

Understanding and Using Cost of Ownership

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Introduction

In January of 1992 the Sales and Marketing Executive council of SEMI (SMECS) chartered a subcommittee to explore the use of cost of ownership within the semiconductor equipment and materials industry. As a result of that work "Understanding and Using Cost of Ownership" was developed to give semiconductor equipment and material suppliers and IC manufacturers an overview of cost of ownership concepts. Through the use of these concepts, the end user can determine the cost structure of virtually any step in the manufacturing process.

This class has been modified to make it more generic in nature while still using semiconductor manufacturing examples where appropriate (e.g., defect limited yield); however, manufacturers and suppliers from any industry can gain significant value from this course.

Cost of ownership can also be used to evaluate the impact of equipment design changes on the manufacturing process. Sensitivity analysis of which product enhancements or competitive advantages provide the largest return to the end user can be achieved through the manipulation of equipment specifications. Additionally, manufacturers can gauge the impact of process changes on existing equipment sets and the relative merits of new equipment designs.

What You Should Learn from this Module

- ☐ The history behind cost of ownership.
- ☐ Why COO is growing in importance.
- ☐ What the future holds for cost of ownership.
- ☐ The course objectives.

History

In the mid-1980's companies became more concerned with understanding the concept of Total Cost of Ownership. Total Cost of Ownership is the analysis of all costs associated with the acquisition, use, and maintenance of a good or service. This analysis takes more than price into consideration. It may also consider product quality, failure costs, administrative costs, and maintenance, among other factors.

What was discovered is that low price does not always yield the lowest total cost or satisfactory performance. Total Cost of Ownership is a tool that allows a company to determine the most cost-effective product or service. Activity Based Costing and Activity Based Cost Management also support the concept that cost allocation should be linked to the activity that causes the cost to be incurred.

Recent trends have increased the interest in Total Cost of Ownership:

1) **Quality Emphasis:**

The tighter the specification, the higher the quality, and the higher the supplier price. How tight a specification should be to see lower reject rates, improved quality, and higher customer satisfaction is a question answered by TCO analysis.

2) **Supply Base Rationalization:**

Reduce the number of suppliers but use suppliers that have high quality standards, low cost, and responsive service. TCO analyses help to determine which suppliers to keep.

3) **Increased Global Competition:**

Japanese businesses have a thorough understanding of how to manage total costs on a purchasing and total product basis. This is a part of their accounting practice. Companies competing on a global basis must have access to cost data to determine their competitive position in the market.

TCO models in the semiconductor industry began at Intel Corporation, where, in the mid-1980's, a concentrated analysis began of the total cost of acquiring, maintaining, and operating purchased equipment. Intel's objective was explicit: develop a purchasing methodology that establishes a sound, quantitative, business-like basis for equipment acquisition. The TCO concept first came to SEMATECH when one of Intel's employees was assigned to SEMATECH in the Strategic/Competitive Analysis area.

In the semiconductor industry, the term Total Cost of Ownership is typically replaced by Cost of Ownership. This is done in recognition of the fact that not all costs are captured by these models.

The original SEMATECH Cost of Ownership models developed were not very user-friendly. However, they have improved over time and have received wide acceptance. During the early 1990's, SEMATECH decided not to introduce any changes to their model so users would become familiar and comfortable with the software. They determined that this would not occur if the software was always in a state of flux.¹

Once Cost of Ownership was an accepted part of the semiconductor industry, SEMATECH decided to move forward in providing enhanced versions of COO software. To that end, SEMATECH contracted Wright Williams & Kelly, Inc. to provide on-going worldwide support and training for COO as well as enhanced software products. These enhanced software models have been commercially available on a worldwide basis since 1995.

¹ Richard L. LaFrance and Stephen B. Westrate, "Cost of Ownership: The Supplier's View," Solid State Technology, July 1993, p 33-37.

Growing Importance

As modeling grows in acceptance, it grows in importance. Cost of ownership is only one of an increasing number of cost modeling efforts. In our rapid maturation as an industry, capital intensity has increased at a rate that threatens the traditional cost/performance curves of the end product.

Since pervasiveness is a requirement for success in any market, these traditional product curves have to be met for the industry to continue growing above macro economic rates. Added to the need for developing an understanding of how changes in various equipment, layout, process, and product parameters affect end product competitiveness is the requirement for predicting these effects in advance.

Cost of ownership has become the single most important component of capital equipment purchasing, at least in the semiconductor industry. It is also being used to evaluate equipment performance from fab/factory to fab/factory and process to process. In companies where the concept is fully understood, it is being used to evaluate joint development projects and product/equipment improvement programs. As the concept proliferated more applications developed.

Currently, cost of ownership models are available for semiconductor front end, assembly and packaging, mask and reticle manufacturing, printed circuit board manufacturing, panel manufacturing (flat panel display, solar panels), and user defined production (contact lenses, cell phones, etc.), multi-step process sequences, wafer sort and final test, Total Cost of Ownership for Energy (TCOe™, LCOE), and software development.

COO application has been expanded beyond a simple cost determinate to the analysis of specific cost drivers. It is being applied in all areas of fabrication by manufacturers and by supplier development teams in all areas of equipment/material product management.

Where is COO Headed?

Cost of ownership has quickly moved to a globally accepted SEMI COO standard (E35). This standardization was further supported by SEMATECH's work to provide a single commercial source for implementation software. The evolution of implementation schemes continues to be focused on application specific models designed to meet the specific requirements of various factory processes.

Additionally, COO models are being required to interface to other cost models, databases, and directly to equipment for real-time COO and OEE. This trend will allow for the reduction in duplication of effort and ensure consistent data across applications. The semiconductor industry leads the way in aggressive implementation of cost of ownership and we are now seeing other industries adapting COO to their needs.

Agenda

Introduction

Cost of Ownership Concept

Cost of Ownership Details

Applications

Potential Misuses

Advanced Applications & Areas of Sensitivity

Exercises and Solutions

Course Objectives

The objective of this course has been and will continue to be the imparting of knowledge on the importance of cost of ownership to all manufacturing industries. The analogy of an onion used in the course is a valid description of the course format. That being a core overlaid with discrete layers of information.

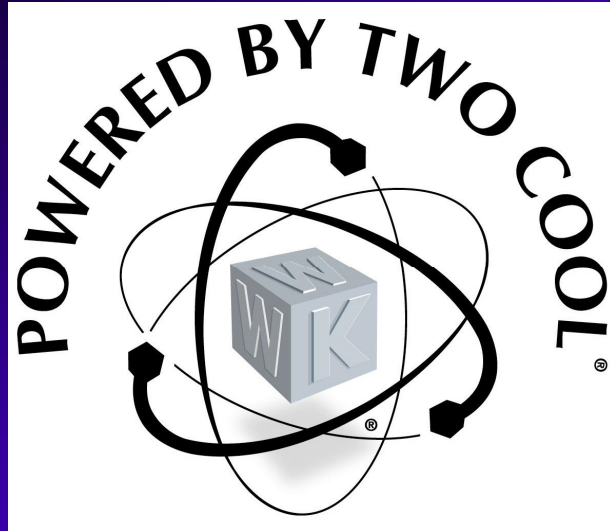
The core of the course is based on a fundamental understanding of cost of ownership concepts. However, it is important that the fundamentals be viewed from a historical perspective in order to understand the driving forces.

It would be a waste of time if the course only provided a backdrop for COO concepts and history. The most important concepts that must be delivered to the student are those that provide an applications orientation. Cost of ownership is a "working" tool and the uses for that tool must be clearly understood.

While applications knowledge is critical to the successful implementation of COO, so is an awareness of the sensitivities being leveraged in the COO evaluation. With all tools, there is the potential for good and bad results. A knowledge of both aspects of the applications spectrum is essential.

In all learning environments, the more senses a student utilizes, the higher the degree of retention and recall. For this reason, exercises with COO software are used as the final reinforcement of the concepts and applications taught in the class.

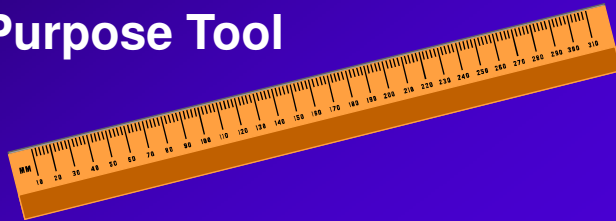
Understanding and Using Cost of Ownership



What's All This COO Stuff?

Cost of Ownership is...

- A Decision Making System
- A Technology
- A Technique for Communicating Information
- A Multi-Purpose Tool



Cost of Ownership is...

- “The full cost of embedding, operating, and decommissioning in a factory environment a process system needed to accommodate the required volume of product material.”

Per SEMI COO Standard E35

How Did We Get Here?

□ Trends

- Quality Emphasis
- Supply Base Rationalization
- Global Competition

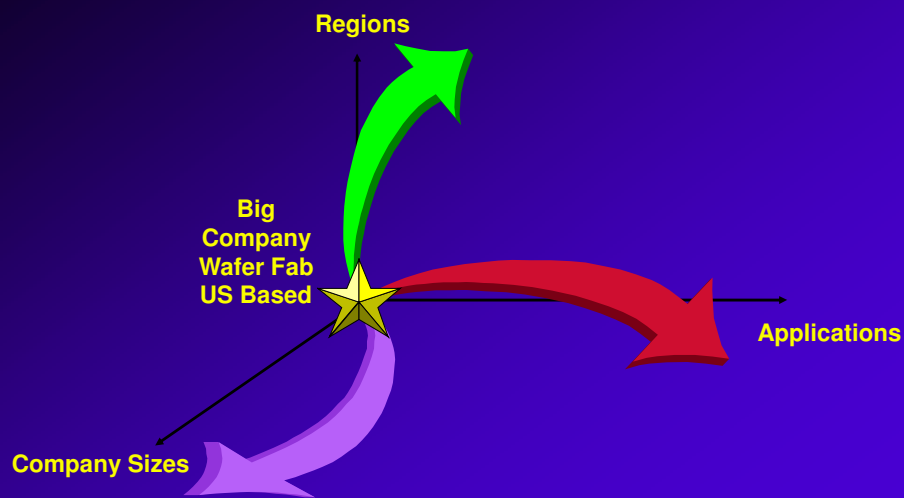
□ Intel

□ SEMATECH

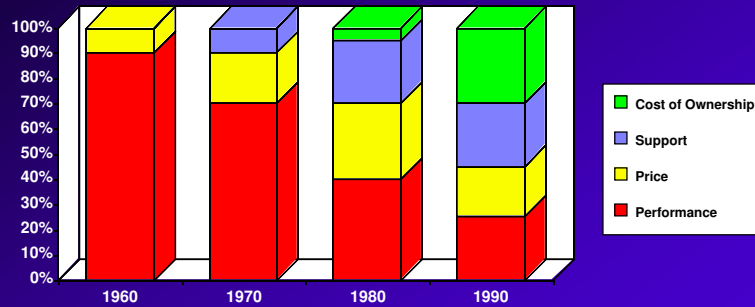
□ WWK



Growth of COO



Decision Components



Courtesy of Wally Rhines, Formerly of Texas Instruments

Where is COO Now?

- SEMI Standards (E10, 35, 79)
- Integrated OEE
- Commercial Supplier
- Application Specific Models
 - Wafer Fab
 - Assembly and Packaging
 - Mask Manufacturing
 - Board Manufacturing
 - Panel Manufacturing
 - User Defined
- Process Sequence Analysis
- Wafer Sort & Final Test

Where is COO Headed?

- **New Industries**
 - Magnetic Media/TF Heads
 - Flat Panel Displays
 - Solar Panels
- **Integration Into Other Models**
 - Capacity Planning
 - Product Costing
 - Discrete-Event Simulation
- **Real-Time Data Acquisition and Reporting**

Discussion Topics

- **Cost of Ownership Concept**
- **Cost of Ownership Details**
- **Applications**
- **Potential Misuses**
- **Areas of Sensitivity and Advanced Applications**
- **Exercises and Solutions**

Course Objectives

- ▣ **Impart Knowledge**
- ▣ **Core Concepts**
- ▣ **Historical Perspective**
- ▣ **Applications Orientation**
- ▣ **Sensitivities**
- ▣ **Reinforcement**



Cost of Ownership Concept

Cost of ownership calculations are driven by four main accounting and manufacturing areas: fixed costs, recurring costs, utilization, and yield. The concept of COO is not unique to semiconductor manufacturing, in fact, it can be applied to almost any process where there are inputs and outputs.

What You Should Learn from this Module

- ☐ The components of the cost of ownership algorithm.
- ☐ The items typically categorized as fixed costs.
- ☐ The items typically categorized as recurring costs.
- ☐ The components of the utilization algorithm.
- ☐ The relationship between cycle time and COO.
- ☐ The components of the basic yield algorithm.
- ☐ The issues involved in applying COO to materials and components.
- ☐ What is not included in COO today.

Cost of Ownership Algorithm

Cost of ownership can be broken into four conceptually important categories: fixed costs, recurring costs, utilization, and yield. The combination of these factors dictates the cost of ownership for the process step being analyzed and can be represented by:

2-2 *Understanding and Using Cost of Ownership*

$$COO = \frac{F\$ + R\$ + Y\$}{L \times T \times Y \times U}$$

Where F\$ are the life time fixed costs, R\$ are the life time recurring costs, and Y\$ are the life time yield costs. L is the useful life of the equipment, T is throughput, Y is the composite yield, and U is the total utilization. All of these factors will be discussed in detail during the course of this seminar.

Fixed Costs

The fixed costs are typically a function of six items as defined by SEMI COO Standard E35: depreciation, qualification, installation, training, moves and rearrangements, and floor space. Depreciation is a function of purchase price and the method employed to allocate costs per year. Typical depreciation methods would include: straight line, declining balance, and sum-of-the-years'-digits. System qualification costs are those costs associated with verifying that the equipment meets production specifications.

Installation costs would include any supplier charges for transportation and installation labor as well as the manufacturer's direct labor and facilities preparation costs. Training costs in this category cover the initial training requirements for personnel to enable the equipment to be used in production. Ongoing training is a recurring cost.

Moves and rearrangements are the costs associated with moving or removing existing equipment to make room for the new equipment. Floor space costs are a function of the depreciation and operating cost per square foot or meter of cleanroom/manufacturing space and the operational footprint of the equipment.

Recurring Costs

The expense of running equipment in production can be broken into seven major categories by SEMI COO Standard E35: materials, consumables, maintenance, labor, support personnel, scrap, and support services. Materials are defined as utilities, supplies, and test/filler wafers/units that are consumed in the production of the product as well as waste disposal costs. Consumables are parts of the equipment that are worn out by the process operation and require replacement in one year or less.

The cost of maintaining a piece of equipment would include service contracts, maintenance labor, repair parts, and ongoing training. Labor is defined as operator labor only. While support personnel includes supervisors and engineering support. Scrap is the cost of lost product and is described in detail later in this section. Support services cover bonuses, stock options, and other benefit packages.

Utilization

Utilization describes the number of hours the equipment is available to produce product out of the total number of hours that the fab/factory is in operation. This value is typically expressed in hours per week and can be conceptualized by the equation:

$$U = 1 - \frac{SM + USM + A + S + Q + E}{H}$$

SM is the scheduled maintenance, USM is the unscheduled maintenance, A is the assist time, S is the standby time, Q is the production qualification time, and E is the process engineering time, all expressed as hours per week. H is the total number of production hours scheduled per week. Utilization is effectively a scaling factor, reducing the output of the process step.

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SEMI Standard E10 defines utilization in two ways. Total utilization measures the availability of an operation for productive use and is defined by the previous equation. Equipment utilization measures the availability of an operation for any use and only considers scheduled maintenance, unscheduled maintenance, and assist time losses.

From a supplier perspective, it is advantageous to maximize equipment utilization. This allows the equipment to produce the maximum number of units per capital dollar invested.

If we examine utilization from a purely cycle time perspective, the exact opposite conclusion would be drawn. Cycle time is minimized when utilization is low and the equipment is waiting idle for the next unit to arrive. This assumes, of course, that the low utilization is due to standby and not unpredictable downtime.

This leaves the factory with a trade-off decision. How does it reduce cycle time and work in process (WIP) costs while at the same time keeping cost of ownership at a reasonable level. The typical answer for a multi-product factory has been to choose a utilization factor (typically called factory loading) of 70% and demand that the equipment be highly reliable. This provides most of the cycle time reduction without paying too high a price in COO.

Yield Costs

Yield costs are those costs associated with lost wafers/units and defective die that are directly attributable to the performance characteristics of the process step. The cost of yield loss for front end processes is described as:

$$Y\$ = W_y \times P\$ + W_d \times T\$ + W_p \times T\$$$

where W_y is the number of wafers/units lost due to breakage and misprocessing caught at that step, $P\$$ is the value of those wafers/units at that step in the process, W_d is the number of die lost to defects expressed as equivalent wafers, $T\$$ is the value of those equivalent wafers at the end of the process flow, and W_p is the number of wafers/units lost to parametric limited yield. This equation is applicable to any manufacturing process if you drop out the defect limited yield components.

For front end metrology steps, the yield equation would look like:

$$Y\$ = W_b \times P\$ + W_d \times T\$ + W_\alpha \times P\$ + W_\beta \times \beta\$$$

where W_b is the number of wafers/units lost due to breakage, W_α is the number of wafers/units lost to alpha error (good product measured as bad), W_β is the number of wafers/units passed due to beta error (bad product measured as good), and $\beta\$$ is the cost of passing bad product. Again, dropping out the W_d makes this applicable to any metrology environment.

For test operations, the equation would reduce to:

$$Y\$ = W_b \times P\$ + W_\alpha \times P\$ + W_\beta \times \beta\$$$

For other packaging and assembly operations the equation becomes:

$$Y\$ = W_b \times P\$$$

In these last two cases wafers can be substituted with the appropriate unit of production (die, etc.).

Materials/Components

One of the most frequently asked questions with regard to cost of ownership modeling is, "my company makes materials (or components) used by equipment. How does COO modeling apply to me?"

While it is true that most of the inputs to a cost of ownership modeling are "equipment" specifications, you must remember that you are really modeling a process step. The question that materials and component suppliers must ask themselves is, "how does my product affect this step in the process?"

Areas of potential impact are lower particulates, higher throughput, lower material consumption, higher reliability, etc. The key to using COO for materials and components is to expand the "thought bubble" to examine the process specifications with and without your product's use. The difference between these two states is your contribution.

Total Cost Model

The preceding discussion has centered around the information used to describe the cost of ownership for a specified process step. Cost of ownership in its present form, however, is not equivalent to "**Total Cost of Ownership.**" A total cost model would also need to consider the interrelationships between steps in the manufacturing process and their impact on bottlenecks and line balance.

Cost of Ownership Concept



COO Comparison

<u>Key Factors</u>	<u>CVD 100</u>	<u>CVD 200</u>
Equipment Cost	\$1,000,000	\$1,200,000
Spares Cost	\$50,000	\$65,000
Consumables Cost	\$9,000	\$18,000
MTBF	1000 hrs	200 hrs
MTTR	3 hrs	2 hrs
Scheduled PM	16 hrs	8 hrs
Raw Throughput	21 wph	26 wph
Production Tests	14	14
MTTT	0.65 hrs	0.50 hrs
Systems/Operator	4	3
Equipment Yield	99.99%	99.999%
Incoming Wafer Value	\$500	\$500
Defect Density	0.1	0.05
Fault Probability	.005	.005
Device Area	2	2
Completed Wafer Value	\$1000	\$1000

Discussion Topics

- ▣ **Cost of Ownership Algorithm**
- ▣ **Fixed Costs**
- ▣ **Recurring Costs**
- ▣ **Utilization**
- ▣ **Yield Costs**
- ▣ **Materials/Components**
- ▣ **Total Cost Model**

Cost of Ownership Algorithm

$$\text{COO} = \frac{\text{F\$} + \text{R\$} + \text{Y\$}}{\text{L} \times \text{T} \times \text{Y} \times \text{U}}$$

F\$ = Fixed Costs R\$ = Recurring Costs

Y\$ = Yield Costs L = Process Life

T = Throughput Y = Composite Yield

U = Utilization

Fixed Costs

$$\text{COO} = \frac{\text{F\$} + \text{R\$} + \text{Y\$}}{\text{L} \times \text{T} \times \text{Y} \times \text{U}}$$

- ▣ Depreciation
- ▣ Installation Costs
- ▣ Initial Training
- ▣ Moves and Rearrangements
- ▣ Floor Space



Recurring Costs

$$\text{COO} = \frac{\text{F\$} + \text{R\$} + \text{Y\$}}{\text{L} \times \text{T} \times \text{Y} \times \text{U}}$$

- | | |
|----------------------|----------------------------|
| ▣ Materials | ▣ Maintenance |
| – Utilities | ▣ Labor |
| – Supplies | ▣ Support Personnel |
| – Test/Filler Wafers | ▣ Scrap |
| – Waste Disposal | ▣ Support Services |
| ▣ Consumables | |



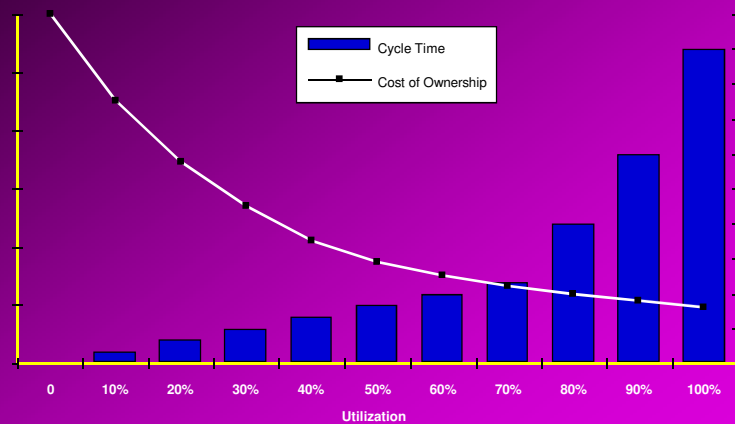
Utilization

$$COO = \frac{F\$ + R\$ + Y\$}{L \times T \times Y \times U}$$

$$U = 1 - \frac{SM + USM + A + S + Q + E}{H}$$

SM = Scheduled Maintenance
USM = Unscheduled Maintenance
A = Assists
S = Standby
E = Engineering
Q = System Qualification
H = Manufacturing Hours

Cycle Time



Yield Costs

$$\text{COO} = \frac{\text{F\$} + \text{R\$} + \text{Y\$}}{\text{L} \times \text{T} \times \text{Y} \times \text{U}}$$

$$\text{Y\$} = \text{W}_y \times \text{P\$} + \text{W}_d \times \text{T\$} + \text{W}_p \times \text{T\$}$$

W_y = Wafers Lost to Equipment Yield

$\text{P\$}$ = Wafer Cost at that Process Level

W_d = Equivalent Wafers Lost to Defect Limited Yield

$\text{T\$}$ = Wafer Cost at End of Process Flow

W_p = Equivalent Wafers Lost to Parametric Limited Yield

Metrology Yield Costs

$$\begin{aligned} \text{Y\$} = & \text{W}_b \times \text{P\$} + \text{W}_d \times \text{T\$} \\ & + \text{W}_\alpha \times \text{P\$} + \text{W}_\beta \times \beta\$ \end{aligned}$$

W_b = Wafers Lost to Breakage

W_α = Wafers Lost to Alpha Error

W_β = Wafers Passed Due to Beta Error

$\beta\$$ = The Cost of Passing Bad Wafers

Metrology Yield Costs

		Actual	
		Good	Bad
Measured	Good		β error
	Bad	α error	

Final Test Yield

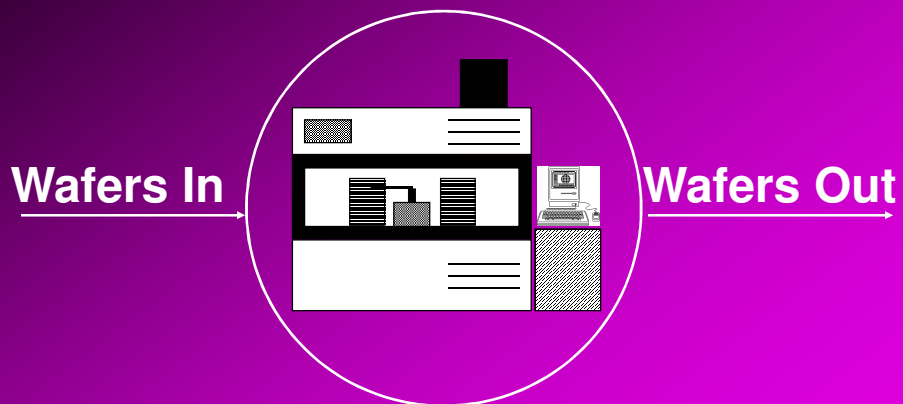
$$Y\$ = W_b \times P\$ + W_{\alpha} \times P\$ + W_{\beta} \times \beta\$$$

Back End Operations Yield

$$Y\$ = W_b \times P\$$$



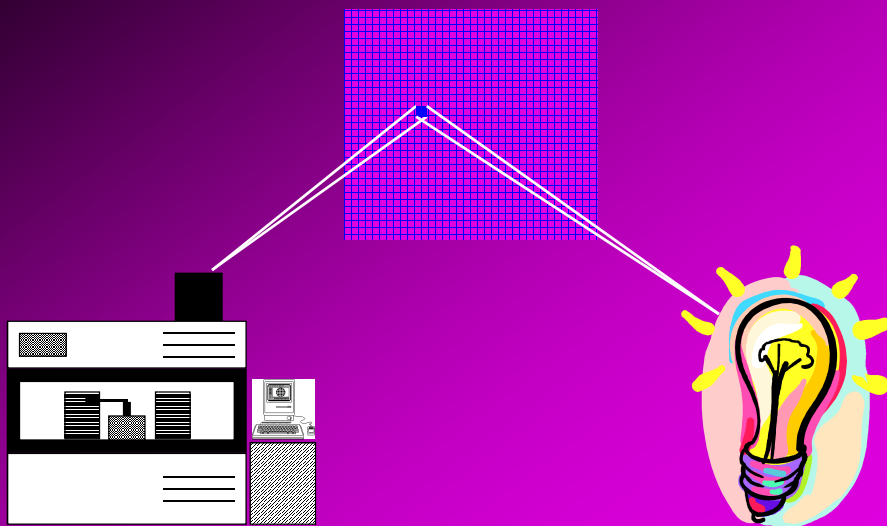
Materials



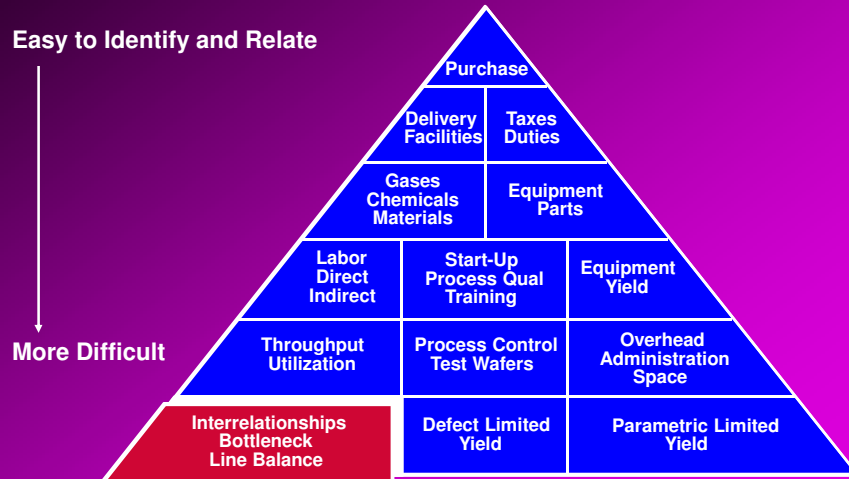
Materials (cont'd)



Components



Total Cost Model



Cost of Ownership Details

Cost of ownership is composed of four main functional areas, fab/factory operating data, equipment/material specifications, cost analysis, and yield models. The manipulation of these items by software algorithms allows for an easy to use yet extensive cost of ownership model.

What You Should Learn from this Module

- ☐ The components of the cost of ownership models.
- ☐ The items typically categorized as fab/factory parameters.
- ☐ The items typically categorized as model specific data.
- ☐ The types of data output available from COO analyses.
- ☐ The components of the detailed yield algorithms.
- ☐ The assumptions made in estimating defect limited yield.

Fab/Factory Parameters

The fab/factory parameters describe the way in which the manufacturer will operate their production environment. Fab/Factory parameters are broken into three distinct sections: throughput data, process data, and administrative rates.

Throughput data includes those items necessary to determine the time the system will be used for non-production purposes and the required unit starts per week or number of systems.

3-2 *Understanding and Using Cost of Ownership*

The process data section provides information to be used in defect and parametric limited yield modeling.

Administrative rates describe the production hours, salary rates, floor space costs, and wafer/unit values. Many of these values are available in the appendix to the SEMI COO Standard E35.

Model Specific Data

The equipment and materials specifications describe the way in which the tool will interact with the production environment. Equipment/material specifications are broken into three areas: throughput data, equipment data, and production data.

Throughput data includes those items necessary to determine the time the system will be unavailable for production purposes and the raw throughput.

The equipment data contains the initial purchase costs, qualification times, footprint, initial training, and defect and equipment yield information.

The production data section provides information on utilities, supplies/consumables, waste disposal, test/filler wafers/units, maintenance, and support personnel requirements.

Cost Analysis

The cost analysis sections are, for the most part, simple mathematical manipulations of the raw data provided by fab/factory parameters and equipment/material specifications. The costs are broken into two main categories: equipment and recurring.

Equipment costs (fixed costs) include those items associated with the initial purchase of the equipment and putting it into production. Floor space costs are also included in this section.

Recurring costs (variable costs) contain materials/consumables, maintenance, and personnel. In the cost analysis tables scrap is included as a production expense but its derivation is more complex than other recurring cost issues. All of these items are dependent on the production hours and unit starts.

