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Impact of 300-mm Automation Integration

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<u>Overview</u>

WWK has estimated the impacts of delays in automation integration for a new 300-mm factory. This analysis was performed using Factory Commander®, a static cost and resource analysis model. We modeled a normal, 12-month production ramp and an accelerated 6-month fast ramp strategy that includes the throughput benefits of automation integration. The fast ramp could allow as much as $319 million per year of additional revenue before yield loss. Although this analysis has not considered yield losses, based on historical analysis of revenue per fab, we forecast a more realistic revenue addition of $150 million per year from the fast ramp, if normal production yields are included.

<u>Introduction</u>

WWK has estimated the impacts of start-up delays in a new 300-mm factory equipped with automation integration. Automation integration goes beyond bay-to-bay automated material handling systems (AMHS). Truly integrated AMHS includes the following:

- Bay-to-bay AMHS
- Intrabay AMHS
- Equipment to AMHS interface robotics
- Automated recipe download

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Editorial Board

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Calendar of Events

September

8	**Silicon Valley Forecast Summit** **Mountain View, CA**
12-14	**SEMICON Taiwan** **Taipei, Taiwan**

October

2-7	**IEEE Model Driven Languages and Systems** **Montego Bay, Jamaica**
19-21	**FPD International** **Yokohama, Japan**

November

1-3	**NanoCommerce/SEMI NanoForum 2005** **Chicago, IL**
4-5	**Nanotechnology in Aerospace and Electronics Conference** **Los Angeles, CA**

December

4-7	**Winter Simulation Conference** **Lake Buena Vista, FL**
7-9	**SEMICON Japan** **Tokyo, Japan**

January 2006

8-11	**Industry Strategic Symposium (ISS)** **Half Moon Bay, CA**
10-13	**Emerging Technologies -Nanoelectronics** **Singapore**

This analysis was performed using Factory Commander®, a static cost and resource analysis model. We used a 6-metal-layer 300-mm copper process. That is about the same complexity as commercial logic and micro processor unit (MPU) chips. We modeled both a normal, 12-month production ramp and an accelerated 6-month fast ramp strategy that includes the throughput benefits of automation integration. The overall results from these analyses are summarized in Table 1.

Wafer Size	300 mm
Number of Die / Wafer	375
ASP / Wafer	$22,500
ASP / Die	$60.00
Benefits with Automation Integration	
Capital savings	$37 Million
Year 1 Revenue	+ $1,597 Million
Year 1 Production	+ 79,850 Wafers
Year 1 Cost / Wafer	- $1,199 per Wafer

Table 1: Automation Integration Simulation Results

Note: average selling price (ASP)/Wafer is at start of production ramp.

Assumptions for this analysis are summarized in Table 2. We assume that expenditures for the cleanroom capital occur 12 months before start of production and the process, test, measurement and inspection equipment expenditures occur 6 months before start of production.[1]

Initial Analysis

Delays in automation integration can be modeled by considering lost revenue and increased costs associated with longer time-to-volume. These delays can impact start of full production in several ways:

- Data analysis errors that require repeating production qualification lots, “engineers at International SEMATECH . . . found that 5% - 20% of messages transferred from equipment to host systems were inaccurate.”[2]
- Inaccurate process recipe downloads that require repeating production qualification lots.
- Equipment downtime due to software errors, “50% of equipment downtime problems are caused by software.”[3]
- Process delays due to waiting for analysis results of send-ahead test wafers.
- Process delays lengthen process cycle time thus extending the learning curve.[4]
- Longer process cycles delay product introduction. Moore’s Law estimates an ASP decline of about 2% to 2.5% per month for leading-edge products.[5]

One benefit of automation integration could be modeled by considering lower costs associated with reduced process load/unload times. Both impacts are compared in Table 3 using the logic process.

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[1] Current production equipment backlogs range from 6 to 18 months. Thus, the use of 6 months is conservative.

[2] Michael Chase, Douglas Scott, and Jeff Nestel-Pratt, “The challenges of macro integration for fully automated 300-mm fabs,” *Solid State Technology*, October 2000, p. 53.

[3] Dick Deininger, AMD, Strategic Business Conference, April 2000.

