Optimizing Inventory Levels using Financial, Lifecycle and Forecast Variance Data

by

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Bachelor of Electrical Engineering & Management, McMaster University (2001)

Submitted to the MIT Sloan School of Management and
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ABSTRACT

Significant inventory write-offs have recently plagued ATI Technologies, a world leader in graphics and media processors. ATI's product-centric culture has long deterred attention from supply chain efficiency. Given that manufacturing lead time exceeds customer order lead time for its semiconductors, ATI relies heavily on their demand forecasting team to instigate supply chain activities.

The PC business unit forecasting team translates market information into product-line forecast and also sets finished goods inventory levels intended to offset demand uncertainty. Today's inventory decisions are made in response to customer escalations, often ignoring financial implications. To add necessary rigor when setting these inventory levels, this thesis presents a model using wafer and unit cost, profit margin, product lifecycle stage and historical forecast error to categorize products into inventory risk levels.

The resultant risk levels become a critical input to monthly demand-supply meetings with marketing, operations and senior executives – the outcome of which are wafer orders and assembly and test plans at the world's largest contract foundries and subcontractors. Finally, the 2006 acquisition of ATI by Advanced Micro Devices (AMD) offers unforeseen flexibility, scale and challenges to the outsourced semiconductor supply chain.

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I. Introduction to ATI Technologies and its Business Model

Overview

ATI Technologies is a world leader in graphics and media processors for desktops, laptops, set-top boxes, game consoles, HDTVs and handheld devices. In its 21 year history, ATI has rapidly grown from a small engineering start-up in Toronto, Ontario, Canada into a global market leader acquired for $5.4 billion by Advanced Micro Devices (AMD) in July 2006.

Corporate and Business Unit

ATI is a matrixed organization with over half its 4000+ employees working for one of two business units (BU): PC and Consumer. The PCBU earns about 80% of ATI's revenues[1], but higher growth rates are expected for the Consumer BU. Each business unit is product-based; design engineers, program managers, product marketing managers and pricing managers comprise the majority. The remainder of employees works in a corporate function, such as operations, sales, corporate finance, corporate marketing, human resources and IT.

Operations

The central ATI Operations Group supports both business units. Within Operations, there is:

1. Asia Operations
2. Strategic (Foundry) Operations
3. Board Operations (including Procurement team)
4. Application Specific Integrated Circuit (ASIC) New Product Introductions (NPI) & Product Engineering
    - Packaging and Test Programs (including yield)
5. Supply Chain:
    - Supply Chain Planning teams aligned to product lines
    - Capacity, Prototype and Operations Planning
    - Supply Chain Systems
        - *Supply Chain Core Team**
        - Data Automation

[1] http://media.corporate-ir.net/media_files/IROL/10/105421/reports/ATI_Q306.pdf.

Supply Chain Core Team*

Reporting to the Supply Chain lead, there are supply planning teams who manage tactical issues with wafer foundry partners and with Outsource Assembly & Test (OSAT) partners. Also reporting into Supply Chain Systems is the *Supply Chain Core Team*, a group formed in late 2005 with mid-level professionals from:

- Procurement
- Sales Operations and Order Fulfillment
- Operations Information Systems (IS)
- ASIC Supply Planning
- Board Supply Planning
- NPI and Product Engineering
- Finance (Product Costing)
- Demand Planning (PCBU Forecasting Team**)

This full-time team owns the *Supply Chain Improvement Program*, being tasked with leading process and IT systems changes to improve ATI's operational efficiency. Its activities are approved by the Supply Chain Steering Committee –Senior VP of Operations, VP of IT, CFO and General Managers from the two business units. During early 2006, the team primarily focused on consulting partner selection for a massive upgrade to ATI's MRP and planning systems.

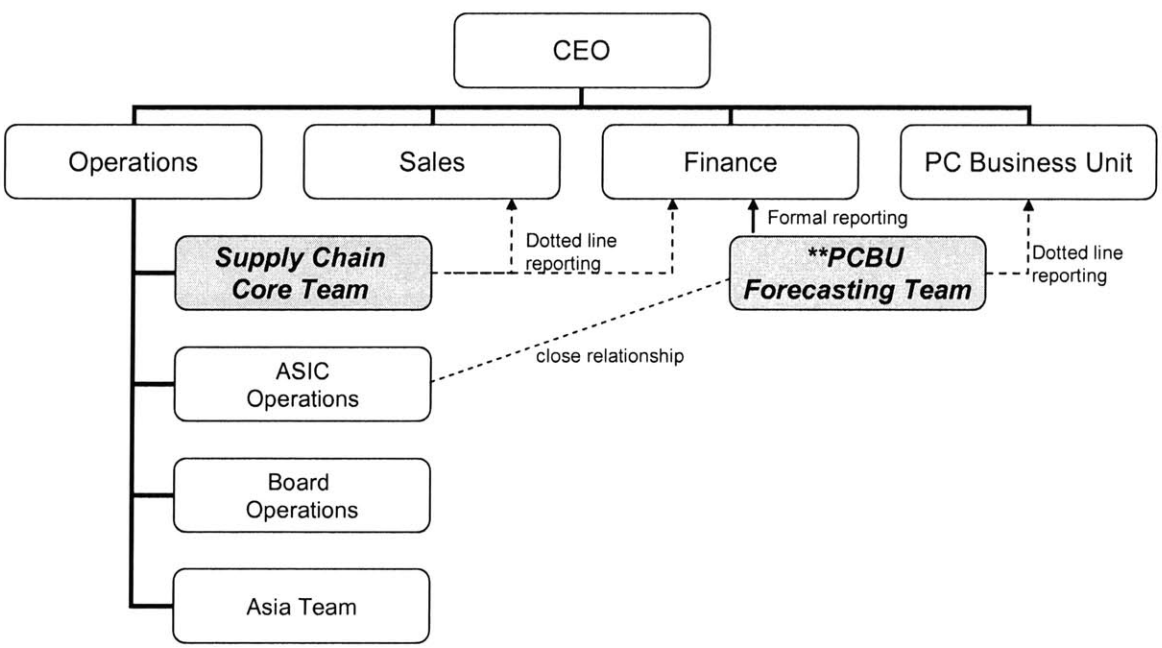

Figure 1: ATI Organization Chart (abridged)

PCBU Forecasting Team**

Of relevance to this project, the PCBU Forecasting Team officially reports into PCBU Finance, a division of Corporate Finance led by the CFO. However this team also dotted line reports into the PCBU General Manager (See Figure 1). In addition, the PCBU forecasting team works closely with Operations' Supply Planning Teams to plan and prioritize materials against the consolidated forecast and to set target inventory levels to offset demand uncertainty. However, market and customer data being used for forecasting comes from sales, product marketing and business management (pricing) teams.

I represented the PCBU Forecasting Team on the ATI Supply Chain Core Team (see Figure 2). My inventory model addresses the PCBU forecasting team's near- to medium-term needs, while preparing the team for longer-term process and systems upgrades planned for the Supply Chain.

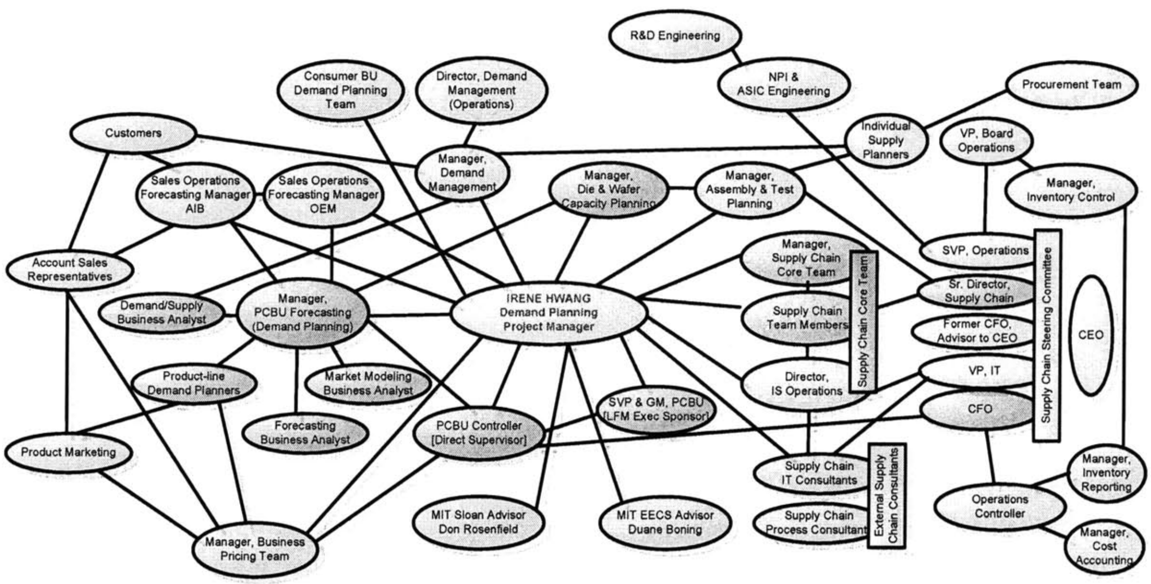

Figure 2: Stakeholder Map

II. Project Scope & Problem Statement

Significant inventory write-offs have plagued ATI. ATI's product-centric culture has long deterred attention from supply chain efficiency. Given that manufacturing lead time exceeds customer order lead time for its semiconductors, ATI relies heavily on their demand forecasting team to direct supply chain activities.

The PC business unit forecasting team translates market information into product-line forecasts and is also responsible for proposing finished goods inventory levels to buffer demand uncertainty. Today's inventory decisions are made in response to customer escalations, often ignoring financial implications. To add necessary rigor when setting inventory levels, this model assumes that wafer and unit cost, margin, lifecycle stage and historical forecast error better categorizes products by inventory risk level.

The resultant risk levels become a critical input to monthly demand-supply meetings with marketing, operations and senior executives – the outcome of which is wafer orders and assembly and test plans at the world's largest contract foundries and subcontractors. Finally, the 2006 acquisition of ATI by Advanced Micro Devices (AMD) offers unforeseen flexibility, scale and challenges to the outsourced semiconductor supply chain.

This thesis presents a quantitative model that derives optimal finished goods inventory levels to offset demand uncertainty.

III. ATI Business Model and Distribution Channels

ATI evolved from manufacturing its own graphics boards to outsourcing its ASIC (Application Specific Integrated Circuit, or 'chip') designs to the world's largest contract foundries and assembly and test houses based primarily in Taiwan. This higher profit margin, or 'fabless' chip model retains semiconductor and board design as core R&D activities, with ATI directing chip packaging, assembly and test specifications. Close cooperation with supply chain partners throughout manufacturing processes is also required to monitor yield, quality and processor performance. See Figures 3 and 4 for a typical ASIC product flow.

