Abstract
The process of designing a Fab from start to finish is a complex one. In today’s environment designing a facility that will be fully operational a year and a half to two down the road can be a real gamble. Adding new technologies and an immature toolset to this process and you are in for a rocky ride. We feel that at this point in time the predictability of tool behavior in the 300mm world is nowhere near the 200mm world thus adding a risk factor to the design. Due to the size of the wafers, automation must be an integral part of the design, however if the toolset performance is uncertain then to what performance are you designing your automation? Following the right design process can, one that forces you to ask all the questions from day one, will boost your confidence level.

Design Process Overview

Objectives of a Good Design Process
✓ To forecast, as accurately as possible, performance demands and understand the resources needed to meet them.
✓ Generate the best possible fab design within a budget boundary.
✓ Get from initial decision to capacity on line as fast as we can!
✓ Build, install and qualify all tools on time and on budget!

From Process Flow to Toolset
Any Fab design must start with a detailed process flow or flows. A good process flow is detailed to the individual step level and describes each step from both process and manufacturing standpoints.

The fab’s physical layout should be based on the predominate flows; out of those a composite flow is superimposed. This flow should capture 80% of the products or processes. Process flows dictate the tool list, the functional areas’ size, and relationships.

In the 200mm fabs, fabs could be designed for running one or two products. However a 300mm wafer fab of a 100,000 sqft and above will have the capacity to supply world consumption on some products, so in most cases it will run more the one product line and probably more than one technology.

Since process flows may be varying in levels of confidence, toolset confidence will match that. But even in a very uncertain flow, you can identify problematic areas and find the right tools to fix them. A thorough analysis of the steps allows you to delay the decision of actual tool selection for those steps until late in the process, when the flow is more certain.

Lastly, our visibility to what market demands will be two years down the road is not very good, so before we invest a couple of billion dollars into a new 300mm fab we must ensure it is extremely flexible. To quote one of the industry top managers “I want to be able to switch from product A to product B on a flip of a dime”, that kind of agility comes from process flow understanding.

Resource Modeling
Clean room space is not the most expensive resource in a fab, and fab design is not just layout and tool locations. To truly understand fab operations all resources must be modeled:
✓ Tool capacity – all tool types must be modeled and fully understood
✓ Product and material flow must be analyzed to create a flow model
✓ Automation requirements, transportation times, different buffer needs, and systems performance clearly defined.
✓ Staffing - operators, technicians, and all support staff requirements are based on a detailed resource model.

Fab Design Guidelines
Obviously, you want the best fab for the least amount of money possible. But while budget constraints are easily determined, the best criteria for fab design are more complex to define. We want to make certain that performance is optimized. Typically people look at either getting the best cycle time or capacity but close scrutiny shows that they are not mutually exclusive. To optimize performance, both are needed. We suggest the composite of the two as a measure for fab performance (as explained in the performance definition). To help the actual design process we suggest the following.

Performance Definition - CT Vs. TPT

Once we identify the optimum level for our facility we can define the quality of our design process by the ability to sustain manufacturing for that WIP and flow level.

Alternative Selection Criteria
Any design process can result in a couple of alternatives to choose from. To help the selection, we define organizational criteria, business criteria, and design alternative selection criteria.

Operational Criteria:
Product/material flow
Productivity/staffing impact
Dispatch method (pull, push, etc.)
Layout flexibility and ramp impact on existing production
Maintenance practices
Ergonomic issues
Automation
Material handling
Modularity to future expansion
Installation/qualification complexity

Business Criteria:
Capacity
Time to on-line capacity
Cost/return on investment
Quality and yield

Design Alternative Selection Criteria:
Total cost of operations (TCO) vs. performance
Budget — project budget vs. performance

Conceptual Stage
Once the design guidelines are set, and resources are understood, create a conceptual layout by locating the different functional areas for the fab. In this stage, it is important to understand the weights of the different functional areas in the fab, analyze the transactions and the number of wafers going between the areas.

At this point, we know how big the functional areas are, as well as the movements between them. You can start designing the shell, based on the block diagram. You can design your building to accommodate the functional areas and therefore, don’t need to know the final location for each tool when you begin building. Keep in mind that we still have enough time to finalize tool location since some tools have lead times of longer than a year. But,

Drawing from “Little’s Law” there is an optimal WIP level for each toolset that allows for the best CT and TPT composite.

(WIP= CT x TPT ==> TPT=WIP/CT)
(40,000 wafers WIP level for the above example)
by starting the construction in parallel to the detailed design stage, you can save 2 to 6 months.

**Automation System Requirements**

Regardless of the final automation system you will choose in order to start building construction you need to know not only transportation volumes but also transportation times and buffer location and sizes. The general type of automation system, e.g. overhead monorail, will need to be factored into the shell design, as well as possible buffer locations and WIP stokers. Once the automation systems requirements are mapped the shell construction can commence. Although for the early construction stages the detailed design of the material handling system is not a must, you want to finalize system selection as soon as possible and custom tailor any system you choose to the performance you need based on the detailed resource modeling. The main difference between 300mm fab and smaller wafer sizes is that manual transportation is not an option. The wafer handling system you will implement will set the pace of the fab for better or worse. Calculating the WIP, buffers for bottleneck tools, and operational goals is the first step to spec the handling system. The main challenge is to create and test a dispatching algorithm that will get the right lot to the right place on the right time.