[4] Elizabeth Campbell, Robert Wright, Joshua Cheatham, Mathias Schulz, and James Berry, “Simulation Modeling for 300-mm Semiconductor Factories,” *Solid State Technology*, October 2000, p. 96.

[5] This translates to 24% to 30% percent lower ASP per year, which is consistent with assumptions in the International Technology Roadmap for Semiconductors (ITRS).

Factor	Assumption	Comments
Starting Wafer Cost	$300	
Wafer Processing Rate	20,000 / mo.	Full production after ramp up
Processing Tools	56	Types of tools
Process Equipment	$502.4 M	
Test Equipment	$4.7 M	Parametric and functional
Measurement and Inspection Equipment	$114.7 M	Assumes 100% inspection
Cleanroom Cost	$215 M	Does not include office and support building requirements
	$3,700 / sq ft	
Operating Labor	409	Number of direct labor operators
Process Steps	410	Includes inspection and test
Process Yield	100%	

Table 2: Modeling Assumptions[6]

Note: The average cost per process equipment is $3.2 Million for the logic process. 100% inspection is normal for initial stages of a production ramp. Inspection sampling plans can be introduced after the product and process have been characterized. Measurement and Inspection equipment released from production by use of sample plans is dedicated to yield and process improvement. Cleanroom cost per square foot is based on Class 1 amortization only.

Delay	Base Throughput	Throughput 5% Increase
0 Months	$2,073	$2,048
2 Months	2,228	2,146
4 Months	2,456	2,356
6 Months	2,832	2,706

Table 3: Model Experimental Design and Cost per Wafer Summary

One benefit of automation integration could be modeled by considering lower costs associated with reduced process load/unload times. Both impacts are compared in Table 3 using the logic process.

Note: This initial analysis used a simplified start rate[7].

For each delay model we looked at 0% and 5% increase in throughput due to automatic loading/unloading that would reduce waiting for operator time in overall equipment effectiveness (OEE). The use of a 5% delta is conservative. One recent reference indicates that at the 20,000 to 25,000 wafers per month run rate, a 10% to 20% reduction in head count can be expected[8] from full automation.

The initial analysis shows a difference of $784 per wafer between the best case (no delay, 5% throughput increase) and the worst case (6 month delay, no throughput increase). The remainder of this report will describe the details behind the cost per wafer differences.

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[6] Most 300-mm fabs are being designed to higher throughput rates; thus, actual investments in cleanroom and equipment will be significantly greater. However, this example illustrates the trends WWK has observed in several installations.

[7] 0 starts per month during start-up delay – 20,000 starts per month for all production months.

[8] Chase, *et al*, p. 60.

Throughput Impact

Table 4 illustrates the components of the first year cost per wafer impacted by a throughput increase of 5% due to reduced interference from process load/unload time. This example assumes that integrated automation would virtually eliminate lot-to-lot setup time and improve OEE.

Cost Component	Savings per Wafer
Depreciation	$39
Maintenance	$18
Labor	$13

Table 4: Throughput Impacts (No Delay Impact)

As expected, higher throughput results in lower labor costs, confirming the observations of Chase, *et al.*[9] However, Table 4 also shows that the throughput impacts on equipment and maintenance reduce costs even more than the labor reduction.

Impacts of Delay

The major driver for cost impacts of a delay in product is reduced output. Another driver is the continual decline of ASP. The initial ASP of $22,500 per 300-mm wafer assumes no yield losses. Since Moore's law predicts an increase in functionality of 25% to 30% per year, we have represented the resulting ASP decline as a smooth 2% per month reduction based on the previous month's ASP. See Figure 1.

Figure 1 compares two initial ramp schemes that were modeled to estimate the impacts of automation integration delay, including the factors listed in the previous section. Both ramp plans start at a nominal rate of 250 wafers per week. This is about 20 half lots.[10] The normal wafer processing cycle for a process of this complexity is about 4 to 6 weeks long. Under ideal conditions (Fast Ramp) after an integrated process is validated by 2 to 4 weeks of output, the start rate is doubled at 4 week intervals to identify and correct operational problems. Full production of 5,000 wafers (200 lots) per week commences after 4 weeks of production at 1,000 and 2,000 wafer per week start rates.