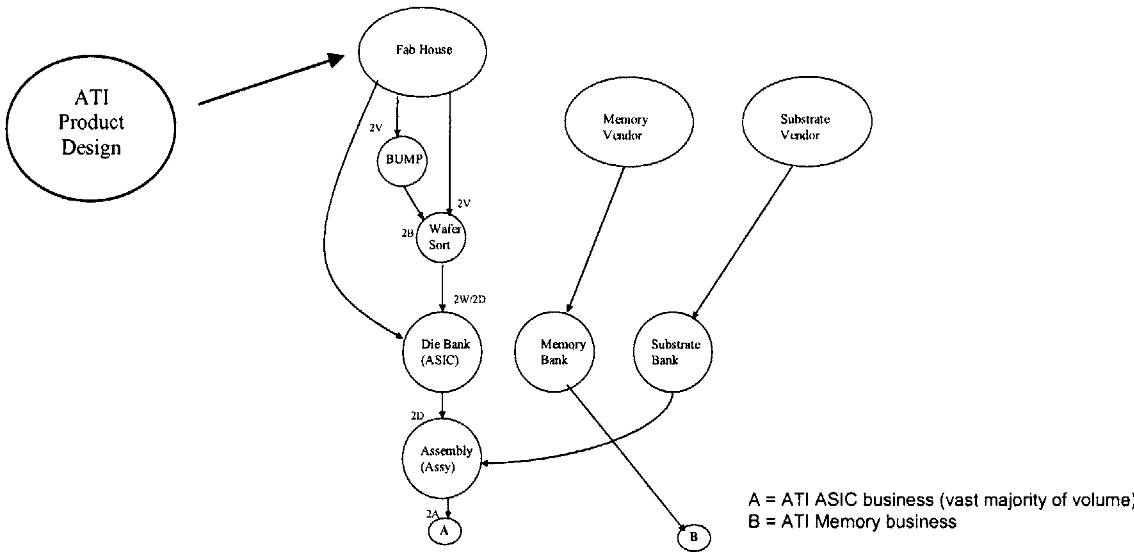

Figure 3: Typical ASIC Assembly Process

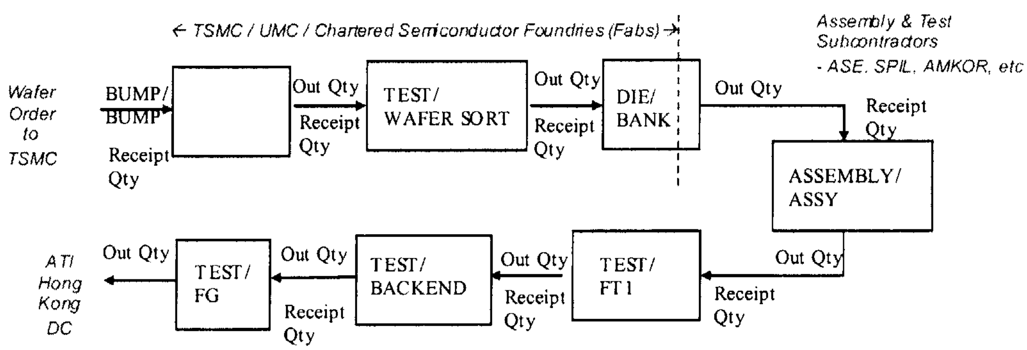

Figure 4: ATI Outsourced Supply Chain

At each work center in Figure 4, ATI supply planners track good quality and wasted inventory using product yield results and then instruct Procurement to issue work service purchase orders to supply chain partners (see also Figure 5). The supply planners update the master database with resultant inventory and build plans.

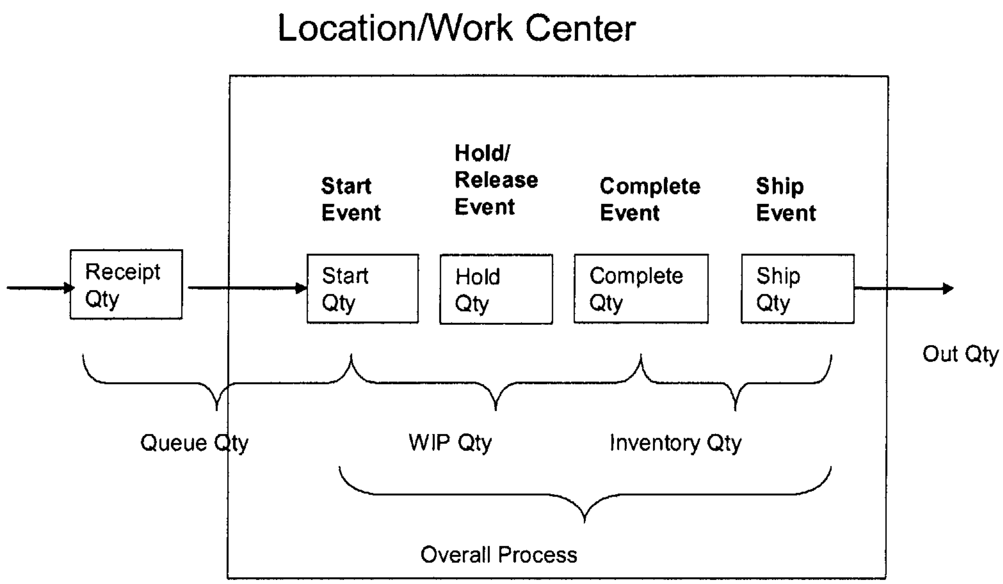

Figure 5: ATI Inventory Tracking at each Work Center

By 2006, the overwhelming majority of revenues came from ASIC sales via OEMs and channel partners. A residual minority came from ATI Board sales through distribution retail channels. However, internal systems and processes were designed for and continue to support this legacy Board model. The major ATI distribution channels are described in Figure 6 below:

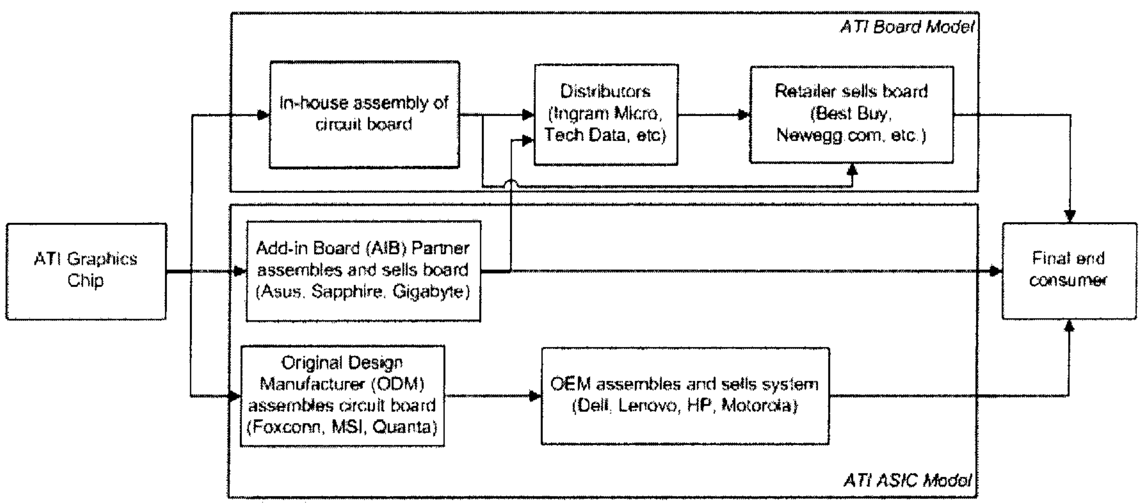

Figure 6: ATI Distribution Models (ASIC, Board)

IV. Supply Planning Strategy

In response to wafer and component order lead-time (12-16 weeks) exceeding customer order lead-time (4 weeks), ATI is officially on a build-to-forecast supply planning strategy. However, daily manual instructions override this policy and planners often respond to customer orders. Outdated and manual systems with only a weekly refresh of forecast changes contribute to this confusion. Based on benchmarking interviews conducted[2], most semiconductor industry peers operate on a build-to-forecast model through die bank, then build-to-order from die bank to finished goods.

V. Detailed View of ATI's Supply Chain

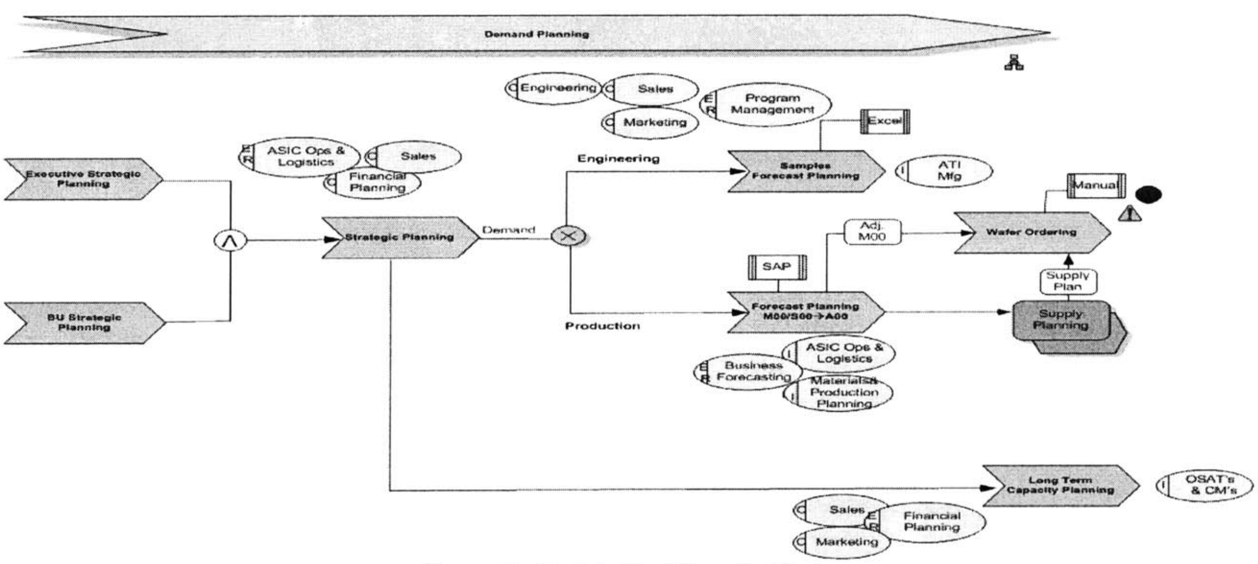

Figure 7: End-to-End Supply Chain

Although organizationally part of Finance and the Business Unit, the PCBU Forecasting Team plays a critical role in directing supply chain activities. Refer also to Figure 1. There are numerous planning, procurement and order fulfillment activities instigated by the forecast itself. The relevant Supply Chain is defined as the end-to-end process from Demand Planning through Logistics, Fulfillment and Distribution (Refer to Figure 7).

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[2] Refer to Appendix III.

VI. Sources of Variability in the Supply Chain

Consistent with well-known operations theory, there are numerous sources of variability that impact the supply chain. Management attention is usually focused on ***supply variations***, such as semiconductor chip yield, manufacturing cycle time, assembly & test cycle time and wafer order lead time. Within cycle time, there are capacity constraints at the wafer fab and with assembly and test machines that supply planners must track. Additionally, queuing times at each processing stage must be well-understood before planners commit supply quantities and schedules to the wider ATI organization.

Receiving less attention – but of equal or greater importance – are ***demand variations***. The manufacturing lead times that ATI is subject to, usually 12 to 16 weeks, exceeds customer order lead time. As such, the build-to-forecast model heavily relies on demand forecasting to plan and prioritize optimal capacity usage. With industry and ATI historical forecast error as high as 40%[3], there is a great deal of ***demand uncertainty***, demanding a more responsive and flexible supply chain.

