ISSN 1094-9739

Information Exchange For Your Application & Use Of Cost Modeling

APPLIED Co$t MODELING

Volume 5, Issue 4

Inside

June 1999

Activity Based Cost Planning

Modeling Fab Refurbishment and Greenfield Facilities

David N. Lauben, Wright Williams & Kelly, Albuquerque, NM
F. Mark Traylor, Wright Williams & Kelly, Austin, TX

Abstract

The capital investment needed to build the next generation of wafer fabrication facilities has grown well beyond the one billion-dollar mark. The industry is in the process of determining the needs for transitioning to the next generation of semiconductor technology. This could include the transition from 200mm to 300mm or advanced production at 200mm. A decision that many organizations have to consider is whether to upgrade existing facilities or build on new or greenfield sites. The use of decision support tools in making these strategic decisions is essential.

This paper describes the issues associated with the fab refurbishment vs. greenfield decision. In addition, the paper describes the usage of activity based cost planning in making a strategic decision. A sample problem was analyzed using Wright Williams & Kelly's Factory Commander™ software. The software allows a user to characterize each factory as an economic alternative, and offers an objective method of comparison.

Introduction

Comprehensive and accurate cost planning is essential for either new wafer fabs or current production lines anticipating major capital modifications. With investments of over a billion U.S. dollars for recently completed wafer fabs, and 1.3-1.5 B$ U.S. projected for 300mm or advanced technology 200mm facilities, a well-formulated business plan is paramount. All possible options and scenarios must be considered to achieve dependable estimates of profit/loss, cash flow, rate of return, or Return of Original Investment (ROI). The

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Published Quarterly
$59.00/year in the U.S.
$69.00/year outside the U.S.

Please send check, money order or purchase order to:

Wright Williams & Kelly
39 California Avenue
Suite 203
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Phone 925-485-5711
Fax 925-485-3791
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14-16 SEMICON West - Assembly & Packaging
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15 SEMI-sponsored seminar
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refurbishment alternative, where a sizeable portion of tooling and facility infrastructure is retrofitted, also requires accurate prediction made early in the project. Though retrofit activities typically require less initial expenditure, it is equally important to know how profitable its resulting product will be.

Economic downturns, such as the one currently facing the semiconductor industry, provide an indirect benefit: the opportunity to plan for future products. Management attentive to this opportunity will increase efforts toward the next product generation. Integrated circuit device fabrication is an especially good example for strategic planning because of the rapid, continuous advances in key technologies. When compared to other, less technology-driven manufacturing, IC production organizations require more frequent R&D advances just to keep pace. Combining this highly competitive environment with narrow profit margins leads to a situation where the viability of a new product depends both on a sustained R&D effort and thorough economic analysis.

The resources required to plan these major projects include a well trained and experienced cost planning staff and the appropriate analysis tools for the task. Software applications, in particular, are an important consideration for proper cost evaluation. The applications used for cost modeling must be versatile enough to capture a wide range of possible assumptions, and at the same time provide accurate and easily interpreted results. Factory Commander™, an activity-based cost and resource-planning tool available from Wright Williams & Kelly, is used for the analysis presented in this paper.

Business Issues

There are many business issues that must be considered in the decision to either refurbish existing facilities or build new. Consideration must be given to the current economic climate, a company's individual financial situation, and the time to market impact on the products that are to be manufactured.

The current economy for semiconductors is widely viewed as shaky for major investments and has led to greater restrictions on corporate expansion budgets. The end result is that a number of major fab projects, domestic and abroad, have been either put on hold or canceled by the major manufacturers in this industry. In particular, the Asian economic crisis and the increased consumer demand for sub-$1000 computers has magnified the pain felt by everyone from microprocessor producers to the industry's equipment suppliers. The effect of this is a revenue reduction for producers of microprocessors and memory devices, and a subsequent reduction in their capital investment expenditure.