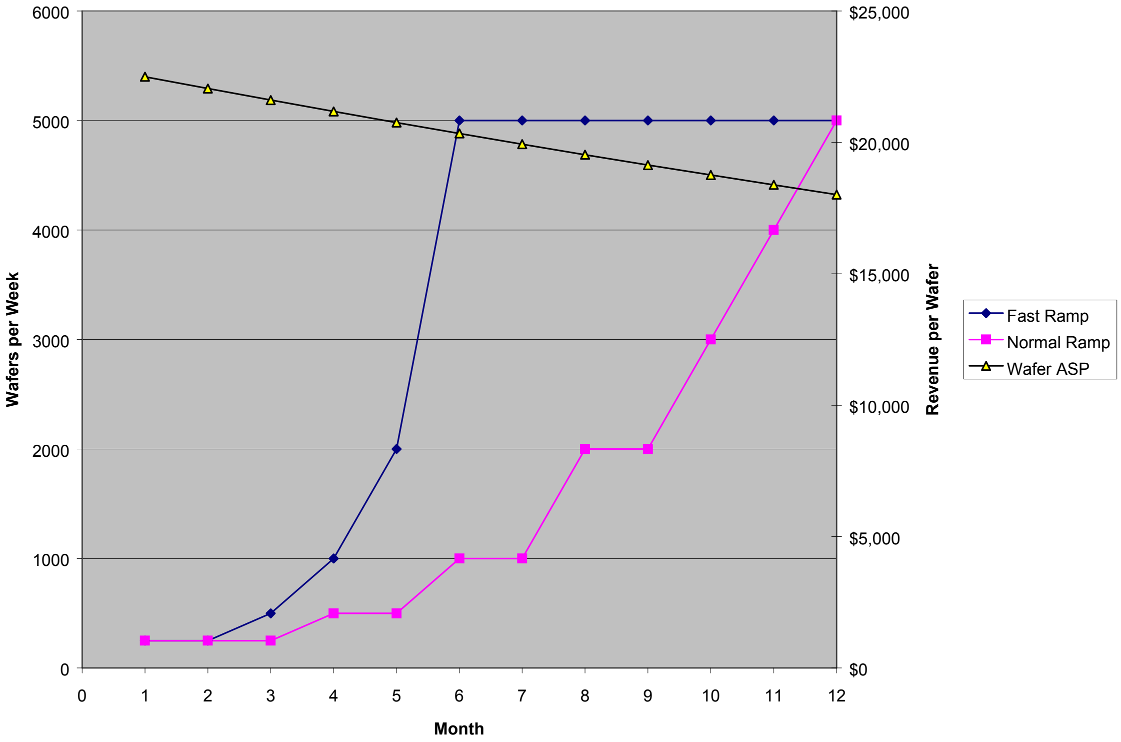

Figure 1: Production Rates and ASP by Month

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[9] Chase, *Op Cit.*

[10] Each wafer carrier (FOUP) holds 25 wafers.

A more normal ramp rate requires 2 full production cycles (3 months) at 250 wafers per week before gradually increasing the production rate. Resolving operations, integration, and automation problems may require 4 to 8 weeks of debugging at each processing rate until production is gradually increased to 5,000 wafers per week 12 months after initial production.

Modeling Results

Table 5 compares the Factory Commander® modeling results for the 2 ramp up scenarios.

	Fast Ramp w/ Automation Integration	Normal Ramp	Benefit
Throughput Rate	5% Increase	Normal	
Capital Expenditure	$800 million	$837 million	$37 million savings
Year 1 Revenue	$3,172 million	$1,575 million`	$1,597 million additional
Year 2 Revenue	$4,232 million	$4,232 million	
Year 1 Production	163,800	82,950	79,850 more wafers
Cost per Wafer	$2,415	$3,614	$1,199 Year 1 saving

Table 5: Model Comparison - Logic

Rob Leachman, University of California at Berkeley, has estimated that a 1 day delay in time to market for a 200-mm fab equals a loss of $3.44 per wafer[11]. In comparing the two ramp scenarios, we estimate a loss of $2.69 for each day lost in time to market over a 5-year product life. While Leachman's analysis and Factory Commander® differ in many details, both models assume 100% yield and the same revenue per square centimeter. Thus, we feel that our analysis is reasonable, if not somewhat conservative.