VII. The Finished Goods Inventory Model

a) Model Objective

The Finished Goods Inventory Model is a financial, lifecycle and historical forecast error-driven reference for the PCBU Forecasting Team to validate other market analyses used to set finished goods inventory targets. Such inventory is intended to supplement baseline forecast builds to offset market demand uncertainty. A product's inventory risk level – the major model output – will justify inventory increases or decreases at monthly Executive reviews.

b) Primary Users and Owner

The primary users will be the Business Planning Managers within the PCBU Forecasting Team. The new model owner will be the Business Planning Specialist who interfaces with ASIC Operations Supply Planners to agree upon safety stock and finished goods inventory levels.

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[3] As of April 2006, ATI Internal Forecast Variance Report.

c) Frequency of Model Update

The inventory risk levels for a given product should be reviewed *monthly* for all new ASIC and board products; major cost declines tend to occur within the initial two production quarters[4]. This process coincides with the PC Business Unit's monthly demand-supply reviews at which major wafer orders are approved. For steady-state or long lifecycle products, a quarterly review of inventory risk levels is sufficient; unit cost, margin, lifecycle and forecast error data change less often.

d) Planning Levels

This model does not sit atop actual data. Rather, it is a simplified weighted criteria matrix relying on real-time user input for cost, lifecycle, margin and forecast error parameters. Thus, each time it is run, the model user can assume a different planning level, from product-family down to the most specific packaged chip SKU. For example, if planners want to determine the inventory risk associated with all RADEON 9200-family finished goods, they aggregate forecast error, lifecycle and cost statistics to reflect product family (as opposed to running model separately for each of RADEON 9200 SE and RADEON 9200 LE product SKUs).

e) Process Changes

Current Process

The Demand Planning team works with Executives and Marketing to finalize the wafer order quantity. This most critical input – having the highest cost and yield-sensitivity – is handled independently from supply planning (assembly, test) and materials procurement.

In parallel, the PCBU Forecast Team's Business Planning Managers review each product SKU and recommend a finished good stock-level quantity. This number is primarily a 'gut-feel' decision, with consideration paid to average monthly shipments, product availability, customer demand and marketing input. There are currently no financial (cost, margin) factors considered when setting these 'demand

[4] See Wafer Cost Analysis, Appendix II.

hedge' inventory levels. The Business Planning Specialist then consolidates these recommended finished goods levels into one spreadsheet and sends it to the Supply Planning team every month.

It is inconsistent whether supply planners actually respond to the demand team's finished goods recommendations. One reason may be that little rigor or justification for these finished goods inventory requests was shown, worsening the mistrust between the demand and supply teams. The supply planners are very time-constrained, having to manually schedule assembly and test times and stock buffers that offset supply chain uncertainty. Recall that supply chain 'safety stock' needs are separate from the demand team's buffer needs; supply stock is driven by yield, materials and capacity uncertainties.

Figure 8 shows the complexity of the existing decision-making process for demand and supply planning. In absence of a fully consolidated ERP/MRP supply chain IT system and with so many stakeholders involved, inconsistent planning decisions are often made by Procurement, Sales, Marketing and Supply Chain team members.

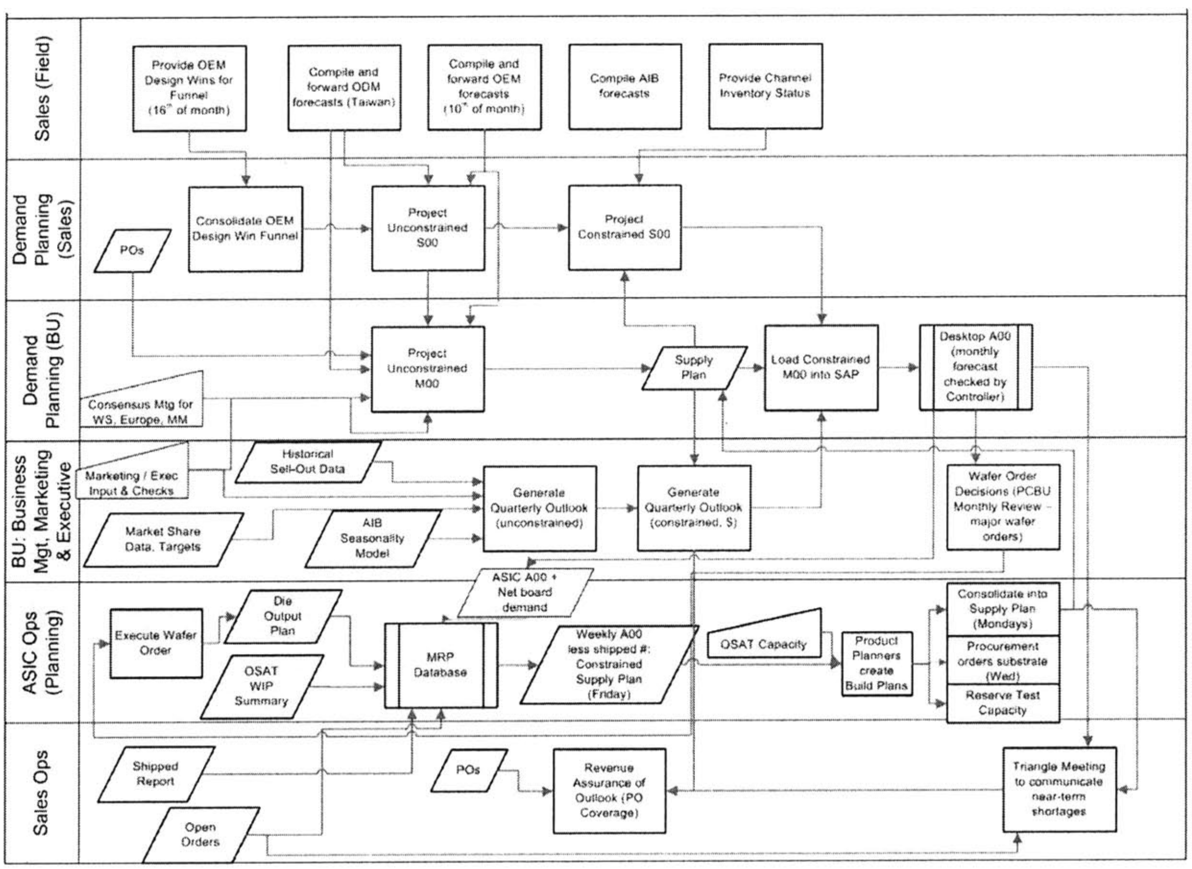


Figure 8: Existing Process for Demand & Supply Planning

Proposed Process

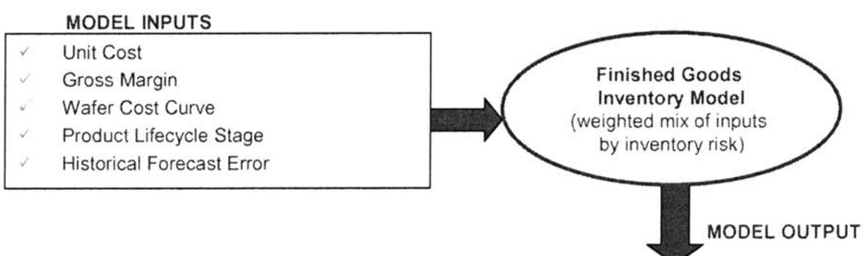
The Finished Goods Inventory Model is designed to validate the 'bottoms-up' quantities derived by demand planners by considering cost, margin, lifecycle and forecast error history. As such, the Business Planning specialist will more confidently reconcile the top-down inventory risk level and quantity (in weeks) with the planning managers' bottoms-up numbers. With this rigorous analytical approach, he is better positioned to convince the Supply Planners to agree to consistently plan for baseline forecast plus this demand hedge quantity.

f) Model Parameters

The key inputs to the Finished Goods Inventory Model are:

1. Unit Cost (COGS)
2. Gross Margin
3. Wafer Cost Curve
4. Product Lifecycle Phase
5. Historical Forecast Error

A visual model representation with sample outputs is shown below in Figure 9:



Products	Inventory Risk Level	Proposed Finished Goods Inventory
Mobile Graphics with On-chi[illegible]ory Flagship 3D Gaming [illegible]sor	5 = Highest Risk	0 to 0.5 weeks
Value Graphics f[illegible]ess PCs Legacy Proces[illegible]asino Terminals Mid-rang[illegible]ics for 3D Gamers	4 = High Risk	0.5 to 1.5 weeks
I[illegible]d Graphics Chipsets	3 = Medium Risk	1.5 to 2 weeks
Legacy Server Graphics Processor	2 = Medium-Low Risk	2 to 2.5 weeks
New Server Graphics Processor	1 = Low Risk	2.5 to 3 weeks

Sample data only

Figure 9: Inventory Model and Sample Output

The inventory risk level (output) recommends how much risk the company is willing to assume for a given product. The higher the risk level (1 through 5), the less inventory recommended for finished goods stock. Each of the five inputs to the model is described in more detail below.

Input: Unit Cost

A product's cost of goods sold (COGS) is a model input to quantify the cost of excess inventory (Co) when supply exceeds demand. High inventory risk thus lower inventory buffers are recommended for high-cost products. The model user selects from one of these four options for unit cost (in order of highest to lowest inventory risk):

- > $25
- $15 - $25 (Default)
- $7 - $15
- < $7

A product's unit cost is correlated with its inventory holding cost and the cost of over-inventory (C_o). High unit cost may also imply high profit margins, which would have an opposite, more desirable effect of typing up capital in high-cost inventory. High unit cost and low profit margin is the worst case combination and implies high inventory risk given high holding cost.

This inventory model balances the impact of cost and profit margin, among the other three inputs (wafer cost, product lifecycle and forecast error). Gross Profit Margin, as a proxy for cost of shortage or under-inventory (C_u), is discussed next.

Input: Gross Margin

Gross Margin is the model input that quantifies the cost of inventory shortage or underage (C_u) and the loss of goodwill (in terms of lost income). For instance, high profit margin products must plan relatively higher inventory levels to avoid product shortage and minimize negative net income impact.

The model user chooses one of four gross margin categories (in order of highest to lowest inventory risk):

- < 20%

- 20 – 30% (Default)
- 30 – 40%
- > 40%

Input: Wafer Cost Curve

Wafer cost is the largest cost contributor. If the wafer price is decreasing faster than average, wafer purchases (for finished goods inventory) must be delayed or decreased until wafer price drops take effect.

Based on historical wafer cost analysis, the major price drops occur within the first two quarters of production (i.e. Accelerated, Medium or Standard cost curves). Thereafter, it is unlikely that wafer prices decline more than 5% quarter-over-quarter. Timing of large wafer orders should be coordinated around this cost curve. See Appendix V on Wafer Cost Analysis[5].

The user selects from one of three Wafer Cost Curves for a given product (in order of highest to lowest inventory risk):

1. Accelerated wafer price decline
    - Initial price drop > 20% (within first two production quarters)
2. Medium wafer price decline
    - Initial price drop 10-20% (within first two production quarters)
3. Standard wafer cost curve (Default)

Additionally, the model user must determine if the product's wafer price declines have already occurred in the past. For instance, if the product is at or beyond its 3rd production quarter, the user selects an additional check box so the model defaults back to the standard cost curve. In this case, ATI should not delay wafer procurement in hopes of another impending price decline.