The problems in Asia combined with the downward price pressures of consumer electronics have had a dramatic effect on the equipment supplier community as well. Equipment suppliers are seeing an even more severe drop in orders and revenues. Out of this has come a high degree of uncertainty about the direction and level of R&D investment that should be made for the next generation of semiconductor manufacturing equipment. For IC manufacturers, this uncertainty translates to one more unknown that must be addressed in the early planning phase. Lean times, in particular, dictate that a detailed, total-cost picture is derived such that costs are quantified down to the manufacturing operation level. Since revenues are being forced downward, so too are production costs. The details of process and tool specific alternatives need to be scrutinized to an even greater degree. Computer modeling is the best means of achieving this with the smallest lifecycle investment.

Another aspect to consider is that, from a historical perspective, recessions in this industry rarely last longer than a year. The economic fluctuations are such that rebounds can come as suddenly as the downturns. So planning greenfield projects is not a totally obsolete practice, just out of favor for the time being. Regardless of the economic highs or lows of the industry, it is essential to plan for a wide range of contingencies, for both the short and long term, and to be prepared to consider as many realistic alternatives as possible.

Greenfield vs. Refurbishment Considerations

It is not surprising that in times such as these, semiconductor manufacturers look toward refurbishment activities rather than new facilities. After all, using an existing facility and retrofitting a portion of the existing tools conserves some of the capital used on facility construction while allowing development of the next generation technology. But for many existing wafer fabs (150mm for example), retrofitting is not feasible. Cleanrooms in many older facilities simply cannot accommodate the tool height requirements or the larger footprints. In this situation, the jump to leading edge manufacturing technologies will dictate a greenfield project.

Modeling Software for Activity-Based Cost Planning

Whether the objective is to refurbish or build new, all possible project costs and risk factors ought to be considered early in the planning phase. The project must always be viable from an ROI or rate of return standpoint, to ensure a sound investment strategy. Factory Commander™ is tailored for just this purpose. This software is designed to report information such as cash flow and income statements that can be used directly as part of a business plan. Additionally, the Factory Commander™ application is a 'bottom-up' activity-based cost model. By this we mean that the modeling of products can be made to match the actual manufacturing process, with the majority of input parameters made at the tool- or step-level of activity. For example, tool downtime, capital cost, process steps yields, and step throughputs are inputs required by the software.

Another important aspect when modeling a factory is that all costs be considered and treated consistently. Both initial and recurring expenditures must be included in such an analysis and, wherever feasible, rolled back to the product costs of the IC devices manufactured in the new operation. This means that both the up-front tool expenditures and construction costs (e.g. utility distribution infrastructure, facility layout design or re-design, tool access) and the recurring production expenditures (consumables, labor, supplies, maintenance, etc.) must not only be accurately estimated, but also evaluated on an equal basis.

Finally, two important uses of modeling are to examine input variable sensitivity and explore alternate 'What if' scenarios. Typically when examining sensitivity, a modeler focuses on a particular input variable, changing its value within a desired range. Each value or level requires a program calculation run to calculate the effect on a predetermined output parameter. For instance, internal rate of return could be the output, and the input variable could be the raw wafer cost. The input low and high values represents the best and worst projections that are realistic for the assumed conditions and based on available information. By evaluating inputs at multiple settings, not only can the best and worst case be determined, but also the rate of change and the nature of the response curve. The rate of change is particularly important because a steep slope represents a highly sensitive response to a given input, and this implies a variable of greater significance. Sensitivity analysis enables a Pareto prioritization of inputs and a better understanding of the effect conditional changes have on the response landscape.

"What-if" scenarios are also widely used in modeling for exploring alternatives. This type of analysis is used extensively in cost modeling to make cost comparisons between two or more possible ways of doing some activity. For instance, a modeler may opt to compare two different planarization techniques: Spin-on-glass versus chemical-mechanical polishing (CMP). Each method would require separate assumptions based on process-specific differences for things such as tool selection and expenditure, raw material usage, process throughput, yield loss, labor requirements and utilization, etc. Running scenarios of this sort adds the "cost factor" into the decision making process.