The impact on Year 1 Net Revenue is a function of the revenue per wafer. Figure 2 shows the additional net revenue from the Fast Ramp strategy as a function of revenue per wafer. This will very for each company and depends on product mix. Note that even in the case of very low revenue per wafer, causing a net loss; the fast ramp strategy lowers the impact of the loss.

Conclusions

Based on an initial ASP per wafer of $22,500 and including the impacts of Moore's Law[12], we estimate that the 5-year average ASP per wafer for the fast ramp is $13,505. The 5-year average ASP per wafer for the normal ramp is $13,021, nearly $500 per wafer lower. This difference is driven by the following factors:

- Higher production in the first year
- Higher OEE and utilization
- Earlier product introduction and higher initial ASP
- Higher throughput lowers equipment and labor costs

Thus, the fast ramp could allow as much as $319 million per year of additional revenue before yield loss. Although this analysis has not considered yield losses, based on historical analysis of revenue per fab, we forecast a more realistic revenue addition of

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[11] James A. Irwin, "The reasonably good status of 300-mm wafer-processing tools," *Solid State Technology*, Oct, 2000, p. 90.

[12] ASP loss = 24% per year

$150 million per year from the fast ramp, if normal production yields are included.

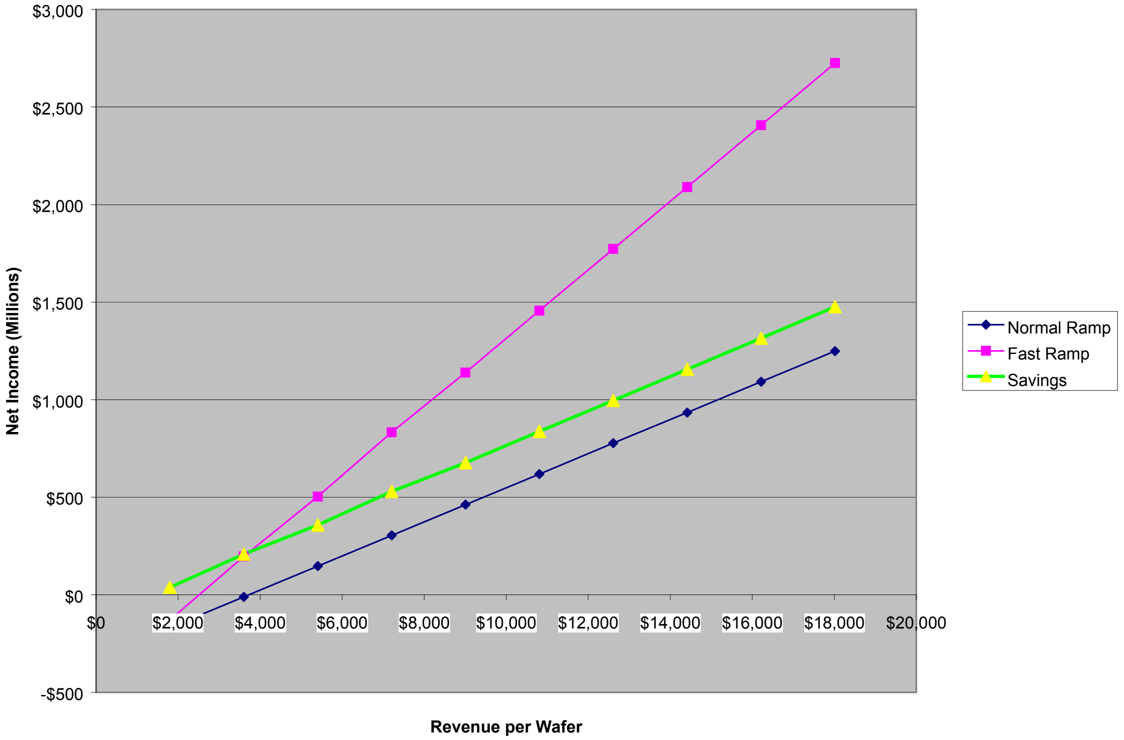

Figure 2: Sensitivity to Revenue per Wafer

WWK Offers Free Cost of Ownership Software

Determine the COO of Manufacturing and Assembly Operations

June 16, 2005 (Pleasanton, CA) –Wright Williams & Kelly, Inc. (WWK), a cost & productivity management software and consulting services company, announced today the availability of a free cost of ownership calculator for use by manufacturing & assembly organizations and OEMs. The calculator is available on its web site (www.wwk.com) under the “Products” link and is based on the company’s powerful TWO COOL® Cost of Ownership (COO) and Overall Equipment Efficiency (OEE) software.