Input: Product Lifecycle Phase

A product's lifecycle phase is a critical model input to assess excess or over-inventory risk (Co). A product near end-of-life (EOL) must plan minimal buffer since the risk of moving excess inventory is highest. A long lifecycle product (such as cellphone, business PC or server chips) has lowest inventory

[5] See Appendix V: Wafer Cost Analysis

risk since demand will eventually consume supply. EOL and Mid-to-Late lifecycle products must never have market hedge, but NPI and long-lifecycle can sustain some level of hedging.

The user enters 1 of 4 product lifecycle phases (in highest to lowest inventory risk):

- End of Life (EOL) in less than 6 months
- Mid-to-Late Lifecycle Phase
- New Product Introduction (NPI) Phase (Default)
- Steady-state production / long lifecycle

Input: Historical Forecast Error

Forecast accuracy is an important model input. If a product line is historically over-forecasted, low inventory target levels will help prevent excess supply or over-inventory. Similarly, if a product is historically under-forecasted, higher inventory levels are sustainable to prevent loss of goodwill and profit margin (high risk of shortage or C_u).

The standard practice of calculating the % forecast error is: [(Actual - Forecast) / (Actual)] * 100. The reason for *actual demand* in the denominator is to assess how forecast deviated from the actual and not how actual deviated from the forecast[6]. This difference between the actual and forecasted demand, over a longer time period, can also be known as "forecast bias". Taking the average of multiple samples of forecast error, i.e. for *n* time periods, the mean absolute percentage error (MAPE) is a well-known measure of accuracy in a fitted time series trend[7].

$$\text{MAPE} = \frac{1}{n}\sum_{t=1}^{n}\left|\frac{A_t - F_t}{A_t}\right|.$$

To run this inventory model, an estimated +/- forecast error is needed per product.

ATI, like many other firms, employs a smoothing algorithm that compares a mean forecast with a mean actual to derive the forecast error for a given 4-month time period. Each data set has their own mean values, μ_1 = mean actual demand and μ_2 = mean forecasted demand. Assuming independence due to rampant unforeseen customer and marketing changes, a normal distribution can be assumed for each.

[6] "Answers to Your Forecasting Questions", *The Journal of Business Forecasting*. Flushing: Winter 2006/2007.Vol.25, Iss. 4; pg. 3.
[7] http://en.wikipedia.org/wiki/Mean_Absolute_Percentage_Error, April 7, 2007,

Assuming x is a normally-distributed random variable with unknown mean μ and unknown variance σ^2. The best estimate for μ is the sample mean ($\underline{x}$) based on historical demand data.

If σ^2 is unknown, it may be estimated by the sample variance s^2, which can be found for a given dataset of n samples by taking the sum of the difference between actual forecast (at time t) and mean forecast over entire time period of t=4 months.

$$S^2 = \frac{1}{n-1}\sum_{j=1}^{n}(x(j)-\bar{x})^2 : \text{ Sample Variance}$$

To make this analysis more robust, the variance about the actual mean assesses the severity and deviation of the forecast error. If not known or not tracked, it can still be estimated using n sample variances about the MAPE, the best estimator for mean error. One method to determine the confidence interval when variance is unknown is to select an appropriate sampling distribution, such as the t-distribution instead of a normal distribution[8].

In a hypothetical product example, forecasted demand mean is 7.1 million units with a standard deviation of 2.3 million. By contrast, the actual demand (shipments + open orders) has a mean of 4.4 million with standard deviation of 720,000. Hence, both the forecast and actual have vastly different deviations about their respective mean demand. Per Figure 10, the actual demand distribution is narrow, indicating that actual demand does not vary nearly as much as forecasted demand, which has a much flatter distribution. This suggests the demand team adjusts forecast numbers perhaps more erratically than necessary. Also, the mean forecasted demand varies greatly from actual demand, signaling a more fundamental data gap issue when forecasting.

An appropriate hypothesis test involves testing the *difference between sample means* and using their respective sample variances in lieu of knowing the underlying process variances.

Null Hypothesis: H_0: $\mu_1 - \mu_2 = \Delta_0$

[8] Douglas C. Montgomery, *Introduction to Statistical Quality Control*, 5th Edition, Chapter 3, pp.105-125.

Where μ_1 = sample mean of actual demand and μ_2 = mean forecasted demand, and Δ_0 target should be agreed upon as the 'forecast accuracy target'.

Test Statistic: $t_0 = (\mu_1 - \mu_2 - \Delta_0) / (\sqrt{(S_1^2/n_1 + S_2^2/n_2)})$, which is distributed as *t* with degrees of freedom given by $v=n_1+n_2-2$[9], where S_1^2 = sample variance of actual demand and S_2^2 = sample variance of forecasted demand. The sample variance is not pooled since S_1 and S_2 are not assumed equal; the variation about the mean forecast and mean actual is not equal per test data in Figures 10 and 11. Thus, an approximate 100(1-α)% confidence interval on the difference in means is given by:

$$\mu_1-\mu_2 - t_{\alpha/2,v}\sqrt{((S_1^2/n_1 + S_2^2/n_2)} \leq \mu_1-\mu_2 \leq \mu_1-\mu_2 + t_{\alpha/2,v}\sqrt{((S_1^2/n_1 + S_2^2/n_2)}$$

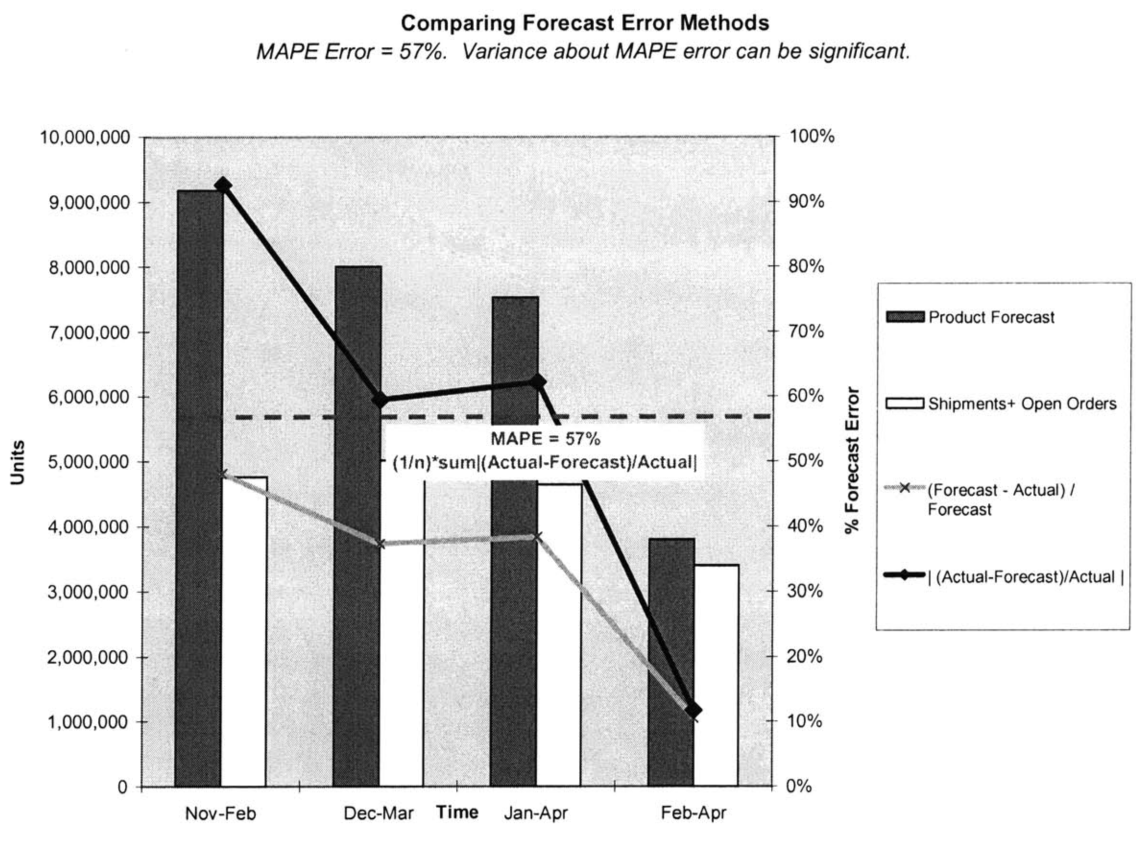


Figure 10: Comparing Forecast Error Calculations & Methods

[9] Ibid., p.120.

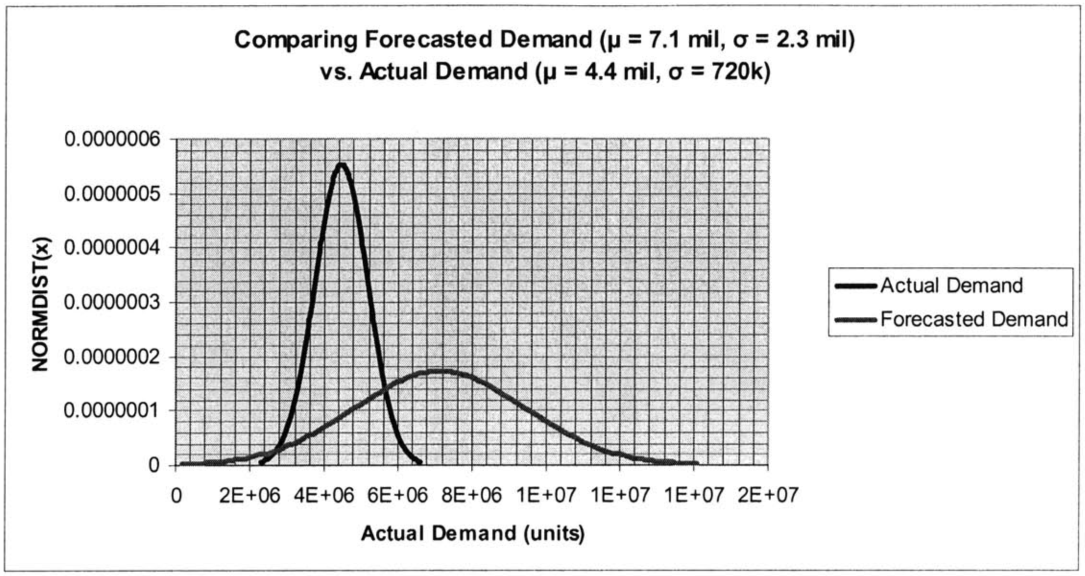


Figure 11: Forecasted vs. Actual Demand

If using *forecasted demand* as the forecast error denominator (i.e. lower line in Figure 10), experts warn that this method may favor supply chain team members because it dampens somewhat over-forecasted error[10]. The ATI forecast error, using MAPE or the supply chain-friendly method with *forecast demand* in the denominator to dampen over-forecast error, has an alarmingly wide range depending on time period, product line and method of tracking forecast accuracy. The consensus forecasted demand recorded within production lead time of 4 months (at time = t - 4) is compared with:

(a) Actual shipments (at time t)

(b) Actual shipments plus open orders (at time t)

Production and material constraints are eliminated when the metric in (b) is used instead of (a). Data analysis of historical results proves that MAPE is indeed higher than ATI's method for product lines severely over-forecasted and under-calls error for historical under-forecasting.

