (%)	Change in cost (%)
Baseline	80%	0.0267	755,418	0%	0%
	60%	0.0269	751,817	25%	0.75%
	40%	0.0273	744,882	50%	2.25%

b. 64 Meg devices

Baseline = 99.8% Yield 100% Throughput	Repairable Die per Wafer(%)	Cost per die ($)	Total Annual Cost to Repair Die ($)	Change in baseline parameter (%)	Change in cost (%)
Baseline	60%	0.1052	897,243	0%	0%
	80%	0.1048	900,997	+33%	-0.38%
	40%	0.1062	889,927	-33%	0.95%

10.6.) Findings of the Sensitivity Analysis

1. The results show that Yield has, by far, the greatest effect on the cost of parts produced on the machine and therefore the Cost of Ownership. The very great effect is due to there being no value added to the parts, the cost of repair of the die being very small and the large penalty (the cost of the die at the Laser Processing System stage) incurred when an almost completed die is scrapped, being high.

2. Reducing throughput reduces the Cost of Ownership from a "Dollars to operate the machine" viewpoint due to the lower number of both good die and (more importantly, because of the high cost of scrap product) scrap die. However, the cost per good die produced, as expected, increases.

3. The cost of capital affects the model almost in proportion to the interest rate as the amount of interest paid on the purchase of the machine is (coincidentally) approximately the same percentage of total cost of operating the machine as the interest rate itself.

4. Utilization of the machine has quite a large effect on the Cost of Ownership - once again, as would be expected for the same reasons as (2) above.

5. Changing the number of repairable die on the wafer has a small effect on the Cost of Ownership. This is because the machine itself is not responsible for the yield loss and therefore no cost is assigned to the machine for this scrap. The increase in the Cost of Ownership is due to the extra time required to handle more wafers (the increased handling overhead) to produce the same number of good die which would be produced with a fewer number of wafers with higher numbers of repairable die per wafer.

A point to note, however, is that although the affect of the number of repairable (good) die per wafer on the Cost of Ownership of the Laser Processing System is not very great, the effect of the number of good die per wafer on the total cost to produce the die is very much greater.

11.) CONCLUSION

A cost of ownership program is well worth the effort. In almost every cases, the program can help a company understand its costs for certain services, items and equipment. The cost impact for upgrading an operation can also be measured to see if a change has a good return on investment.

SEMATECH model is a very popular model with most companies. It was intended to standardize the calculation of Cost of Ownership, or at least give an insight about an improved way of calculating COO to semiconductor industry audience, and the terminology used in the model.

We took SEMATECH model as a basis and customized the model based on Electro Scientific Industries Inc.'s needs and requirements (Appendix I).

The customized ESI model suggests that the cost of producing in Asia is about 10% less per die than in the USA using baseline values or both types of devices. However, the difference becomes smaller as the utilization increases and the throughput increases. One other figure to come out of this is that due to the high cost of scrap die at the Laser Processing stage, the lower the yield, the smaller the difference in overall cost per die as the labor costs become a smaller percentage of the Cost of Ownership.

If the labor costs in Asia in comparison to the USA (also Europe and Japan) cause the production cost per die to be 10% lower, why are there are still Wafer Fabs being built in these "high labor cost" areas of the world? The effect of yield may possibly be the reason as in order to bring up a new product to a high overall yield as quickly as possible, a high technical level of expertise is required. The "lower labor cost" areas perhaps do not have this expertise in depth and would therefore be used to produce mature, lower end cost products. Also, any cost advantage of producing in a lower labor cost area is reversed if the yield is as little as 0.1% below that in the "high labor cost" areas of the world.

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APPENDIX I - ESI COST OF OWNERSHIP MODEL