“WWK was founded on the principal of helping our clients better manage their billion dollar asset portfolios,” stated David Jimenez, President of Wright Williams & Kelly, Inc. “Normally, the only way to access our simplified Turbo COOL™ routine is by licensing our flagship software package, TWO COOL®. However, we felt with the increasing global focus on manufacturing and assembly costs and the raising competitive nature of manufacturing in China, that easy access to this first step in cost of ownership modeling would help place all manufacturers and their suppliers on an equal footing with regards to their ability to analyze their cost positions.”

With more than 3,000 users worldwide, Wright Williams & Kelly, Inc. is the largest privately held operational cost management company serving technology-dependent and technology-driven companies. WWK maintains long-term relationships with prominent industry resources including International SEMATECH, SELETE, Semiconductor Equipment and Materials International (SEMI), and national labs and universities. Its client base includes most of the top 10 semiconductor manufacturers and equipment and materials suppliers as well as leaders in nano-technology, MEMS, thin film record heads, magnetic media, flat panel displays, and solar panels.

A WIP-Centered View of the Fab: Part 2: Overall WIP Effectiveness

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Introduction

As we discussed in Part I (Winter 2005 Applied Cost Modeling newsletter), a common approach in monitoring fab performance is to take an equipment-centered approach. This involves measuring overall equipment effectiveness (OEE) for bottlenecks, recording A20 and A80 and downtime characteristics, and tracking the time that equipment spend in particular states (especially the dreaded "standby with work in-process (WIP) waiting" state). The equipment-centered view is very important in running a fab, because the individual equipment are so expensive.

In this two-part article, however, we propose a parallel WIP-centered view of the fab. That is, for an individual lot, we look at the time that the lot spends in various states (processing, waiting, traveling, etc.), and these are analogous to equipment states. We also use the WIP state information to calculate a performance measure parallel to OEE, called overall WIP effectiveness (OWE). We believe that understanding exactly where lots are spending their time is an important step in improving cycle time, and that WIP states and overall WIP effectiveness have the potential to add a great deal to the understanding of the fab.

In Part I we defined and discussed standardized WIP states. In this article (Part II) we will define the performance measure, OWE. OWE measures that percentage of time that a lot spends in a "value-added" state, out of the total time that the lot spends in the fab.

WIP States

The six basic WIP states that we proposed in Part I were:

- Processing
- In Queue
- On Hold
- Post-Processing (e.g. waiting for unload)
- Traveling
- In Crib (extended hold, or storage near the end of the line)

We also noted that it might be useful to break down the Processing Time category into regular process time for a lot vs. time spent by the lot either being reworked or waiting for a rework child. Similarly, we said that it might be necessary to break process time into required process time vs. process time caused by speed losses.

Overall WIP Effectiveness

To measure OWE, we need to break down the above states into value-added vs. non-value-added. Clearly, time in queue, time on hold, and time waiting to unload are not value-added for the lot.

Travel time is somewhat more controversial. Some travel time is needed to process the lot. However, no actual improvement is made to the lot during the travel time, and cycle time would be improved by shrinking the travel time. Therefore, for the purposes of this metric, we will consider travel time to be non-value-added.

Time in crib (extended hold, or storage near the end of the line), is similarly not value-added (and in fact increases the risk of obsolescence for the lot). The only time that value is really being added to the lot, then is during non-rework process time. Even then, some question may arise about the value-added nature of inspection steps. However, we believe that some amount of inspection does improve the quality of the resulting lots. Therefore, we will treat the inspection steps as part of process time for our calculations.