Yield Models

The major exceptions to the simple mathematics used in most of the cost calculations are the yield models. There are three areas that impact yield in process tools, equipment yield, defect limited yield (semiconductor front end processes only), and parametric limited yield.

Equipment yield is an input from equipment specifications and indicates the yield loss due to product breakage and misprocessing caught at that step and attributable to that step.

Defect limited yields are predicted from information on die size, defect density, and fault probability. A more detailed explanation of defect limited yield modeling is included in section 9 in this manual.

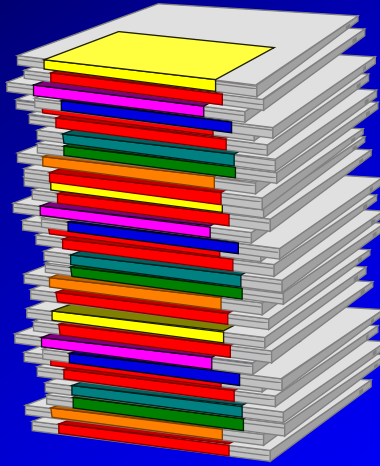
Fault probability determines the chances that a physical defect on the wafer will lead to an electrical defect. Fault probability is a function of the minimum critical defect size, minimum feature size, feature pitch, and the defect inspection method. A more detailed explanation of fault probability is included in section 9 in this manual.

Parametric limited yield has historically not been an input to COO models. This has changed with later versions of software.

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Parametric limited yield is that component of yield loss associated with the distribution of a particular equipment performance specification. An example would be the relationship between the film thickness uniformity for CVD and the yield of the device. The parametric limited yield is not estimated by the model but is a direct input.

Cost of Ownership Details

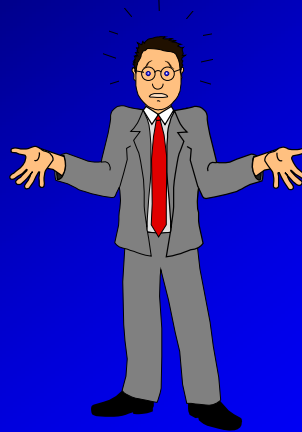


Discussion Topics

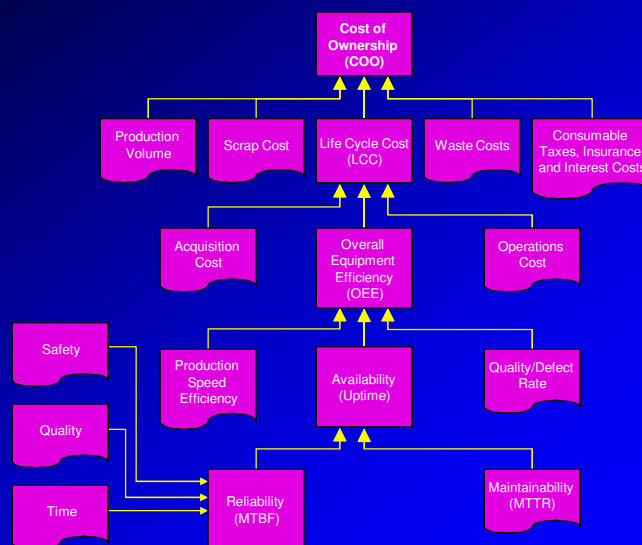
- **Equipment Performance Metrics**
- **Fab/Factory Operating Data**
- **Model Specific Data**
- **Cost Analysis**
- **Yield Models**

Equipment Performance Metrics

- MTBF (MTBI)
- MTTR
- RAM
- OEE
- LCC
- COO



Equipment Performance Metrics (cont'd)



Courtesy of Dr. Vallabh Dhudshia, formerly of Texas Instruments

Equipment Performance Metrics (cont'd)

- **MTBF - Mean Time Between Failure**
- **MTBI - Mean Time Between Interrupt**
- **MTTR - Mean Time to Repair**
- **RAM - Reliability, Availability & Maintainability**
- **OEE - Overall Equipment Efficiency**
- **LCC - Life Cycle Costing**
- **All are part of COO**

Fab/Factory Parameters

Throughput Data		
Time Not Available (Per System)		
Engineering Usage	0.00	Hours/Week
Standby	0.00	Hours/Week
Production Tests Scheduled	14	/Week
MTTT	0.25	Hours
Whole System Requirements	1	Single System
Volume Requirement	0	Fully Loaded
Lot Size	24	Wafers/Lot
Redo Rate	0.00	%

Fab/Factory Parameters (cont'd)

Process Data	
Wafer Size	200 mm
Wafer Coverage	80.00 %
Die Area	1.00 cm ²
Fault Probability	5.00 %
Clustering Parameter	1.00
Parametric Limited Yield Loss	0.25 %

Fab/Factory Parameters (cont'd)

Scheduled Production	
Hours/Week/Shift	42.00 Hours
Shifts/Week	4 Shifts
Days/Year	365.00 Days
Operator/Maint. Productive Time	80.00 %

Burdened Salary Rates/Year	
Engineering	100,000 Currency
Supervision	80,000 Currency

Burdened Labor Rates/Hour	
Operator	25 Currency
Maintenance	30 Currency

Fab/Factory Parameters (cont'd)

Space Rates/Year		
Class 1	400	Currency/ft2
Class 10	250	Currency/ft2
Class 100	100	Currency/ft2
Other	50	Currency/ft2

Other Support Services/Year		
Employee Related	0	Currency
Production Related	0	Currency

Fab/Factory Parameters (cont'd)

Administrative Rates		
Inflation Rate	4.00	%
Life of Equipment	7.00	Years
Depreciation Life	5.00	Years
Salvage Value	0	Currency
Depreciation Method	str	
Declining Balance Factor	200	%
Insurance	0.00	% BV
Personal Property Taxes	0.00	% BV
Interest	0.00	% Rate

Fab/Factory Parameters (cont'd)

Currency		
Input Currency	Currency	
Output Currency	Currency	
Currency Exchange Rate	1.00	
Other Costs		
Spare Parts Inventory Costs/System	0	Currency/Year
Test Wafer Cost	100	Currency/Wafer
Value of Incoming Wafer	500	Currency/Wafer
Value of Completed Wafer	1,000	Currency/Wafer
Moves and Rearrangements/System	0	Currency
ESH Permits and Preparation	0	Currency

Model Specific Data

Time Not Available		
Scheduled Maintenance	14.00	Hours/Week
Primary Wafer Based Maint.	0	Layers
Primary Time/Wafer Quantity	0.00	Hours
Secondary Wafer Based Maint.	0	Layers
Secondary Time/Wafer Quantity	0.00	Hours
MTBF	200.00	Hours
Average Response Time	0.10	Hours
MTTR	10.00	Hours
MTBA	12.00	Hours
MTTA	1.00	Minutes
Throughput Data		
Throughput at Capacity/System	35.00	Layers/Hour
Systems/Operator	3	Systems

Model Specific Data (cont'd)

Original Cost/System		
Equipment Cost	1,000,000	Currency
Transportation Cost	10,000	Currency
Installation Cost	5,000	Currency
Other Depreciable Costs	0	Currency
System Qualification		
Engineering	40.00	Man-Hours
Maintenance	20.00	Man-Hours
Operator	80.00	Man-Hours
Supplies/Consumables	0	Currency
Other Material	0	Currency
Other Costs	0	Currency

Model Specific Data (cont'd)

Floor Space/System		
Class 1	75.00	Square Feet
Class 10	0.00	Square Feet
Class 100	50.00	Square Feet
Other	0.00	Square Feet
Training Required/System		
Operators	80.00	Man-Hours
Engineers	24.00	Man-Hours
Maintenance	80.00	Man-Hours
Other Costs	4,000	Currency
Yield		
Equipment Yield	99.99	%
Defect Density	0.01	Per cm2
Defect Measurement	2	

Model Specific Data (cont'd)

Utilities			
Utility	Wafer, Time, or Lot Based	Quantity Per Layer/Lot	Price Per Quantity
Electricity	T		2,000.00
Natural Gas			
City Water			
DI Water			
Chilled Water	T		1,500.00

Model Specific Data (cont'd)

Supply/Consumables			
Supply/Consumable	Wafer, Time, or Lot Based	Quantity Per Layer/Lot	Price Per Quantity
Gas/Chemical 1	W	1	0.10
Gas/Chemical 2			
Gas/Chemical 3			
Gas/Chemical 4			
Gas/Chemical 5			
Plant Exhaust			
Bulk Chemicals			
Specialty Chemicals	T		125,000.00
Bulk Gases			
Expendables			
Manufacturing Tooling			
Rent of Equipment			
Protective Clothing			
Office Supplies			
Computer Software			
Expensed Equipment			
Computer Supplies			
Forms			

Model Specific Data (cont'd)

Other Production Costs/System	
Other Production Costs	0 Currency/Year
Waste Disposal Costs	0 Currency/Year
Other Material Costs	
Test Wafers	1.40 Wafers/Week
Other Materials	0 Currency/Year
Personnel/System	
Engineers	4.00 Hours/Week
Supervision	1.33 Hours/Week
Contract Labor	0 Currency/Year

Model Specific Data (cont'd)

Parts & Technicians																			
Repair Parts/System	15,000 Currency/Year																		
Maintenance Technicians	<table border="1"> <thead> <tr> <th>Shift 1</th> <th>Shift 2</th> <th>Shift 3</th> <th>Shift 4</th> <th>Shift 5</th> <th>Shift 6</th> </tr> </thead> <tbody> <tr> <td>Scheduled</td> <td>1.00</td> <td>0.00</td> <td>0.00</td> <td>0.00</td> <td>0.00</td> </tr> <tr> <td>Unscheduled</td> <td>0.00</td> <td>0.00</td> <td>0.00</td> <td>0.00</td> <td>0.00</td> </tr> </tbody> </table>	Shift 1	Shift 2	Shift 3	Shift 4	Shift 5	Shift 6	Scheduled	1.00	0.00	0.00	0.00	0.00	Unscheduled	0.00	0.00	0.00	0.00	0.00
Shift 1	Shift 2	Shift 3	Shift 4	Shift 5	Shift 6														
Scheduled	1.00	0.00	0.00	0.00	0.00														
Unscheduled	0.00	0.00	0.00	0.00	0.00														
Warranty																			
Warranty Period	12 Months																		
Warranty Shift Coverage	1 Shifts																		
Repair Parts Coverage	yes																		
Labor Coverage	<table border="1"> <thead> <tr> <th>Shift 1</th> <th>Shift 2</th> <th>Shift 3</th> <th>Shift 4</th> <th>Shift 5</th> <th>Shift 6</th> </tr> </thead> <tbody> <tr> <td>Repair</td> <td>yes</td> <td>no</td> <td>no</td> <td>no</td> <td>no</td> </tr> <tr> <td>Sched. Maint.</td> <td>no</td> <td>no</td> <td>no</td> <td>no</td> <td>no</td> </tr> </tbody> </table>	Shift 1	Shift 2	Shift 3	Shift 4	Shift 5	Shift 6	Repair	yes	no	no	no	no	Sched. Maint.	no	no	no	no	no
Shift 1	Shift 2	Shift 3	Shift 4	Shift 5	Shift 6														
Repair	yes	no	no	no	no														
Sched. Maint.	no	no	no	no	no														

Model Specific Data (cont'd)

Contract

Repair Parts Coverage

	Shift 1	Shift 2	Shift 3	Shift 4	Shift 5	Shift 6
Annual Contract/System	15,000	15,000	15,000	15,000	0	0
Repair Labor	yes	yes	yes	yes	no	no
Sched. Maint. Labor	no	no	no	no	no	no

Other Costs

Annual Supplier Training/System Currency

Annual Software Contract/System Currency

Cost Analysis

Management	Pareto	OEE
Cost Per System		1,000,000 Currency
Number Of Systems Required		1 Systems
Total Depreciable Costs		1,015,000 Currency
Equipment Utilization Capability		87.04 Percent
Production Utilization Capability		84.96 Percent
Composite Yield		99.69 Percent
Good Wafer Equivalents Out Per Week		4,979.88 G.W.E.'s
Good Wafer Equivalent Cost		
With Scrap		5.24 Currency
Without Scrap		2.19 Currency
Average Monthly Cost		
With Scrap		113,447 Currency
Without Scrap		47,283 Currency
Scrap Allocation		
Equipment Yield		1.64 Percent
Defect Limited Yield		16.35 Percent
Parametric Limited Yield		82.01 Percent

Cost Analysis (cont'd)

LIFE OF EQUIPMENT

Equipment Costs	1,305,363 Currency
Cost Per Good Wafer Equivalent	0.72 Currency
Cost Per Good cm2 Out	0.0029 Currency
Recurring Costs	8,224,179 Currency
Cost Per Good Wafer Equivalent	4.52 Currency
Cost Per Good cm2 Out	0.0180 Currency
Total Costs	9,529,541 Currency
Total Cost Per Good Wafer Equivalent	5.24 Currency
Total Cost Per Good cm2 Out	0.0209 Currency
Cost Per Productive Minute	3.05 Currency

Cost Analysis (cont'd)

Management

Pareto

OEE

COST DRIVERS PER GOOD WAFER EQUIVALENT

Scrap	3.058 Currency
Material/Consumables	0.672 Currency
Depreciation	0.558 Currency
Maintenance	0.366 Currency
Labor	0.346 Currency
Floor Space Costs	0.152 Currency
Support Personnel	0.052 Currency
Other Materials	0.032 Currency
Training	0.005 Currency
System Qualification Costs	0.002 Currency
ESH Preparation and Permits	0.000 Currency
Moves And Rearrangements	0.000 Currency
Other Support Services	0.000 Currency

Cost Analysis (cont'd)

(All Costs in Currency)	Year 1	Year 2	Year 3	Year 4	Year 5
Equipment Costs					
Depreciation	203,000	203,000	203,000	203,000	203,000
Moves And Rearrangements	0				
ESH Preparation and Permits	0				
System Qualification Costs	4,426				
Floor Space Costs	35,000	36,400	37,856	39,370	40,945
Training	9,496				
Cost/Year	251,922	239,400	240,856	242,370	243,945
Cumulative Cost	251,922	491,322	732,178	974,548	1,218,493
Cost/Good Wafer Equivalent	0.97	0.92	0.93	0.93	0.94
Cumulative Cost	0.97	0.95	0.94	0.94	0.94
Cost/Good cm2 Out	0.0039	0.0037	0.0037	0.0037	0.0037
Cumulative Cost	0.0039	0.0038	0.0037	0.0037	0.0037

Cost Analysis (cont'd)

Recurring Costs					
Utilities	3,500	3,640	3,786	3,937	4,095
Supplies/Consumables	151,047	157,089	163,373	169,908	176,704
Waste Disposal	0	0	0	0	0
Other Materials	7,300	7,592	7,896	8,212	8,540
Maintenance	71,015	89,455	93,033	96,755	100,625
Personnel					
Operators	79,570	82,753	86,063	89,505	93,085
Engineering	9,524	9,905	10,301	10,713	11,142
Supervision	2,533	2,635	2,740	2,850	2,964
Contract Labor	0	0	0	0	0
Other Support Services	0	0	0	0	0
Value of Equivalent Wafers Scrapped	793,971	793,971	793,971	793,971	793,971
Cost/Year	1,118,460	1,147,039	1,161,162	1,175,850	1,191,125
Cumulative Cost	1,118,460	2,265,499	3,426,661	4,602,511	5,793,635
Cost/Good Wafer Equivalent	4.31	4.42	4.47	4.53	4.59
Cumulative Cost	4.31	4.36	4.40	4.43	4.46
Cost/Good cm2 Out	0.0171	0.0176	0.0178	0.0180	0.0183
Cumulative Cost	0.0171	0.0174	0.0175	0.0176	0.0178

Yield Models

- **Equipment Yield**
- **Defect Limited Yield**
- **Parametric Limited Yield**



Equipment Yield

- **Wafer Breakage**
- **Misprocessing**
 - Caught at That Process Step



Defect Limited Yield

- Negative Binomial Model

$$Y = \frac{1}{1 + \frac{(A_a \times D \times P)^\alpha}{\alpha}}$$

A_a = Device Active Area

D = Defect Density

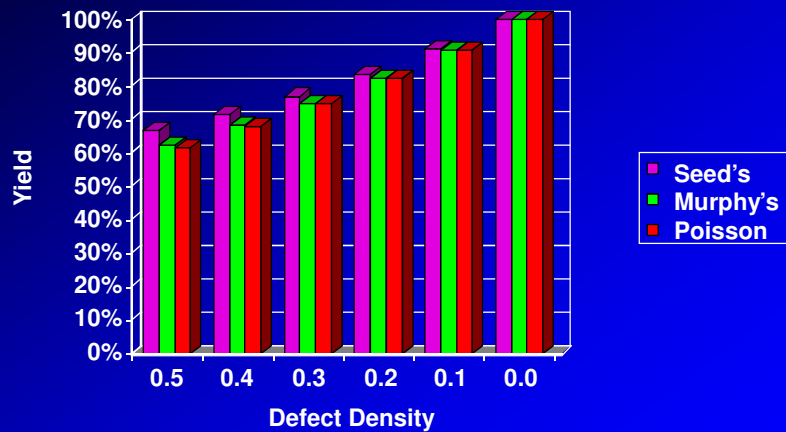
P = Fault Probability

α = Clustering Parameter

Yield Model Clustering Parameters

Yield Model	α	Degree of Clustering
Seed's	1	High
Murphy's	~4.5	Moderate
Poisson	>7	Negligible

Clustering Parameter Impact



Defect Limited Yield Considerations

- Degree of Defect Clustering
- Size Population
- Process Step
- Defect Changes Over Time

Parametric Limited Yield

□ Device Specifications

- Film Thickness Uniformity
- Dopant Concentration Uniformity
- Upper and Lower Control Limits

□ Equipment Performance

- Process C_{pk}

□ Difficult to Model

- Empirical Measurements



Applications

Cost of ownership modeling can be applied to a wide variety of situations involving equipment and materials. The benefit of these analyses is applicable to both suppliers and manufacturers. The areas that are typically examined from a cost of ownership perspective are product benchmarking, competitive analysis, materials impact, project prioritization, technology evaluation, process optimization, and sales.

What You Should Learn from this Module

- ☐ The difference between benchmarking and competitive analysis.
- ☐ The application of COO to materials evaluations.
- ☐ How to prioritize engineering projects.
- ☐ How to use COO to differentiate technically equivalent processes.
- ☐ The correct way to use COO to evaluate suppliers before you purchase and to evaluate your installed base.
- ☐ Under what conditions a supplier should consider using COO as a sales tool.

Product Benchmarking

Product benchmarking allows the equipment supplier the ability to gauge their products with respect to industry requirements and best-of-breed performance and processes. To successfully complete a cost of ownership benchmark, the equipment

4-2 *Understanding and Using Cost of Ownership*

manufacturer must have good market research on the industry's fab/factory operating parameters for different product types (logic, memory, ASIC) as well as detailed best-of-breed performance/process specifications.

The areas of greatest concern and impact on benchmark results are yield, productivity, maintenance, and consumables. Equipment specifications must represent actual performance under the process conditions described in the fab/factory parameter input and not just paper specifications. If this information is unavailable or incomplete then the benchmarking process can still be successful in focusing the company's attention on where to improve market research and competitive intelligence gathering.

Competitive Analysis

While product benchmarking allows an equipment or material supplier to gauge individual products and processes against the best-of-breed in each area of interest, competitive analysis provides information on current strengths and weaknesses in the market. This information is the basis for determining whether cost of ownership can currently be used as a sales tool.

The competitive analysis is handled in an identical manner to product benchmarking except that the comparative specifications are taken from each competing product, not a best-of-breed composite. The greatest impacts on a competitive analysis are yield, productivity, maintenance, and consumables. Again, equipment specifications must represent actual performance under the process conditions described in the fab/factory parameter input.

Materials Impact

While cost of ownership is usually associated with equipment performance, it can be applied to materials (and components) as well. For material suppliers, cost of ownership requires greater market research on equipment and competitive materials specifications.

Once specifications are available for the process and equipment the material will be used in, it is a relatively straight forward process to determine the benefit of different material choices. The process areas that materials can impact include yield (defects, parametric), productivity, consumables cost and usage, and waste disposal.

Project Prioritization

A far more important initial use of cost of ownership for both manufacturers and equipment and material suppliers is engineering project prioritization. That is, understanding which projects will provide the largest cost/benefit impact on the manufacturing process.

Project evaluation starts with a standard cost of ownership analysis with the unit starts per week set to fully load a single machine. Once a baseline cost of ownership is run, the projects of interest can be evaluated. By modifying one parameter at a time, a measurement of the cost per unit impact of the specification changes can be determined.

Armed with the improved unit cost performance and the cost of implementing the improved specification, an estimated return on investment for the end user can be made. In this case the implementation costs would include any equipment or material purchased from the supplier and other implementation costs incurred by the end user.

4-4 *Understanding and Using Cost of Ownership*

$$\text{ROI} = \frac{\Delta \text{Cost/Unit} \times \text{Units/Year}}{\text{Development Costs}}$$

Applying this ROI technique to each engineering project will provide insight into which improvements will provide the largest return to both the manufacturer and the equipment or material supplier.

Another return on investment equation is also used by suppliers to prioritize projects. A comparable equation has the ROI as follows:

$$\text{ROI} = \frac{\{\text{ASP} - \text{Manufacturing Cost}\} * \text{Units Sold}}{\text{Development Costs}}$$

In this case, {Average Selling Price - Manufacturing cost} is the margin for the product. The development costs are only those costs incurred by the supplier in the development of the product. The ROI should be calculated over the reasonably anticipated life of the product, typically 3-5 years.

Ultimately, the key is to find projects where both suppliers and manufacturers have good ROI's. This creates a win-win scenario. It is also important to recognize that the supplier ROI and Customer ROI equations are not independent from each other, though it may appear that way at first. In most cases, the ASP value used in the supplier ROI analysis is a large component of the customer's Development Cost. This interdependence provides the ability to seek mutually beneficial projects.

Technology Evaluation

The preceding discussion has centered on the application of cost of ownership to equipment and material suppliers. Technology evaluation has its main use as a tool for manufacturers.

Many steps in the manufacturing process have multiple solutions that encompass radically different technologies (e.g. CMP and chemical planarization). Cost of ownership modeling allows the manufacturer to determine the lowest cost combination of equipment and materials.

Technology evaluation starts with performance data on the process of interest. If there is more than one choice for equipment and materials, then a matrix of equipment/material combinations is analyzed. The resultant data provides valuable input into the purchase decision.

Process Optimization

Process optimization is another tool for the manufacturer. It is the means by which the impact of process changes on existing equipment is determined and new equipment and materials purchases are evaluated.

For existing equipment and material sets, changes in the current process can have significant impact on total costs. A design shrink can impact minimum defect size considerations, effectively increasing the defect density and scrap costs. Changes in wafer size can also seriously change throughput capabilities and requirements.

Process optimization is also the technique applied to new equipment and materials purchases. In this case, the manufacturing process is defined and new equipment and materials are evaluated against the process requirements. Those products yielding the lowest cost per unit performance will most likely be given priority in the purchase evaluation.

If a process road map has been determined prior to the purchase of equipment and materials then the product useful life and/or

long-term cost structure can be determined. The least expensive materials and equipment for today's process may not have the lowest cost over a three-year period given future technical requirements.

Sales Tool

The most complex area of application for cost of ownership modeling is its use as a sales tool. This application can be broken into two categories, reactive and pro-active.

The typical scenario for sales use of cost of ownership is in response to an RFQ from a manufacturer. This request either asks for specific input to a cost of ownership model the manufacturer uses as a standard or for the equipment or materials supplier to provide their own complete model.

If you are providing your own model, you will need to establish a strong relationship with the manufacturer to help educate them on different assumptions that may exist in your competition's cost models. For the manufacturer who has their own model, you should ask them to run a set of fictitious data through their model and the same data through yours to check for correlation. Any discrepancies must be understood prior to providing final performance data.

If cost of ownership is to be used on a pro-active basis, both a product benchmark and competitive analysis must be run first. Understanding your true cost advantages and the assumptions under which those advantages hold is essential to having your data accepted. Any areas of contention should be avoided as they will lead to a loss of credibility on this and other issues. It is always harder to recover lost ground at an account than it is to properly set the stage for cooperation.

Applications



Discussion Topics

- ❑ **Product Benchmarking**
- ❑ **Competitive Analysis**
- ❑ **Materials Impact**
- ❑ **Project Prioritization**
- ❑ **Technology Evaluation**
- ❑ **Process Optimization**
- ❑ **Sales**

Product Benchmarking

- **Best-of-Breed**
 - Results
 - Processes
- **Not Competitive Analysis**
- **Current Product Performance**
 - Yield
 - Productivity
 - Maintenance
 - Consumables



Competitive Analysis

- **Comparative Analysis**
- **Current Product Performance**
 - Yield
 - Productivity
 - Maintenance
 - Consumables
- **Current Competition**
 - Actual Performance



Competitive Analysis (cont'd)

THROUGHPUT DATA

Time Not Available	Engineering Usage	5.00	5.00	Hours/Week
(Per System)	Standby	10.00	10.00	Hours/Week
	Production Tests Scheduled	5	5	Number/Week
	MTTT	0.25	0.25	Hours
Whole System Requirements				Systems
Volume Requirement		9000	9000	Layers/Week
Lot Size		24	24	Wafers/Lot
Redo Rate				%

MODEL SPECIFIC DATA

THROUGHPUT DATA

Time Not Available	Scheduled Maintenance	14.00	14.00	Hours/Week
(Per System)	Primary Wafer Based Maintenance			Layers
	Primary Time Per Wafer Quantity			Hours
	Secondary Wafer Based Maintenance			Layers
	Secondary Time Per Wafer Quantity			Hours
	MTBF	200.00	200.00	Hours
	Average Response Time	0.10	0.10	Hours
	MTTR	10.00	10.00	Hours
	MTBA	12.00	12.00	Hours
	MTTA	1.00	1.00	Minutes
Throughput At Capacity/System		33.00	35.00	Layers/Hour
Number Of Systems/Operator		2	2	Systems

Competitive Analysis (cont'd)

MANAGEMENT REPORT

Cost Per System	\$1,000,000	\$1,000,000	Dollars
Number Of Systems Required	3	2	Systems
Total Depreciable Costs	\$3,045,000	\$2,030,000	Dollars
Equipment Dependent Utilization	87.16%	87.16%	Percent
Production Utilization	86.41%	86.41%	Percent
Composite Yield	98.75%	98.75%	Percent
Good Wafer Equivalents Out Per Week	8887.76	8887.76	G.W.E.'s
Good Wafer Equivalent Cost With Scrap	\$10.02	\$8.85	Dollars
Without Scrap	\$3.96	\$2.79	Dollars
Cost Per Productive Minute	\$3.81	\$5.04	Dollars
Average Monthly Cost With Scrap	\$371,042	\$327,628	Dollars
Without Scrap	\$146,580	\$103,167	Dollars
Scrap Allocation	4.18%	4.18%	Percent
Equipment Yield	12.50%	12.50%	Percent
Defect Limited Yield	83.32%	83.32%	Percent
Parametric Limited Yield			

Competitive Analysis (cont'd)

MODEL SPECIFIC DATA

THROUGHPUT DATA

Time Not Available (Per System)	Scheduled Maintenance	14.00	28.00 Hours/Week
	Primary Wafer Based Maintenance		Layers
	Primary Time Per Wafer Quantity		Hours
	Secondary Wafer Based Maintenance		Layers
	Secondary Time Per Wafer Quantity		Hours
	MTBF	200.00	200.00 Hours
	Average Response Time	0.10	0.10 Hours
	MTTR	10.00	10.00 Hours
	MTBA	12.00	12.00 Hours
	MTTA	1.00	1.00 Minutes
Throughput At Capacity/System		35.00	35.00 Layers/Hour
Number Of Systems/Operator		2	2 Systems

EQUIPMENT DATA

Original Cost/System	Equipment Cost	\$1,000,000	\$800,000 Currency
----------------------	----------------	-------------	--------------------

Competitive Analysis (cont'd)



Materials Impact

- **Baseline Current Equipment**
- **Measure Improvements**
 - Yield
 - Defect Reduction
 - Parametric Control
 - Productivity
 - Consumables
 - Waste Disposal



Project Prioritization

- **Product Specifications**
- **Fully Loaded Single Machine**
- **Change Parameter of Interest**
- **Measure Per Wafer Impact**



Project Prioritization (cont'd)

□ Determine ROI

$$\text{ROI} = \frac{\Delta \text{ Cost/Unit x Units/Year}}{\text{Development Costs}}$$



Project Prioritization (cont'd)

EQUIPMENT DATA				
Original Cost/System	Equipment Cost	\$1,000,000	\$1,000,000	Currency
	Transportation Cost	\$10,000	\$10,000	Currency
	Installation Cost	\$5,000	\$5,000	Currency
	Other Depreciable Costs			Currency
System Qualification Costs (Per System)	Engineering	40.00	40.00	Man-Hours
	Maintenance	20.00	20.00	Man-Hours
	Operator	80.00	80.00	Man-Hours
	Supplies/Consumables			Currency
	Other Material			Currency
	Other Costs			Currency
Floor Space/System	Class 1	75.00	75.00	Square Feet
	Class 10			Square Feet
	Class 100	50.00	50.00	Square Feet
	Other			Square Feet
Training Required (Per System)	Operators	80.00	80.00	Man-Hours
	Engineers	24.00	24.00	Man-Hours
	Maintenance	80.00	80.00	Man-Hours
	Other Costs	\$4,000	\$4,000	Currency
Equipment Yield		99.90%	99.90%	%
Defect Density		0.01	0.02	per cm2
Defect Measurement (Electrical=1, Physical=2)		2	2	



Project Prioritization (cont'd)