Example Problem

In this example we will consider two scenarios of factories planning to produce high performance logic ICs. Both scenarios represent 300mm wafer facilities implementing state-of-the-art copper interconnect technology with nominal line widths of 0.25 micron. One scenario is a greenfield, the other an existing facility to be refurbished. For convenience, we will refer to these models as Greenfield and Refurb. The Greenfield model assumes that the new facility is to be built on an identified but previously unused site where sufficient resources are currently available. These resources include sufficient real estate availability, a qualified labor pool, adequate municipal utilities, and favorable tax incentives. The Refurb model assumes that, up until recently, logic ICs using a mature process technology were produced on 200mm wafers. The plan in this situation is to exchange or modify the necessary equipment to accommodate 300mm wafers and the newer technology.

Both modeling scenarios were based on the most recent data available from a variety of sources. The manufacturing process is that of a four-layer copper metalization using standard oxide dielectric and shallow trench isolation with tungsten plugs. Both scenarios cover a 7-year timeframe, that include a 12- to 18-month construction period and a ramp up to maximum capacity by the third year of production. Major cash expenditures are incurred during the construction period and at the start of the first three years of production. U.S. dollars were used as the currency for these analyses. Table 1 summarizes the major assumptions used in both models.

Table 1 – Modeling Assumptions for Greenfield and Refurb Scenarios

- Device manufacturing technology based on a 4 layer, copper interconnect process requiring 330 steps.
- Bay & chase cleanroom design configuration, requiring a 60,000 sq. ft. (5,545 m^2) class 1 space
- Modeling time frame of 7 years, including a 12-18 month construction period (See Table 2 for scenario differences).
- Wafer start rate of 80,000 per year (1538 wafer starts per week) for Year 1. The production plan is to ramp the volume by 80,000 wafers each year, to a maximum in Year 3 of 240,000 wafers per year (4615 weekly starts) and remain at that level throughout the remaining two years.
- $10,000 average sales price (ASP) per wafer for first year. $1,000 reduction in ASP assumed for each subsequent year.
- 5-year straight line depreciation for equipment
- 80% overall yield for the process. Assumed constant over time.
- Facility implementation rate represents initial cost per unit of floor space. Includes all costs to design the facility, construct the building shell, and design and build the cleanroom.
- Operation rate is the annual cost for manufacturing space on a ‘per unit of floor space’ basis. This rate includes the general operation and sustaining costs for the facility, and excludes the equipment-specific maintenance.
- Contract maintenance is assumed for all process tools. Annual per system cost range from $40k to $910k, with an average of $208k per tool.
- $78M initial annual consumable expenditure. Consumables modeled at the process and incurred at each step and are representative of current use rates.
- $400 starting wafer cost.
- Labor modeled as function of the tool’s requirements. A 3-to-1 ratio of equipment to operators is used across the process. This means that on average, one person can effectively operate three equipment systems.
- 80% operator efficiency (percentage of time available for production activities).
- $48,000 / year average burdened operator salary. Burdened salaries include benefits and other personnel-specific overhead costs.
- Overhead estimated at 40% of revenue. It includes indirect labor salaries and all selling, general and administration costs.
- Inflationary effects ignored.

Key differences between the two models are summarized in Table 2.

Table 2 - Contrasting Assumptions Between Greenfield and Refurb Scenarios

	GREENFIELD	REFURBISHMENT
Equipment Purchase and Reuse	Entirely new tool set. Total expenditure over product lifetime: $646M	Re-use of 24 different equipment groups. Of these, enough systems are available for the first year's production volume. Additional tools are needed for both expansion and new process. Total new tool expenditure over product lifetime: $535M
Construction Delay	18 months	12 months. Production will be stopped for 200mm product until construction is completed.
Equipment Downtime (Scheduled & Unscheduled)	Average downtime percentage: 3.3% for all equipment, ranging between 1 and 10.1%	Added downtime of 5% for equipment that is reused. Average downtime percentage: 5.1% for all equipment.
Facility Implementation	New Facility at total design and construction cost of $400M. Includes construction of new central utilities building and other support buildings.	Existing Facility Used. Expansion required of existing cleanroom. Total cost: $60M.
Annual Operational Rate	$150/sq.ft. ($1,623 / m^2)	Additional expense due to higher utility use of older equipment. $205/sq.ft. ($2,218 /m^2)
Automated Material Handling System Cost	40% of equipment capital expenditure.	60% of equipment capital expenditure. Higher rate for additional refurbishment cost.