As shown later in the *Academic Support for Model Thesis* section, ignoring open orders in inventory and order policy creates an unstable supply chain with highly variable inventory levels[11]. So ATI must be cautious when responding to forecast error metric (a). It is very noteworthy that

[10] "Answers to Your Forecasting Questions", *The Journal of Business Forecasting.* Flushing: Winter 2006/2007.Vol.25, Iss. 4; pg. 3.

[11] Kai Hoberg et al, "Analyzing the effect of the inventory policy on order and inventory variability with linear control theory", *European Journal of Operational Research*, 176 (2007) pp. 1620-1642.

semiconductor forecasting and inventory model successes, such as at ON Semiconductor, avoid MAPE error calculations and reporting, in favor of well-understood inventory performance metrics, such as days of inventory[12].

Despite numerous statistical distributions available to determine the precise forecast errors, this inventory model *greatly simplifies its usage of forecast error data* because:

1) Historical and current data exhibit huge variation between forecasted and actual demand (in both directions). Based on this, for ATI, the mean error is statistically more relevant than the variance about each mean.
2) There is an inconsistent understanding and definition of forecast error (MAPE, etc.) internally and externally. Simplicity is critical to ensure this model is adopted.
3) Industry success stories (i.e. ON Semiconductor) heavily favor well-understood inventory performance metrics over reporting and reacting to exact forecast % errors.

Therefore, this inventory model focuses on the delta between the *mean* actual and *mean* forecasted demand, rather than on the variations about each mean. The proposed inventory model considers an individual product line's forecast error to reflect how well a demand planner is forecasting within lead time the actual customer demand. The exact percentage error is less relevant than the relative and consistent over- or under-forecast errors. The model user inputs one of four forecast error buckets (in order of highest to lowest inventory risk):

- > +20% High over-forecast error
- 10 to 20% Medium over-forecast error
- -10% to +10% Minimal forecast error
- < -10% High under-forecast error

These buckets were determined using industry and interview benchmark data on forecasting best practices[13].

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[12] Tim Williams, "Forecasting Journey at ON Semiconductor", *The Journal of Business Forecasting*, Spring 2006, pp.29-30.
[13] See Appendix III (d): Benchmarking Findings.

Input: Parameter Weightings

This model is a simplified weighted criteria matrix to determine the inventory risk level of a given product family or SKU based on user input parameters. The user can adjust the default weightings if applicable (Refer to Table 1). For instance, if historical forecast error data is not available, that category weight should be set to zero.

Input Parameter	Default Category Weights
1. Unit Cost (COGS)	2x
2. Lifecycle Stage	3x
3. Gross Margin	1x
4. Historical Forecast Error	2x
Sum of Default Weights	8x
Default Total Score	32 (8 x 4 = highest risk score)

Table 1: Input Parameters and Default Weights

g) Model Calculations

As described earlier, the model computes a product's total inventory risk *score* based on the *sumproduct* of input parameter scores (1,2,3 or 4) and category weights (2x,3x,1x,2x is default).

For instance, if all default settings are used (shown in shaded boxes in Table 2), the total score is 2*3 (COGS) + 3*2 (Lifecycle) + 1*3 (Margin) + 2*2 (Forecast Error) + 0 = 19. A score of 19 out of a maximum total score of 32 outputs a *Medium* Inventory Risk Level. By default, the model advises 1.5 to 2 weeks of finished goods (see Table 3).

Additionally, if the Wafer Cost Curve is *Medium* (score of 1) or *Accelerated* (score of 2), the weighted total score's Inventory Risk Level is advanced by 1 or 2 risk levels respectively. For instance, if the initial score indicates Medium Inventory Risk but the wafer cost curve is *Accelerated*, the final risk level advances from Medium → High → Highest Risk. This only takes effect if anticipated wafer cost declines have not yet occurred, i.e. the product is within its first two production quarters.

Criteria Weights ->	2	3	1	2	0
Inventory Risk Scores	**COGS**	**Lifecycle**	**Margin**	**Forecast Error**	**Wafer Cost Curve**
Score of 4 =	> $25	EOL in < 6 mos	< 20%	> +20%	N/A
Score of 3 =	**$15-25**	Mid to Late Lifecycle	**20-30%**	10 to 20%	N/A
Score of 2 =	$7-15	**NPI Initial Launch**	30-40%	**-10% to +10%**	Accelerated
Score of 1 =	< $7	Steady-state / long lifecycle	> 40%	< - 10%	Medium

Table 2: Criteria Weights and Input Parameter Options

h) Model Outputs

The model output is an Inventory Risk Level (1 to 5) for a given product, based on the total score computed using the weight input parameter scores (Cost, Lifecycle, Margin and Forecast Error). Associated with each inventory risk level is a Proposed Finished Goods Inventory Level expressed in weeks. The five inventory risk levels by total score are shown in Table 3.

Total Risk Score (using Default Weights)	Inventory Risk Level	Proposed Finished Goods Inventory
28 to 32 (max)	5 = Highest Risk	0 to 0.5 weeks
23 to 27	4 = High Risk	0.5 to 1.5 weeks
18 to 22	3 = Medium Risk	1.5 to 2 weeks
13 to 17	2 = Medium-Low Risk	2 to 2.5 weeks
8 (min) to 12	1 = Low Risk	2.5 to 3 weeks

Table 3: Model Outputs (Inventory Risk Levels) based on Total Score

i) Model Test Case Scenarios

Test case results are shown in Table 4 to validate the model's consistency with external analyses by the PCBU Forecasting Team.

Products used for Model Testing	Cost (2x)	Product Lifecycle (3x)	Gross Margin (1x)	Historical Forecast Error (2x)	Wafer Cost Curve (0, 1 or 2)	Total Score	Inventory Risk Level (default score buckets)	Proposed Finished Goods Inventory
Mobile chip with memory	2	4	3	4	1	32	5 = Highest Risk (28 to 32)	0 to 0.5 weeks
Desktop midstream	3	3	4	3	1	30		
Desktop enthusiast board	4	4	1	3	1	32		
Desktop value chip	2	4	3	3	0	25	4 = High Risk (23 to 27)	0.5 to 1.5 weeks
Embedded display legacy controllers	3	4	2	2	0	24		
Northbridge controller with graphics	2	3	3	3	0	22	3 = Medium Risk (18 to 22)	1.5 to 2 weeks
Mobile Northbridge controller	2	2	4	2	0	18		
Legacy server chip	1	2	1	2	0	13	2 = Medium-Low Risk (13 to 17)	2 to 2.5 weeks
Southbridge controller	1	1	4	3	0	15		
Next-Gen server controller	1	1	1	1	0	8	1 = Low Risk (8 to 12)	2.5 to 3 weeks

Table 4: Model Test Case Results

As expected, high-cost, short-lifecycle products that are not forecasted well exhibit higher inventory risk than do long-lifecycle, lowest-cost products.

j) Key Assumptions for Model

1. This model is intended to quantify the finished goods buffer created to offset *market demand* uncertainty. As such, the calculation of "safety stock" required for cycle time, capacity, manufacturing lead time and yield variations is handled separately by the individual supply planners.
2. This model simply categorizes products by inventory risk. Thus, it should be used in conjunction with relevant external analyses to set actual quantities. The user can translate Inventory Risk Level output into any inventory level (in weeks) and quantity. For example, the team may determine that Highest Inventory Risk products for fiscal year quarter 1 (seasonally the highest

demand quarter) warrant 2 weeks of finished goods stock (rather than 0 to 0.5 weeks per the model).

3. There is no automatic or direct actions taken from this model's output. The business planning specialist reconciles this model's recommendation (in Inventory Risk Level and # of weeks) with existing analyses and executive discussions, then provides finished goods quantity levels – at the product SKU level – to the supply team via Excel, for input into the master MRP database.
4. The PC Business Unit will continue to manage wafer cost negotiations and procurement decisions. Wafer cost continues to be the primary component of unit cost, but its variability and cost curve is now more predictable using the historical analysis incorporated into the model.

VIII. Academic Support for Model Thesis

a) Inventory Theory and Policies

There is a vast amount of research literature on both stochastic inventory models and linear control theory. In developing the model for ATI, both theories are relevant. First, stochastic inventory models are very useful for optimal inventory policies such as order quantity with stationary demand. But linear control theory is argued to be more suitable for arbitrary or harder-to-predict demand[14] more relevant to short lifecycle semiconductors like ATI's graphics processors.

The bullwhip effect is the phenomenon observed when demand variations are amplified as one moves upstream in the supply chain (further from the customer)[15]. Academic studies of the bullwhip effect in the frequency domain argue that all operationally efficient inventory policies trigger the bullwhip effect, independent of the demand process. However if future order commitments are included in a firm's policy, then supply chain variations can be dampened or eliminated[16].

A firm's inventory policy has a dramatic effect on the variability of order quantities and inventory levels. As such, for firms like ATI whose demand is forecast well in advance of customer orders, it is critical to put thoughtful diligence into inventory policy and its impact on supply chain. For instance, an 'inventory on-hand policy' sets order quantities in response to existing on-hand inventory but ignores open orders. Dell, for example, chooses an inventory target of 10 days demand, based on the cover time concept to hedge demand uncertainty[17]. ATI historically targeted 2-3 weeks of demand to hedge

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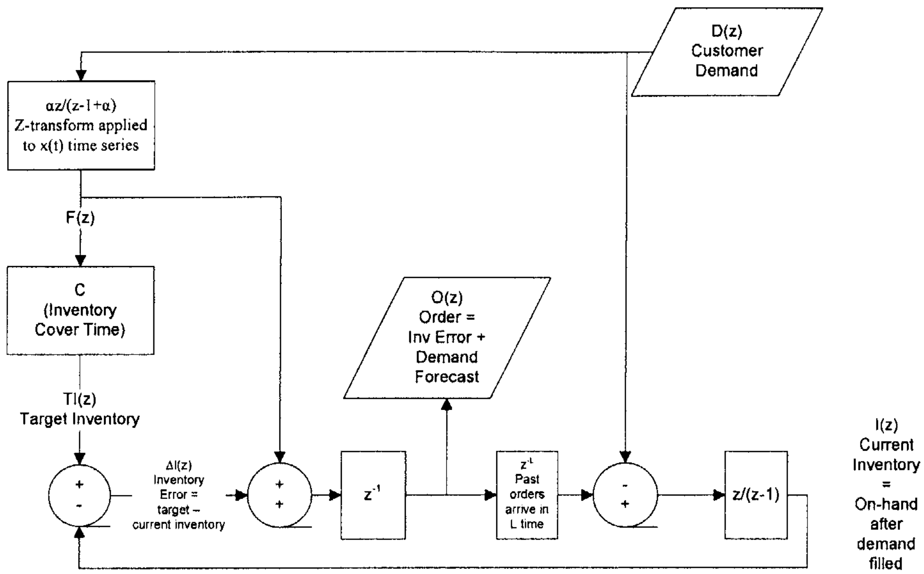
[14] Kai Hoberg et al, "Analyzing the effect of the inventory policy on order and inventory variability with linear control theory", *European Journal of Operational Research*, 176 (2007) pp. 1620-1642.
[15] http://en.wikipedia.org/wiki/Bullwhip_effect, April 2007.
[16] C. Daganzo, Y. Ouyang, *Characterization of the Bullwhip Effect in Linear, Time-Invariant Supply Chains*, Management Science, Vol. 52, No. 10, October 2006, p.1545.
[17] R. Kapuscinski, R.Q. Zhang, P. Carbonneau, R. Moore, B. Reeves, *Inventory decisions in Dell's supply chain,* Interfaces 34 (3) 2004, pp. 191-204.

uncertainty. A typical inventory on-hand policy is shown below in Figure 11 assuming the inventory system is transformed into the frequency domain using the z-transform[18].