MANAGEMENT REPORT

Cost Per System	\$1,000,000	\$1,000,000	Dollars
Number Of Systems Required	1	1	Systems
Total Depreciable Costs	\$1,015,000	\$1,015,000	Dollars
Equipment Dependent Utilization	87.16%	87.16%	Percent
Production Utilization	86.41%	86.41%	Percent
Composite Yield	98.75%	98.61%	Percent
Good Wafer Equivalents Out Per Week	4492.98	4486.26	G.W.E.'s
Good Wafer Equivalent Cost With Scrap	\$8.83	\$9.59	Dollars
Without Scrap	\$2.77	\$2.77	Dollars
Cost Per Productive Minute	\$5.09	\$5.52	Dollars
Average Monthly Cost With Scrap	\$165,335	\$179,334	Dollars
Without Scrap	\$51,864	\$51,864	Dollars
Scrap Allocation Equipment Yield	4.18%	3.72%	Percent
Defect Limited Yield	12.50%	22.22%	Percent
Parametric Limited Yield	83.32%	74.06%	Percent

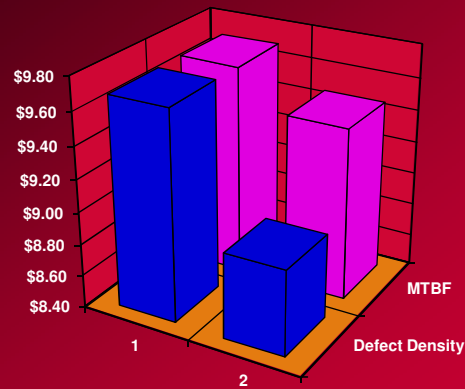
Project Prioritization (cont'd)

MODEL SPECIFIC DATA

THROUGHPUT DATA

Time Not Available (Per System)	Scheduled Maintenance	14.00	14.00	Hours/Week
	Primary Wafer Based Maintenance			Layers
	Primary Time Per Wafer Quantity			Hours
	Secondary Wafer Based Maintenance			Layers
	Secondary Time Per Wafer Quantity			Hours
	MTBF	100.00	1000.00	Hours
	Average Response Time	0.10	0.10	Hours
	MTTR	10.00	10.00	Hours
	MTBA	12.00	12.00	Hours
	MTTA	1.00	1.00	Minutes
Throughput At Capacity/System		35.00	35.00	Layers/Hour
Number Of Systems/Operator		2	2	Systems

Project Prioritization (cont'd)



Technology Evaluation

- **Competitive Analysis**
- **Multiple Solutions**
 - Equipment
 - Materials
 - Combination

Process Optimization

Existing Equipment/Material

- Process Change Impact
 - » Change in C_{pk}

Equipment/Material Purchase

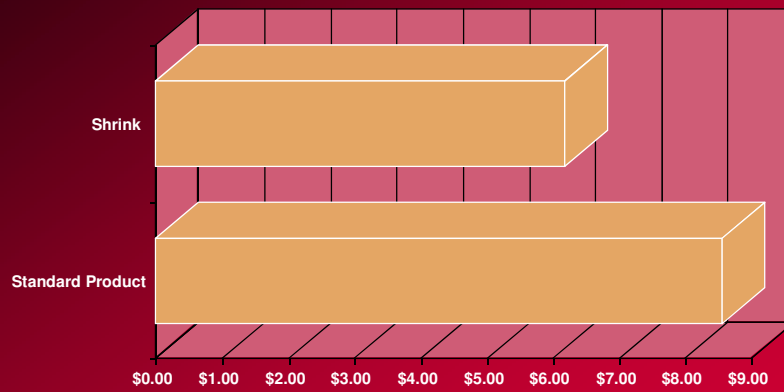
- Process Capabilities
- Process Roadmap

Process Optimization (cont'd)

PROCESS DATA

Wafer Size	150.00	150.00 mm
Wafer Coverage	80.00%	85.00% %
Die Area	1.00	0.90 cm ²
Fault Probability	10.00%	15.00% %
Clustering Parameter	1.00	1.00
Parametric Limited Yield Loss	1.00%	0.50% %

Process Optimization (cont'd)



Sales Tool

□ Reactive

— RFQ Response

» Input Only

- Run Fictitious Data
- Cross Check Results
- Establish Control Procedure

» Complete Model

- Educate
- List Assumptions

Sales Tool (cont'd)

□ Pro-Active

- Benchmark
- Competitive Analysis
 - » Understand True Cost Advantages
 - » Understand Assumptions
- Avoid Unsupportable Areas
- Educate
 - » Supplier Will Have A Clear Message
 - » Customer Will See COO Supports The Message
- Sales Script



From the Supplier's View

□ Many Groups Interact With The Customer

□ Information Handling

□ Constructive Relationship

- Trust With Sensitive Data
- Use Data Positively
- Working Relationship Makes Both Stronger
 - » Win-Win
 - » Partnerships
 - » True Account and Supplier Management



Potential Misuses

While cost of ownership can be successfully applied to many situations, its also has the potential to be misused. The major areas of concern include its use as a sales tool, its ability to confuse the uninitiated, and its sensitivity to specific inputs.

What You Should Learn from this Module

- ☐ The danger signs of when cost of ownership will hurt the sales situation.
- ☐ When does COO just confuse the issue.
- ☐ How easy is it to slip one by when you're not looking?

Sales Tool

Using cost of ownership initially as a sales tool is typically dangerous. Without first going through an extensive product benchmarking study and competitive analysis, it will be impossible to gauge the products competitive position on cost. Providing competitively inferior production performance information will almost always lose the order.

The steps required to turn cost of ownership modeling into an effective sales tool include product benchmarking, competitive analysis, cost of ownership training, and message control. The prerequisite is that the competitive analysis shows an advantage either short or long-term. If this is not the case, then cost of ownership should be used for engineering project prioritization until a cost advantage can be realized.

Once there has been a competitive advantage established, the messenger (sales, applications, marketing) must be trained. This

training must include cost of ownership modeling concepts, the operation of the cost of ownership model, its areas of sensitivity, the competitive situation, and the ability to defend its assumptions. Additionally, a sales and marketing script must be provided to explain any difference between published specifications and the achievable performance parameters used in the model.

Confusion Creation

While cost of ownership is designed to highlight areas of importance in the design and purchase of equipment and materials, it has the potential to muddy the waters to the uninitiated. Confusion can be generated through the initial complexity of the subject, the added evaluation criteria, and competitive openings.

Using cost of ownership with prospects that have little or no experience can be dangerous. The subject is straight forward, but the details can be confusing initially. If cost of ownership is a requirement of the situation, then take the time to educate the customer (internal or external).

Cost of ownership also creates an additional evaluation criterion for purchases. When there is competition for an order, cost of ownership can provide an avenue for product differentiation. On the other hand, if no competition currently exists, either in the market or with the prospect, cost of ownership will add little or no value in securing the order. In fact, it may delay the order long enough to allow competitors access to the account.

Finally, some of the achievable performance specifications may be difficult to prove. This can provide an opportunity for your competitors to create uncertainty in the prospect's mind. If cost of ownership is used as a sales tool, have data to back-up performance claims.

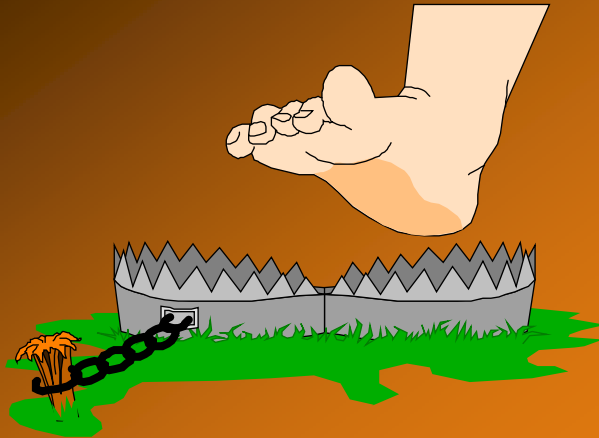
Input Sensitivity

Certain input parameters in cost of ownership modeling can have tremendous impact on the cost per layer out: yield, throughput, maintenance, and consumables. These factors must be tightly controlled or slight manipulations can be used to eliminate the product from purchase considerations.

Control of the situation can be accomplished by providing only hard copies (or the equivalent, such as a locked PDF file) of the cost model. If the cost model is unavailable, modifying results will be more difficult. Also, involving several levels of management within the prospects operation is not only good account management, but acts as protection against data being misapplied to the product's disadvantage.

An example of how input parameters can be misapplied would be to choose a volume requirement that is an even multiple of a system's throughput. This will guarantee a minimum number of systems for that equipment while, more often than not, placing competitive systems at an artificial disadvantage.

Potential Misuses



Discussion Topics

- ❑ Sales Tool
- ❑ Confusion Creation
- ❑ Input Sensitivity

Sales Tool

- **Use without Extensive Analysis**
 - Difficult to Gauge Competitive Position
 - Potential for Inferior Product Position
- **Many Interactions**
 - Easy to Lose Control of Data Flow
- **Missing Training**
 - Hard to Defend Model Assumptions

Confusion Creation

- **Conflicting Data**
 - Differences Between Purchase Specifications and Performance Claims
- **Additional Evaluation Criteria**
 - Potential for Product Differentiation
 - Delay Purchase Decision
 - Competitive Opening
- **Difficult to Prove Some Claims**
 - Avoid Vaporware !!

Input Sensitivity

□ Maintain Complete Control

- Yield
- Throughput
- Maintenance
- Consumables

□ Verify Key Inputs

□ Provide Hardcopy Only

- Easier to Implement Revision Control

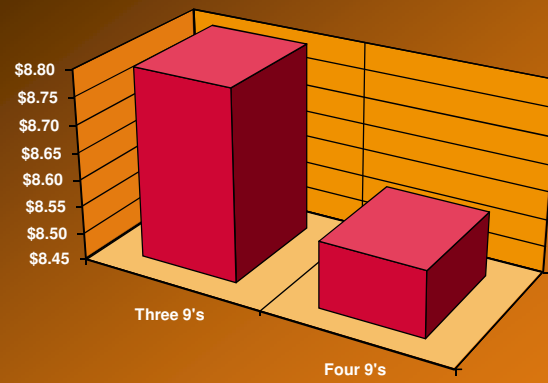


Input Sensitivity (cont'd)

EQUIPMENT DATA					
Original Cost/System	Equipment Cost	\$1,000,000	\$1,000,000	Currency	
	Transportation Cost	\$10,000	\$10,000	Currency	
	Installation Cost	\$5,000	\$5,000	Currency	
	Other Depreciable Costs			Currency	
System Qualification Costs (Per System)	Engineering	40.00	40.00	Man-Hours	
	Maintenance	20.00	20.00	Man-Hours	
	Operator	80.00	80.00	Man-Hours	
	Supplies/Consumables			Currency	
	Other Material			Currency	
	Other Costs			Currency	
Floor Space/System	Class 1	75.00	75.00	Square Feet	
	Class 10			Square Feet	
	Class 100	50.00	50.00	Square Feet	
	Other			Square Feet	
Training Required (Per System)	Operators	80.00	80.00	Man-Hours	
	Engineers	24.00	24.00	Man-Hours	
	Maintenance	80.00	80.00	Man-Hours	
	Other Costs	\$4,000	\$4,000	Currency	
Equipment Yield		99.90%	99.99%	%	
Defect Density		0.01	0.01	per cm2	
Defect Measurement (Electrical=1, Physical=2)		2	2		



Input Sensitivity (cont'd)



Areas of Sensitivity and Advanced Applications

Certain parameters within the cost of ownership calculations can have significant impact on the bottom line. Specifically, these areas are: yield, throughput, maintenance, MTBF, and consumables. Additionally, there are times when metrics other than COO are better choices to answer management questions.

What You Should Learn from this Module

- ☐ The importance of sensitivity analysis.
- ☐ The relative sensitivities of the major COO cost drivers.
- ☐ How to look at process sequences.
- ☐ The differences between COO and OEE.
- ☐ It is very difficult to accurately predict COO results before running the model.

Importance of Sensitivity Analysis

Modeling cost of ownership is not always easy. Data availability varies. Some data is unknown or unavailable. The available data may not exactly match the operation being modeled. It may come from older models of equipment, different processes, different wafer/product sizes, or different packages.

Sensitivity analysis is an important tool for understanding the impact of data variation on COO. A simple sensitivity analysis may plot the change in COO over a range of values for an input

parameter. More complex sensitivity analyses may consider other COO output estimates or multiple input parameters.

Sensitivity analysis is also a useful tool for considering the impact of unknown or unavailable data on COO. While the exact value of an input variable may be unknown, estimates are frequently within a known range of values. A simple sensitivity analysis may plot the change in COO over this range. If the change in COO is small, then a simple estimate will be sufficient. If the change in COO is large, then the range of initial estimates should be refined.

Yield

Yield is both one of the most influential parameters and one of the most difficult to determine. Yield loss has many sources and is often proprietary; however, many times the yield will be known within a certain range. A sensitivity analysis of yield over the expected range helps to communicate the impact of yield on COO.

COO considers three sources of yield:

- Equipment Yield
- Parametric Yield
- Defect Limited Yield (semiconductor front end only)

Equipment yield is an input parameter which describes the average wafer/unit breakage and unrecoverable misprocessing, caught at that process step, which is inherent to the equipment under evaluation.

This parameter has a very substantial impact on the bottom line because it is not a yield model input but is removed directly from yield. A 1% decrease in equipment yield can increase total costs per unit out of that process step by 50%!

Parametric yield is typically detected at electrical test, or some other test, when certain characteristics are not within acceptable operating windows. The product may function but not meet user criteria. Parametric yield is most often estimated using empirical information.

Defect density is only one of four input parameters in determining defect limited yield. The other three variables; device active area, clustering parameter, and fault probability are functions of device design rules and physics. The defect density of interest is a function of the minimum defect size required for the IC manufacturing process. Defect limited yield is determined by:

$$Y = \frac{1}{\frac{A_a * D * P}{(1 + \frac{A_a * D * P}{\alpha})^\alpha}}$$

Where A_a is the active area of the device, D is the defect density, “ α ” is the clustering parameter, and P is the probability that a defect will be fatal. The defect limited yield must be examined for each layer type (critical, non-critical).

The probability of a detected defect causing an electrical failure on a device is a function of several factors. The most important is the method by which the defects were detected. If the measurement technique was electrically-based then the fault probability is, by definition, equal to 1. For defects measured by physical methods, the model becomes:

$$P = \frac{S^2}{W \times (W + F)}$$

S is the minimum critical defect size. W is the minimum device feature size and F is the feature pitch. This model is overly simplistic and is used for illustrative purposes only.

A change of 0.01 particles per square centimeter per wafer pass can lead to a 15% increase in total costs per layer out. Yield has the greatest impact on cost of ownership.

Throughput

Throughput is a major factor in determining production schedules and is important to cost of ownership calculations because it determines the number of systems required. With process equipment purchase prices typically in excess of \$1 million, the fewer systems required the better.

The input factors that impact the number of systems required are the raw throughput under process recipe conditions and scheduled and unscheduled (MTBF, MTTR, MTBA, MTTA) maintenance.

For the most part, throughput tracks linearly with unit costs. That is, a 30% decrease in throughput will increase costs per unit out by 30%. It should be noted that under certain conditions the cost per unit out may seem discontinuous with throughput. Moving from 9,000 unit starts per week to 10,000 may cause the cost per unit out to go up 25%.

Conceptually, the cost per unit out is independent of the number of unit starts required; however, while units can be added in small increments, throughput is added in integers of complete systems and the cost per unit out is a function of how efficiently each tool is utilized.

Maintenance

Maintenance costs can have a small but significant effect on total unit costs. The major areas of concern are labor for scheduled maintenance and service contracts, repair parts, and test and repair labor outside of warranty. A doubling of these costs from \$34,000 per system per year to \$68,000 can lead to a 4% increase in total costs per unit out.

MTBF

Mean time between failure (MTBF) is related to reliability of the equipment, quality of maintenance, quality of repair parts, and proper application and operation of the equipment. Low MTBF has a negative impact on net throughput but may also impact other operations. These other impacts are not included in COO but would impact a factory level cost model, such as Factory Commander® or Factory Explorer®.

Materials/Consumables

Material and consumable costs have a similar impact to maintenance costs. Materials and consumables are typically a higher expense than maintenance and, therefore, have a larger percentage impact on the bottom line. Typical materials and consumables are electricity, cooling water, process chemicals and gases, and process support expendables. A doubling of these costs from \$125,000 per system per year to \$250,000 can lead to a 16% increase in total costs per unit out.

Process Sequence Analysis

The development of cost of ownership provided manufacturers with a methodology for evaluating the life cycle costs of individual processes and the equipment and materials used by

those processes; however, knowing those costs does not provide a complete understanding of the cost of a process sequence. Other operational modeling methods can analyze processes under differing conditions to more clearly indicate process cost drivers.

Process sequence COO is not just the sum of the individual operational COO estimates. Process sequence COO must also consider the impact of the throughput rates of the equipment used in the processes. Only the bottleneck equipment will be at full capacity. Since COO is calculated at the equipment's full capacity, the actual COO of the equipment used in a process step will be higher due to unused capacity. The difference between the process sequence COO and the sum of the fully loaded equipment COO values is called the cost of unused capacity or the cost of capacity mismatch.

OEE Applications

Overall equipment efficiency (OEE) is another measure of manufacturing equipment productivity. It was developed as an equipment efficiency metric in Japan to measure the efficiency of a manufacturing technique called Total Productive Maintenance (TPM). TPM is a program to improve overall factory operations. There are many elements of TPM involving group activities, operating metrics, operator involvement, and operating procedures. OEE is the product of the efficiency metrics of availability, performance, and quality.

$$P = A \times P \times Q \times 100$$

where A = availability, P = performance, and Q = quality.

Availability is the same as the total utilization decimal as defined by SEMI Standard E10. Availability can be estimated from the E10 states of the equipment by comparing uptime to total time.

$$A = \frac{E + S + R}{E + S + R + D + N}$$

where E = engineering time, S = standby time, R = regular productive time, D = downtime, and N = non-scheduled time.

Performance can be estimated from the E10 uptime states and from the throughput. This value needs to know actual throughput as defined by E35 and ideal throughput, which is not defined by E35.

$$P = \frac{R}{E + S + R} \times \frac{TPT}{Ideal}$$

where TPT = E35 throughput rate and Ideal = ideal throughput rate.

Quality can be estimated from the COO yield information.

$$Q = Y_e \times Y_d \times Y_p$$

where Y_e = equipment yield, Y_d = defect limited yield (semiconductor front end only), and Y_p = parametric limited yield.

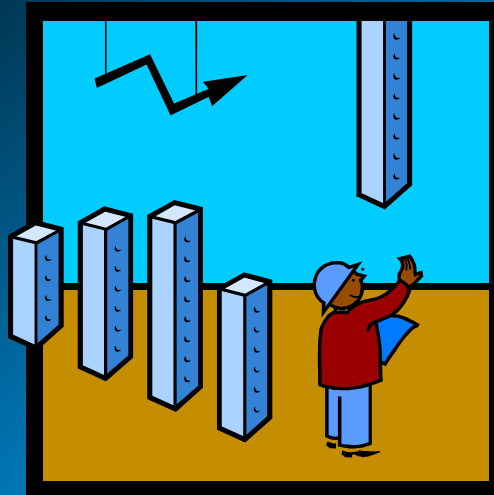
OEE provides an important metric for estimating COO. The performance, availability, and quality factors in OEE are important inputs to COO; however, OEE does not consider any cost related factors or cost impacts. Thus, a complete analysis of COO requires estimates of OEE.

Since equipment decisions have long term impacts on the profitability of manufacturing companies, the more complete estimate of COO is a better model for the analysis of these decisions. In cases of installed equipment, OEE provides a

6-8 *Understanding and Using Cost of Ownership*

useful metric for performance analysis. In these cases, many of the costs have already been expended. Even if a new piece of equipment provided significant improvements in operating costs it is unlikely to replace an existing piece of equipment that has satisfactory performance. As a caution, improving OEE for equipment that is not a bottleneck or near bottleneck is likely a waste of time and money. Doing so, would just increase the standby time of those equipment.

Areas of Sensitivity and Advanced Applications



Discussion Topics

- ❑ Importance of Sensitivity Analysis
- ❑ Illustrations of Sensitivity Analysis
- ❑ Process Sequence Applications
- ❑ OEE Applications
- ❑ COO Comparison Solution

Importance of Sensitivity Analysis

- **Data Varies**
- **Some Data is Unknown**
- **Data May Come from Similar but Different Tools**
 - Older Model
 - Different Wafer/Product Size or Package
 - Different Process
- **Some Data are Estimates**

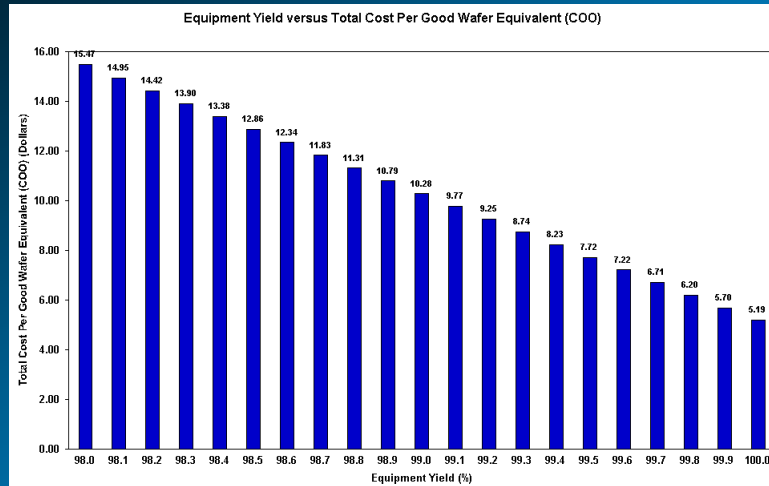


Yield Sensitivity

- **Yield is Often Unknown or Confidential**
- **Yield Estimates have Wide Variation**
- **Sources of Yield Loss**
 - Defects
 - Breakage
 - Misprocessing
 - Parametric



Yield (cont'd)



Throughput

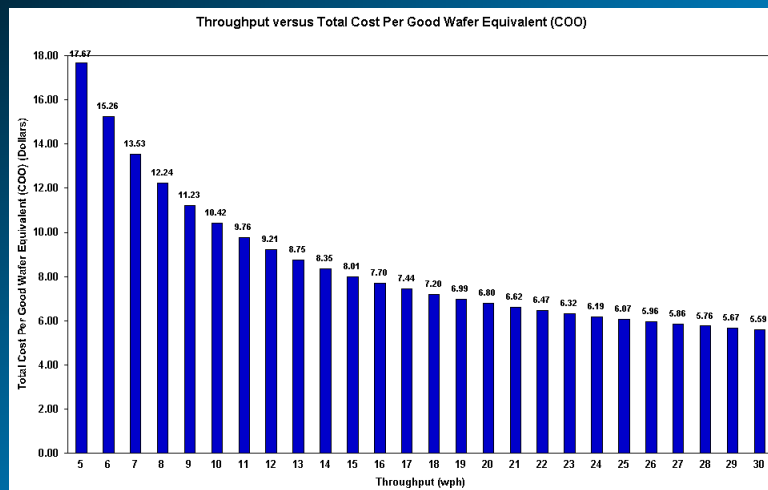
- Throughput May be Measured Under Several Conditions
 - Supplier Estimates
 - New Tool Start-Up Conditions
 - Process Recipe Conditions
- COO Assumes Raw Throughput
 - Process Recipe Conditions
 - Includes Setup Activities

Other Net Throughput Impacts

- Scheduled Maintenance
- Unscheduled Maintenance
- Assists
- Production Tests
- Engineering Usage



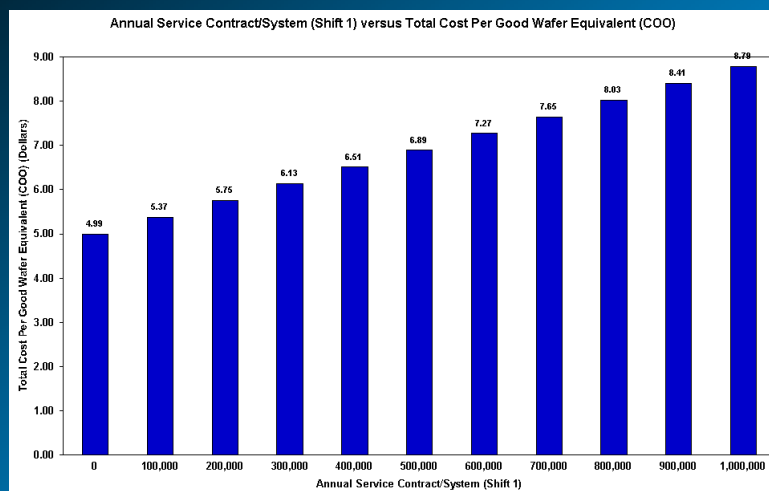
Throughput (cont'd)



Maintenance Costs

- Cost of Repair Labor
- Scheduled Maintenance Labor
- Repair Parts
- Warranty Impact
- Service Contracts

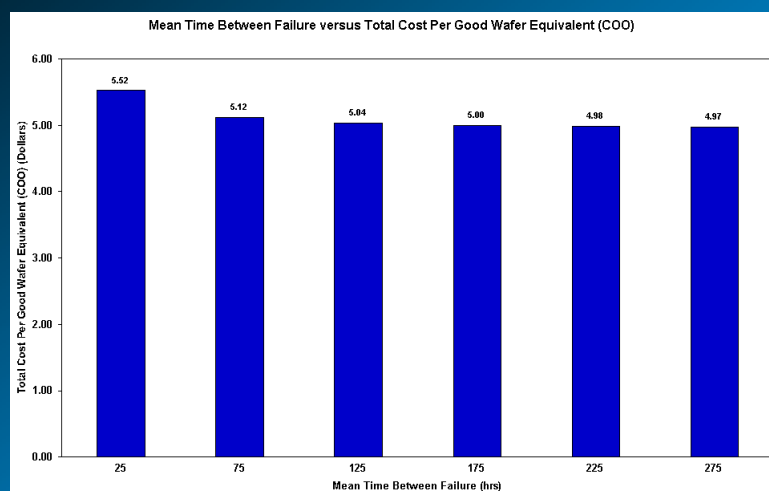
Maintenance (cont'd)



Mean Time Between Failure

- MTBF Relates to
 - Reliability
 - Maintenance
 - Repair Parts
 - Proper Application & Operation
- Low MTBF Impacts Net Throughput
- Low MTBF Can Impact Other Steps
 - These Other Impacts are not Included in COO

MTBF



Materials/Consumables

□ Utilities

- Electricity
- Cooling Water

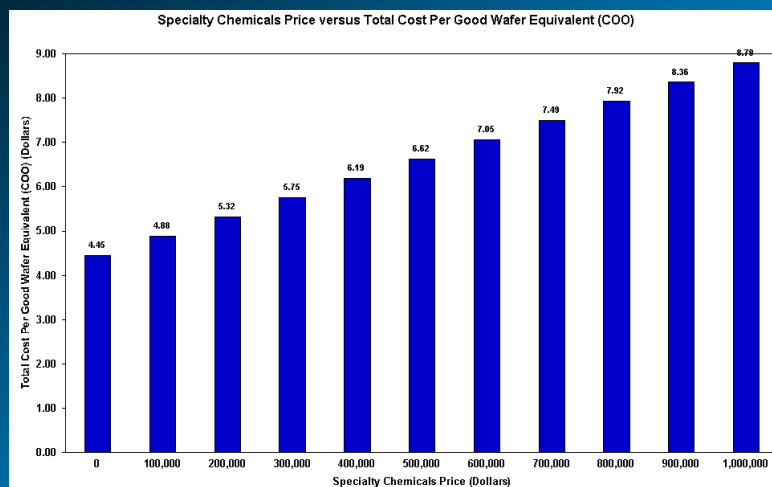
□ Supplies

- Process Chemicals

□ Process Support Expendables

- Shields
- Lamps

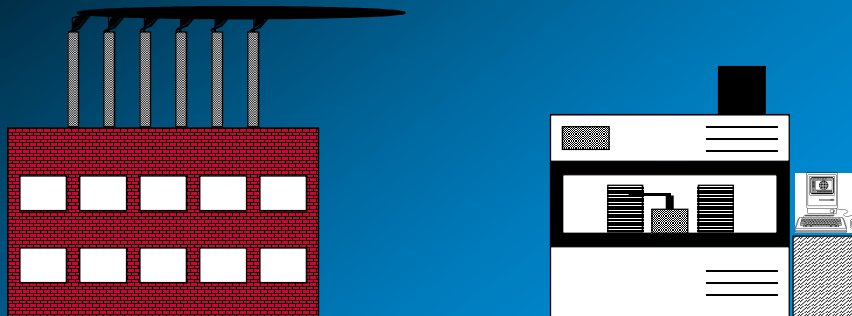
Materials/Consumables (cont'd)



Materials/Consumables (cont'd)

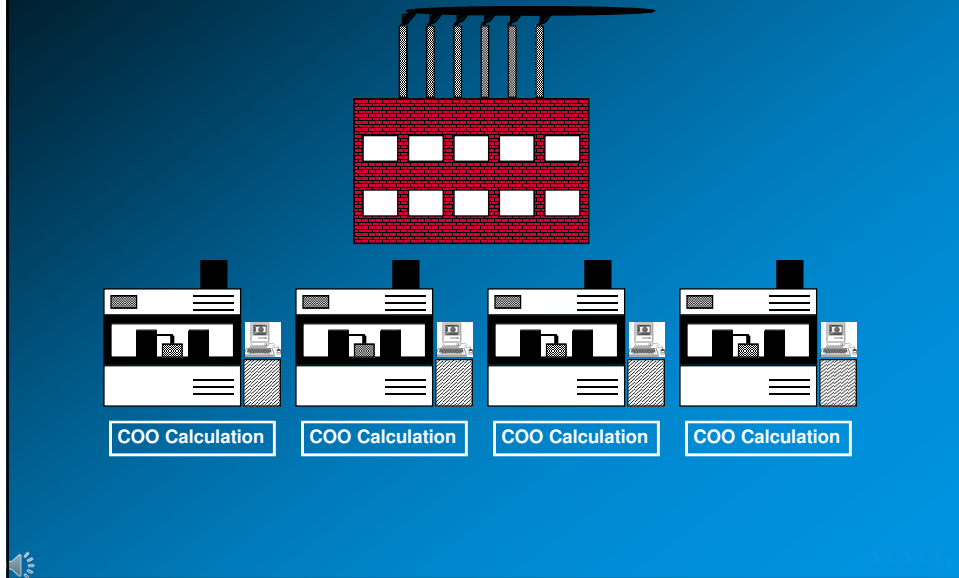
- Many Materials are Used at More than 1 Process Operation
 - Gases
 - Chemicals
- Materials Leverage may be Greater than Impact at 1 Step
- May Need a System-Wide View