**Detailed Layout Design**

Once the high level design is finished, and building construction began, detailed layout and A&E design is required. Detailed design pinpoints each tool’s location and the support infrastructure it needs. For every tool the interface with the wafer handling system and WIP storage needs to be defined accurately. Detailed design should include the following:

- Detailed CAD drawing including verified footprints for tools, AMHS, service space, and conforming to building and OSHA codes.
- Utility matrix
- Tool install and qual sequence
- Phasing in and ramp plan

**Phases and Ramp Plan**

There is no way to install and quall a full blown fab all at once, therefore a careful ramp plan should be devised to minimize risk and allow as many exit points as possible. From design begins start to first tool install, there is enough time for market to change dramatically, creating the right log term capacity plan should include building for best possible scenario, and populating tools pessimistically. In a new technology project we should also allow for an organizational learning curve thus incorporating the fact that initial productivity and yields will not be as good as our ultimate goal. Thorough process qualification on a separate R&D fab and a creative use of short loops lots can reduce learning curves and decrease technology risk factor. Following a pre-defined ramp plan can ease the process.

- Early Toolset – Proving fab capability manage the technology and manufacture sellable products will be broken to the following steps:
  - Tool Qual – Vendor and internal tool qual
  - Process Qual – getting a full process certification, ideally this step should be done in and R&D process and not on an untested line.
  - Short Loop – running parts of the process on the new toolset and verifying manufacturability
  - Full Loop – certifying the new fab to run the process

- Redundancy toolset – No single point of failure across the line, at the end of this process a fab is considered viable and can function commercially.
- Ramp Steps – going to full-blown capacity in several steps. This process is not open ended and there are a finite number of smart options for a ramp pace.

Note: although for early ramp stages you do not need full automation, and wafer transportation capabilities, it is wise to make sure that the system is up and running from day one and that adding the new stops for late arrival tools is just throwing a software switch or flag on.

**Project Management Approach**

The more complex the project the more likely it is to fail. While it is unlikely that a fab design and build process will fail completely it is very likely that it will end up exceeding the budget and finishing late. The cost of failure on this large a project may be not only in budget or revenues but also in market share. To make sure that the gains achieved by aggressive design schedules are not wasted in the execution stage, the building construction, tool install, and qual phases must be managed. We suggest the “critical chain” project management philosophy by Eliyahu M. Goldratt. At the risk of over simplifying the critical chain, its essence is creating the understanding of what the project’s critical tasks are, identifying their real duration and creating contingency plans without sacrificing time or budget. To implement the critical chain you need to identify all activities, get their real duration, and reduce fudge factors across the schedule. The identified fudge factors are removed, and the time saved is divided by three:

- A third goes to the activity owner – he now has a known slack built into his activity.
- Third to a central project buffer – which will allow project manager to compensate for lateness in tasks.
- A third is reduced from the project duration.

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Business Process Development
It is important to keep in mind, that even once the building is ready and all the tools are hooked up, you still might not have the best of breed fab. As a matter of fact, there are many business transactions that need to be defined. Doing so ahead of time will allow you to include them in the design process. For a real good design, you must map all business processes ahead of time and create SOP to cover them. In 300mm fabs, all manufacturing processes must be pre-defined since, automated wafer transportation and automated decision making is an integral part of any 300mm fab.

Examples of typical major business processes that should be covered as part of a fab design are:

- **Shift management** – general assignment, reporting and escalation processes definitions.
- **Maintenance practices** – starting from manufacturing and maintenance update procedures and going down to the specific tool manuals and repair SOP’s.
- **Tool and recipe SOP** – creating a tested operator instructions for all steps in all flows, and all general admin activities.
- **WIP Management** – general WIP policy that will dictate WIP locations and volume.

In 300mm fab design there are new issues that while in an un-automated fab could be left open to daily operation to solve, must be pre-defined in an automated fab.

Buffer Strategy
As the basis for any automated manufacturing management, the right buffers should be set. For that we need to identify buffer ‘locations’ in the flow. Analyze a composite process flow and define the bottleneck tools. The actual identification of the bottlenecks calls for advanced resource modeling that considers the following factors:

- **Tool dedication**
- **Facility Lot Size**
- **Batch policy**
- **Tools’ run rate**

To control your buffers in an automated environment you must integrate them with an Event Driven Dispatching (EDD™) module, and

Global Release
When releasing new lots to the line we will consider the following factors:

- **Technology type**
- **Customer commitment due date**
- **MAX WIP level in the line (by technology) to support desired X factor**
- **Fab due date - will include a standard time buffer (STB) from the customer committed due date**
- **On time delivery goal - will set the goal CT confidence level, thus setting the STB**
- **Quantity and frequency of actual starts will follow this concept:**
  - Lot out triggers lot start - continuous starting
  - Last lot in order i starts at the beginning of the X factor determined by technology