Block Diagram of Inventory-on-hand policy

Figure 12: Inventory On-Hand Policy

- Target inventory (*ti*) is computed as $ti = f_t{*}C$ where
  - f = demand forecast
  - C = inventory cover time, i.e. 2 weeks (of demand to hedge uncertainty)
  - L = lead time
  - I_t = current inventory
- Inventory Error = $\Delta i_t = ti_t - I_t$
- Order quantity $O_t = \Delta i_t + f_t$
- After order is placed, the demand ordered previous with leadtime L arrives and actual demand D_t occurs.
- Any mismatch of available inventory and actual demand results in a backorder.

However, research indicates that if stochastic inventory policy is analyzed using linear control theory, inventory is unstable for any positive lead times [19]. The implication from this simplistic inventory policy is that small demand variations, inevitably occurring in long lead time products like semiconductors, cause uncontrollable order and inventory oscillations. Ignoring open orders with increasing lead times create unbounded oscillation in an uncontrollable supply chain.

[18] Kai Hoberg et al, "Analyzing the effect of the inventory policy on order and inventory variability with linear control theory", *European Journal of Operational Research*, 176 (2007) pp. 1622-1625.
[19] Ibid, pp.1629-1630.

To stabilize a supply chain's response to demand variations, base-stock inventory policies have proven more attractive. Base-stock policies are used where order cost are very low when compared to inventory holding costs. Since graphics processors are relatively small items, creating an inventory policy for ATI starting with base-stock theory makes sense. The main difference is the incorporation of open order information into setting inventory levels. Installation-stock and Echelon-stock inventory policy differ by incorporating local or system-wide information, respectively. Since ATI's outsourced supply chain is largely managed by internal ASIC operations team members, assuming system-wide information in an Echelon-stock inventory policy is a wise choice. With this, target inventory positions are computed by extending demand forecasts over lead times and inventory cover times of downstream stages:

Target inventory (ti) at Echelon $= f^{*}\Sigma(L+C)$, *sum of all downstream stages*

The proposed inventory policy as demonstrated by this model is for ATI is to differentiate their cover time requirements for different products (expressed in # of weeks finished goods stock).

An alternative way to understand this model is in terms of its differentiated *service levels*[20]. Basically, high-risk products are assigned a lower service level target than low-risk products. In reality however, since product lifecycle is such a dominant input factor for ATI, the incoming demand on a high-risk product should be lower and hence the lower service-level target seems an acceptable starting point for internal debate.

b) Industry Case Study to Support Inventory Model

Between the late 1990s and 2005, ON Semiconductor – previously Motorola's Semiconductor Components Group – designed and implemented an award-winning inventory optimization tool that is now fully integrated into their supply chain. With a clear lack of forecast metrics and incentives, ON Semiconductor first moved the forecasting team into the supply chain organization. It then suffered from disruptive, frequent 'forecast overrides' from Business Unit groups. An incentive-driven, consensus-

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[20] M.A. Cohen, V. Deshpande, K. Donohue, "Threshold Inventory Rationing Policy for Service-Differentiated Demand Classes", *Management Science*, Vol. 49, No.6, June 2003, pp. 683-703.

based forecast model emerged, with input and accountability from sales and marketing. The linear programming engine that drove supply chain planning was initially separate from the demand model used to set safety stocks[21]. These early issues are exhibited today at ATI Technologies.

Central to the independently-designed inventory model for ATI, ON Semiconductor's "ABC product rank" classifies products by their customer service levels based on revenue and strategic importance. Differentiating products is a critical foundation for ON's Inventory Optimization Tool which eventually integrated demand and supply needs to generate an unconstrained factory forecast[22]. ON Semiconductor's 2005 model enhancements now utilize ABC product rank, product lifecycle and forecast error to determine optimal safety stock based on customer service level[23]. Again, these very parameters (and others, such as wafer cost and gross margin) are critical factors in the ATI model.

Finally, ON management realized that forecast error metrics, such as Weighted Mean Absolute Percentage Error (WMAPE) were not well-understood among senior managers and decision-makers. Not only did error percentages convey forecast team incompetence, ON also believe that process effectiveness must be measured in terms of business metrics and Key Performance Indicators (KPIs), such as days of supply and dollar ($) of inventories[24].

This thesis presents an inventory model for ATI that is created with existing literature on demand and supply planning in mind. The sales and operations planning process – a well-known concept of regular, executive-level meetings to make decisions based on demand and supply uncertainties and constraints – is a necessary part of this model's full impact at ATI. When implemented with full participation, an S&OP process will improve trust and communications among stakeholders, increase demand accuracy and right-size inventory levels[25].

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[21] Tim Williams, "Forecasting Journey at ON Semiconductor", *The Journal of Business Forecasting*, Spring 2006, pp.29-30.
[22] Ibid., pp.30-31.
[23] Ibid., p.31.
[24] Ibid., p.32.
[25] *In praise of inventory*, Art Raymond FDM; Jan 2006; 78, 1; ABI/INFORM Global pg. 26.

As ATI uses this model to demonstrate its rigor in requesting inventory levels throughout its supply chain, it can also increase its negotiating leverage over its ever-so-powerful manufacturing partners[26]. If a firm can better quantify probabilistic risk (of demand uncertainties) with its suppliers, it can negotiate better contracts[27]. By consistently justifying its varying inventory levels and mix using this model, ATI can strive towards the coveted 'single-number-forecast' goal, eliminating redundant inventory buffers throughout its supply chain.

IX. Research Methodology for Entire Project

The methodology used to complete the project is shown below:

1. Complete an 'As-Is' process mapping exercise using 20 internal interviews to understand the current Demand and Supply Planning process[28].
2. Conduct 15 benchmarking interviews in demand & supply planning and semiconductor industry[29].
3. Identify process and decision-making gaps to qualify the need for a financial, forecast-error and lifecycle-driven Inventory Model
4. Determine appropriate structure of decision-making model by collaborating with PCBU Forecasting Team and supply chain stakeholders[30].
5. Leverage knowledge through workshops as the business unit lead for the Supply Chain Core Team.
6. Meet frequently with operations, finance, executive and BU stakeholders to create and analyze relevant test case scenarios, making necessary adjustments to improve usability of model.
7. Ensure knowledge transfer and model usage to the Demand Planning team by overseeing two months of implemented usage by team.

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[26] Refer to Appendix I: Industry Strategic Analysis.
[27] *Demand visibility improves demand forecasts,* Jared Schrieber, The Journal of Business Forecasting; Fall 2005; 24, 3; ABI/INFORM Global pg. 32.
[28] Refer to Appendix II: Internal Process Mapping & Interview Findings.
[29] Refer to Appendix III: Benchmarking: Approach, Interview Sources & Questions and Findings.
[30] Refer to Appendix II, III.

X. Recommendations for ATI Technologies

The following observations and recommendations were shared with ATI's General Managers, CFO and SVP of Operations at the end of the internship. An MIT Sloan School of Management's *Three Lenses* analysis is in Appendix VI.

Observation	Recommendations
1. Forecasting team indirectly receives market and customer data.	• Assign forecast accuracy ownership to marketing. • Provide cost and margin data to inventory decision makers • Systematize marketing information sharing outside of ad hoc emails (intranet, regular meeting, etc) • Resource the forecasting team by revenue impact - not by product/BU
2. ATI's model adds significant churn and extra work throughout supply chain.	• Consider re-assigning wafer decisions from BU to Procurement • Re-communicate A00 definition • Assess opportunity to scale back micro-management of material
3. Inventory owner and strategy is unclear: • Supply and capacity planners plan for on-time delivery and safety stock • Operations finance assesses inventory provisions/write-downs • Board operations has inventory control team • PCBU forecasting group proposes FG buffer levels and A00 consolidated forecast • Business mgt/product mgt tasked with moving excess inventory through deals • Procurement does not order inventory	• If ownership and strategy exists – communicate more widely within ATI. • If not, create central corporate inventory team with proper incentives and authority
4. Unable to identify ATI's end-to-end supply chain strategy.	• BU and Ops must agree upon and widely communicate ATI's supply chain strategy (build-to-forecast, die bank, finished goods strategy, etc). • Align performance incentives • Central dashboard for terminology, definitions and operating model
5. Need to create quantitative goals that can be impacted by team member.	• Agree upon current forecast accuracy performance

Observation	Recommendations
	• Set future quantitative goals that forecasting owners can own, impact and achieve
6. Invest accordingly in IT systems upgrades.	• Opportunity to leverage AMD forecasting and MRP systems if ok • Process discipline and change management are most underestimated challenges • Review benchmarking results – many top peer firms do **not** have top notch IT systems but operate more efficiently. • Ensure 'change agents' are empowered directly and indirectly

XI. Conclusion

There is a delicate risk and cost balance between the inventory shortage and excess in the high-risk, high-volatility PC and Consumer Electronics markets which ATI serves. Each product's target inventory level depends on a weighted mix of its unit cost, gross margin, lifecycle stage and forecast error. In the semiconductor business, long production lead times place huge responsibility on Demand Planning teams to accurately forecast customer demand to direct ATI's outsourced supply chain. To foster intra- and inter-company trust among demand and supply chain stakeholders, the Demand Planning team can demonstrate thoughtfulness and rigor when requesting inventory mix and levels from its supply team. This decision-making model and the accompanying internal process changes will help ATI 'right-size' its inventories while keeping customer satisfaction and financial performance as top priorities.

Looking Beyond 2006

As ATI Technologies is now integrated into a much larger semiconductor manufacturer, Advanced Micro Devices (AMD), it is even more imperative to have rigorous and clear decision-making processes in the combined organization. Inventory mix and level decisions should always be made with cost, lifecycle, profit and forecast error in mind. The supplier power threat to which ATI was vulnerable is lessened with AMD's foundry expertise and facilities. An efficient internal and external demand and supply planning process is more critical than ever as ATI's business diversifies and grows within a much larger organization now.