Standard COO Process

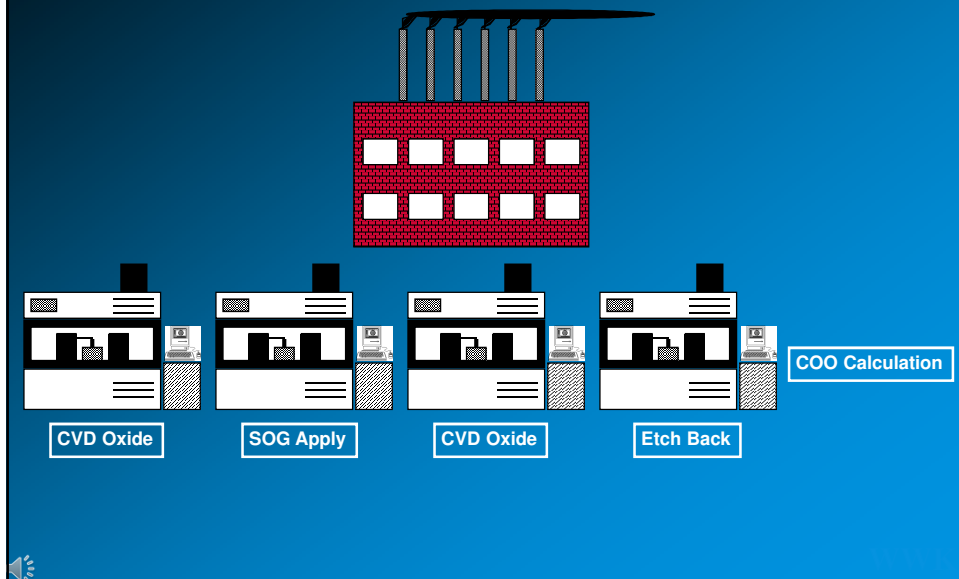


COO Calculation

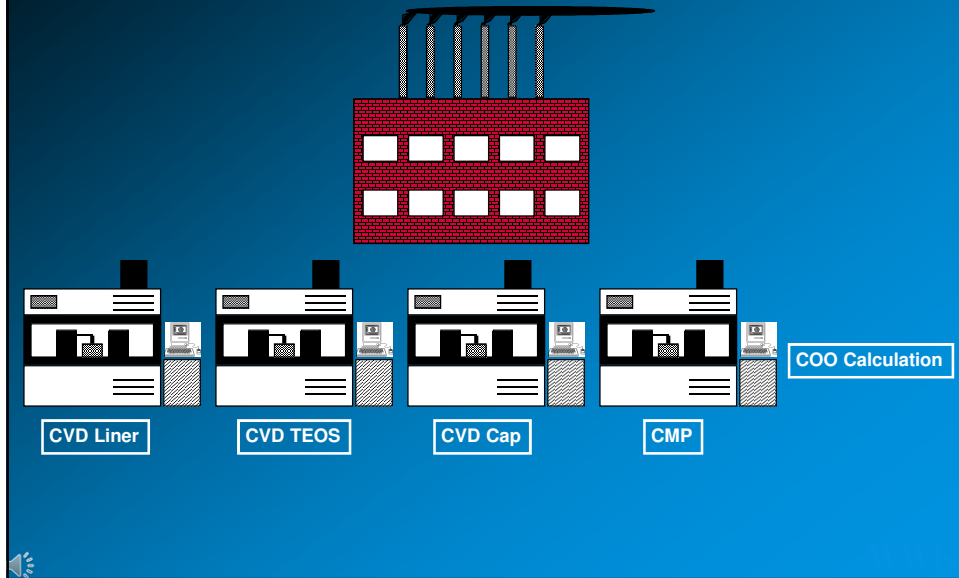
Process Sequence Applications



Spin On Glass Example

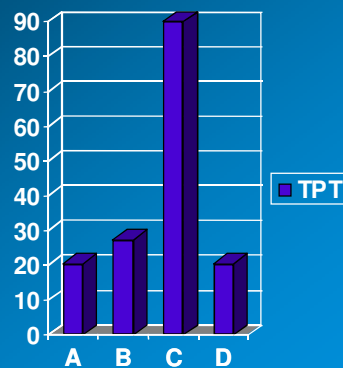


CMP Example



Process Sequence Applications (cont'd)

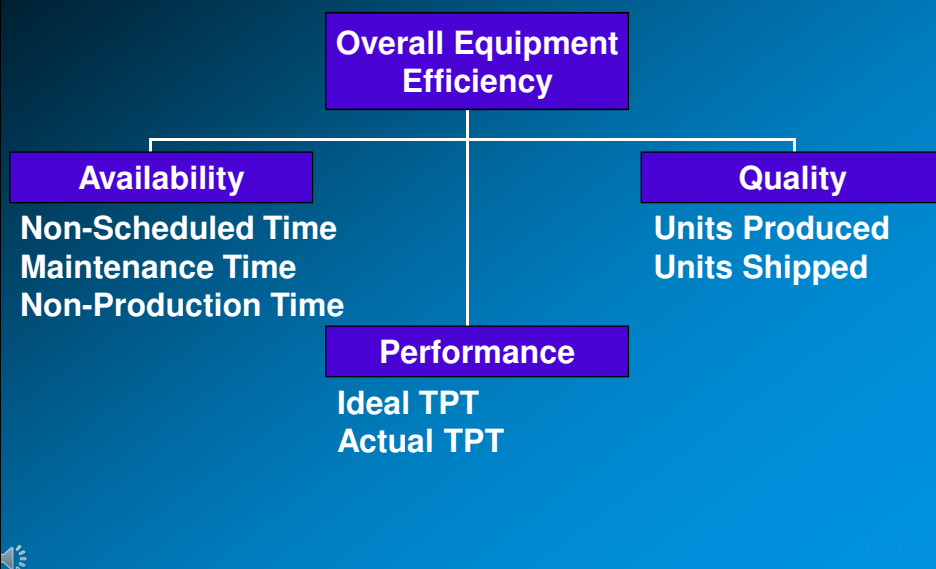
- Need to Consider Different TPT Rates
- Need to Consider Different Step Yields



OEE Applications

- ❑ Overall Equipment Efficiency
- ❑ Part of TPM (Total Productive Maintenance)
- ❑ Useful for Analyzing Existing Processes and Equipment
- ❑ Focus on Operations and Methods

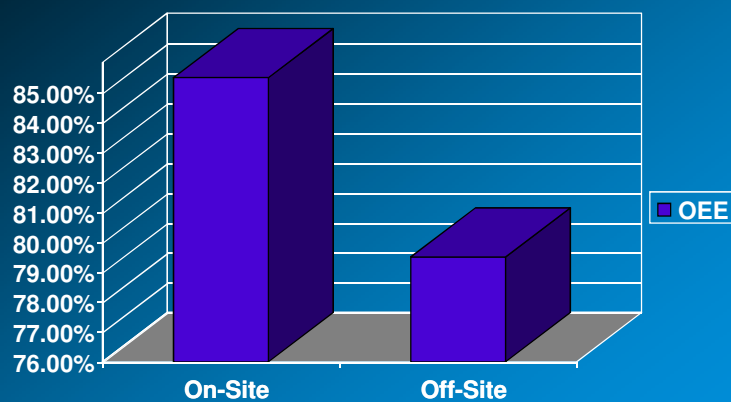
OEE Applications (cont'd)



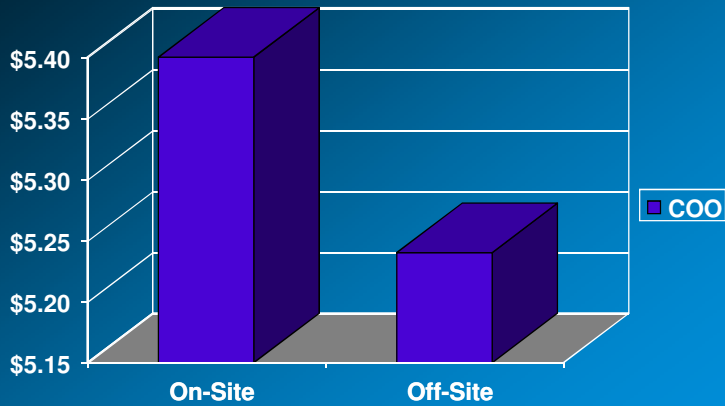
OEE Applications (cont'd)

	On-Site	Off-Site
Response	0.25 hr	4 hr
MTTR	4 hr	8 hr
\$/Shift	\$25,000	\$5,000

OEE Applications - OEE



OEE Applications - COO



COO Comparison

Key Factors	CVD 100	CVD 200
Equipment Cost	\$1,000,000	\$1,200,000
Spares Cost	\$50,000	\$65,000
Consumables Cost	\$9,000	\$18,000
MTBF	1000 hrs	200 hrs
MTTR	3 hrs	2 hrs
Scheduled PM	16 hrs	8 hrs
Raw Throughput	21 wph	26 wph
Production Tests	14	14
MTTT	0.65 hrs	0.50 hrs
Systems/Operator	4	3
Equipment Yield	99.99%	99.999%
Incoming Wafer Value	\$500	\$500
Defect Density	0.1	0.05
Fault Probability	.005	.005
Device Area	2	2
Completed Wafer Value	\$1000	\$1000

Conclusions

**Cost of Ownership is Critical
for Purchase Decisions**

- ▣ **Material and Component
Evaluations Can be More
Complex**



Conclusions (cont'd)

- ▣ **Most Important Application is
for Project Prioritization**
- ▣ **COO is the Ideal Tool to Create
an Open Dialog Between
Manufacturers and Suppliers**



Exercises and Solutions

Equipment Costs	2
Throughput at Capacity	6
Defect Density	10
Equipment Yield	14
Volume Requirement and Utilization	18
Life of Equipment and Depreciation Life.....	22
Warranty Period	26
Service Choices.....	30
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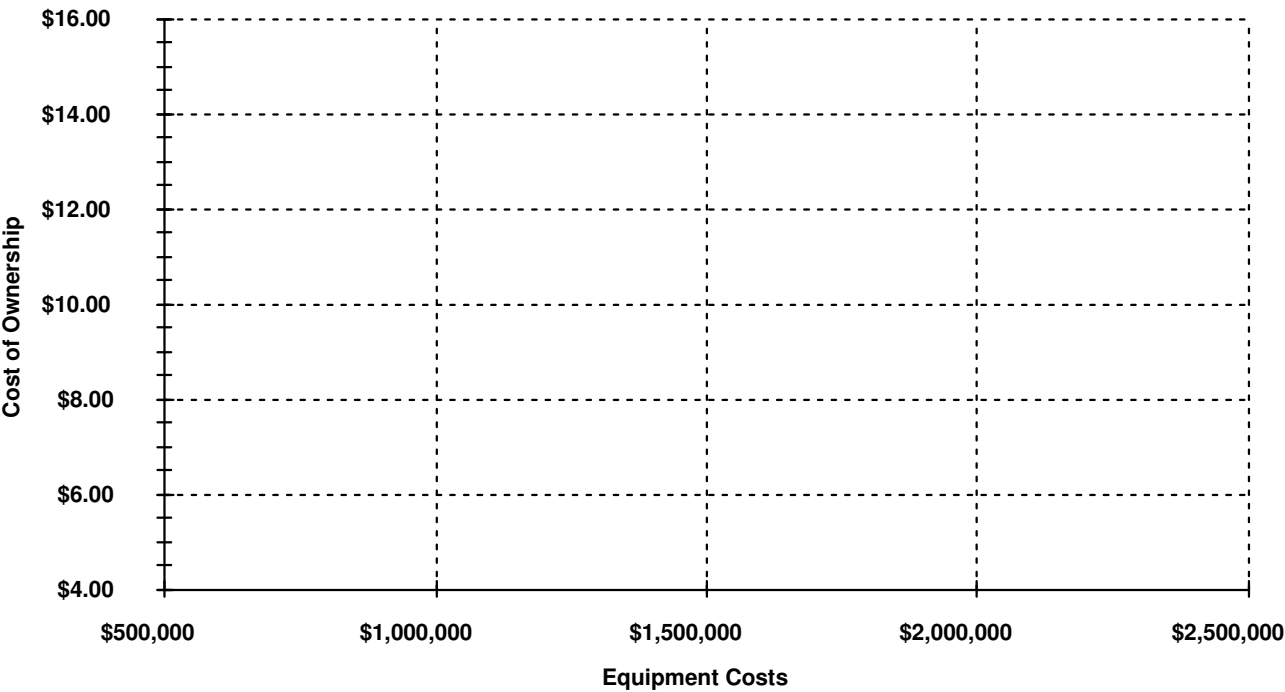


Exercise #1

Equipment Costs

This exercise will demonstrate the sensitivity of cost structure to equipment costs. Starting with the default parameters, enter the following equipment cost data in the "**EQUIPMENT DATA**" section. Record the corresponding cost of ownership from the "**MANAGEMENT**" report tab. Once the data has been collected, chart equipment costs versus cost of ownership.

Equipment Costs	Cost of Ownership
\$500,000	
\$1,000,000	
\$1,500,000	
\$2,000,000	
\$2,500,000	



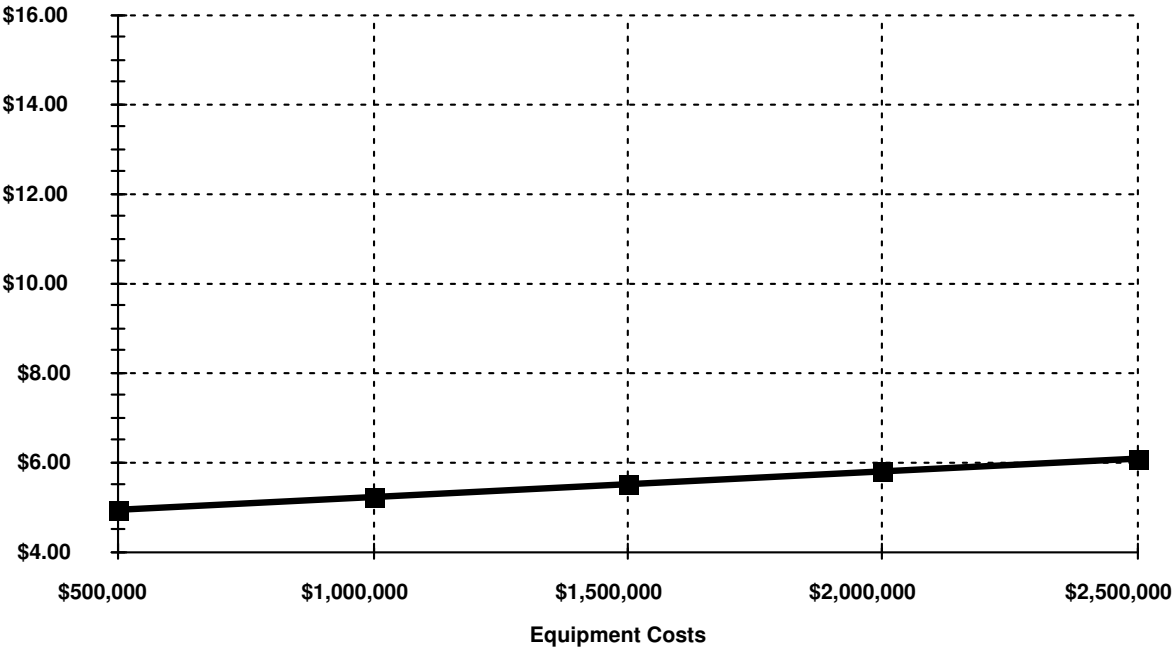


Exercise #1 Solution

Equipment Costs

Equipment costs have a linear relationship to cost of ownership. While the impact is noticeable, the slope of the line is typically modest. The slope and intersection are significantly impacted by the length of time the equipment is in operation.

Equipment Costs	Cost of Ownership
\$500,000	\$4.97
\$1,000,000	\$5.24
\$1,500,000	\$5.52
\$2,000,000	\$5.79
\$2,500,000	\$6.07



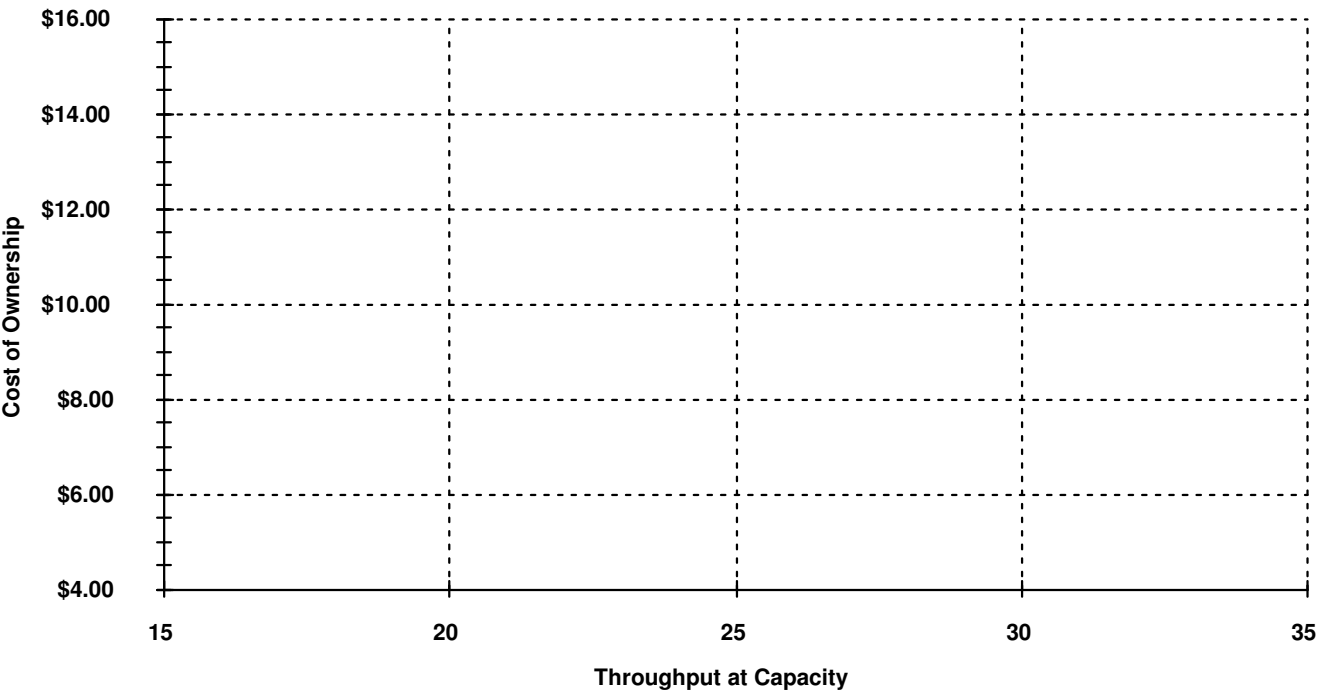


Exercise #2

Throughput at Capacity

This exercise will demonstrate the sensitivity of cost structure to throughput. Starting with the default parameters, enter the following throughput data in the "**MODEL SPECIFIC DATA**" section. Record the corresponding cost of ownership from the "**MANAGEMENT**" report tab. Once the data has been collected, chart throughput at capacity versus cost of ownership.

Throughput at Capacity	Cost of Ownership
15	
20	
25	
30	
35	



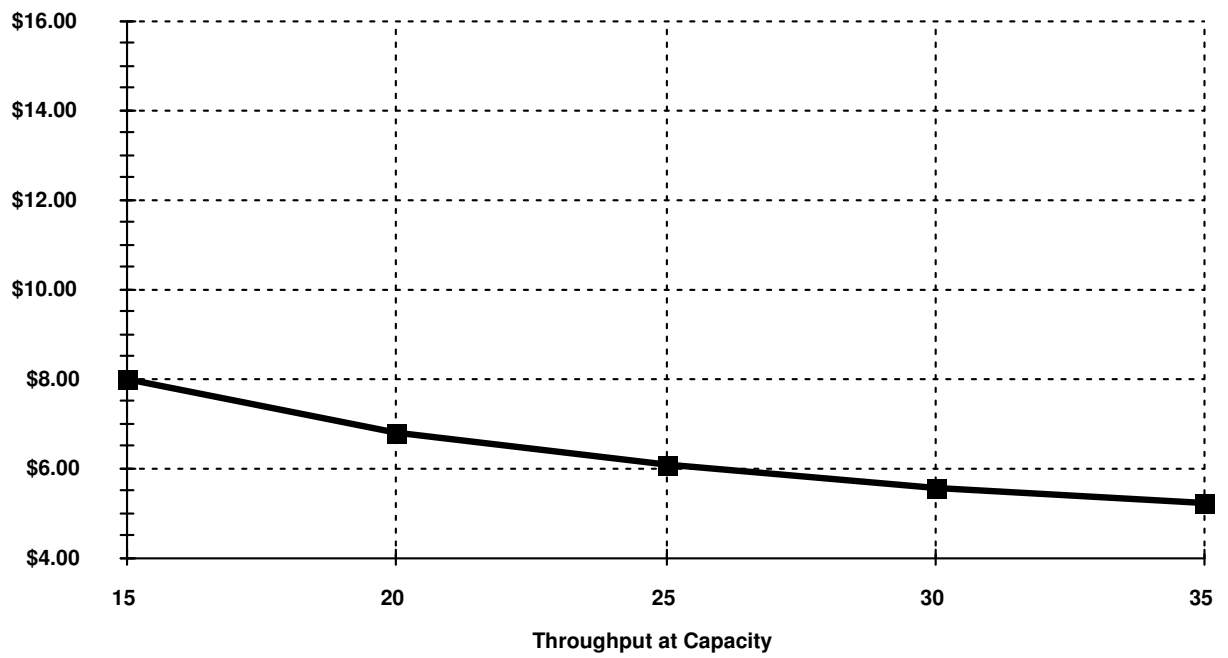


Exercise #2 Solution

Throughput

Throughput is one of the most significant factors in cost of ownership. The curve is non-linear and asymptotic to both axes. This means that moderate improvements in throughput to "slow" systems will have a major impact on the cost of ownership. The same level of improvement to "fast" systems will have minimal impact. The cost of ownership of very high throughput systems will approach the recurring cost of ownership including scrap.

Throughput at Capacity	Cost of Ownership
15	\$8.01
20	\$6.80
25	\$6.07
30	\$5.59
35	\$5.24



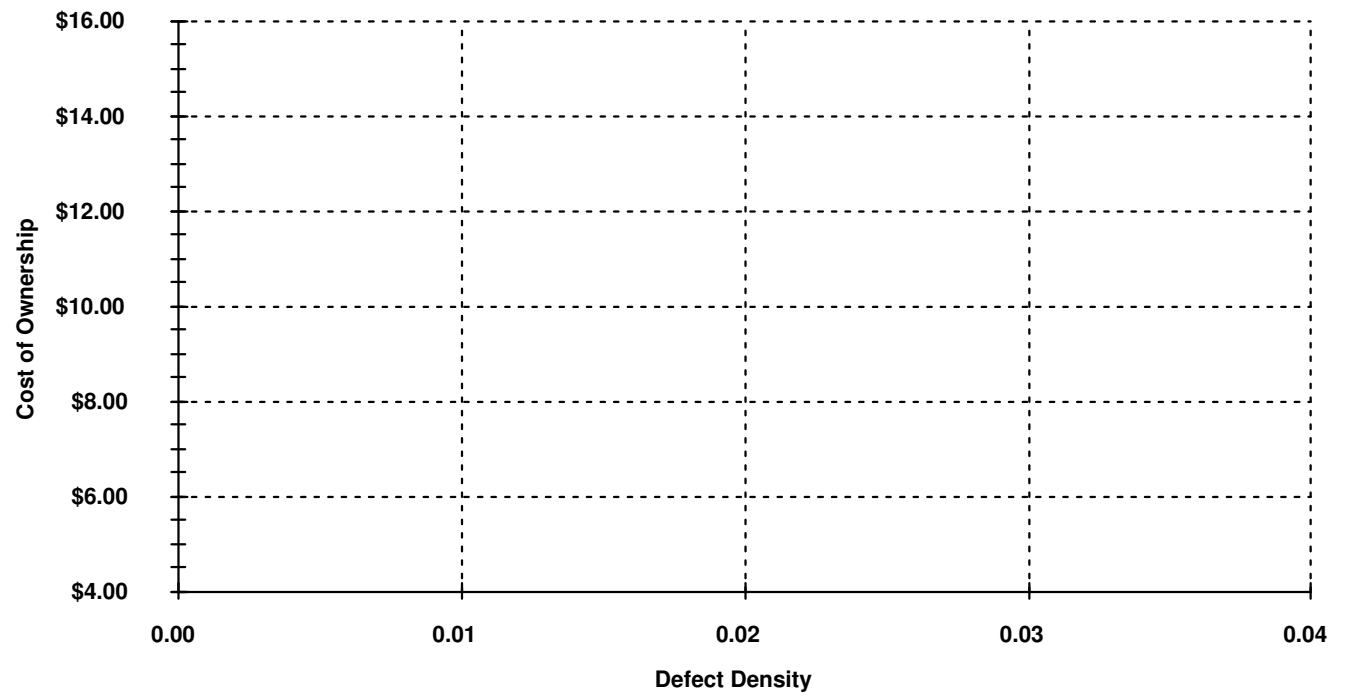


Exercise #3

Defect Density

This exercise will demonstrate the sensitivity of cost structure to defect density and defect limited yield. Starting with the default parameters, enter the following defect density data in the "**YIELD**" section. Record the corresponding total cost of ownership from the "**MANAGEMENT**" report tab. Once the data has been collected, chart defect density versus cost of ownership.

Defect Density	Cost of Ownership
0.00	
0.01	
0.02	
0.03	
0.04	



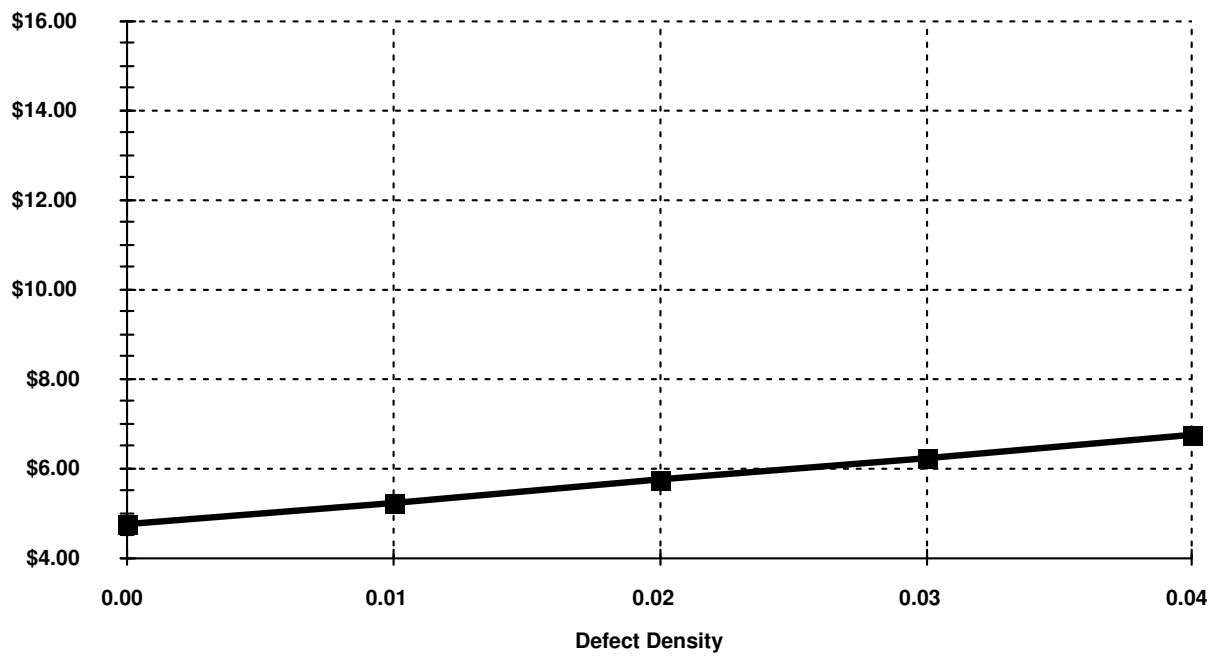


Exercise #3 Solution

Defect Density

Yield issues are the main cost drivers in COO. The slope and its intersection are impacted by the device active area, fault probability, and value of the completed wafer.