Scenario Results

The internal rate of return, also known as the discounted cash-flow rate of return (DCFRR), presented in Table 3 as an average over the 7-year time frame. This metric accounts for the timing of cash flows as well as the time value of money. A considerable difference exists between these two situations. Provided both options are feasible, these results would suggest that the decision should be made to go with a refurbishment project. Of course, the decision for either of these projects must include a host of other considerations such as the new product's time to market, the strategic position of the product both internally in the company and in the market place, the product's long term economic viability, and the available capital.

Table 3 – Scenario Result Comparison

Metric	**Greenfield**		**Refurbishment**	
Internal Rate of Return (7-year average)	6.6%		18.3%	
Total Capital Expenditure* (M$)	1287		790	
Annual Expenditure (M$)				
Pre-production	400		1292	
Year 1	651		509	
Year 3	1,044		1,114	
Year 5	714		741	
Wafer Cost ($)	Depr.	Expend.**	Depr.	Expend**
Year 1	8,474	10,152	7,346	7,950
Year 3	5,357	5,435	5,284	5,797
Year 5	4,557	3,717	4,484	3,857

* Single payment equivalent at start of project using 5% interest rate

** "Depr." represents depreciation of equipment and building capital expenditures. "Expend." represents expended cost for that year. All values include overhead and non-production expenses. Year 1 "Expend." quantities exclude building capital incurred during construction period.

The significant advantage attributed to the refurbishment scenario is its reuse of existing equipment and facility and the smaller capital expenditure necessary for both assets. The Total Expenditure figures presented in Table 3 reflect this difference. These expenditures are compared on a net present value basis and take into account all building design and construction costs, tool capital, and tool installation required during the initial 3-year ramp up. When compared to the Greenfield, Refurb scenario generated savings of 15% for equipment and 101% savings for the facility capital.

The total expenditure figures presented in Table 3 are annualized expenditures for all operation and capital resources: materials, consumables, labor, maintenance, utilities, overhead, building capital, and tool capital. The additional resources incurred by the production ramp-up account for the increase seen in the third year. As would be expected, increasing the weekly wafer starts from 6150 to 18,450 between Years 1 and 3 resulted in both additional operating and tool expenditures. The wafer cost presented in Table 3 includes overhead and non-production costs modeled at 40% of revenue. Figure 1 shows how the production costs per wafer are distributed by category for the Refurb scenario.

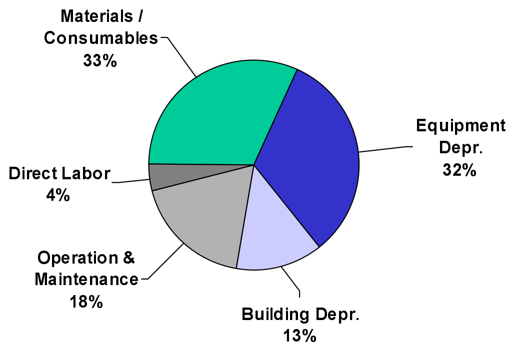

Figure 1. First Year Production Cost per Wafer for Refurbished Facility

For the many of input parameters used in this example, a wide variation can exist that reflect difference due to time, location, economic conditions and other influences. One assumption in particular is the consequences resulting from a drop in the wafer's average sales price (ASP). When the ASP is assumed to be 75% of the values specified in Table 2, the internal rate of return drops to 1.8% for the Greenfield and 9.5% for the Refurb scenario. This difference emphasizes the importance of sensitivity analysis and significant impact average sales price has toward total profitability. Fluctuations in other factors, such as facility capital, additional process and/or metrology equipment capital, or consumable utilization rates must also be considered in a similar regard.