Thus, all of the time that the lot spends in the fab, with the exception of non-rework process time, is non-value added time, and our formulas for OWE are as follows:

1. For a lot, history to date:
OWE = 100% * Total non-rework theoretical process time / Total cycle time

2. For an area (e.g. etch) for one shift:
OWE = 100% * Total relevant non-rework theoretical process time / Total relevant cycle time

Formula 2 is calculated by considering all lots that visited the area (etch) at any time during the shift, whether or not the lots were processed within the shift. For each of these lots, total relevant cycle time is the time within the shift that the lot was the responsibility of the area. For example, in a 6am to 6pm shift, if lot A arrives to etch at noon and stays in etch past the end of the shift, total relevant cycle time within the shift is 6 hours. However, if lot A arrives to etch at noon, is processed and leaves etch at 2pm, then total relevant cycle time is 2 hours. Total relevant cycle time for etch is the sum of total relevant cycle time for each individual lot that visited etch any time during the shift. Similarly, total relevant non-rework theoretical process time is the sum of theoretical process times for lots processed in etch within the shift, truncated at shift boundaries. E.g. a theoretical process time that continues past the end of the shift is only counted up to the end of the shift.

Formula 2 may be applied to days or weeks rather than shifts – simply truncate process times and cycle times at the day or week boundaries. Formula 2 may also be applied to other levels in the fab hierarchy, e.g. an equipment group, by considering only the lots that visited the equipment group within the shift. It can also be rolled up to the entire fab, in which case all lots would be considered.

Comparison to Existing Metrics

OWE offers a nice parallel interpretation, when compared to OEE. We maximize OEE (for equipment) by dedicating the factory to keeping the equipment running good wafers at top speed. We maximize OWE (for a lot) by dedicating the factory to keeping the lot running at 1 X theoretical, with no delays. Neither is a perfect measure for the entire factory, but both tell you something useful. For OWE, a low value tells you that a lot spent most of its time in some non-value-added state. Conversely a high value (near 1.0) tells you that the lot spent most of its time in the fab actually being processed on equipment at or near its theoretically best processing rate.

OWE is very close to being the inverse of the traditional cycle time x-factor for a lot. Cycle time x-factor, as defined in earlier issues of this newsletter, is total cycle time for a shipped lot, divided by theoretical cycle time for the lot. The difference when calculating OWE is that rather than comparing the total cycle time to some theoretical number, we look at the actual history of the time that the lot has spent in the fab. This is something that we can do largely by keeping track of WIP states for the lot, and will tend to be more accurate than comparisons to some manually maintained theoretical cycle time value.

Similarly, OWE is something like the inverse of Dynamic X-factor. As discussed back in issues 4.08 and 5.03 (FabTime newsletters), Dynamic X-factor (DXF) looks at the total amount of WIP in the fab, and then divided by the WIP that is currently being processed on equipment. Over time, DXF can be shown to be equal to the average cycle time x-factor for lots exiting the fab. However, DXF is a fab-level metric. It can be scaled down to areas, but is not designed to give information about individual lots. Overall WIP Effectiveness is a lot-level metric. Also, DXF is a point-in-time estimate, so any changes that occur between observations are lost. OWE is a cumulative metric – it captures performance over time.

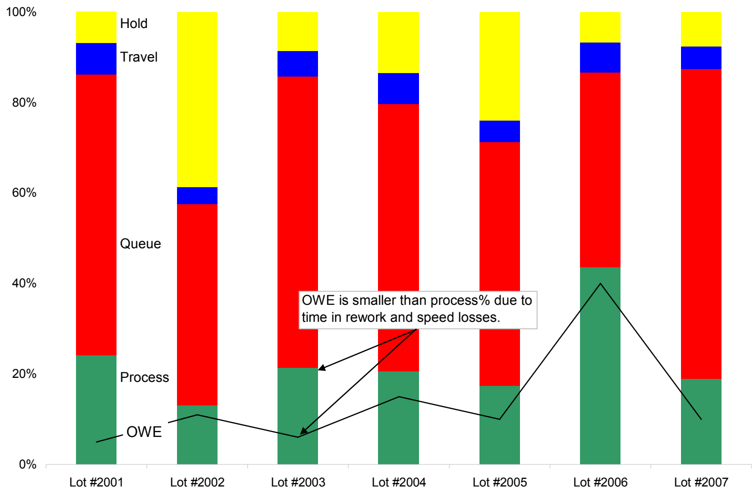
WIP states and OWE (formula 1) highlight lots with cycle time problems and provide a detailed analysis of historical cycle time losses. This information is a good starting point for cycle time improvement projects, e.g. reducing hold times.

WIP states and OWE (formula 2) provide a shift-level summary of cycle time performance and a view of current cycle time losses. This information is useful for trending, goal-setting, and comparison across shifts, to spot a problem as it develops.