Appendices

I. Industry Strategic Analysis
II. Internal Process Mapping & Interview Findings
III. Benchmarking: Approach, Interview Sources & Questions and Findings
IV. Actual View of Inventory Model
V. Wafer Cost Curve Analysis
VI. Three Lenses Analysis

Appendix I: ATI Technologies: Industry Strategic Analysis

Rivalry/Competition – HIGH THREAT

- Innovation and product leadership benefits are short-lived, with typical lifecycles ~9-18 months
- If ATI does not capitalize with sufficient market supply, customers will quickly switch to competitors (relatively low switching costs)
- Main competitor has the same supply chain partners in their outsourced model

Supplier Power – HIGH THREAT

- Primary competitor has the same supply chain partners in outsourced wafer manufacturing, assembly & test packaging process
- But graphics processors is low percentage of wafer fab's overall diversified business so their negotiating leverage is high

Barriers to Entry – MEDIUM THREAT

- High intellectual capital required to design leading graphics processors
- But high-volume multimedia chip design is becoming more mainstream/commoditized with more competitive players entering (Intel, TI etc)
- Outsourced manufacturing means lower capital investment outlay rests on fabless firms

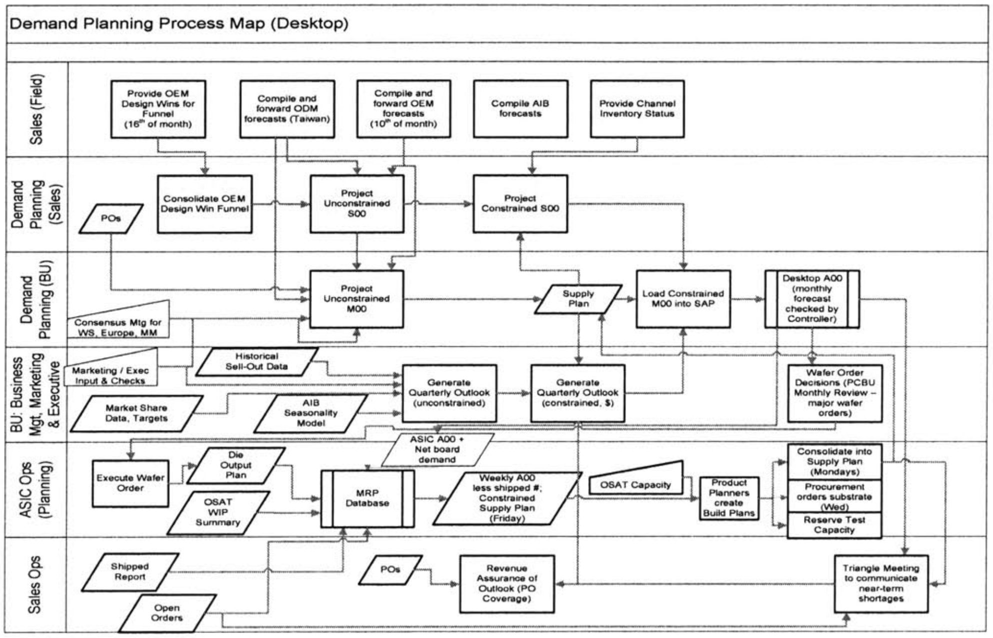
Buyer Power – LOW THREAT

- In PC business, ATI and one other notable competitor used dominate the graphics space, but Intel now offers low-cost alternatives (there are 3 graphics suppliers from which to choose)
- PC makers are consolidating so top 5 players dominate the volume of business, but they have little choice for graphics technology

Substitutes – LOW THREAT

- Every PC needs a graphics controller with the advent of 3D gaming, Windows Vista™ Operating System and video and multimedia applications

Appendix II: Internal Process Mapping & Interview Findings



<u>Internal Interview Findings</u>

- Central PCBU Forecasting team was created in September 2005
    - \$61M inventory write-down FYQ405 prompted need for one focused team
    - Forecast metric tracking began in Oct 2005 (vs. shipments, open orders)
    - Limited resources assigned to complex, data-intensive manual process
- Historical error not being captured for use as future demand input
- Market models not always incorporated into forecast
- Safety stock decisions are not centralized or rigorously determined
    - Forecast accuracy should be explicitly linked to inventory excess/shortage (historical data analysis underway)
    - Inventory is owned by Business Unit with frequent order changes by Operations
- Per-customer judgment is 'gut-feel' and is not centrally captured for new planners
- Lots of executive over-ride, especially with wafer-ordering
- Sales & Operations Planning process is weak in constraining build forecast

Appendix III: Benchmarking: Approach, Interview Sources & Questions and Findings

Appendix III (a): Benchmarking Approach

- Objective
    - To benchmark ATI's Demand Planning process with other firms (semi- and non-semiconductor).

- Benefits
    - To provide baseline and justification for process changes in area of Demand and Supply Planning.
    - To appropriately scope Demand Planning thesis project for ATI benefit.

- Interviewed 10-15 MIT alumni, ATI and personal contacts involved with:
    - Demand planning/forecasting in any industry OR
    - Supply/capacity planning in the semiconductor industry

- Discussion Topics with Interviewees (See Appendix III (c)):
    - Forecast methodology & inputs
    - Inventory effort of accuracy
    - Frequency of sales updates
    - Which metrics are used? Tied to incentives or not?
    - Interaction between Supply and Demand Planners
    - MRP Software vs. Excel (automated vs. manual)
    - Outsourcing production concerns
    - General thoughts on process effectiveness
    - Capacity decision making

Appendix III (b): Interview Sources

Benchmarking Interview Sources	Interview Date
Dell, Foxconn	2/22/2006
HP, Apple	4/4/2006
Intel - CPU supply forecasting, Capital One	4/5/2006
Intel, Adidas-Solomon	4/6/2006
Qualcomm	4/7/2006
DEC, Axcelis	4/7/2006
Dell	4/11/2006
P&G, Raytheon	4/13/2006
Intel - Supply Chain Planning	4/21/2006
Qualcomm	4/21/2006
Qualcomm, LSI Logic	4/21/2006
Intel - MMBP Forecasting	4/26/2006
Intel	4/28/2006

Appendix III (c): Benchmark Interview Questions

Introduction: My thesis project is focused on forecasting and demand planning's effect on inventory and supply chain decisions.

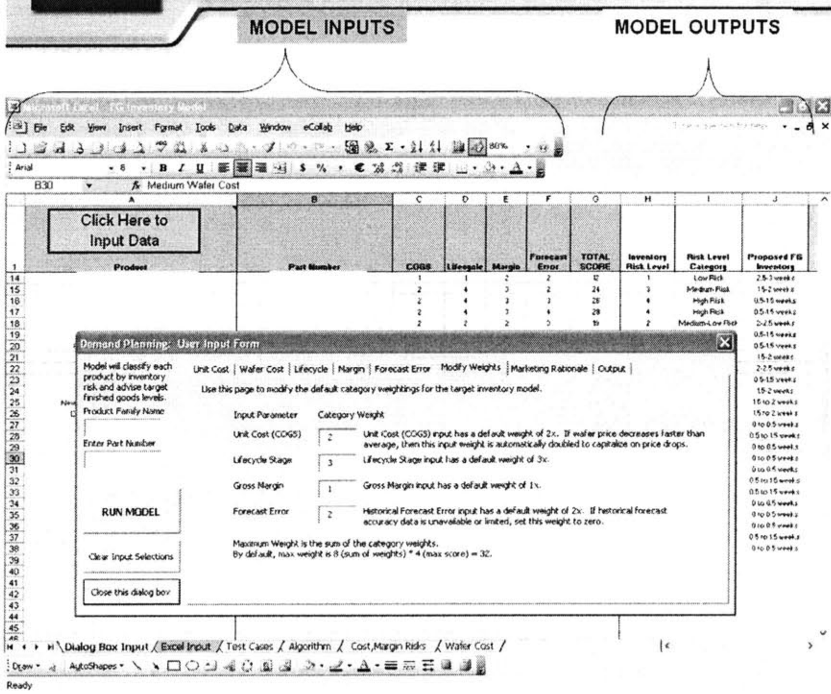
1. Does Company X own its manufacturing facilities? In your opinion, what are the pros and cons of owning the production facilities?
2. How many different forecasts are inputs to the MRP? Is a consensus process used (if so, between whom?)?
3. Are both statistical and historical methods used as inputs? What about seasonality? How relevant is the past in determining the future of Company X's business?
4. How does one plan for end of fiscal quarter demand spikes when these times differ from customers/end user demand spikes?
5. How closely should build forecasts be tied to financial guidance (in your opinion)?
6. How did benchmarking help in your thesis? Any guidance on how to structure info collection?
7. What sort of software tools were evaluated for planning groups? Successful or not? ("Avoid the tool trap" warnings are everywhere)
8. How were the stakeholders organized? Supportive or not of your project?
9. What were the key metrics used (if any)? How rigorously were they incorporated into HR incentives? Were these metrics 'fair' and 'widely published'?
10. To the best of your knowledge, were your changes/process recommendations implemented? Are they still used today? Why or why not?
11. What would you have done differently?
12. What were your biggest barriers/challenges? How did you deal with them?
13. ATI is a fabless semiconductor firm. What processes would remain the same, or differ if production facilities are not owned by firm?
14. How "accurate" is considered acceptable for demand forecasting? Who owns it (BU or Sales, or how did they interact to sanity-check the forecast?)
15. Software used for planning / DP Forecasting / MRP / execution? (Oracle, SAP, standalone DP/ERPs)? Are they 'user-friendly', or lots of manual touch points?
16. Any guidance on quantifying and controlling the inventory impact of forecast accuracy?
17. General thoughts on LFM and its role in your career track to date.

Appendix III (d): Benchmark Findings

- Corporate Business Model drives supply chain and forecasting processes
  - Retail commodity differs from build-to-order and build-to-forecast
- Historical and market models formally incorporated into forecast
  - Usually a central owner or group for both forecast and allocation
  - Varying interactions between demand and supply planning groups
- End-to-end supply chain process flows from Business & Market Strategy
  - Especially the link between forecast accuracy and inventory decision-making
  - Clear definitions for revenue/margin links and MRP inputs are required
  - Most firms lack sophisticated, enterprise-wide MRP system and rely on Excel
- **~20-30% forecast inaccuracy** is considered an acceptable target among peers
  - Demand should only be updated if changes fall outside of target accuracy range
- Use of *different* forecasting methods within single firm is common
  - Method often depending on product lifecycle, variability and velocity (turns)
  - **ATI should categorize products relevantly**
- Disciplined use of metrics in forecasting and supply chain is required
- Analytical data facilitates **good discussion** between Demand & Supply teams

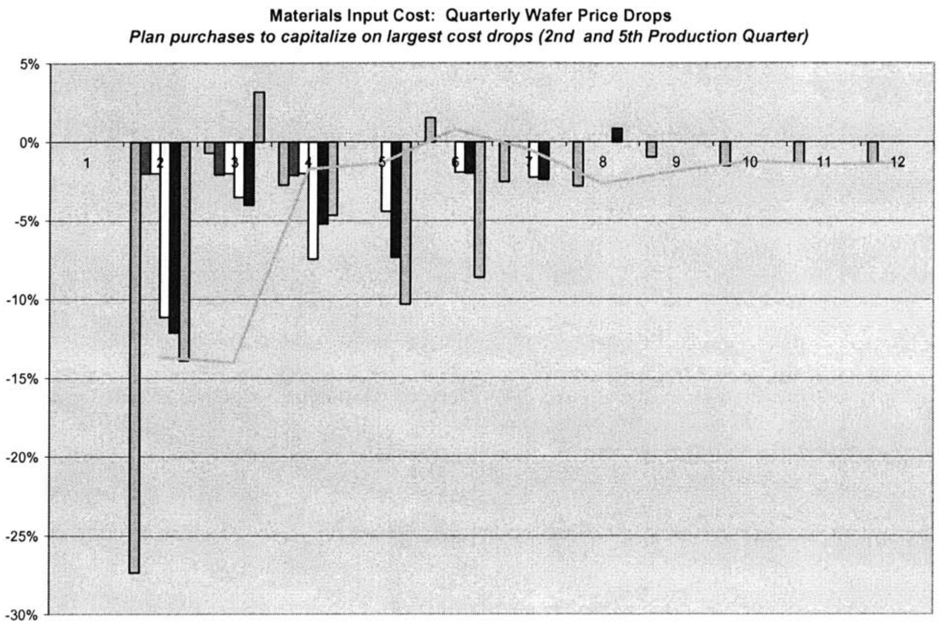
Appendix IV: Actual View of Inventory Model

Actual View of Inventory Model



- 5 User Inputs:
  1. Cost
  2. Wafer Cost Curve
  3. Lifecycle
  4. Margin
  5. Forecast Error
- Optional Inputs:
  - Override default weights
  - Marketing Rationale
  - BU guidance/ instructions
- 3 Model Outputs:
  1. Inventory Risk Level (1, 2, 3, 4 or 5 = highest)
  2. Risk Level Category (Low, Medium-Low, Medium, High, Highest)
  3. Proposed Inventory Levels (BU buffer) (# of weeks)

Appendix V: Wafer Cost Curve Analysis



Wafer costs comprise the majority of a given product's unit cost. The manufacturing of this materials input into ATI's supply chain is handled by Taiwan Semiconductor Manufacturing Corporation (TSMC) and other notable foundries based in Asia. As shown, a typical graphics processor's wafer prices charged to ATI will drop significantly by the 2nd quarter of production. This is due to economies of scale and scope incurred by the foundry as well as rapidly maturing fab technology resulting in better output yield.