Defect Density	Cost of Ownership
0.00	\$4.74
0.01	\$5.24
0.02	\$5.75
0.03	\$6.25
0.04	\$6.75



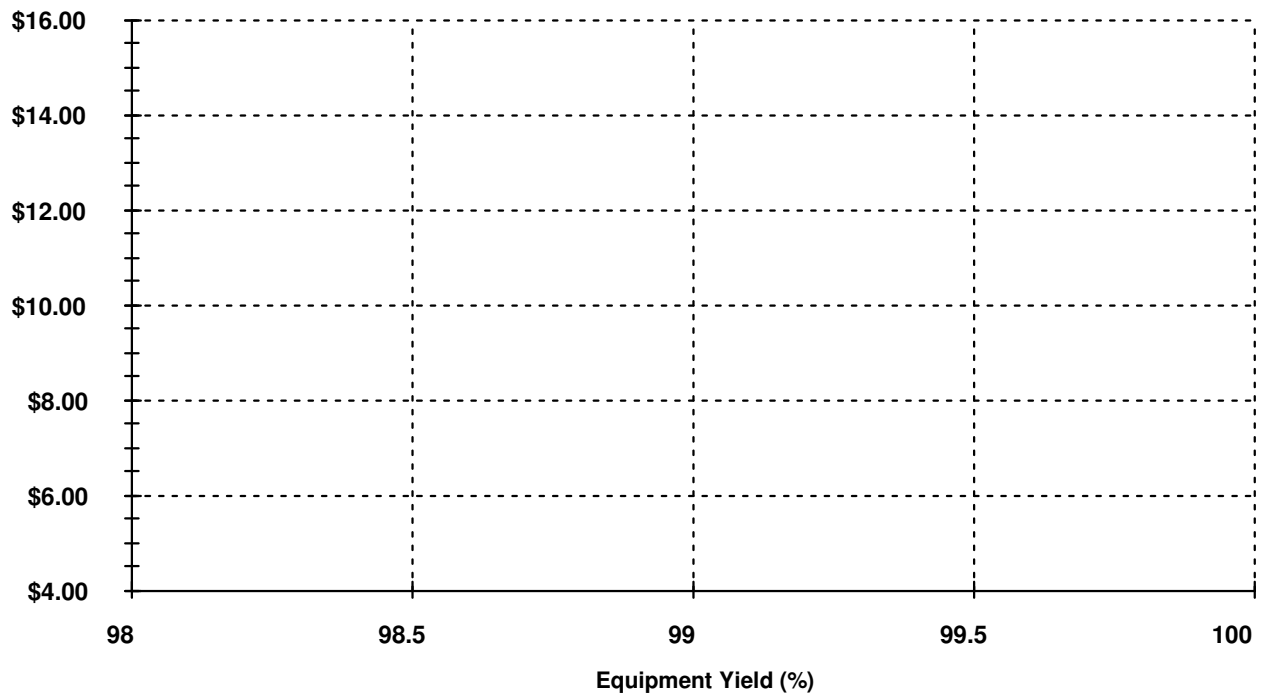


Exercise #4

Equipment Yield

This exercise will demonstrate the sensitivity of cost structure to equipment yield. Starting with the default parameters, enter the following equipment yield data in the "**YIELD**" section. Record the corresponding cost of ownership from the "**MANAGEMENT**" report tab. Once the data has been collected, chart equipment yield versus cost of ownership.

Equipment Yield (%)	Cost of Ownership
98.0	
98.5	
99.0	
99.5	
100	



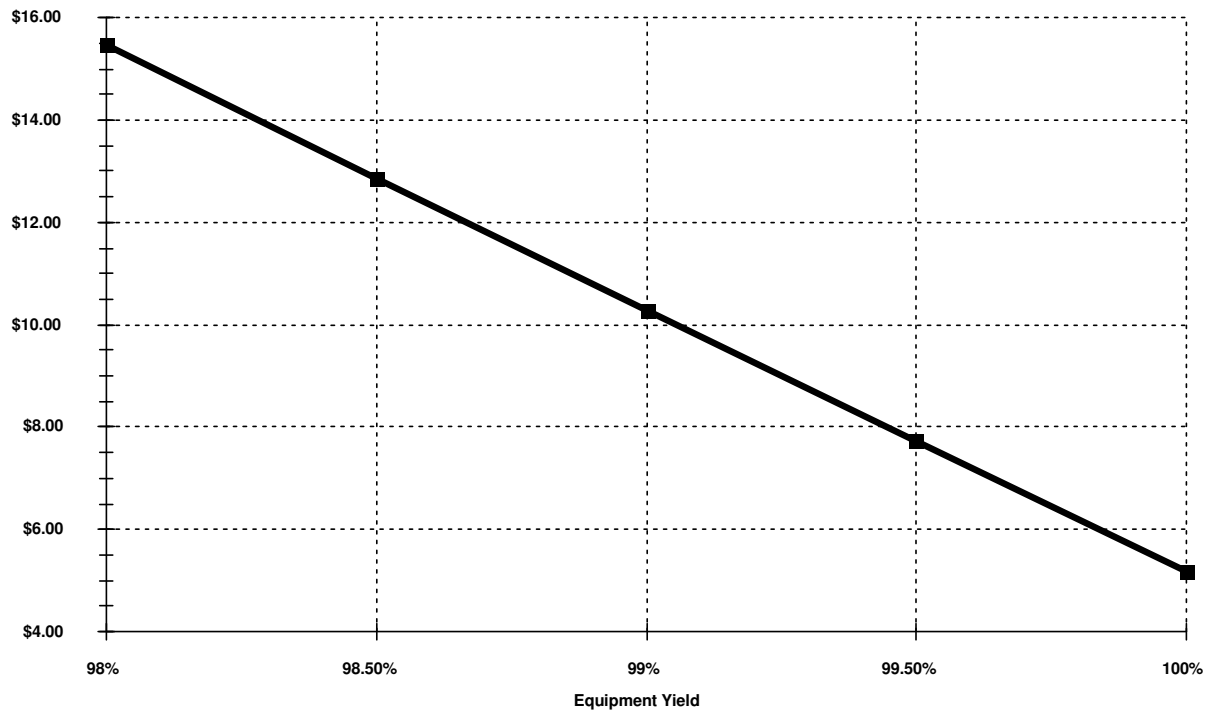


Exercise #4 Solution

Equipment Yield

Equipment yield has a significant impact on cost because it describes a process whereby entire units are lost. The curve is solely impacted by the yield and value of the unit at that step in the process (e.g., accumulated manufacturing cost through this step).

Equipment Yield (%)	Cost of Ownership
98.0	\$15.47
98.5	\$12.86
99.0	\$10.28
99.5	\$7.72
100	\$5.19



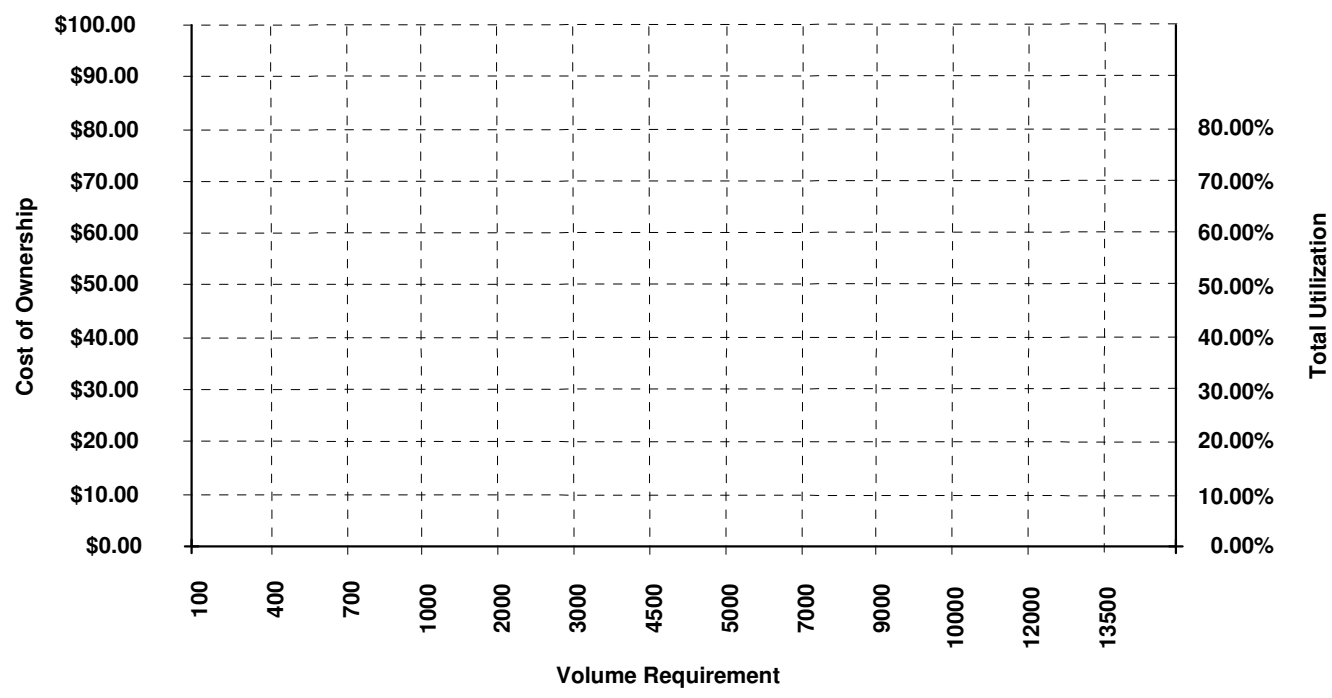


Exercise #5

Volume Requirement and Utilization

This exercise will demonstrate the sensitivity of cost structure and utilization to volume requirement. Starting with the default parameters, **change "Whole System Requirements" to zero (after entering the first volume requirements value) and** enter the following volume requirement data in the "**FAB/FACTORY PARAMETER INPUT**" section. Record the corresponding cost of ownership from the "**MANAGEMENT**" report tab and the total utilization from a separate, automated sensitivity analysis (Analysis Tools menu) or from the COO Calculation Report. Once the data has been collected, chart volume requirement and total utilization versus cost of ownership.

Volume Requirement	Cost of Ownership	Total Utilization
100		
400		
700		
1000		
2000		
3000		
4500		
5000		
7000		
9000		
10000		
12000		
13500		



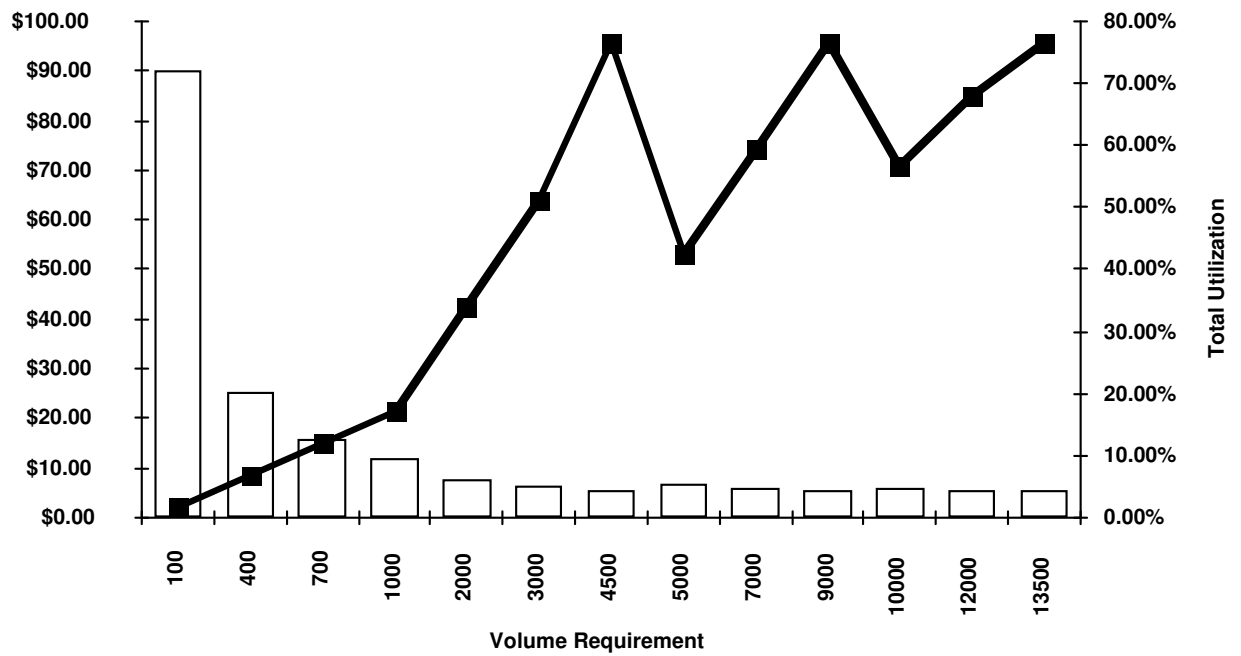


Exercise #5 Solution

Volume Requirement and Utilization

This exercise looks at the varying load requirements on a varying number of machines. At very low unit starts the cost of ownership is extremely high. This is due to the equipment costs being averaged over very few units. As more units are produced, the costs decrease to a minimum associated with a fully loaded single machine. Adding one more unit start causes COO to increase due to the need for additional equipment; however, the equipment is underutilized. Again, as more units are added, another minimum is reached. As each new equipment is added, the maximum cost decreases. This is due to having more and more units over which to amortize the equipment costs of the additional equipment.

Volume Requirement	Cost of Ownership	Total Utilization
100	\$90.13	1.70%
400	\$25.16	6.80%
700	\$15.88	11.90%
1000	\$12.17	17.01%
2000	\$7.84	34.01%
3000	\$6.40	51.02%
4500	\$5.43	76.53%
5000	\$6.97	42.52%
7000	\$5.98	59.52%
9000	\$5.43	76.53%
10000	\$6.11	56.69%
12000	\$5.67	68.03%
13500	\$5.43	76.53%



Cost of ownership is represented by the bar chart and utilization by the line chart.



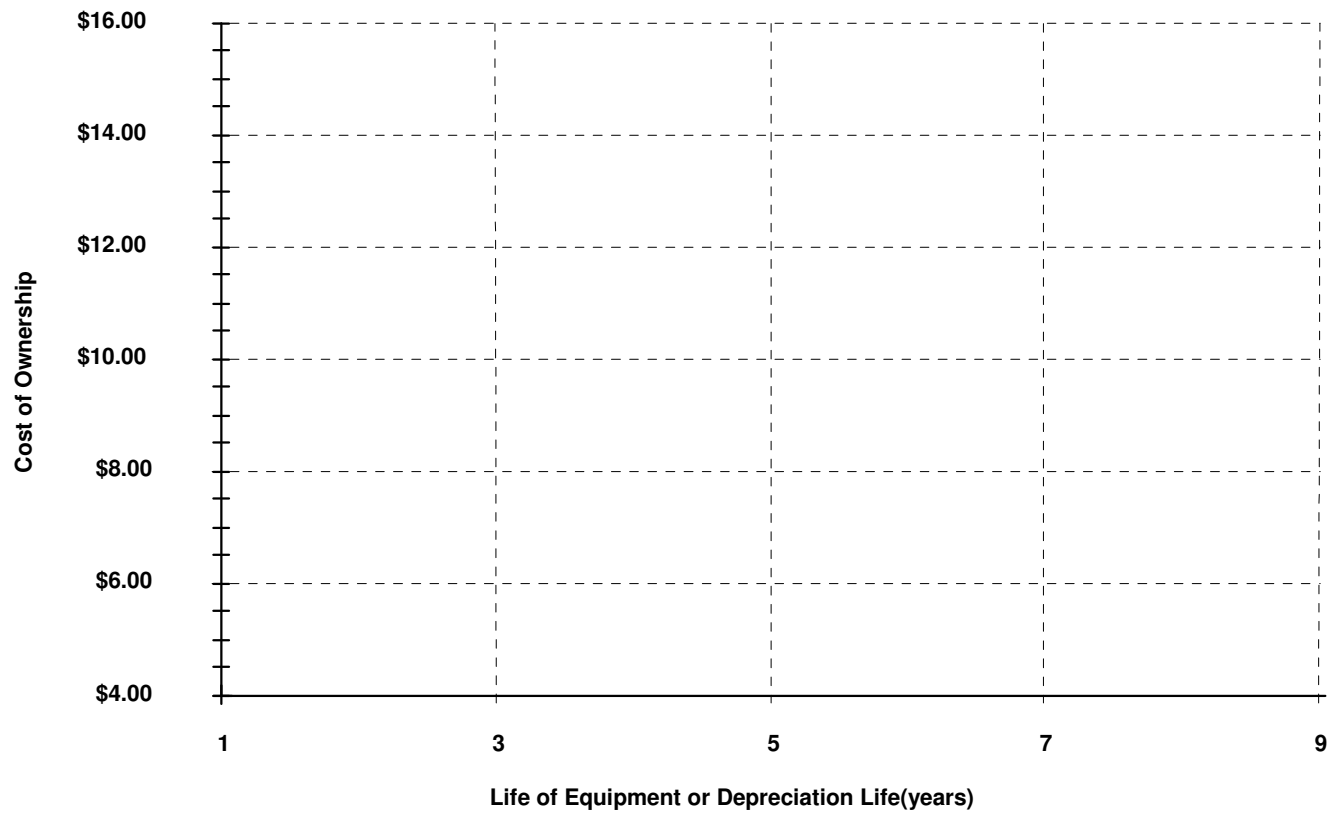
Exercise #6

Life of Equipment and Depreciation Life

This exercise will demonstrate the sensitivity of cost structure to life of equipment and depreciation life. Starting with the default parameters, enter the following life of equipment and depreciation life data in the "**ADMINISTRATIVE RATES**" section (subsection under Administrative Rates Category). Record the corresponding cost of ownership from the "**MANAGEMENT**" report tab. Once the data has been collected, chart life of equipment and depreciation life versus cost of ownership.

Life of Equipment	Cost of Ownership
1	
3	
5	
7	
9	

Depreciation Life	Cost of Ownership
1	
3	
5	
7	
9	





Exercise #6 Solution

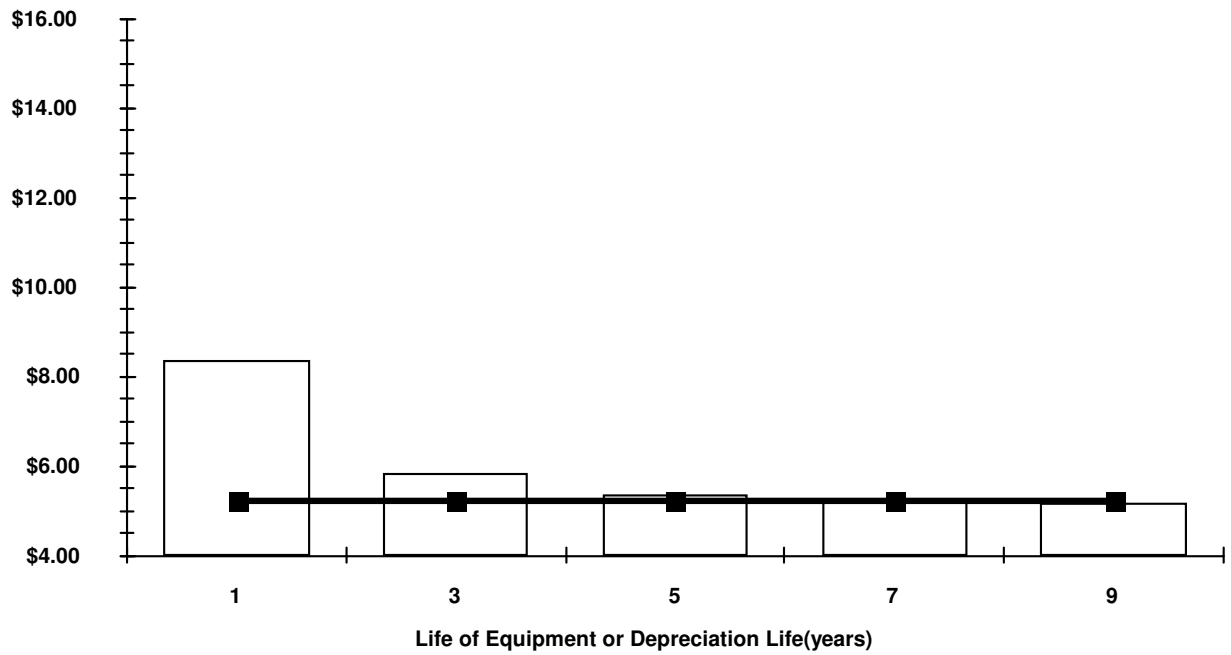
Life of Equipment and Depreciation Life

The life of equipment significantly impacts COO by determining the total number of good units the factory will produce in its life. The equipment costs are amortized over the number of units produced. The larger the number of units, the lower the equipment cost component per unit. The diminishing returns effect is a function of the starting and ending points at each step on the curve (3:1, 5:3, 7:5, etc.).

Life of Equipment	Cost of Ownership
1	\$8.40
3	\$5.86
5	\$5.40
7	\$5.24
9	\$5.19

In this example, the depreciation life has no impact on COO since 100% of the equipment cost (less any salvage value) is always captured. Where depreciation life would have an impact is for administrative costs that are a function of book value (interest, personal property taxes, and insurance).

Depreciation Life	Cost of Ownership
1	\$5.24
3	\$5.24
5	\$5.24
7	\$5.24
9	\$5.24



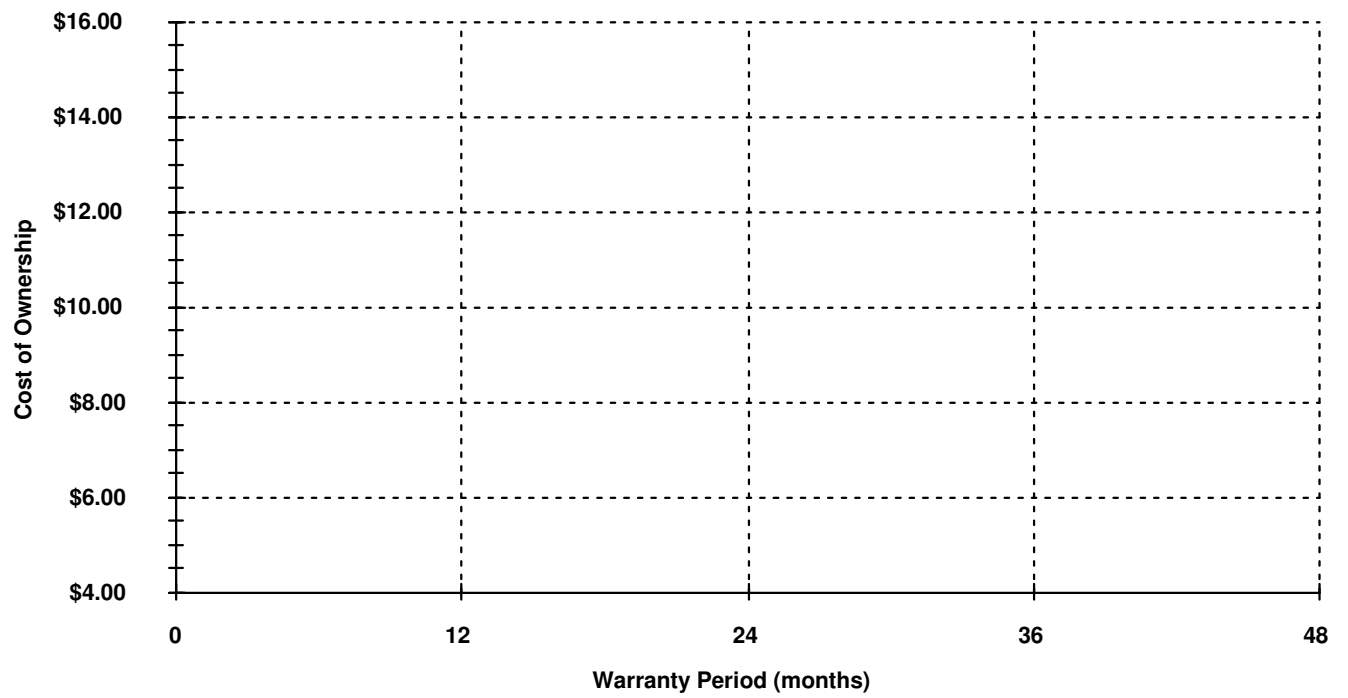


Exercise #7

Warranty Period

This exercise will demonstrate the sensitivity of cost structure to the warranty period. Starting with the default parameters, enter the following warranty period data in the "**MAINTENANCE COSTS**" section. Record the corresponding cost of ownership from the "**MANAGEMENT**" report tab. Once the data has been collected, chart warranty period versus cost of ownership.

Warranty Period	Cost of Ownership
0	
12	
24	
36	
48	



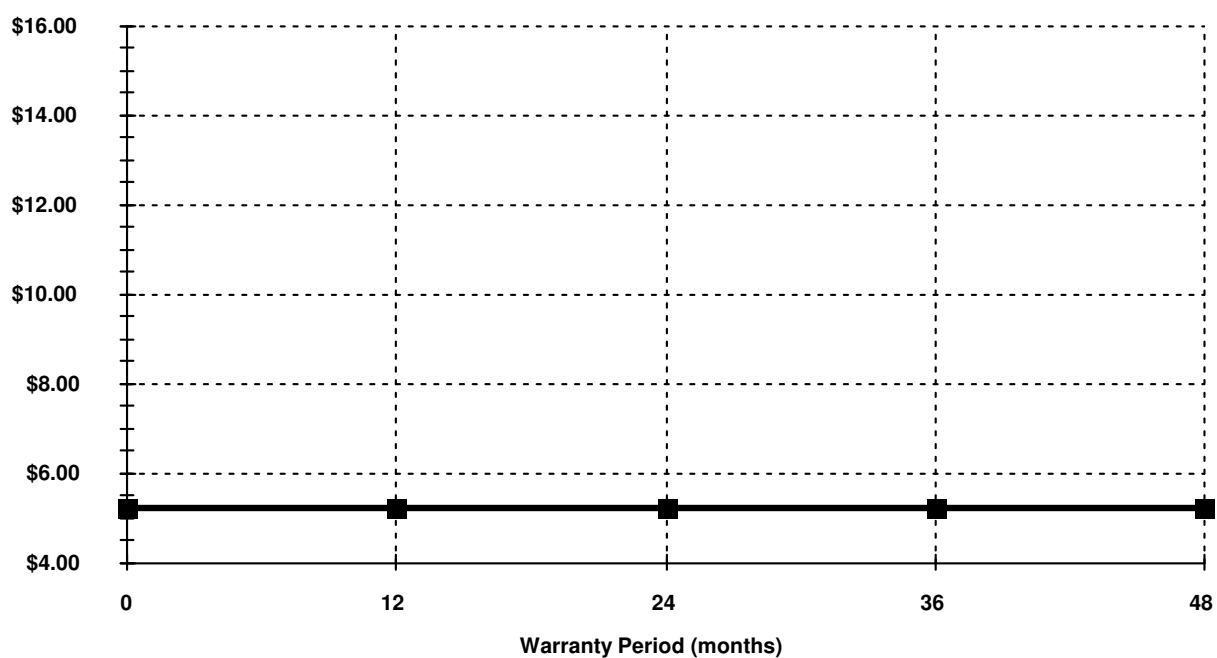


Exercise #7 Solution

Warranty Period

The impact of the length of the warranty period will be driven by the reliability of the equipment and/or service contract pricing. Under typical conditions, the length of the warranty period will have very minimal effect. Why then the push by some equipment suppliers to tout longer warranties? COO is not the only driving force. Longer warranties create a product positioning statement of reliability and confidence on the part of the manufacturer.

Warranty Period	Cost of Ownership
0	\$5.25
12	\$5.24
24	\$5.23
36	\$5.23
48	\$5.22



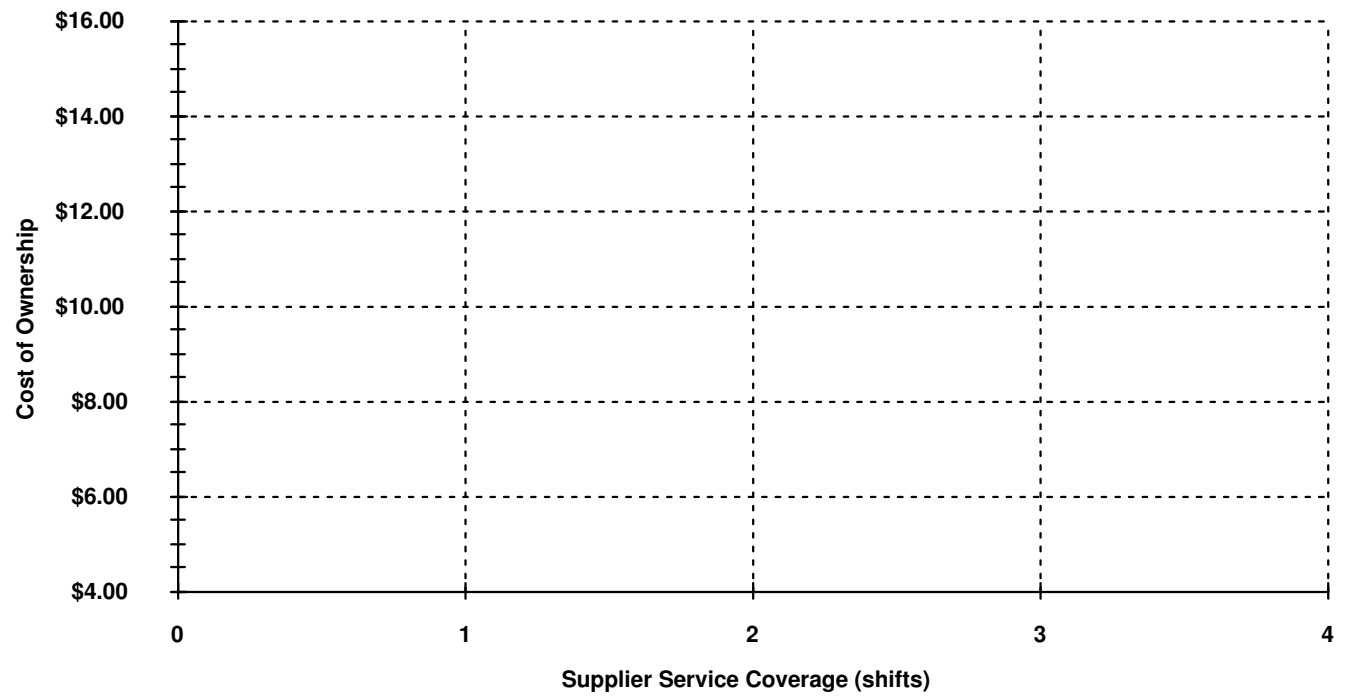


Exercise #8

Service Choices

This exercise will demonstrate the sensitivity of cost structure to service choices. Starting with the default parameters, enter the following five service data sections, row by row, from various locations in the "**MODEL SPECIFIC DATA**" section. Record the corresponding cost of ownership from the "**MANAGEMENT**" report tab. Once the data has been collected, chart required supplier service coverage versus cost of ownership.