Real Time Dispatching
Real time dispatching is should be truly defined as being event triggered. Mapped here are the two major events that could trigger a dispatch, tool X calls for a new lot, or Buffer B calls for a lot. The dispatching algorithm should follow a combination of routines to determine the right lot to dispatch, to compensate for curtain floes in the critical ratio, we developed a derivative called the M ratio™:

$$M\text{ ratio (}\text{lot} i\text{)} = CR\text{ (}\text{lot} i\text{)} \times \% \text{ of remaining Work}$$

$$CR - \text{Critical Ratio}$$

$$\% \text{ Remaining work} = \text{process steps to finish} / \text{total # of steps in process}$$

- Dispatch triggered by tool - run the lot with the min M ratio
- Dispatch triggered by buffer - Fastest Lot to Buffer

Critical factoring of changeover need for the lot time to arrival to the trigger

Fab Optimization Routines

- **Tool changeover rules** – when does the dispatch algorithm recommends a changeover and when should it enforce one.
- **Batch policies** – once we have a recommended batch policy per tool, when do we brake that policy and how do we track to see that the policy is still valid.
- **Lot size optimization** – original lot size is determined by batch processing tools “optimized lot size” how do we use floor data to validate lot size as mix changes.
- **Tool speed optimization** (cluster tool modeling), how can we alter flow to tools to enhance performance on the fly.
- **Service tools optimization using queuing theory**, incorporating the analysis into fab execution system.
- **X factor modeling** – determining per flow and updating on the fly.
- **Test and dummy wafers quantity and usage optimization**
- **PM planning and execution to increase up time.**
Recovery Procedures

- Tool recovery – in a major catastrophe we need to have a process that prioritize tool fix following bottleneck Index logic. The ability to change dispatch algorithm and buffer policies requires a real time BNI calculation
- Notification procedures – who will the fab management system treat as the automatic recipient for events notices
- Escalation procedures – when does an event get escalated by system, e.g. from litho tech, to tech manager, to fab manager.
- Interactive repair process (MES - CMMS - Technician - Vendor)

Basic Fab Run Rules

The fact that full automation is a fact of life changes organizational responsibilities, these topics need to be answered based on manufacturing management automation level.

- Tools operators – how much intervention is required from an operator in the new reality and how much judgment does he now have.
- Maintenance technicians – what part of the diagnostic phases is still in their hands and how is their work schedule derived.
- Engineering – what is the mechanism to maintain visibility for to process related issues with decreased human interaction.
- What are the managerial roles and responsibilities in a fully automated fab
- PM / Repair procedures
- Fab performance measurements
- Fab management business processes
- Quality and yield management process

Information Systems (IS)

Once all business processes are defined, you need to have the right systems in place to support them. Many organizations do not follow a defined process of selecting a system. Identify all the relevant system needed, analyze them, and then look for vendors who can fill most of those needs. It is best to stick to off the shelf systems. However, in many cases you will not find an off the shelf solution and there will be module or modules to be custom developed. The most common information systems found in a fab are:

- Manufacturing Execution System
- Computerized Maintenance Management System
- Enterprise Resource Planning
- Facilities Control System
- Visual Management - clean room personnel and management updates.

Trends in 300mm Fabs

When mapping the 300mm lines out there we can see that most fabs started as either R&D or pilot lines. Commercial demands hopefully will drive higher volumes manufacturing. The 300mm wafer size and fab automation issues demand management processes to become more mature. Realistically to enable us to achieve economy of scale, product mix will be higher then 200mm level, thus creating a more complex environment. As in the past Yields and Cycle time will continue to be the focus, an ever shrinking time to market demands will force the rapid performance improvements to the point where 300m lines will need to reach mature operations much a much shorter time then 200mm fab had.

Conclusion

Building a new 300mm facility equals Mega dollars with a capital M. The struggle for every new fab design is finding the equilibrium between opting for best facility performance and minimizing costs. Going through the right fab design and project management process reduces overall time to capacity, reduces total cost of operations and thus allows for a better performing fab for less. Starting a new 300mm design without fully understanding this process is a contribution to your competitors. When a company spends 2 to 3 Billion dollar on a new 300mm fab it must deliver a real competitive edge.

The cost of going through the right design and management process is negligible, even when ignoring TCO and just looking at investment cost, typically we can see huge savings in time and budget when compared to a traditional design process.

And a word to the wise, the base for a new fab should be not just technology but also a solid market forecast. Having a precise forecast with a good fallback plan is a must. Achieving the throughput to get the cost benefits from the increased wafer size should be a known breakeven point. If those parameters are not clear to the organization then pragmatically it should forego 300mm and invest the money in reducing product development time, actual development of new products, or whatever provides a real competitive edge. As we learned in each and every down-term there is nothing sadder then a brand new fab working at 40% capacity.