Also, historical analysis of ATI's wafer pricing show a strong correlation between wafer price and total number of layers of a given ASIC product:

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.911225
R Square	0.83033
Adjusted R Square	0.828928
Standard Error	743.0787
Observations	123

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	326965580.2	3.27E+08	592.1509	1.95139E-48
Residual	121	66812081.16	552166		
Total	122	393777661.3			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-7399.527	438.3819934	-16.87918	1.36E-33	-8267.419559	-6531.634	-8267.419559	-6531.63401
X Variable 1	328.9462	13.51788093	24.33415	1.95E-48	302.183949	355.70837	302.183949	355.7083699

The inventory model allows the user to input whether a given product is on an accelerated, medium or standard cost curve. A product whose 2nd quarter price drop is imminent should never be over-ordered since the input cost is rapidly declining. The product lifecycle stage and process technology are the primary factors to adjust the inventory risk level by the wafer cost curve risk.

Appendix VI: Three Lenses Analysis

Strategic Lens Analysis

Based on ATI's organizational structure including two business units and a central operations function, there are notable strategic gaps as the PCBU Forecasting Team sets each product's inventory levels. Beside each gap is a proposed process, systems or organizational solution.

Strategic Lens Gap	Proposed Solution(s)
1. The PCBU Forecasting Team is responsible for consolidating forecast inputs. However, this team reports into Finance and not into product marketing, pricing or sales. They own the analysis of macro-market and customer-based demand signals, but rely heavily on second-hand information not interfacing with customers directly. Further, the forecasting team does not currently have access to wafer cost or margin data – critical inputs when determining target inventory levels that are designed to offset demand uncertainty. Therefore, the separation of forecasting from marketing and sales contributes to high forecast error – the primary cause of over-inventory.	➢ Provide cost and margin data to forecasting team decision makers ➢ Systematize marketing information sharing outside of ad hoc emails (intranet, regular meeting, etc)
2. Silicon wafers are the largest cost contributor to a graphics processor. However, wafer decisions are not owned by the Supply Chain. Rather, foundry deals are made by the CEO, strategic operations or BU executives. Wafer purchase quantities are determined by marketing executives and merely executed by supply planning (note: not Procurement, whose core expertise is securing favorable pricing deals). As such, the supply chain's largest cost component – its die bank inventory - is instigated by people external to the supply chain.	➢ Assign wafer procurement execution to the procurement team. ➢ Consider supply chain ownership of wafer quantity decisions.
3. Inventory process and ownership is lacking and incentives may not be aligned. While product inventory appears on each business unit's balance sheet, there are many disparate groups with autonomy to create or move inventory: b) The supply planners are expected to meet on-time delivery (OTD) metrics as their top priority. In doing so, finished goods inventory may be packaged from die bank into the wrong SKU too early, or the planner may hold extra inventory to offset spikes in customer orders. This often results in excess inventory. c) The operations finance group has an inventory team responsible for valuing excess inventory and write-downs. This group also works with engineering to value fall-out inventory (not insignificant) and determines resale potential. This group approaches the business unit's pricing and marketing teams to move excess inventory via customer deals. d) The board operations group has an inventory control team responsible for inventory management between stages at OSAT assembly & test houses.	➢ Create central corporate inventory team with proper incentives and authority

Strategic Lens Gap	Proposed Solution(s)
e) Operations as a whole is under heavy scrutiny for excess inventory, but their OTD metric is driving incorrect behavior described above in (a). Safety stock requests are often ignored by supply planners in response to executives' push to lower inventory – contradicting the forecasting team's requests to hold finished goods stock for demand upside. f) The PCBU Forecasting group is tasked with setting finished goods inventory levels to offset demand uncertainty (market hedge). Being responsible for forecast accuracy, this team is also held accountable for inventory levels.	
4. The PCBU Forecasting group's performance goals do not include quantitative forecast accuracy targets. Rather they are challenged to simply improve accuracy. However, certain products have high over-supply cost C_O and demand low forecast error (high cost, late lifecycle products). Other products' have high under-supply cost C_U so can sustain excess inventory or higher forecast error (low cost, high margin, steady lifecycle products). The new inventory model categorizes products accordingly by inventory risk level, prioritizing products that require more diligent forecast analysis.	➢ Agree upon current forecast accuracy performance ➢ Set future quantitative goals that forecasting owners can impact and achieve
5. The ATI operations model is officially build-to-forecast through finished goods. However various internal groups act on a build-to-order (postponement) after die bank. The confusion around a central planning strategy means inconsistent actions among planners; some products are planned in response to customer escalation and orders, while others are still built-to-forecast. Excess inventory accumulates throughout the manufacturing process. ATI's die bank strategy is also unclear.	➢ BU and Ops must agree upon and widely communicate ATI's supply chain strategy
6. ATI lacks a centralized data system for materials and capacity planning and forecasting. This worsens the planning strategy confusion noted earlier, since forecast is only updated weekly but planning actions may respond to real-time orders. The Supply Chain Core Team is tasked with improving this, but the prevalence of multiple, offline spreadsheets makes it increasingly difficult to share real-time information, analyze and learn from historical trends, and coordinate cross-functional improvement projects. I believe ATI must mirror its semiconductor peers and move to postponement once its systems improve.	➢ Invest significantly in SAP APO and/or leverage AMD's MRP systems to centralize planning data and reporting
7. ATI is not using a 100% turnkey or outsourced model. ATI procures wafers, substrate and memory in addition to OSAT	➢ Assess ATI's opportunity to move to 100%

Strategic Lens Gap	Proposed Solution(s)
assembly & test services. It is unclear why ATI assigns resources to track material and issues purchase orders for each OSAT assembly & test phase.	outsourced model with phased-out approach to tracking material at each stage.
8. There are numerous committees and stakeholders affected by the PCBU Forecast and finished goods inventory decisions. A common vision is not shared among the Operations Steering Committee, the Supply Chain Steering Committee, the PCBU Demand-Supply Team, Operations Finance and Inventory Control. While forecast accuracy is a key contributor to inventory reduction, ATI is not allocating sufficient number of influential experts to this area (there are 3 Forecasting managers for PCBU – driving 80% of ATI's $2.5 billion revenue).	➢ Assign marketing forecast accuracy ownership ➢ Increase headcount for forecasting team allocated by revenue impact
9. Misalignment on the definition of consolidated forecast among Operations, PCBU and Consumer BU teams. The most recent agreement has been: g) 0-3 month forecast to be demand constrained by materials supply and capacity. h) 3-6 month forecast to be a mix of constrained and unconstrained demand. i) 6-12 month forecast to be 100% unconstrained demand to indicate market and sales potential. Theoretically, ATI can access necessary foundry and test capacity to meet this demand. Despite directing the shared Supply Chain with its forecast (known as A00), the Consumer business unit operates autonomously from the PCBU.	➢ Create central, intranet-based supply chain dashboard that communicates and defines strategy, terms and data for all stakeholders

Cultural Lens Analysis

Work Culture

The ATI culture allows firefighting and short-term, quarter-end deliveries override long-term strategic decisions. Executives have been known to override product allocation decisions when a customer calls them directly to escalate. This occurs irrespective of the strategic weight or profitability of that account. Also, engineering needs take precedence over marketing, operations or human resources. There is a tendency of top executives to work long hours and travel cross-continent weekly translates into an 'always-on' mentality with the majority of middle and senior managers addicted to their RIM Blackberry devices.

The Old vs. New Guard

ATI has grown quickly in its 20 year history. However, being the only significant semiconductor firm in the Toronto area, the pool for new talent is limited to other relevant technology firms and local universities. Most notably, a significant number of Operations team members come from Celestica, a well-known contract manufacturer who incurred huge layoffs due to Asian manufacturing threats. The culture of ex-Celestica employees – ATI's "new guard" – values process-driven decision-making, team-bonding and work-life balance; they trivialize engineering or marketing calls for supply chain flexibility. They conflict with ATI's "old guard": engineering and marketing folks who tend to have the support of senior executives. Nonetheless, there is persistent frustration and circular arguments that diminish overall productivity.

Silicon Valley (Santa Clara) vs. Toronto vs. Taiwan
There are three main offices within ATI: Santa Clara, Toronto and Taiwan. Each have distinct and sometimes conflicting cultures. The corporate headquarters and operations headquarters are in Toronto but all the front-line manufacturing teams are in Taiwan. While the tenure of Toronto-based employees is longer due to fewer high-tech opportunities elsewhere, the tenure of Taiwan operations employees is very short. As such, Taiwan operations teams get frustrated by slow or unclear decision-making in Toronto, thereby contributing to high turnover brought about by worker confusion and dissatisfaction. Long hours and unclear processes plague the entire organization. Santa Clara is the worldwide sales and engineering headquarters. Their culture of high-risk, entrepreneurial creativity and customer needs conflict with Toronto operations and support staff. Further, they may be alienated from Taiwanese operations since Toronto teams facilitate between sales and operations.

People Culture
As with most entrepreneurial start-ups, ATI assigned people managers assigned based on tenure or technical know-how. Although HR has invested significantly in structuring processes and training around performance and people management, there are notable instances where this process is relegated to paperwork or not followed through with.

Political Lens Analysis

When faced with identical questions regarding inventory and operational direction, the senior executives lack alignment. The firm takes pride in its 'entrepreneurial' spirit with power centralized in a handful of people from each business unit. There is persistent mistrust between supply chain teams and the demand planners who reside in the business unit. The rationale for demand-driven inventory decisions, for instance, is not made clear to supply planners but may be perfectly justifiable.

Marketing and cost information are critical inputs for optimal inventory and supply chain priority decisions. But critical decision-making data is not shared from the finance and product teams. ATI remains an engineering-driven, product-centric culture, so operations and supply chain have relatively low power. Even the business unit's forecasting team – the BU team that owns the supply chain relationship – has limited access to cost, price or margin data. They are expected to make 'marketing' decisions but timely customer and market data is not openly disseminated from the relatively powerful product management teams. Further, the operations finance team is territorial over cost information and wafer approvals and the business pricing teams limit access to pricing data.

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