		Average	Unscheduled	Annual Service	Contract Repair	Contract Repair	Cost of
MTBF	MTTR	Response Time	Maintenance Technicians	Contract Price	Parts Coverage	Labor Coverage	Ownership
100	8	0.25	2, 2, 2, 2	0, 0, 0, 0	no	no, no, no, no	
200	4	8	0, 0, 0, 0	\$15k, 0, 0, 0	yes	yes, no, no, no	
200	4	4	0, 0, 0, 0	\$15k, \$15k, 0, 0	yes	yes, yes, no, no	
200	4	2	0, 0, 0, 0	\$15k, \$15k, \$15k, 0	yes	yes, yes, yes, no	
200	4	0.25	0, 0, 0, 0	\$15k, \$15k, \$15k, \$15k	yes	yes, yes, yes, yes	



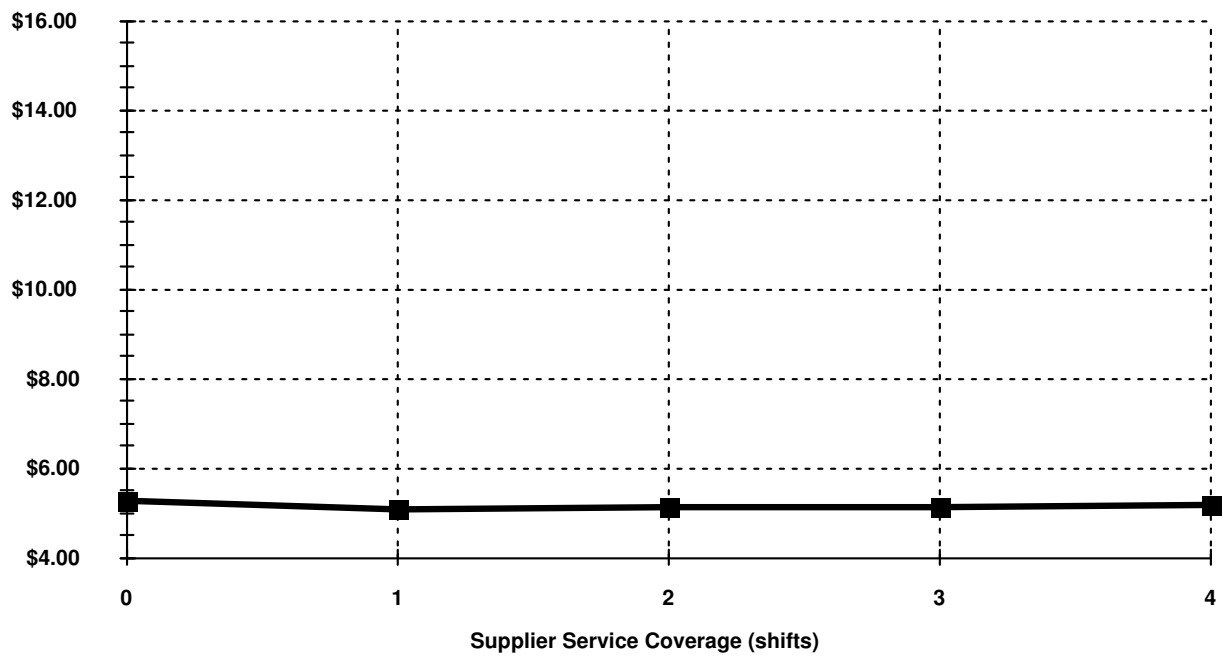


Exercise #8 Solution

Service Choices

The previous exercises have examined the impact of single variables on COO. In this exercise we look at how variables impact each other and the cost of ownership. In determining a service strategy, a manufacturer must decide between in-house and supplier service. Factors to consider are the number of shifts covered and their impact on average response time. Also, the quality of the personnel will impact MTBF, MTTR, and the number of technicians required per equipment down. In this exercise the higher quality personnel from the supplier overcomes the response time advantages of the in-house approach. The cost of service contracts exceeds the benefits of response time reduction after one shift of supplier coverage.

MTBF	MTTR	Average Response Time	Unscheduled Maintenance Technicians	Annual Service Contract Price	Contract Repair Parts Coverage	Contract Repair Labor Coverage	Cost of Ownership
100	8	0.25	2, 2, 2, 2	0, 0, 0, 0	no	no, no, no, no	\$5.26
200	4	8	0, 0, 0, 0	\$15k, 0, 0, 0	yes	yes, no, no, no	\$5.11
200	4	4	0, 0, 0, 0	\$15k, \$15k, 0, 0	yes	yes, yes, no, no	\$5.12
200	4	2	0, 0, 0, 0	\$15k, \$15k, \$15k, 0	yes	yes, yes, yes, no	\$5.16
200	4	0.25	0, 0, 0, 0	\$15k, \$15k, \$15k, \$15k	yes	yes, yes, yes, yes	\$5.19





Exercise #9

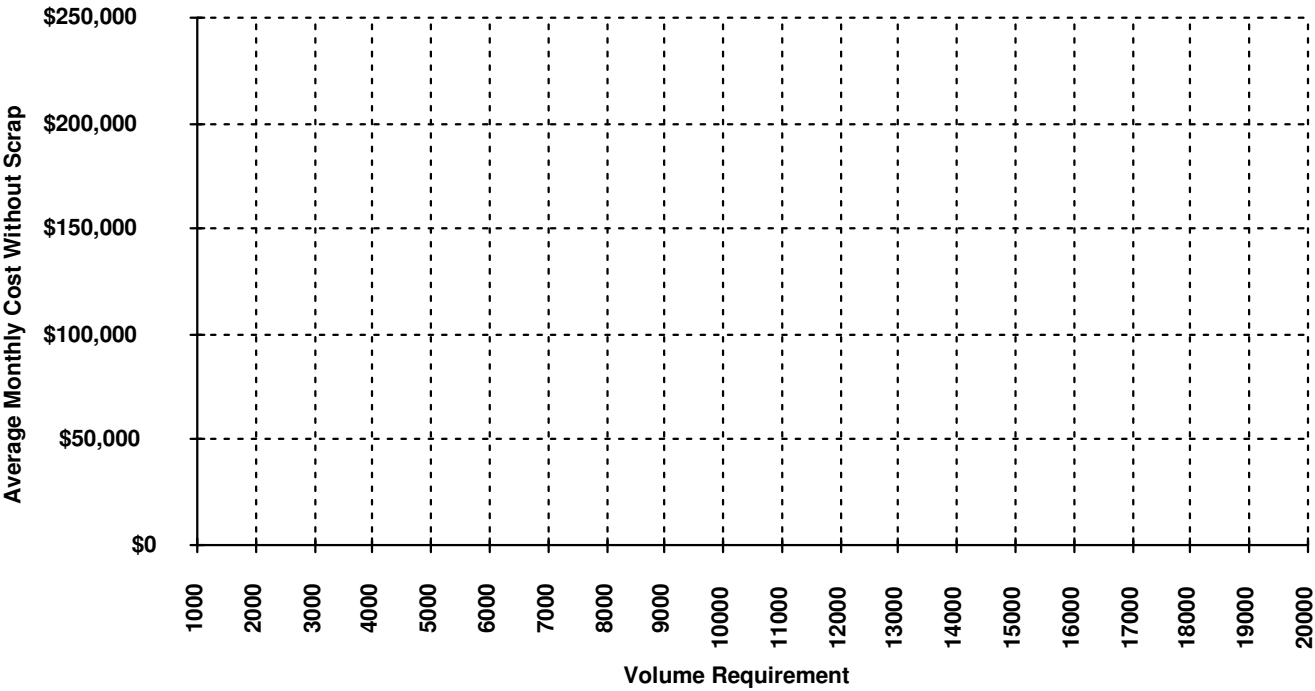
Monthly Costs

This exercise will demonstrate the sensitivity of cost structure to volume requirement. Starting with the default parameters, **change "Whole System Requirements" to zero (after entering the first volume requirements value) and** enter the following volume requirement data in the "FAB/FABORY PARAMETER INPUT" section. Record the corresponding average monthly cost without scrap from the "MANAGEMENT" report tab. Once the data has been collected, chart volume requirement versus average monthly cost without scrap.

Next, change the equipment cost to \$500,000, the throughput at capacity to 30, and re-enter the volume requirement data. Once the data has been collected, graph the data on the same chart. Which system is more cost effective at 3,000 unit starts per week? 9,000? 20,000?

Volume Requirement	Average Monthly Cost Without Scrap
1000	
2000	
3000	
4000	
5000	
6000	
7000	
8000	
9000	
10000	
11000	

12000	
13000	
14000	
15000	
16000	
17000	
18000	
19000	
20000	





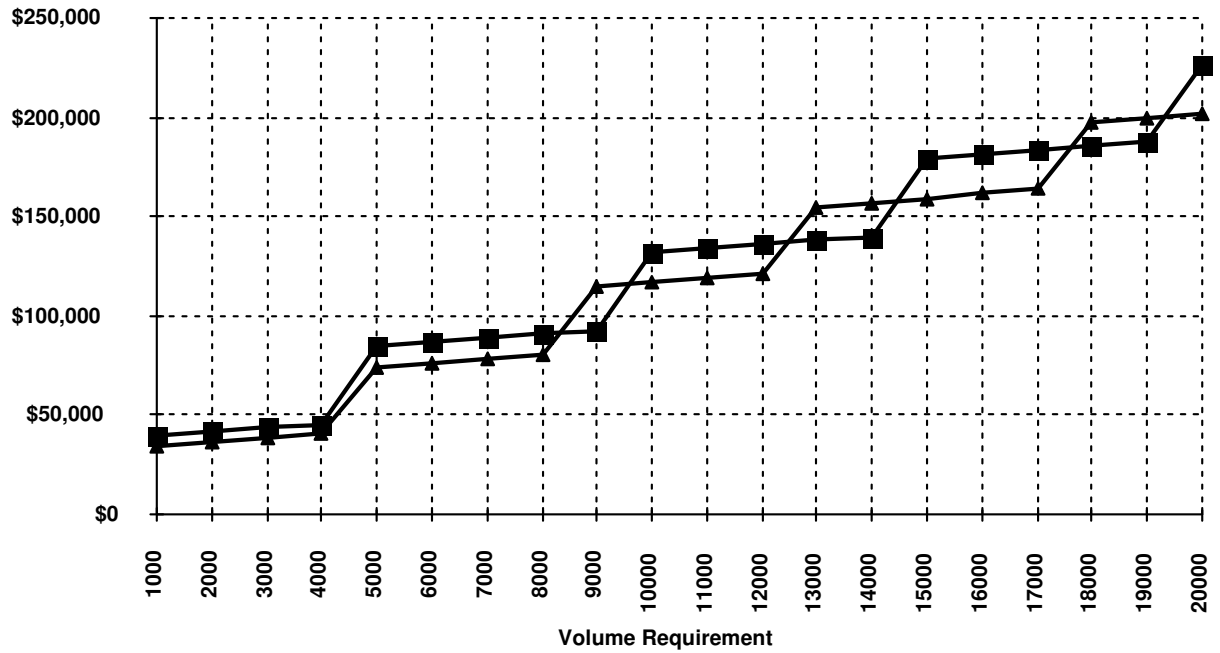
Exercise #9 Solution

Monthly Costs

There are three components to the monthly cost curve. The slope of the lines is driven by the recurring costs and the step height is a function of equipment costs. The length between steps is a function of throughput. As you can see, differences between equipment performance in these categories can cause the curves to intersect multiple times. This means that for a factory environment there is no single COO answer but a continuum of answers based on the size of the factory. Equipment 2 has a lower COO at 3,000 and 20,000 unit starts but a higher COO at 9,000.

Volume Requirement	Average Monthly Cost Without Scrap
1000	\$39,475~~\$33,767
2000	\$41,429~~\$35,965
3000	\$43,383~~\$38,163
4000	\$45,338~~\$40,361
5000	\$84,813~~\$74,128
6000	\$86,767~~\$76,326
7000	\$88,721~~\$78,524
8000	\$90,675~~\$80,722
9000	\$92,629~~\$114,489
10000	\$132,104~~\$116,687
11000	\$134,058~~\$118,885
12000	\$136,013~~\$121,083
13000	\$137,967~~\$154,850
14000	\$139,921~~\$157,048
15000	\$179,396~~\$159,246
16000	\$181,350~~\$161,444

17000	\$183,304~~\$163,643
18000	\$185,259~~\$197,409
19000	\$187,213~~\$199,607
20000	\$226,688~~\$201,806



Cost of Ownership Exercises



Example Exercises

- ❑ Equipment Costs
- ❑ Throughput at Capacity
- ❑ Defect Density
- ❑ Equipment Yield
- ❑ Volume Requirement & Utilization
- ❑ Life of Equipment & Depreciation
- ❑ Warranty Period
- ❑ Service Choices
- ❑ Monthly Costs

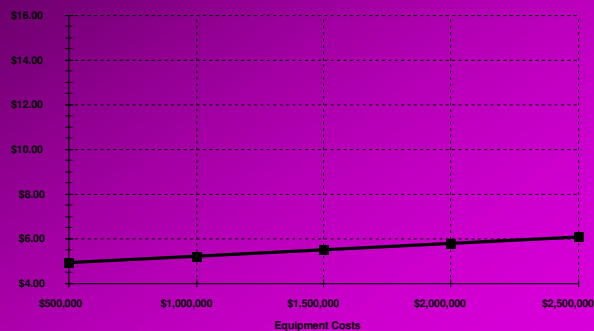
Equipment Costs - Input

- This exercise will demonstrate the sensitivity of cost structure to equipment costs. Starting with the default parameters, enter the following equipment cost data in the "EQUIPMENT DATA" section. Record the corresponding cost of ownership from the "MANAGEMENT" report tab. Once the data has been collected, chart equipment costs versus cost of ownership.

Equipment Costs	Cost of Ownership
\$500,000	
\$1,000,000	
\$1,500,000	
\$2,000,000	
\$2,500,000	

Equipment Costs - Solution

- Equipment costs have a linear relationship to cost of ownership. While the impact is noticeable, the slope of the line is typically modest. The slope and intersection are significantly impacted by the length of time the equipment is in operation.



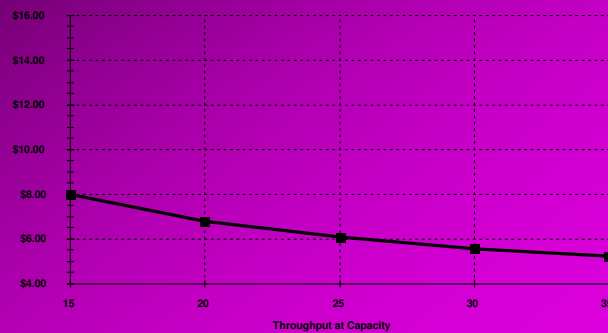
Throughput at Capacity - Input

- This exercise will demonstrate the sensitivity of cost structure to throughput. Starting with the default parameters, enter the following throughput data in the "MODEL SPECIFIC DATA" section. Record the corresponding cost of ownership from the "MANAGEMENT" report tab. Once the data has been collected, chart throughput at capacity versus cost of ownership.

Throughput at Capacity	Cost of Ownership
15	
20	
25	
30	
35	

Throughput at Capacity - Solution

- The curve is non-linear and asymptotic to both axes. This means that moderate improvements in throughput to "slow" systems will have a major impact on the cost of ownership. The same level of improvement to "fast" systems will have minimal impact. The cost of ownership of very high throughput systems will approach the recurring cost of ownership including scrap.



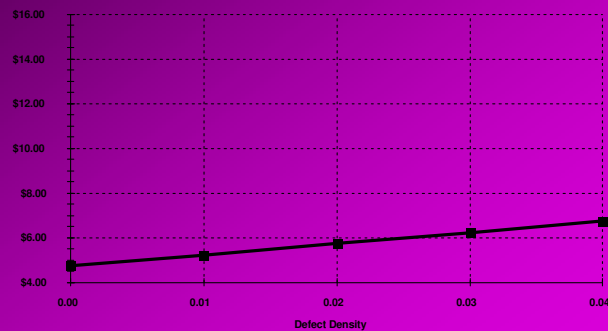
Defect Density - Input

- This exercise will demonstrate the sensitivity of cost structure to defect density and defect limited yield. Starting with the default parameters, enter the following defect density data in the "YIELD" section. Record the corresponding total cost of ownership from the "MANAGEMENT" report tab. Once the data has been collected, chart defect density versus cost of ownership.

Defect Density	Cost of Ownership
0.00	
0.01	
0.02	
0.03	
0.04	

Defect Density - Solution

- Yield issues are the main cost drivers in COO. The slope and its intersection are impacted by the device active area, fault probability, and value of the completed wafer.



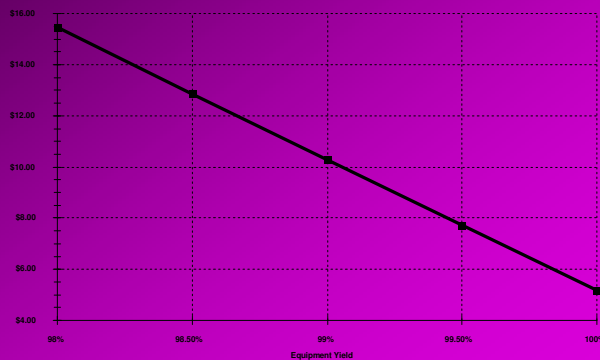
Equipment Yield - Input

- This exercise will demonstrate the sensitivity of cost structure to equipment yield. Starting with the default parameters, enter the following equipment yield data in the "YIELD" section. Record the corresponding cost of ownership from the "MANAGEMENT" report tab. Once the data has been collected, chart equipment yield versus cost of ownership.

Equipment Yield (%)	Cost of Ownership
98.0	
98.5	
99.0	
99.5	
100	

Equipment Yield - Solution

- Equipment yield has a significant impact on cost because it describes a process whereby entire products are lost. The curve is solely impacted by the yield and value of the unit at that step in the process.



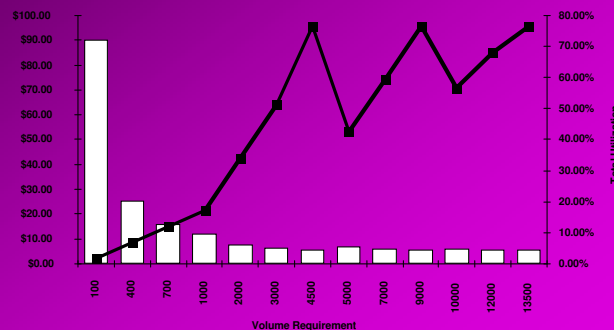
Volume Requirement & Utilization - Input

- This exercise will demonstrate the sensitivity of cost structure and utilization to volume requirement. Starting with the default parameters, change "Whole System Requirements" to zero and enter the following volume requirement data in the "FAB/FACTORY PARAMETER INPUT" section. Record the corresponding cost of ownership from the "MANAGEMENT" report tab and the total utilization from the "COO" report. Once the data has been collected, chart volume requirement and total utilization versus cost of ownership.

Volume Requirement	Cost of Ownership	Total Utilization
100		
400		
700		
1000		
2000		
3000		
4500		
5000		
7000		
9000		
10000		
12000		
13500		

Volume Requirement & Utilization - Solution

- The preceding exercises looked at the cost impact of various parameters on a fully loaded single machine. This exercise looks at the load requirements on a varying number of machines. At very low unit starts the COO is extremely high. This is due to the equipment costs being averaged over very few units. As more units are produced, the costs decreases to a minimum associated with a fully loaded machine. Adding one more unit start causes COO to increase due to the need for additional equipment. The equipment is underutilized. Again, as more units are added, another minimum is reached. As each new equipment is added, the maximum cost decreases. This is due to having more and more units over which to amortize the equipment costs of the additional equipment. Below, the COO values are the bars and the line is utilization.



Life of Equipment and Depreciation - Input

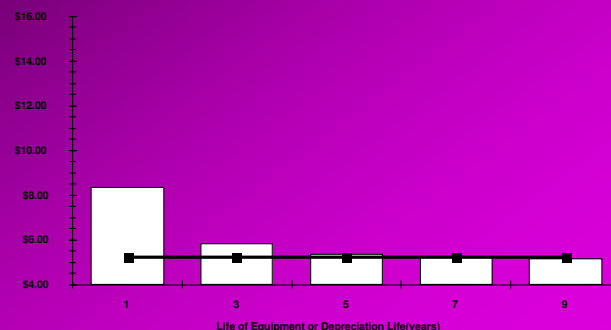
- This exercise will demonstrate the sensitivity of cost structure to life of equipment and depreciation life. Starting with the default parameters, enter the following life of equipment and depreciation life data in the "ADMINISTRATIVE RATES" section. Record the corresponding cost of ownership from the "MANAGEMENT" report tab. Once the data has been collected, chart life of equipment and depreciation life versus cost of ownership.

Life of Equipment	Cost of Ownership
1	
3	
5	
7	
9	

Depreciation Life	Cost of Ownership
1	
3	
5	
7	
9	

Life of Equipment and Depreciation - Solution

- The life of equipment (bars) significantly impacts COO by determining the total number of good units the factory will produce in its life. The equipment costs are amortized over the number of units produced. The larger the number of units, the lower the equipment cost component per unit. The diminishing returns effect is a function of the starting and ending points at each step on the curve (3:1, 5:3, 7:5, etc.).
- In this example, the depreciation life (line) has no impact on COO since 100% of the equipment cost (less any salvage value) is always captured. Where depreciation life would have an impact is for administrative costs that are a function of book value (interest, personal property taxes, and insurance).



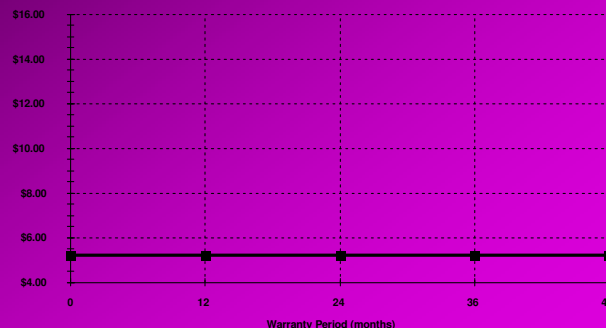
Warranty Period - Input

- This exercise will demonstrate the sensitivity of cost structure to the warranty period. Starting with the default parameters, enter the following warranty period data in the "MAINTENANCE COSTS" section. Record the corresponding cost of ownership from the "MANAGEMENT" report tab. Once the data has been collected, chart warranty period versus cost of ownership.

Warranty Period	Cost of Ownership
0	
12	
24	
36	
48	

Warranty Period - Solution

- The impact of the length of the warranty period will be driven by the reliability of the equipment and/or service contract pricing. Under typical conditions, the length of the warranty period will have very minimal effect. Why then the push by some equipment suppliers to tout longer warranties? COO is not the only driving force. Longer warranties create a product positioning statement of reliability and confidence on the part of the manufacturer.



Service Choices - Input

- This exercise will demonstrate the sensitivity of cost structure to service choices. Starting with the default parameters, enter the following five service data sections, row by row, from various locations in the "MODEL SPECIFIC DATA" section. Record the corresponding cost of ownership from the "MANAGEMENT" report tab. Once the data has been collected, chart required supplier service coverage versus cost of ownership.

MTBF	MTTR	Average Response Time	Unscheduled Maintenance Technicians	Annual Service Contract Price	Contract Repair Parts Coverage	Contract Repair Labor Coverage	Cost of Ownership
100	8	0.25	2, 2, 2, 2	0, 0, 0, 0	no	no, no, no, no	
200	4	8	0, 0, 0, 0	\$15k, 0, 0, 0	yes	yes, no, no, no	
200	4	4	0, 0, 0, 0	\$15k, \$15k, 0, 0	yes	yes, yes, no, no	
200	4	2	0, 0, 0, 0	\$15k, \$15k, \$15k, 0	yes	yes, yes, yes, no	
200	4	0.25	0, 0, 0, 0	\$15k, \$15k, \$15k, \$15k	yes	yes, yes, yes, yes	

Service Choices - Solution

- The previous exercises have examined the impact of single variables on COO. In this exercise we look at how variables impact each other and COO. In determining a service strategy, a manufacturer must decide between in-house and supplier service. Factors to consider are the number of shifts covered and their impact on average response time. Also, the quality of the personnel will impact MTBF, MTTR, and the number of technicians required per equipment down. In this exercise the higher quality personnel from the supplier overcomes the response time advantages of the in-house approach. The cost of service contracts exceeds the benefits of response time reduction after one shift of supplier coverage.

MTBF	MTTR	Average Response Time	Unscheduled Maintenance Technicians	Annual Service Contract Price	Contract Repair Parts Coverage	Contract Repair Labor Coverage	Cost of Ownership
100	8	0.25	2, 2, 2, 2	0, 0, 0, 0	no	no, no, no, no	\$5.26
200	4	8	0, 0, 0, 0	\$15k, 0, 0, 0	yes	yes, no, no, no	\$5.11
200	4	4	0, 0, 0, 0	\$15k, \$15k, 0, 0	yes	yes, yes, no, no	\$5.12
200	4	2	0, 0, 0, 0	\$15k, \$15k, \$15k, 0	yes	yes, yes, yes, no	\$5.16
200	4	0.25	0, 0, 0, 0	\$15k, \$15k, \$15k, \$15k	yes	yes, yes, yes, yes	\$5.19

Monthly Costs - Input

- This exercise will demonstrate the sensitivity of cost structure to volume requirement. Starting with the default parameters, change "Whole System Requirements" to zero and enter the following volume requirement data in the "FAB/FACTORY PARAMETER INPUT" section. Record the corresponding average monthly cost without scrap from the "MANAGEMENT" report tab. Once the data has been collected, chart volume requirement versus average monthly cost without scrap.
- Next, change the equipment cost to \$500,000, the throughput at capacity to 30 and re-enter the volume requirement data. Once the data has been collected, graph the data on the same chart. Which system is more cost effective at 3,000 layer starts per week? 9,000? 20,000?



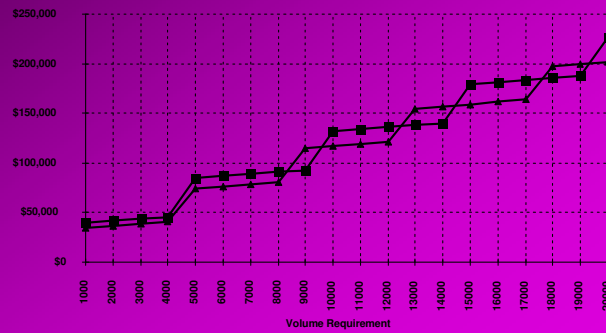
Monthly Costs - Input

Volume Requirement	Average Monthly Cost Without Scrap
1000	
2000	
3000	
4000	
5000	
6000	
7000	
8000	
9000	
10000	
11000	
12000	
13000	
14000	
15000	
16000	
17000	
18000	
19000	
20000	



Monthly Costs - Solution

- There are three components to the monthly cost curve. The slope of the lines are driven by the recurring costs and the step height is a function of equipment costs. The length between steps is a function of throughput. As you can see, differences between equipment performance in these categories can cause the curves to intersect multiple times. This means that for a factory environment there is no single COO answer but a continuum of answers based on the size of the factory. Equipment 2 has a lower COO at 3,000 and 20,000 unit starts but a higher COO at 9,000.



Wright Williams & Kelly, Inc.

Certificate of Completion

is hereby granted to

to certify that he/she has completed to satisfaction

Understanding and Using
Cost of Ownership



Model Input Details

Section 8 provides a detailed look at the input requirements for informational input, fab/factory parameters, and equipment/material specifications. At the end of section 8 is a complete print out of TWO COOL®.

INFORMATIONAL INPUT

The "INFORMATIONAL INPUT" section provides for input of information which is used for report headers and is also saved with filed charts and sensitivity analyses.

8-2 *Understanding and Using Cost of Ownership*

Informational Input	
Originator	John Doe
Process	Deposition
Supplier	Any Supplier
Comments	This cell allows for the input of comments.
Company	IC Maker, Inc.
Log Point	1
Model	CVD 100
Site	Wafer Fab 1

INFORMATIONAL INPUT

Originator	Identification of the individual who created the cost of ownership analysis.
Process	Process step description (deposition, wire bond, write, screen print, bake, juice...)
Supplier	Name of the supplier of the equipment.
Comments	Available for detailed user notes.
Company	Provides for input of the name of the company for which the analysis is being run.
Log Point	Additional identification of the exact analysis point in the process.
Model	Identifies the analysis in report/chart headers and in the save/open dialog boxes.
Site	Differentiate between analyses run for the same Company but at different locations.

FAB/FACTORY PARAMETER INPUT

The "FAB/FACTORY PARAMETER INPUT" section describes the way in which the device manufacturer runs their production line for the process step under analysis.

Fab Parameter Input		
Throughput Data		
Time Not Available (Per System)		
Engineering Usage	0.00	Hours/Week
Standby	0.00	Hours/Week
Production Tests Scheduled	14	/Week
MTTT	0.25	Hours
Whole System Requirements	1	Single System
Volume Requirement	0	Fully Loaded
Lot Size	24	Wafers/Lot
Redo Rate	0.00	%
Process Data		
Wafer Size	200	mm
Wafer Coverage	80.00	%
Die Area	1.00	cm ²
Fault Probability	5.00	%
Clustering Parameter	1.00	
Parametric Limited Yield Loss	0.25	%

8-4 *Understanding and Using Cost of Ownership*

THROUGHPUT DATA

Engineering Usage	Hours/week that each system is used for non-production purposes.
Standby	Hours/week that each system is waiting on product.
Production Tests Scheduled	Number of system qualification tests/week.
MTTT	Set-up, process, and inspection time for a test unit (inspection only if product).
Whole System Requirements	The number of fully loaded systems to be analyzed.
Volume Requirement	Number of additional product-passes each week this process step is required to run.
Lot Size	Amount of product in a lot.
Redo Rate	The rate at which product is reworked.