Other factors that were not considered in this example but may need to be addressed in real world assessments include the lost opportunity from the construction activities. Case in point is that with a refurbishment, production must be halted until the product is completed, resulting in a potential loss of revenue. Conversely, greenfields have the advantage of allowing new site construction to run concurrently with manufacture of the earlier generation product. Therefore, if the prior generation products are still profitable, a comprehensive analysis must consider the potential revenue lost during this construction period. Similar consideration ought to be given to the time delay differences between the two scenarios. If this difference were significant for the greenfield, and the product has a characteristic rapid decline in revenue over time, then adjustment to the wafer's ASP should be factored into the analysis. In this situation, an advantage would be attributed to the refurbishment because of its ability to get higher-value product to market earlier.

Conclusion

The examples presented are not intended to suggest what the exact cost of a major project might be, or to imply that the refurbishment alternative is always the better option. Instead, it is to emphasize the importance of modeling as a means of systematically evaluating the alternatives of a given situation. Using sophisticated modeling tools enabled the authors to accommodate a wide range of considerations and assumptions into the analysis. A decision of this magnitude would require that each organization develop a model that best represents their unique business position. Then the methodology presented here can be used to perform an objective analysis.

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Cost, Cost, Cost!!!

By: Charles E. Bauer, Ph.D.

The battle hymn of the advanced packaging arena for the past decade resounds in our ears which ever way we turn. Cost invariably rises to the top of every list of critical decision parameters, and ball grid array (BGA)/chip scale package packaging is no exception.

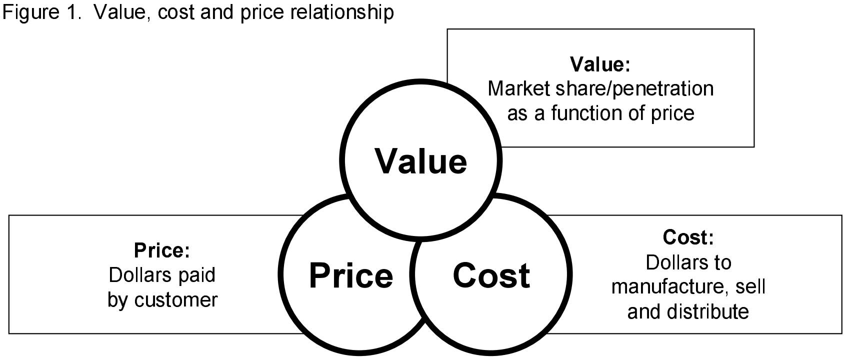
But how can we change the way we think in order to compete with more traditional packaging structures and technologies and remain profitable? One powerful tool results from applying the marketing and finance developed concept of "target costing."

Target costing requires evaluating costs before production. In fact the most successful companies determine target production costs even before the engineering process begins! How? By analyzing the market, particularly the competitive environment, and understanding the value of the product they wish to introduce. This provides a clear basis for end product pricing within the boundaries of corporate profitability expectations. The bottom line becomes "What will the customer pay for a specific functionality offered?" — which drives the engineering and design effort.

An old axiom from the project management arena professes that 80 percent of one's effort should go into studying, researching and planning the project; and the rest is easy. Target costing follows the same principle to maximize profitability. Thorough customer research means that a company can focus engineering efforts on functions that are important to customers and our costs in those areas of less importance to the customer. This not only leads to greater profitability but also enhances customer satisfaction. And customer satisfaction drives market penetration and market share.

Previously this column discussed a unified picture or model coupling packaging, interconnection and assembly. Similarly cost, price and value relate to each other in a symbiotic manner depicted in Figure 1. Value assessment takes precedence over pricing and cost in the target costing approach. Regardless of business or corporate culture, key value determinants include customer characteristics and the type of product or service offered for sale.

Figure 1. Value, cost and price relationship



In advanced packaging there may be several levels of customers, each with different needs and expectations. These include the semiconductor supplier (performance), package assembler (ease of manufacture and yield), contract manufacturer (infrastructure compatibility, rework) and original equipment manufacturer (OEM) (availability, cost, reliability). For such a seemingly simple product, an advanced semiconductor package presents a very complex customer base and a resulting set of expectations to meet!