Example

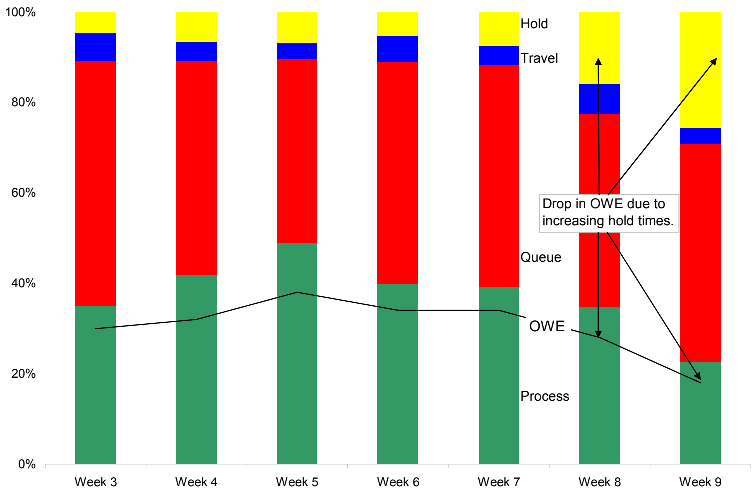
Chart 1 shows a comparison of OWE and WIP states for individual lots, with some WIP states (post-processing, crib) eliminated for clarity. Chart 2 shows a trend of fab OWE and WIP states over several workweeks. Here again some WIP states (post-processing, crib) are eliminated for clarity.

WIP States and Overall WIP Effectiveness by Lot



OWE is smaller than process% due to time in rework and speed losses.

Fab WIP States and Overall WIP Effectiveness Trend



Drop in OWE due to increasing hold times.

Conclusions

By looking at cycle time losses, we can identify opportunities for improvement. In the first part of this two-part series we proposed a set of WIP States that apply to the time that each lot spends in the fab. That is, we proposed breaking up a lot's history, and measuring how much time it spends in several basic states such as queue, process, post-process, hold, transport, and crib. In this second part of the series, we drew on the WIP State data to calculate a single metric, OWE. OWE measures value-added time (theoretical non-rework processing time) relative to total cycle time. OWE is similar to OEE, in that we maximize it by keeping lots moving, with no delays (much like we maximize OEE by keeping an equipment running with no delays). Driving OWE up towards 100% will drive towards improved cycle time, through the reduction of non-value-added time. Understanding the WIP States that lie beneath OWE gives further insight into how to make this improvement.

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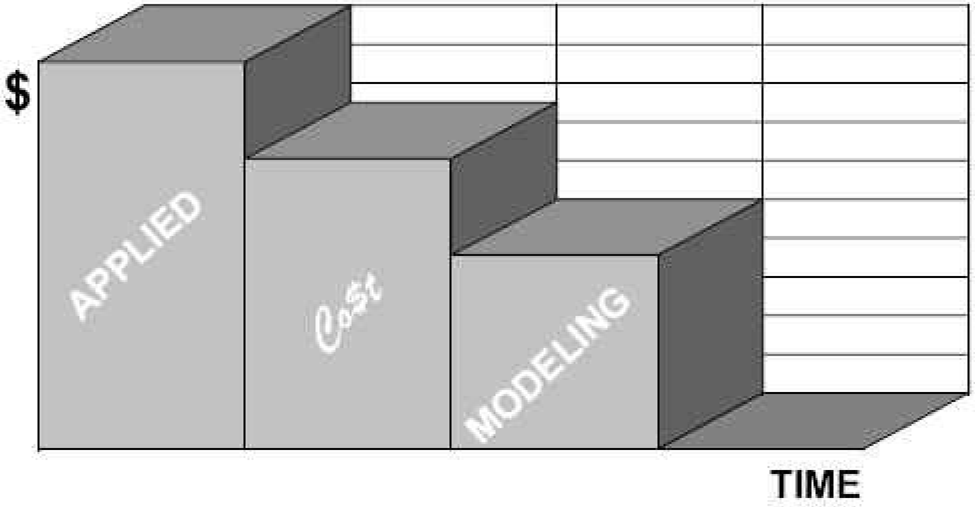

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