PROCESS DATA

Wafer (Unit, Mask) Size	The diameter or size of the product being processed.
Wafer (Unit, Mask) Coverage	% of total product area covered by sub-product with some yield expectations.
Die Area	The electrically active area of the device. (Wafer fab only)
Fault Probability	Percentage of total particles landing on the wafer that are fatal. (Wafer fab only)
Clustering Parameter	The factor describing the degree of clustering of defects on a wafer. (Wafer fab only)
Parametric Limited Yield Loss	The percentage parametric limited yield loss for this process step.

Fab Parameter Input		
Scheduled Production		
Hours/Week/Shift	42.00	Hours
Shifts/Week	4	Shifts
Days/Year	365.00	Days
Operator/Maint. Productive Time	80.00	%
Burdened Salary Rates/Year		
Engineering	100,000	Currency
Supervision	80,000	Currency
Burdened Labor Rates/Hour		
Operator	25	Currency
Maintenance	30	Currency
Space Rates/Year		
Class 1	400	Currency/ft2
Class 10	250	Currency/ft2
Class 100	100	Currency/ft2
Other	50	Currency/ft2
Other Support Services/Year		
Employee Related	0	Currency
Production Related	0	Currency

8-6 *Understanding and Using Cost of Ownership*

ADMINISTRATIVE RATES

Hours/Week/Shift	Number of hours each shift works per week.
Shifts/Week	Total number of shifts per week. Hours/shift/week * shifts/week must be ≤ 168 .
Days/Year	Work days per year.
Operator/Maint. Productive Time	Percentage of time an hourly worker is productive when product is available.
Engineering	Yearly salary rate for engineers including all overhead.
Supervision	Yearly salary rate for supervisors including all overhead.
Operator	Hourly pay rate for operators including all overhead.
Maintenance	Hourly pay rate for maintenance including all overhead.
Class 1	Cost of maintaining a class 1 cleanroom on a yearly basis.
Class 10	Cost of maintaining a class 10 cleanroom on a yearly basis.
Class 100	Cost of maintaining a class 100 cleanroom on a yearly basis.
Other	Cost of maintaining a >class 100 cleanroom on a yearly basis.
Employee Related	Support services costs/year/employee (bonuses, stock options).
Production Related	Support services costs/year that are production related.

Fab Parameter Input		
Administrative Rates		
Inflation Rate	4.00	%
Life of Equipment	7.00	Years
Depreciation Life	5.00	Years
Salvage Value	0	Currency
Depreciation Method	str	
Declining Balance Factor	200	Percent
Insurance	0.00	Percent BV
Personal Property Taxes	0.00	Percent BV
Interest	0.00	Percent Rate
Currency		
Input Currency	Currency	
Output Currency	Currency	
Currency Exchange Rate	1.00	
Other Costs		
Spare Parts Inventory Costs/System	0	Currency/Year
Test Wafer Cost	100	Currency/Wafer
Value of Incoming Wafer	500	Currency/Wafer
Value of Completed Wafer	1,000	Currency/Wafer
Moves and Rearrangements/System	0	Currency
ESH Permits and Preparation	0	Currency

8-8 *Understanding and Using Cost of Ownership*

ADMINISTRATIVE RATES

Inflation Rate	Support services costs/year that are production related.
Life of Equipment	Average CPI inflation rate for the analysis period.
Depreciation Life	Number of years equipment will be in operation.
Salvage Value	Number of years over which equipment will be depreciated.
	The salvage value of the depreciable assets at the end of useful life.
	Straight line = str, declining balance = db, sum-of-the-years'-digits = sum.
Depreciation Method	The declining balance factor for depreciation. Double declining balance = 2.
Declining Balance Factor	Insurance costs calculated as a percent of the mid-year book value.
Insurance	Personal property tax costs calculated as a percent of the mid-year book value.
Personal Property Taxes	Financing costs calculated by simple interest applied to mid-year book value.
Interest	Currency to be displayed by input fields
Input Currency	Currency to be displayed by output fields
Output Currency	The number of input currency units to output currency units.
Currency Exchange Rate	
Spare Parts Inventory Carrying Costs/System	The cost incurred in carrying spare parts inventory/year/system.
Test Wafer (Unit, Mask) Cost	The cost of consumed test units or test unit coatings.
Value Of Incoming Wafer (Unit, Mask) At This Point In Process	The processing value of the product up to and including this process step in flow.
Value Of Completed Wafer (Unit, Mask) At End Of Process Flow	The processing value of the product at the end of the process flow.
Moves And Rearrangements/System	The cost of moving installed equipment to make room for new equipment.
Environmental, Safety, and Health Permits and Preparation	The cost of preparing for and obtaining environmental, safety, and health permits.

MODEL SPECIFIC DATA

Model Specific Input		
Time Not Available		
Scheduled Maintenance	14.00	Hours/Week
Primary Wafer Based Maint.	0	Layers
Primary Time/Wafer Quantity	0.00	Hours
Secondary Wafer Based Maint.	0	Layers
Secondary Time/Wafer Quantity	0.00	Hours
MTBF	200.00	Hours
Average Response Time	0.10	Hours
MTTR	10.00	Hours
MTBA	12.00	Hours
MTTA	1.00	Minutes
Throughput Data		
Throughput at Capacity/System	35.00	Layers/Hour
Systems/Operator	3	Systems

THROUGHPUT DATA

Scheduled Maintenance	Scheduled maintenance/week/system.
Primary Wafer (Unit, Mask) Based Maintenance	Number of product-passes processed between production based scheduled maintenance.
Primary Time Per Wafer (Unit, Mask) Quantity	Time required for each product based scheduled maintenance procedure.
Secondary Wafer (Unit, Mask) Based Maintenance	Number of product-passes processed between product based scheduled maintenance.
Secondary Time Per Wafer Quantity	Time required for each product based scheduled maintenance procedure.
MTBF	Mean time between failures.
Average Response Time	Average time to respond to a down system.
MTTR	Mean time to repair.
MTBA	Mean time between assists.
MTTA	Mean time to assist.
Throughput At Capacity/System	Raw throughput of system at production process conditions.
Number Of Systems/Operator	Number of systems an operator can run at one time.

8-10 Understanding and Using Cost of Ownership

Model Specific Input		
Original Cost/System		
Equipment Cost	1,000,000	Currency
Transportation Cost	10,000	Currency
Installation Cost	5,000	Currency
Other Depreciable Costs	0	Currency
System Qualification		
Engineering	40.00	Man-Hours
Maintenance	20.00	Man-Hours
Operator	80.00	Man-Hours
Supplies/Consumables	0	Currency
Other Material	0	Currency
Other Costs	0	Currency

EQUIPMENT DATA

Equipment Cost
Transportation Cost
Installation Cost
Other Depreciable Costs
Engineering
Maintenance
Operator
Supplies/Consumables
Other Material
Other Costs

Original purchase price of system.
Cost to transport from FOB point to factory.
Cost to install system in factory.
Any other costs associated with the equipment purchase.
Time required by engineering to qualify system for production.
Time required by maintenance to qualify system for production.
Time required by operators to qualify system for production.
Supplies/consumables costs required to qualify system.
Test units and other material costs to qualify system.
Any other costs associated with system qualification.

Model Specific Input		
Floor Space/System		
Class 1	75.00	Square Feet
Class 10	0.00	Square Feet
Class 100	50.00	Square Feet
Other	0.00	Square Feet
Training Required/System		
Operators	80.00	Man-Hours
Engineers	24.00	Man-Hours
Maintenance	80.00	Man-Hours
Other Costs	4,000	Currency
Yield		
Equipment Yield	99.99	%
Defect Density	0.01	Per cm2
Defect Measurement	2	

EQUIPMENT DATA

Class 1	System class 1 footprint.
Class 10	System class 10 footprint.
Class 100	System class 100 footprint.
Other	System class 100+ footprint.
Operators	Initial training requirements of operators.
Engineers	Initial training requirements of engineers.
Maintenance	Initial training requirements of maintenance.
Other Costs	Initial additional training costs.
Equipment Yield	Yield resulting from this process's whole product loss (broken and misprocessed).
Defect Density	Defect density at specified detection limit. (Wafer fab only)
Defect Measurement	
(Electrical=1, Physical=2)	Input for the type of defect measurement. (Wafer fab only)

8-12 Understanding and Using Cost of Ownership

Model Specific Input			
Utilities			
Utility	Wafer, Time, or Lot Based	Quantity Per Layer/Lot	Price Per Quantity
Electricity	T		2,000.00
Natural Gas			
City Water			
DI Water			
Chilled Water	T		1,500.00

Supply/Consumables			
Supply/Consumable	Wafer, Time, or Lot Based	Quantity Per Layer/Lot	Price Per Quantity
Gas/Chemical 1	W	1	0.10
Gas/Chemical 2			
Gas/Chemical 3			
Gas/Chemical 4			
Gas/Chemical 5			
Plant Exhaust			
Bulk Chemicals			
Specialty Chemicals	T		125,000.00
Bulk Gases			
Expendables			
Manufacturing Tooling			
Rent of Equipment			
Protective Clothing			
Office Supplies			
Computer Software			
Expensed Equipment			
Computer Supplies			
Forms			

All Prices are in Currency

The top section covers utilities used to operate the equipment but do not include items consumed in the manufacturing process, which are listed in the bottom section. Input is allowed in time, wafer (unit, mask), and lot-based increments on a line-by-line basis. If a "T" is entered in column "2" then the cost listed in column "4" will be interpreted as the annual cost per system. If

a "W" ("U", "M") is entered in column "2" then the cost listed in column "4" will be interpreted as the cost for a single unit quantity of the total quantity used per wafer (unit, mask) pass as listed in column "3". If a "L" is entered in column "2" then the cost listed in column "4" will be interpreted as the cost for a single unit quantity of the total quantity used per lot as listed in column "3". The labels listed in column "1" can be changed for the exact requirements of any analysis and will be saved to the database with other input data.

Electricity usage costs/year/system. Annual cost/system is 2000 currency.
Natural Gas usage costs/year/system. Annual cost/system is 0 currency.
City Water usage costs/year/system. Annual cost/system is 0 currency.
DI Water usage costs/year/system. Annual cost/system is 0 currency.
Chilled Water usage costs/year/system. Annual cost/system is 1500 currency.

Gas/Chemical 1 usage costs/year/system. Annual cost/system is 26047 currency.
Gas/Chemical 2 usage costs/year/system. Annual cost/system is 0 currency.
Gas/Chemical 3 usage costs/year/system. Annual cost/system is 0 currency.
Gas/Chemical 4 usage costs/year/system. Annual cost/system is 0 currency.
Gas/Chemical 5 usage costs/year/system. Annual cost/system is 0 currency.
Plant Exhaust usage costs/year/system. Annual cost/system is 0 currency.
Bulk Chemicals usage costs/year/system. Annual cost/system is 0 currency.
Specialty Chemicals usage costs/year/system. Annual cost/system is 125000 currency.
Bulk Gases usage costs/year/system. Annual cost/system is 0 currency.
Expendables usage costs/year/system. Annual cost/system is 0 currency.
Manufacturing Tooling usage costs/year/system. Annual cost/system is 0 currency.
Rent of Equipment usage costs/year/system. Annual cost/system is 0 currency.
Protective Clothing usage costs/year/system. Annual cost/system is 0 currency.
Office Supplies usage costs/year/system. Annual cost/system is 0 currency.
Computer Software usage costs/year/system. Annual cost/system is 0 currency.
Expensed Equipment usage costs/year/system. Annual cost/system is 0 currency.
Computer Supplies usage costs/year/system. Annual cost/system is 0 currency.
Forms usage costs/year/system. Annual cost/system is 0 currency.

8-14 Understanding and Using Cost of Ownership

Model Specific Input		
Other Production Costs/System		
Other Production Costs	0	Currency/Year
Waste Disposal Costs	0	Currency/Year
Other Material Costs		
Test Wafers	1.40	Wafers/Week
Other Materials	0	Currency/Year
Personnel/System		
Engineers	4.00	Hours/Week
Supervision	1.33	Hours/Week
Contract Labor	0	Currency/Year

PRODUCTION DATA

Other Production Costs	Other production supply usage costs/year/system.
Waste Disposal Costs/System (Annually)	Waste disposal costs/year/system.
Test Wafers (Units, Masks)	Number of test units required to maintain production.
Other Materials (Annually)	Other material usage costs/year/system.
Engineers	Engineering coverage requirements/system.
Supervision	Supervision coverage requirements/system.
Contract Labor (Annually)	Contract labor coverage requirement costs/year/system.

Model Specific Input						
Parts & Technicians						
Repair Parts/System	15,000					Currency/Year
Maintenance Technicians	Shift 1	Shift 2	Shift 3	Shift 4	Shift 5	Shift 6
Scheduled	1.00	0.00	0.00	0.00	0.00	0.00
Unscheduled	0.00	0.00	0.00	0.00	0.00	0.00
Warranty						
Warranty Period	12					Months
Warranty Shift Coverage	1					Shifts
Repair Parts Coverage	yes					
Labor Coverage	Shift 1	Shift 2	Shift 3	Shift 4	Shift 5	Shift 6
Repair	yes	no	no	no	no	no
Sched. Maint.	no	no	no	no	no	no
Contract						
Repair Parts Coverage	yes					
	Shift 1	Shift 2	Shift 3	Shift 4	Shift 5	Shift 6
Annual Contract/System	15,000	15,000	15,000	15,000	0	0
Repair Labor	yes	yes	yes	yes	no	no
Sched. Maint. Labor	no	no	no	no	no	no
Other Costs						
Annual Supplier Training/System	4,000					Currency
Annual Software Contract/System	0					Currency

8-16 *Understanding and Using Cost of Ownership*

PRODUCTION DATA

Annual Repair Parts/System	Repair parts replacement costs if not covered by warranty and service contracts.
Scheduled Maintenance Technicians	Ave. # of technicians needed to perform a scheduled maintenance procedure.
Unscheduled Maintenance Technicians	Ave. # of technicians needed to perform an unscheduled maintenance procedure.
Warranty Period	Length of warranty period.
Warranty Shift Coverage	Number of shifts that are covered under warranty.
Warranty Repair Parts Coverage	Are repair parts included under warranty (Yes, No)?
Warranty Repair Labor Coverage	Is repair labor included under warranty (Yes, No)?
Warranty Scheduled Maintenance Labor Coverage	Is scheduled maintenance labor included under warranty (Yes, No)?
Contract Repair Parts Coverage	Are repair parts included under service contract (Yes, No)?
Annual Service Contract/Shift Per System	Service contract costs/shift/system/year.
Contract Repair Labor Coverage	Is repair labor included under service contract (Yes, No)?
Contract Scheduled Maintenance Labor Coverage	Is scheduled maintenance labor included under service contract (Yes, No)?
Annual Supplier Training/System	On-going training costs/year/system.
Annual Software Contract/System	Software upgrade contract costs/year/system.

TWO COOL®

Sample Print Out

Originator: John Doe
Supplier: Any Supplier
Process: Deposition
Comments: This cell allows for the input of comments.

Company: IC Maker, Inc.
Log Point: 1
Model: CVD 100

Site: Wafer Fab 1
Created:
Revised:

Throughput Data

Time Not Available (Per System)		
Engineering Usage	0.00 Hours/Week	Hours/week that each system is used for non-production purposes.
Standby	0.00 Hours/Week	Hours/week that each system is waiting on wafers.
Production Tests Scheduled	14 Number/Week	Number of system qualification tests/week.
MTTT	0.25 Hours	Set-up, process, and inspection time for a test wafer (inspection only if product).
Whole System Requirements	1 Single System	The number of fully loaded systems to be analyzed.
Volume Requirement	0 Fully Loaded	Number of additional layer starts each week this process step is required to run.
Lot Size	24 Wafers/Lot	Number of wafers in a lot.
Redo Rate	0.00 Percent	The rate at which wafers are reworked.

Process Data

Wafer Size	200.00 mm	The diameter of the wafer being processed.
Wafer Coverage	80.00 Percent	% of total wafer area covered by product devices with some yield expectations.
Die Area	1.00 cm2	The electrically active area of the device.
Fault Probability	5.00 Percent	Percentage of defects landing on the wafer that are fatal.
Clustering Parameter	1.00	The factor used to describe the degree of clustering of defects on a wafer.
Parametric Limited Yield Loss	0.25 Percent	The percentage parametric limited yield loss for this process step.

Originator: John Doe
Supplier: Any Supplier
Process: Deposition
Comments: This cell allows for the input of comments.

Company: IC Maker, Inc.
Log Point: 1
Model: CVD 100

Site: Wafer Fab 1
Created:
Revised:

Administrative Rates

Scheduled Production

Hours/Week/Shift	42.00 Hours	Number of hours each shift works per week.
Shifts/Week	4 Shifts	Total number of shifts per week. Hours/shift/week * shifts/week must be <=168.
Days/Year	365.00 Days	Work days per year.
Operator/Maintenance Productive Time	80.00 Percent	Percentage of time an hourly worker is productive when wafers are available.

Burdened Salary Rates (Annually)

Engineering	100,000 Currency	Yearly salary rate for engineers including all overhead.
Supervision	80,000 Currency	Yearly salary rate for supervisors including all overhead.

Burdened Labor Rates

Operator	25 Currency/Hour	Hourly pay rate for operators including all overhead.
Maintenance Technician	30 Currency/Hour	Hourly pay rate for maintenance technician including all overhead.

Space Rates (Annually)

Class 1	400 Currency/ft2	Cost of maintaining a class 1 cleanroom on a yearly basis.
Class 10	250 Currency/ft2	Cost of maintaining a class 10 cleanroom on a yearly basis.
Class 100	100 Currency/ft2	Cost of maintaining a class 100 cleanroom on a yearly basis.
Other	50 Currency/ft2	Cost of maintaining a >class 100 cleanroom on a yearly basis.

Other Support Services (Annually)

Employee Related	0 Currency	Support services costs/year/employee (bonuses, stock options).
Production Related	0 Currency	Support services costs/year that are production related.

Administrative Rates

Inflation Rate	4.00 Percent	Average CPI inflation rate for the analysis period.
Life of Equipment	7.00 Years	Number of years equipment will be in operation.
Depreciation Life	5.00 Years	Number of years over which equipment will be depreciated.
Salvage Value	0 Currency	The salvage value of the depreciable assets at the end of useful life.
Depreciation Method	str	Straight line = str, declining balance = db, sum-of-the-years'-digits = sum.
Declining Balance Factor	200 Percent	The declining balance factor for depreciation. Double declining balance = 200.
Insurance	0.00 Percent BV	Insurance costs calculated as a percent of the mid-year book value.
Personal Property Taxes	0.00 Percent BV	Personal property tax costs calculated as a percent of the mid-year book value.
Interest	0.00 Percent Rate	Financing costs calculated by simple interest applied to mid-year book value.

Currency

Input Currency	Currency	
Output Currency	Currency	
Currency Exchange Rate	1.00	The number of input currency units to output currency units.

Other Costs

Annual Spare Parts Inventory Carrying Costs/System	0 Currency	The cost incurred in carrying spare parts inventory/year/system.
Test Wafer Cost	100 Currency/Wafer	The cost of consumed test wafers or test wafer coatings.
Value Of Incoming Wafer At This Point In Process	500 Currency/Wafer	The processing value of the wafer previous to this process step in the process flow.
Value Of Completed Wafer At End Of Process Flow	1,000 Currency/Wafer	The processing value of the wafer at the end of the process flow.
Moves And Rearrangements/System	0 Currency	The cost of moving installed equipment to make room for new equipment.

Originator: John Doe
Supplier: Any Supplier
Process: Deposition
Comments: This cell allows for the input of comments.

Company: IC Maker, Inc.
Log Point: 1
Model: CVD 100

Site: Wafer Fab 1
Created:
Revised:

Throughput Data

Time Not Available (Per System)

Scheduled Maintenance	14.00 Hours/Week	Scheduled maintenance/week/system.
Primary Wafer Based Maintenance	0 Layers	Number of layers processed between wafer based scheduled maintenance.
Primary Time Per Wafer Quantity	0.00 Hours	Time required for each wafer based scheduled maintenance procedure.
Secondary Wafer Based Maintenance	0 Layers	Number of layers processed between wafer based scheduled maintenance.
Secondary Time Per Wafer Quantity	0.00 Hours	Time required for each wafer based scheduled maintenance procedure.
MTBF	200.00 Hours	Mean time between failures.
Average Response Time	0.10 Hours	Average time to respond to a down system.
MTTR	10.00 Hours	Mean time to repair.
MTBA	12.00 Hours	Mean time between assists.
MTTA	1.00 Minutes	Mean time to assist.
Throughput At Capacity/System	35.00 Layers/Hour	Raw throughput of system at production process conditions.
Number Of Systems/Operator	3 Systems	Number of systems an operator can run at one time.

Equipment Data

Original Cost/System

Equipment Cost	1,000,000 Currency	Original purchase price of system.
Transportation Cost	10,000 Currency	Cost to transport from FOB point to fab.
Installation Cost	5,000 Currency	Cost to install system in fab.
Other Depreciable Costs	0 Currency	Any other costs associated with the equipment purchase.

System Qualification Costs/System

Engineering	40.00 Man-Hours	Time required by engineering to qualify system for production.
Maintenance Technician	20.00 Man-Hours	Time required by maintenance technician to qualify system for production.
Operator	80.00 Man-Hours	Time required by operators to qualify system for production.
Supplies/Consumables	0 Currency	Supplies/consumables costs required to qualify system.
Other Material	0 Currency	Test wafers and other material costs to qualify system.
Other Costs	0 Currency	Any other costs associated with system qualification.

Floor Space/System

Class 1	75.00 Square Feet	System class 1 footprint.
Class 10	0.00 Square Feet	System class 10 footprint.
Class 100	50.00 Square Feet	System class 100 footprint.
Other	0.00 Square Feet	System class 100+ footprint.

Training Required/System

Operators	80.00 Man-Hours	Initial training requirements of operators.
Engineers	24.00 Man-Hours	Initial training requirements of engineers.
Maintenance Technicians	80.00 Man-Hours	Initial training requirements of maintenance technicians.
Other Costs	4,000 Currency	Initial additional training costs.

Yield

Equipment Yield	99.99 Percent	Yield resulting from this process's whole wafer loss (broken and misprocessed).
Defect Density	0.01 per cm2	Defect density at specified detection limit.

Site: Wafer Fab 1
Created:
Revised:

Input for the type of defect measurement.

Originator: John Doe
Supplier: Any Supplier
Process: Deposition
Comments: This cell allows for the input of comments.

Company: IC Maker, Inc.
Log Point: 1
Model: CVD 100

Site: Wafer Fab 1
Created:
Revised:

Production Data

Utility Usage/System/Year

	Wafer/Time/Lot Based(W, T, L)	Quantity Per Layer/Lot	Price Per Quantity	
Electricity	T		2,000.00	Currency
Natural Gas				Currency
City Water				Currency
DI Water				Currency
Chilled Water	T		1,500.00	Currency

Electricity usage costs/year/system. Annual cost/system is 2000 Currency.
 Natural Gas usage costs/year/system. Annual cost/system is 0 Currency.
 City Water usage costs/year/system. Annual cost/system is 0 Currency.
 DI Water usage costs/year/system. Annual cost/system is 0 Currency.
 Chilled Water usage costs/year/system. Annual cost/system is 1500 Currency.

Supply/Consumable Costs
/System/Year

	Wafer/Time/Lot Based(W, T, L)	Quantity Per Layer/Lot	Price Per Quantity	
Gas/Chemical 1	W	1	0.10	Currency
Gas/Chemical 2				Currency
Gas/Chemical 3				Currency
Gas/Chemical 4				Currency
Gas/Chemical 5				Currency
Plant Exhaust				Currency
Bulk Chemicals				Currency
Specialty Chemicals	T		125,000.00	Currency
Bulk Gases				Currency
Expendables				Currency
Manufacturing Tooling				Currency
Rent of Equipment				Currency
Protective Clothing				Currency
Office Supplies				Currency
Computer Software				Currency
Expensed Equipment				Currency
Computer Supplies				Currency
Forms				Currency

Gas/Chemical 1 usage costs/year/system. Annual cost/system is 26047 Currency.
 Gas/Chemical 2 usage costs/year/system. Annual cost/system is 0 Currency.
 Gas/Chemical 3 usage costs/year/system. Annual cost/system is 0 Currency.
 Gas/Chemical 4 usage costs/year/system. Annual cost/system is 0 Currency.
 Gas/Chemical 5 usage costs/year/system. Annual cost/system is 0 Currency.
 Plant Exhaust usage costs/year/system. Annual cost/system is 0 Currency.
 Bulk Chemicals usage costs/year/system. Annual cost/system is 0 Currency.
 Specialty Chemicals usage costs/year/system. Annual cost/system is 125000 Currency.
 Bulk Gases usage costs/year/system. Annual cost/system is 0 Currency.
 Expendables usage costs/year/system. Annual cost/system is 0 Currency.
 Manufacturing Tooling usage costs/year/system. Annual cost/system is 0 Currency.
 Rent of Equipment usage costs/year/system. Annual cost/system is 0 Currency.
 Protective Clothing usage costs/year/system. Annual cost/system is 0 Currency.
 Office Supplies usage costs/year/system. Annual cost/system is 0 Currency.
 Computer Software usage costs/year/system. Annual cost/system is 0 Currency.
 Expensed Equipment usage costs/year/system. Annual cost/system is 0 Currency.
 Computer Supplies usage costs/year/system. Annual cost/system is 0 Currency.
 Forms usage costs/year/system. Annual cost/system is 0 Currency.

Originator: John Doe
Supplier: Any Supplier
Process: Deposition
Comments: This cell allows for the input of comments.

Company: IC Maker, Inc.
Log Point: 1
Model: CVD 100

Site: Wafer Fab 1
Created:
Revised:

Other Production Costs/System

Other Production Costs	0	Currency/Year	Other production supply usage costs/year/system.
Waste Disposal Costs/System	0	Currency/Year	Waste disposal costs/year/system.
Other Material Costs			
Test Wafers	1.40	Wafers/Week	Number of test wafers required to maintain production.
Other Materials	0	Currency/Year	Other material usage costs/year/system.

Personnel/System

Engineers	4.00	Hours/Week	Engineering coverage requirements/system.
Supervision	1.33	Hours/Week	Supervision coverage requirements/system.
Contract Labor	0	Currency/Year	Contract labor coverage requirement costs/year/system.

Maintenance Costs

Parts & Technicians

Annual Repair Parts/System

15,000 Currency

	Shift 1	Shift 2	Shift 3	Shift 4	Shift 5	Shift 6	
Scheduled Maintenance Technicians	1.00	0.00	0.00	0.00	0.00	0.00	Technicians
Unscheduled Maintenance Technicians	0.00	0.00	0.00	0.00	0.00	0.00	Technicians

Warranty

Warranty Period 12 Months
Warranty Shift Coverage 1 Shifts
Repair Parts Coverage yes

	Shift 1	Shift 2	Shift 3	Shift 4	Shift 5	Shift 6
Repair Labor Coverage	yes	no	no	no	no	no
Scheduled Maintenance Labor Coverage	no	no	no	no	no	no

Contract

Repair Parts Coverage

yes

	Shift 1	Shift 2	Shift 3	Shift 4	Shift 5	Shift 6	
Annual Service Contract/System	15,000	15,000	15,000	15,000	0	0	Currency
Repair Labor Coverage	yes	yes	yes	yes	no	no	
Scheduled Maintenance Labor Coverage	no	no	no	no	no	no	

Other

Annual Supplier Training/System 4,000 Currency
Annual Software Contract/System 0 Currency

Originator: John Doe
Supplier: Any Supplier
Process: Deposition
Comments: This cell allows for the input of comments.