Consider each of these levels of customers and how their individual needs add up. The semiconductor supplier is most concerned with satisfying the end customer, the OEM. Technically this means the package cannot degrade the chip performance through introduction of parasitic capacitance or inductance, false switching in digital devices or variations in output for linear devices. Cost tolerance of the semiconductor supplier results from a comparison of the available alternatives meeting the minimum technical performance demands of the OEM. For example, controlled impedance and integrated passive component capability in ceramic technologies may be traded off against lower dielectric loss and greater electrical conductivity in organic technologies in order to meet overall cost targets.

For the package assembler cost is king, but yield is God. Package designs and structures requiring narrow process windows, additional processing or inspection and specialized tooling become more and more undesirable as yield suffers. By way of example here, BGA substrates offer customizable electrical characteristics to semiconductor suppliers, but have been standardized with respect to sizes, easing the specialized tooling requirements placed on package assemblers.

The contract manufacturer is the next level in the food chain, and printed wiring board (PWB) assembly again demands high yield. However, compatibility with existing PWB assembly equipment becomes a major cost driver in this arena. Throughput degradation and capital expenditures required by new or specialized packages meet severe resistence and can kill any new technology regardless of its technical merits. Fine-pitch quad flat packages and tape carrier packages are notorious for demanding slower, high precision placement machines as well as excessive inspection and rework/repair. Area array packages resolve many high pin count packaging requirements due to their self-alignment capabilities and compatibility with high capacity/throughput component placement machines, however, they may require hardware modifications and/or controlled lighting adjustments for vision based placement equipment.

Finally, the OEM demands that packages be readily available in sufficient quantity to satisfy the end product market and from multiple sources to reduce supply risk as well as to reduce cost. The package must meet both end customer and product warranty reliability expectations. And ALL of this at an acceptable cost!

In today's advanced packaging world each application presents a different set of specific requirements both technically and from the cost perspective, making it imperative for new packaging technology purveyors to understand the markets they may or may not serve. Memory, for example, must meet the "penny a pin" target, regardless of its validity, or eventually die on the vine.

Appropriate use of target costing results in the intelligent deployment of engineering resources where the greatest impact on customer satisfaction and product differentiation can be achieved, not on "across the board" cost reductions. Market penetration accelerates and market share grows by paying such attention to the customer needs and paring costs in areas less critical to winning the customer's business.

As engineers, be certain to listen to your marketing folks when they talk about customer expectations. And ask your marketing folks to share their knowledge and insights into customer characteristics on a regular basis to enhance both your knowledge of their needs and your own value to your company!

Infineon Technologies Expands Factory Explorer® User Base

Partners with Wright Williams & Kelly for Enhancements

Wright Williams & Kelly (WWK) has announced that Infineon Technologies (formerly Siemens Semiconductors) has expanded its user base for WWK's Factory Explorer® capacity and simulation analysis product and is partnering with WWK regarding future product enhancements. Under this partnership, Infineon engineers will work directly with WWK's Factory Explorer® development team to shape future product enhancements. Chance & Robinson, Inc. will also participate in the development effort, providing semiconductor-specific factory simulation expertise.

"My team has used Factory Explorer® since 1996 and we've been quite pleased with the results. Our implementations have gone smoothly and WWK has been very responsive to our requests for service and support," stated Steven Brown, Manager of Infineon's Munich-based Factory Modeling and Simulation Group. "We plan to expand the use of Factory Explorer® in our test and assembly facilities and this partnership ensures Factory Explorer® will fit our needs throughout the implementation."

WWK Adds Another Top 10 IC Manufacturer to Its TWO COOL® Client List

Wright Williams & Kelly (WWK) announced today that it has shipped its latest version of TWO COOL® Cost of Ownership (COO) and Overall Equipment Effectiveness (OEE) software to another top 10 semiconductor manufacturer. The shipments were made to multiple locations in the Eastern U.S. and Europe.

"This shipment is yet another milestone in the continued market acceptance of TWO COOL® as the only viable standard in COO and OEE metrics," states David Jimenez, WWK's Vice President and General Manager. "While I wish we could disclose our client's name, the supplier side of the semiconductor industry will soon know as another dominant player starts asking them to provide equipment performance and cost data in the TWO COOL® format. It is my understanding that such cooperation will be a requisite part of their RFQ process."

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