Company: IC Maker, Inc.
Log Point: 1
Model: CVD 100

Site: Wafer Fab 1
Created:
Revised:

Cost Per System	1,000,000	Currency	Original purchase price of system.
Number Of Systems Required	1	Systems	Volume requirement/maximum layers/week/system rounded up.
Total Depreciable Costs	1,015,000	Currency	Sum of all capitalized expenses/system * number of systems.
Equipment Utilization Capability	87.04	Percent	% of hours/week system is not undergoing scheduled or unscheduled maintenance.
Production Utilization Capability	84.96	Percent	% of hours/week system is not undergoing any maintenance or production tests.
Composite Yield	99.69	Percent	Equipment yield * probe yield.
Good Wafer Equivalents Out Per Week	4,979.88	G.W.E.'s	Volume requirement * composite yield.
Good Wafer Equivalent Cost			
With Scrap	5.24	Currency	Total costs/year/(good wafer equivalents/year) including scrap costs.
Without Scrap	2.19	Currency	Total costs/year/(good wafer equivalents/year) excluding scrap costs.
Average Monthly Cost			
With Scrap	113,447	Currency	The average monthly total cost including scrap over the life of the equipment.
Without Scrap	47,283	Currency	The average monthly total cost excluding scrap over the life of the equipment.
Process Scrap Allocation			
Equipment Yield	1.64	Percent	The percentage of the total scrap costs represented by equipment yield.
Defect Limited Yield	16.35	Percent	The percentage of the total scrap costs represented by defect limited yield.
Parametric Limited Yield	82.01	Percent	The percentage of the total scrap costs represented by parametric limited yield.
Equipment Costs (Over Life of Equipment)	1,305,363	Currency	Sum of equipment costs from life summary table.
Per Good Wafer Equivalent	0.72	Currency	Sum of equipment costs/year/(good wafer equivalents/year).
Per Good cm2 Out	0.0029	Currency	Sum of equipment costs/year/(good wafer equivalents/year)/cm2/layer.
Recurring Costs (Over Life of Equipment)	8,224,179	Currency	Sum of recurring costs from life summary table.
Per Good Wafer Equivalent	4.52	Currency	Sum of recurring costs/year/(good wafer equivalents/year).
Per Good cm2 Out	0.0180	Currency	Sum of recurring costs/year/(good wafer equivalents/year)/cm2/layer.
Total Costs (Over Life of Equipment)	9,529,541	Currency	Total costs from life summary table.
Per Good Wafer Equivalent (Cost Of Ownership)	5.24	Currency	Total costs/year/(good wafer equivalents/year).
Per Good Wafer Equivalent Supported	5.24	Currency	Cost of ownership value * sampling rate
Per Good cm2 Out	0.0209	Currency	Total costs/year/(good wafer equivalents/year)/cm2/layer.
Per Productive Minute	3.05	Currency	Total lifetime costs/total lifetime available minutes
Per Good Secondary Unit Equivalent (Cost Of Ownership)	0.00	Currency	Total costs/year/(good Secondary Unit equivalents/year).
Cost Drivers per Good Wafer Equivalent			
Scrap	3.058	Currency	Sum of scrap costs from life summary table
Material/Consumables	0.672	Currency	Sum of material/consumables costs from life summary table
Depreciation	0.558	Currency	Sum of depreciable costs from life summary table
Maintenance	0.366	Currency	Sum of maintenance costs from life summary table
Labor	0.346	Currency	Sum of labor costs from life summary table
Floor Space Costs	0.152	Currency	Sum of floor space costs from life summary table
Support Personnel	0.052	Currency	Sum of support personnel costs from life summary table
Other Materials	0.032	Currency	Sum of test wafers and other material costs from life summary table
Training	0.005	Currency	Sum of training costs from life summary table
System Qualification Costs	0.002	Currency	Sum of qualification costs from life summary table
ESH Preparation and Permits	0.000	Currency	Sum of ESH permit costs from life summary table
Moves And Rearrangements	0.000	Currency	Sum of moves and rearrangement costs from life summary table
Other Support Services	0.000	Currency	Sum of other support services costs from life summary table

Originator: John Doe
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Process: Deposition
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Company: IC Maker, Inc.
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Equipment Utilization Capability	87.04 Percent	% of hours/week system is not undergoing scheduled or unscheduled maintenance.
Total Utilization	84.96 Percent	% of hours per week that system is producing product.
Production Utilization Capability	84.96 Percent	% of hours/week system is not undergoing any maintenance or production tests.
Time/System Not Available		
Scheduled Maintenance	14.00 Hours	Scheduled maintenance if running 168 hours/week. Done off hours if not 168.
Engineering Usage	0.00 Hours	Hours/week that each system is used for non-production purposes.
Standby	0.00 Hours	Hours/week that each system is waiting on wafers.
Production Test	3.50 Hours	Number of production tests/day * time/test * days/week.
Unscheduled Repair And Test	7.58 Hours	Number of unscheduled downs * time to test and repair.
Assists	0.20 Hours	Number of assists * time/assist.
Total Non-Productive Hours/Week	25.28 Hours	Total from cells in this section.
Hours Available/System		
Hours/Week	142.72 Hours	Hours available/week - non-productive hours/week.
Hours/Year	7,442.06 Hours	Productive hours/week * weeks/year.
Maximum Layers/Week/System	4,995.35 Layers	Raw throughput/hour * productive hours/week. Includes reworked layers.
Volume Requirement	4,995 Layers/Week	Number of layers each week that this step is required to run. Includes rework.
Systems Required	1 Systems	Volume requirement/maximum layers/week/system rounded up.
System Hours Required (Per Week)		
Production	142.72 Hours	Volume requirement/raw throughput adjusted for re-do rate.
Scheduled Maintenance	14.00 Hours	Scheduled maintenance/system * number of systems.
Engineering Usage	0.00 Hours	Engineering usage/system * number of systems.
Standby	0.00 Hours	Standby/system * number of systems.
Production Test	3.50 Hours	Production tests/system * number of systems + (lots redone * time/test).
Unscheduled		
Response Time	0.07 Hours	Number of downs * response time/down.
Repair And Test	7.50 Hours	Number of downs * repair time/down.
Assists	0.20 Hours	Number of assists * time/assist.
Total Hours/Week	168.00 Hours	Total from cells in this section.
Probe Yield/Layer	99.70 Percent	The product of the defect and parametric limited yields.
Composite Yield/Layer (Equipment * Probe)	99.69 Percent	Equipment yield * probe yield.
Layers Out/Week		
At Maximum Throughput	4,979.88 Layers	Maximum layers/week/system * # of systems * composite yield. Reduced by rework.
At Equipment Yield	4,994.85 Layers	Production starts * equipment yield.
At Effective Yield	4,979.88 G.W.E.'s	Production starts * effective yield (composite, alpha, & beta). Reduced by rework.
Good Wafer Equivalent Cost		
With Scrap	5.24 Currency	Total costs/year/(good wafer equivalents/year) including scrap costs.
Without Scrap	2.19 Currency	Total costs/year/(good wafer equivalents/year) excluding scrap costs.
Average Monthly Cost		
With Scrap	113,447 Currency	The average monthly total cost including scrap over the life of the equipment.
Without Scrap	47,283 Currency	The average monthly total cost excluding scrap over the life of the equipment.
Process Scrap Allocation		
Equipment Yield	1.64 Percent	The percentage of the total scrap costs represented by equipment yield.
Defect Limited Yield	16.35 Percent	The percentage of the total scrap costs represented by defect limited yield.
Parametric Limited Yield	82.01 Percent	The percentage of the total scrap costs represented by parametric limited yield.

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Cost Of Equipment

Depreciable	1,015,000	Currency	Sum of all capitalized expenses/system * number of systems.
One-Time Costs			
Moves And Rearrangements	0	Currency	The cost of moving installed equipment to make room for new equipment.
ESH Preparation and Permits	0	Currency	The cost of preparing for and obtaining environmental, safety, and health permits.
System Qualification			
Engineering	1,826	Currency	Engineering cost for system qualification.
Maintenance	600	Currency	Maintenance cost for system qualification.
Operator	2,000	Currency	Operator cost for system qualification.
Supplies/Consumables	0	Currency	Supplies/consumables costs required to qualify system.
Other Material	0	Currency	Test wafers and other material costs for system qualification.
Other Costs	0	Currency	Other costs for system qualification.
Training Costs	9,496	Currency	Initial training costs for all system.
Total	1,028,922	Currency	Total for initial costs for systems.
Maintenance Costs/Year			
Maintenance Labor	22,015	Currency	Maintenance hours/week * weeks/year * burdened labor rate.
Repair Parts	0	Currency	Repair parts costs/year/system * number of systems.
Supplier Service Contract	60,000	Currency	Service contract cost/shift/system * required shifts * number of systems.
Supplier Training	4,000	Currency	Supplier training costs/year/system * number of systems.
Software Contract	0	Currency	Software contract costs/year/system * number of systems.
Total	86,015	Currency	Total maintenance costs/year after warranty period.
Floor Space Costs/Year	35,000	Currency	Footprint * cost/square foot * number of systems. For each cleanroom class.
Operating Costs/Year			
Utility Usage	3,500	Currency	Sum of utility costs/year/system * number of systems.
Supplies/Consumables Costs	151,047	Currency	Sum of supply/consumable costs/year/system * number of systems.
Waste Disposal Costs	0	Currency	Waste disposal costs/year/system
Total	154,547	Currency	Total of utility, supply, waste disposal, and consumable costs/year.
Other Material Costs/Year			
Test Wafers	7,300	Currency	Test wafers/week * weeks/year * test wafer cost * number of systems.
Other Materials	0	Currency	Other material costs/year/system * number of systems.
Total	7,300	Currency	Total test wafer and other material costs/year.
Scrap/Year			
Whole Wafers	26	Wafers	Number of wafers lost/year due to equipment yield.
Defective Die (Equivalent Wafers)	780.95	Wafers	Equivalent wafers lost due to defective die. Equipment yield - composite yield.
Alpha Error	0.00	Wafers	Number of wafers lost/year due to alpha error
Beta Error	0.00	Wafers	Number of wafers lost/year due to beta error
Total	806.99	Wafers	Total lost wafers.

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Scrap Cost/Year

Whole Wafers	13,024	Currency	Number of whole wafers lost * cost/incoming wafer.
Defective Die (Equivalent Wafers)	780,947	Currency	Number of equivalent wafers lost due to defective die * end of process wafer cost.
Alpha Error	0	Currency	Number of wafers lost/year due to alpha error * cost/error
Beta Error	0	Currency	Number of wafers lost/year due to beta error * cost/error
Total	793,971	Currency	Sum of above wafer loss costs.

Personnel Cost/Year

Operators	79,570	Currency	Operator headcount * hours/year * burdened labor rate/hour.
Engineers	9,524	Currency	Engineering headcount * burdened salary rate/year.
Supervision	2,533	Currency	Supervisor headcount * burdened salary rate/year.
Contract Labor	0	Currency	Contract labor costs/system * number of systems.
Total	91,627	Currency	Total personnel costs/year.

Equivalent Employees:

Operators

	All Shifts	Per Shift	
System Qualification	0.01	0.00	Operator qualification hours/total life of equipment hours.
Training	0.01	0.00	Operator initial training hours/total life of equipment hours.
Operations	1.45	0.36	Operator production hours/(hours/shift * operator efficiency * systems/operator).
Total	1.47	0.37	Sum of all operator functions.

Maintenance

System Qualification	0.00	0.00	Maintenance qualification hours/total life of equipment hours.
Training	0.01	0.00	Maintenance initial training hours/total life of equipment hours.
Operations	0.42	0.10	System maintenance hours/(hours/shift * maintenance efficiency).
Total	0.43	0.11	Sum of all maintenance functions.

Engineering

System Qualification	0.00	0.00	Engineering qualification hours/total life of equipment hours.
Training	0.00	0.00	Engineering initial training hours/total life of equipment hours.
Operations	0.10	0.02	Process and equipment engineering hours per week/total hours per week.
Total	0.10	0.03	Sum of all engineering functions.

Supervision Operations

	0.03	0.01	Production supervision hours per week/total hours per week.
Total Equivalent Employees	2.03	0.51	Sum of above totals.

Originator: John Doe
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Company: IC Maker, Inc.
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(All Costs in Currency)	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7
Equipment Costs							
Depreciation	203,000	203,000	203,000	203,000	203,000	0	0
Moves And Rearrangements	0						
ESH Preparation and Permits	0						
System Qualification Costs	4,426						
Floor Space Costs	35,000	36,400	37,856	39,370	40,945	42,583	44,286
Training	9,496						
Cost/Year	251,922	239,400	240,856	242,370	243,945	42,583	44,286
Cumulative Cost	251,922	491,322	732,178	974,548	1,218,493	1,261,076	1,305,362
Cost/Good Wafer Equivalent	0.97	0.92	0.93	0.93	0.94	0.16	0.17
Cumulative Cost	0.97	0.95	0.94	0.94	0.94	0.81	0.72
Cost/Good cm2 Out	0.0039	0.0037	0.0037	0.0037	0.0037	0.0007	0.0007
Cumulative Cost	0.0039	0.0038	0.0037	0.0037	0.0037	0.0032	0.0029
Recurring Costs							
Utilities	3,500	3,640	3,786	3,937	4,095	4,258	4,429
Supplies/Consumables	151,047	157,089	163,373	169,908	176,704	183,772	191,123
Waste Disposal	0	0	0	0	0	0	0
Other Materials	7,300	7,592	7,896	8,212	8,540	8,882	9,237
Maintenance	71,015	89,455	93,033	96,755	100,625	104,650	108,836
Personnel							
Operators	79,570	82,753	86,063	89,505	93,085	96,809	100,681
Engineering	9,524	9,905	10,301	10,713	11,142	11,587	12,051
Supervision	2,533	2,635	2,740	2,850	2,964	3,082	3,205
Contract Labor	0	0	0	0	0	0	0
Other Support Services	0	0	0	0	0	0	0
Value of Equivalent Wafers Scrapped	793,971	793,971	793,971	793,971	793,971	793,971	793,971
Cost/Year	1,118,460	1,147,039	1,161,162	1,175,850	1,191,125	1,207,011	1,223,533
Cumulative Cost	1,118,460	2,265,499	3,426,661	4,602,511	5,793,635	7,000,646	8,224,179
Cost/Good Wafer Equivalent	4.31	4.42	4.47	4.53	4.59	4.65	4.71
Cumulative Cost	4.31	4.36	4.40	4.43	4.46	4.49	4.52
Cost/Good cm2 Out	0.0171	0.0176	0.0178	0.0180	0.0183	0.0185	0.0187
Cumulative Cost	0.0171	0.0174	0.0175	0.0176	0.0178	0.0179	0.0180
Total Cost							
Cost/Year	1,370,382	1,386,439	1,402,018	1,418,220	1,435,070	1,249,594	1,267,819
Cumulative Cost	1,370,382	2,756,821	4,158,839	5,577,059	7,012,129	8,261,723	9,529,541
Cost/Good Wafer Equivalent	5.28	5.34	5.40	5.46	5.53	4.81	4.88
Cumulative Cost	5.28	5.31	5.34	5.37	5.40	5.30	5.24
Cost/Good cm2 Out	0.0210	0.0212	0.0215	0.0217	0.0220	0.0191	0.0194
Cumulative Cost	0.0210	0.0211	0.0212	0.0214	0.0215	0.0211	0.0209

Originator: John Doe**Supplier:** Any Supplier**Process:** Deposition**Comments:** This cell allows for the input of comments.**Company:** IC Maker, Inc.**Log Point:** 1**Model:** CVD 100**Site:** Wafer Fab 1**Created:****Revised:**

(All Costs in Currency)	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7
Annual Costs (x1000)							
Equipment	252	239	241	242	244	43	44
Material/Consumables	155	161	167	174	181	188	196
Other Material	7	8	8	8	9	9	9
Maintenance	71	89	93	97	101	105	109
Labor	80	83	86	90	93	97	101
Support Personnel	12	13	13	14	14	15	15
Other Support Services	0	0	0	0	0	0	0
Scrap	794	794	794	794	794	794	794
Total	1,370	1,386	1,402	1,418	1,435	1,250	1,268
Cumulative Total Costs (x1000)							
Equipment	252	491	732	975	1,218	1,261	1,305
Material/Consumables	155	315	482	656	837	1,025	1,221
Other Material	7	15	23	31	40	48	58
Maintenance	71	160	254	350	451	556	664
Labor	80	162	248	338	431	528	628
Support Personnel	12	25	38	51	65	80	95
Other Support Services	0	0	0	0	0	0	0
Scrap	794	1,588	2,382	3,176	3,970	4,764	5,558
Total	1,370	2,757	4,159	5,577	7,012	8,262	9,530
Annual Costs per Good Wafer Equivalent							
Equipment	0.97	0.92	0.93	0.93	0.94	0.16	0.17
Material/Consumables	0.60	0.62	0.64	0.67	0.70	0.72	0.75
Other Material	0.03	0.03	0.03	0.03	0.03	0.03	0.04
Maintenance	0.27	0.34	0.36	0.37	0.39	0.40	0.42
Labor	0.31	0.32	0.33	0.34	0.36	0.37	0.39
Support Personnel	0.05	0.05	0.05	0.05	0.05	0.06	0.06
Other Support Services	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Scrap	3.06	3.06	3.06	3.06	3.06	3.06	3.06
Total	5.28	5.34	5.40	5.46	5.53	4.81	4.88
Cumulative Costs per Good Wafer Equivalent							
Equipment	0.97	0.95	0.94	0.94	0.94	0.81	0.72
Material/Consumables	0.60	0.61	0.62	0.63	0.64	0.66	0.67
Other Material	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Maintenance	0.27	0.31	0.33	0.34	0.35	0.36	0.37
Labor	0.31	0.31	0.32	0.33	0.33	0.34	0.35
Support Personnel	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Other Support Services	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Scrap	3.06	3.06	3.06	3.06	3.06	3.06	3.06

Originator: John Doe
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Total	5.28	5.31	5.34	5.37	5.40	5.30	5.24
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Originator: John Doe
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Process: Deposition
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(All Costs in Currency)	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7
Annual Costs per Good cm2 Out							
Equipment	0.0039	0.0037	0.0037	0.0037	0.0037	0.0007	0.0007
Material/Consumables	0.0024	0.0025	0.0026	0.0027	0.0028	0.0029	0.0030
Other Material	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Maintenance	0.0011	0.0014	0.0014	0.0015	0.0015	0.0016	0.0017
Labor	0.0012	0.0013	0.0013	0.0014	0.0014	0.0015	0.0015
Support Personnel	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Other Support Services	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Scrap	0.0122	0.0122	0.0122	0.0122	0.0122	0.0122	0.0122
Total	0.0210	0.0212	0.0215	0.0217	0.0220	0.0191	0.0194
Cumulative Costs per Good cm2 Out							
Equipment	0.0039	0.0038	0.0037	0.0037	0.0037	0.0032	0.0029
Material/Consumables	0.0024	0.0024	0.0025	0.0025	0.0026	0.0026	0.0027
Other Material	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Maintenance	0.0011	0.0012	0.0013	0.0013	0.0014	0.0014	0.0015
Labor	0.0012	0.0012	0.0013	0.0013	0.0013	0.0013	0.0014
Support Personnel	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Other Support Services	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Scrap	0.0122	0.0122	0.0122	0.0122	0.0122	0.0122	0.0122
Total	0.0210	0.0211	0.0212	0.0214	0.0215	0.0211	0.0209
Percent of Total Costs - Annual							
Equipment	18.38%	17.27%	17.18%	17.09%	17.00%	3.41%	3.49%
Material/Consumables	11.28%	11.59%	11.92%	12.26%	12.60%	15.05%	15.42%
Other Material	0.53%	0.55%	0.56%	0.58%	0.60%	0.71%	0.73%
Maintenance	5.18%	6.45%	6.64%	6.82%	7.01%	8.37%	8.58%
Labor	5.81%	5.97%	6.14%	6.31%	6.49%	7.75%	7.94%
Support Personnel	0.88%	0.90%	0.93%	0.96%	0.98%	1.17%	1.20%
Other Support Services	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Scrap	57.94%	57.27%	56.63%	55.98%	55.33%	63.54%	62.62%
Total	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Percent of Total Costs - Cumulative							
Equipment	18.38%	17.82%	17.61%	17.47%	17.38%	15.26%	13.70%
Material/Consumables	11.28%	11.44%	11.60%	11.77%	11.94%	12.41%	12.81%
Other Material	0.53%	0.54%	0.55%	0.56%	0.56%	0.59%	0.61%
Maintenance	5.18%	5.82%	6.10%	6.28%	6.43%	6.72%	6.97%
Labor	5.81%	5.89%	5.97%	6.06%	6.15%	6.39%	6.59%
Support Personnel	0.88%	0.89%	0.91%	0.92%	0.93%	0.97%	1.00%
Other Support Services	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Scrap	57.94%	57.60%	57.27%	56.95%	56.61%	57.66%	58.32%

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Total	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
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Supplier: Any Supplier
Process: Deposition
Comments: This cell allows for the input of comments.

Company: IC Maker, Inc.
Log Point: 1
Model: CVD 100

Site: Wafer Fab 1
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(All Costs in Currency)		Year 1	Life of Equipment Uninflated	Life of Equipment Inflated
Equipment Costs				
Depreciation		203,000	1,015,000	1,015,000
Moves And Rearrangements		0	0	0
ESH Preparation and Permits		0	0	0
System Qualification Costs		4,426	4,426	4,426
Floor Space Costs		35,000	245,000	276,440
Training		9,496	9,496	9,496
Cost/Year		251,922	181,989	186,480
Cost/Good Wafer Equivalent		0.97	0.70	0.72
Cost/Good cm2 Out		0.0039	0.0028	0.0029
Recurring Costs				
Utilities		3,500	24,500	27,644
Supplies/Consumables		151,047	1,057,330	1,193,015
Waste Disposal		0	0	0
Other Materials		7,300	51,100	57,658
Maintenance		71,015	587,102	664,368
Personnel				
Operators		79,570	556,988	628,465
Engineering		9,524	66,667	75,222
Supervision		2,533	17,733	20,009
Contract Labor		0	0	0
Other Support Services		0	0	0
Value of Equivalent Wafers Scrapped		793,971	5,557,798	5,557,798
Cost/Year		1,118,460	1,131,317	1,174,883
Cost/Good Wafer Equivalent		4.31	4.36	4.52
Cost/Good cm2 Out		0.0171	0.0173	0.0180
Total Cost				
Cost/Year		1,370,382	1,313,306	1,361,363
Cost/Good Wafer Equivalent		5.28	5.06	5.24
Cost/Good cm2 Out		0.0210	0.0201	0.0209
Annual Costs (x1000)				
Equipment		252	182	186
Material/Consumables		155	155	174
Other Material		7	7	8
Maintenance		71	84	95
Labor		80	80	90
Support Personnel		12	12	14
Other Support Services		0	0	0
Scrap		794	794	794
Total		1,370	1,313	1,361

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Supplier: Any Supplier
Process: Deposition
Comments: This cell allows for the input of comments.

Company: IC Maker, Inc.
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(All Costs in Currency)	Year 1	Life of Equipment Uninflated	Life of Equipment Inflated
Annual Costs per Good Wafer Equivalent			
Equipment	0.97	0.70	0.72
Material/Consumables	0.60	0.60	0.67
Other Material	0.03	0.03	0.03
Maintenance	0.27	0.32	0.37
Labor	0.31	0.31	0.35
Support Personnel	0.05	0.05	0.05
Other Support Services	0.00	0.00	0.00
Scrap	3.06	3.06	3.06
Total	5.28	5.06	5.24
Annual Costs per Good cm2 Out			
Equipment	0.0039	0.0028	0.0029
Material/Consumables	0.0024	0.0024	0.0027
Other Material	0.0001	0.0001	0.0001
Maintenance	0.0011	0.0013	0.0015
Labor	0.0012	0.0012	0.0014
Support Personnel	0.0002	0.0002	0.0002
Other Support Services	0.0000	0.0000	0.0000
Scrap	0.0122	0.0122	0.0122
Total	0.0210	0.0201	0.0209
Percent of Total Costs - Annual			
Equipment	18.38%	13.86%	13.70%
Material/Consumables	11.28%	11.77%	12.81%
Other Material	0.53%	0.56%	0.61%
Maintenance	5.18%	6.39%	6.97%
Labor	5.81%	6.06%	6.59%
Support Personnel	0.88%	0.92%	1.00%
Other Support Services	0.00%	0.00%	0.00%
Scrap	57.94%	60.46%	58.32%
Total	100.00%	100.00%	100.00%

Originator: John Doe
Supplier: Any Supplier
Process: Deposition
Comments: This cell allows for the input of comments.

Company: IC Maker, Inc.
Log Point: 1
Model: CVD 100

Site: Wafer Fab 1
Created:
Revised:

Overall Equipment Efficiency ***Availability Efficiency**

Engineering Usage
 Standby
 Hours Available/System (Productive Time)
 Down Time
 Scheduled Maintenance
 Unscheduled Maintenance
 Test
 Assist
 Non-Scheduled Time
 Equipment Uptime
 Total Time

Performance Efficiency *

Throughput At Capacity/System
 Theoretical Throughput *
 Operational Efficiency
 Rate Efficiency

Quality Efficiency

Equipment Yield
 Defect Limited Yield
 Parametric Limited Yield
 Alpha Error Factor
 Beta Error Factor
 Redo Rate

84.69 Percent**84.96 Percent**

0.00 Hours/Week
 0.00 Hours/Week
 142.72 Hours/Week
 25.28 Hours/Week
 14.00 Hours/Week
 7.58 Hours/Week
 3.50 Hours/Week
 0.20 Hours/Week
 0.00 Hours/Week
 142.72 Hours/Week
 168.00 Hours/Week
100.00 Percent
 35.00 Layers/Hour
 [35.00] Layers/Hour
 100.00 Percent
 100.00 Percent
99.69 Percent
 99.99 Percent
 99.95 Percent
 99.75 Percent
 100.00 Percent
 100.00 Percent
 0.00 Percent

Availability efficiency * performance efficiency * rate of quality * 100%.**Equipment uptime/total time.**

Hours/week that each system is used for non-production purposes.
 Hours/week that each system is waiting on wafers.
 Hours available/week - non-productive hours/week.
 The sum of scheduled and unscheduled maintenance, test, and assist time.
 Scheduled maintenance if running 168 hours/week. Done off hours if not 168.
 Number of unscheduled downs * time to test and repair.
 Number of production tests/day * time/test * days/week.
 Number of assists * time/assist.
 168 hours - (number of hours each shift works/week * total number of shifts/week).
 The hours when the equipment is in a condition to perform its intended function.
 All time during the period being measured.

Operational efficiency * rate efficiency.

Raw throughput of system at production process conditions.
 Layers/hour processed under ideal conditions of continuous productive time.
 Productive time/equipment uptime.
 (Actual layer output/productive time)/theoretical throughput.
(Actual layer output - (redo + scrap))/actual layer output.
 Yield resulting from this process's whole wafer loss (broken and misprocessed).
 The percentage defect limited yield for this process step.
 The percentage parametric limited yield for this process step.
 1 - the percentage alpha error for this process step
 1 - the percentage beta error for this process step
 The rate at which wafers are reworked.

* Theoretical Throughput has not been entered.

Throughput at Capacity used instead for OEE calculation.

Defect Limited Yield

Yield considerations are the most critical factors in cost of ownership calculations. Yield is impacted by wafer breakage and misprocessing defect limited yield, and parametric yield.

Yield estimates are strongly dependent upon the modeling method and assumptions that are used. Probe yield is not only a function of defect limited yields but is also impacted by parametric yield distributions.

The wafer breakage and misprocessing errors are equipment specifications and are not modeled but are an input in the cost of ownership calculations. This section will deal with the calculations used in determining the yield impact of defects.

Yield Model

The random defect limited yield calculations used in TWO COOL® are based on a negative binomial model¹. The basic formula for the negative binomial model is represented by:

$$Y = \frac{1}{(1 + \frac{A * D}{\alpha})^{\alpha}}$$

Y is the defect limited yield. A is the critical device area and D is the defect density. “α” is the clustering parameter.

The clustering parameter can be used to fit the negative binomial to several common yield model distributions based upon the degree of clustering.

¹C.H. Stapper, "Fact and Fiction in Yield Modeling," Microelectronics Journal, Vol. 20, Nos. 1-2, 1989.

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Yield Distribution	Clustering Parameter	Degree of Clustering
Seed's Model	$\alpha = 1$	High
Murphy's Model	$\alpha \sim 4.5$	Moderate
Poisson Model	$\alpha > 7$	Negligible

The negative binomial model must be modified further to reduce the critical device area to workable terms. This is done by substituting the critical device area with fault probability terms. Fault probability is covered in further detail later in this chapter.

Once this is done the modified yield formula becomes:

$$Y = \frac{1}{\left(1 + \frac{A_a * D * P}{\alpha}\right)^\alpha}$$

Where A_a is the active area of the device and P is the probability that a defect will be fatal. The active area of the device should be used in the "**PROCESS DATA**" cell labeled "Die Area".

Assumptions

TWO COOL® v2.0-2.1.3 used the modified Seed's formula which sets the degree of clustering to 1. This means that the model assumes that defects are highly clustered on the wafer. This is not necessarily true and, therefore, products may have lower yields than predicted by this model.

TWO COOL® v2.2 and later allowed the degree of clustering to be set by the user over a range of 0 to 10. Thus, the yield model can better reflect the variations in processing parameters. The clustering factor may be entered in the "**PROCESS DATA**" cell labeled "Clustering Parameter." If the clustering parameter is not known, use the Seed's Model with $\alpha = 1$. This formula is still an industry accepted basis for defect yield modeling.

The defect density reported is for a minimum detection limit; however, the model does not take into consideration the sensitivity of the product to different defect sizes in the defect population nor does the model attempt to look at the different sensitivities of individual process steps.

Additionally, factors such as equipment age, time since last cleaning, and chemical age all impact the defect density. None of these factors are considered unless specific inputs are included in the reported defect density.

Fault Probability

The probability of a detected defect causing an electrical failure on a device is a function of several factors. The most important is the method by which the defects are detected. If the measurement technique is electrically-based then the fault probability is, by definition, equal to 1. For defects measured by physical methods, the model becomes more complex.

The following discussion centers on the definition of critical device area as mentioned earlier and the derivation of fault probability.

Probability Model

Earlier in this chapter, the negative binomial model was modified by substituting the critical device area with fault probability terms. That substitution was derived from work by Stapper² where:

$$A = A_d * P * L$$

²C.H. Stapper, "Modeling of Defects in Integrated Circuit Photolithographic Patterns," Journal of Research Development, 28(4), July 1984, p461-475

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A is the critical device area. A_d is the total device area. P is the fault probability and L is the ratio of device active area to total area. This formula further simplifies to the substitution:

$$A = A_a * P$$

Where A_a is the active device area. Again, the active area of the device should be used in the "**PROCESS DATA**" cell labeled "Die Area".

Based on the above work by Stapper³, fault probability as a function of minimum defect size and critical device dimensions can be calculated:

$$P = \frac{S^2}{W*(W+F)}$$

S is the minimum critical defect size. W is the minimum device feature size and F is the feature pitch.

The calculations made with this formula should not be entered into the "**PROCESS DATA**" cell labeled "Fault Probability". This model is overly simplistic and is used for illustrative purposes only. Yet even in this simplistic model, it is nearly impossible to determine the minimum critical defect size without very specific information about the process step, device, and empirical fab data.

An example value of $P=0.05$ is found in the appendix to SEMI Standard E35. This and the other example values are not an official part of the standard but are examples for initial estimates of Cost of Ownership. An actual value is preferred and may be

³ibid

estimated from company experience, specific equipment characteristics, process, product, and application.