Introduction

During the monthly executive meeting of Hitachi Global Storage Technologies (Hitachi GST) on Monday, April 4, 2005, the Chief Operating Officer, Mr. Bob Hall, and the Vice President of Finance, Mr. Jim McDonald, the Vice President of Marketing, Mrs. Emily Wong, the Vice President of Manufacturing, Mr. Clint Dire were having a heated debate regarding the market timing decision for the next generation hard disc drive, code named Branco. During the meeting, Clint reminded everyone that the previous product line, Phantom, was announced too early. The processes to build this product were not ready and hence the firm struggled to pass the requirements of key customers. When it finally passed customer requirements and tests, the manufacturing processes for the product still had low yields, which cost the company dearly. Emily, however, reminded that early entry enabled Hitachi GST to be the first in the market and capture a large market share, which she claimed, positioned the company as a market leader for current and future product offerings. Jim agreed but suggested that despite the fact that customers were satisfied with the product, the company lost money on this product due to high production costs. Bob was determined to make the right timing decision for Branco. So, he emphasized that Hitachi GST has always introduced top quality and inspirational new products. As a result, the firm enjoyed a strong reputation. Profitability should now be the primary goal.

During such market-timing strategy meetings, each executive often represents and highlights his/her organization’s viewpoint. The timing decision, in general, depends on whether Hitachi GST should invest more time in product and process design and improvement or push the product to market before competitors. This trade-off impacts various profit drivers and functional areas within Hitachi GST. Each functional group, such as Manufacturing, also has access to different sets of information and control various processes that are essential for introducing the product in a timely fashion. From the marketing organization’s perspective, Emily often advocates early entrance to capture large market share. She also argues that depending on the success of a product, a dynamic pricing strategy may be used to increase revenue. Clint, however, prefers delaying market entry to achieve higher manufacturing yields and lower production costs. According to him, the time window prior to market entry is the opportune time to improve manufacturing yields. The Research and Development Group, which reports directly to Clint, also emphasizes that product and process improvement activities increase the chances of...
getting the product qualified and meeting customer requirements. However, a long delay may cause Hitachi GST to miss the qualification window altogether. From the accounting and finance organization’s perspective, Jim often suggests that the opportunity cost of building and carrying the new product should be weighed against not entering the market at all. Each group presents their own perspective using historical and current market information. At the end of the day, the decisions are often decided based on which executive makes the "strongest" argument. Bob takes into account everyone’s perspective in the final timing decision but the feeling among managers is such that the firm needs a more systematic and integrative analysis that considers all risks and rewards associated with timing decisions. Hence, Bob has requested his executive team to develop an integrated framework and policy for time-to-market decisions as well as post-introduction pricing and production decisions. He is not only interested in building a decision support tool but also wants the team to build a systematic business analysis process that will help the firm to make better timing and production decisions for its new product offerings.

**Synopsis of Challenges**

Hitachi GST has two types of customers: manufacturers and distributors. Manufacturers are computer assemblers, such as Dell Computers, whereas distributors are resellers who sell hard drives to retailers. For a computer manufacturer, hard disk drives are critical components. As such, a manufacturer agrees to buy a new product line from Hitachi GST only if the new product passes a series of qualification tests determining the conformance to the manufacturer's product, overall quality and performance, and manufacturing process integrability. Because of the complexity and rigorousness of these tests, the outcome of qualification process is uncertain. The conventional wisdom is such that investing more time to improve process performance and component quality increases the chances of passing customer qualification. The distributors do not require qualification tests. However, sales to manufacturers are several times larger than to distributors. Hence, qualification is a critical determinant of Hitachi GST's profit.

The marketing organization states that Hitachi GST’s market share depends on the order of qualification relative to other hard disk drive suppliers. To ensure availability, each manufacturer (customer) qualifies multiple hard disk drive suppliers. Early entrants make headway in establishing relationships and contractual agreements, which positively affect their market share. Figure 1 illustrates a customer’s percentage allocation of his business among qualified suppliers. For this particular product Hitachi GST was the first to qualify and enter the market. The figure illustrates that a supplier’s average market share depends on the order of qualification. In particular, the customer buys more from those suppliers who qualify earlier. One reason for this inverse relationship is that earlier applicants have more time to establish better relationships with various departments within the customer organization. They also have more time to satisfy the customer’s minor requests for adjustments in the manufacturing processes. Hence, they tend to have better “score cards” with higher average points, which results in higher allocation of the customer’s business. One Hitachi GST manager explains “The early applicants have the advantage of proving themselves early in providing reliable supply. And the customer simply rewards the leaders and penalizes the laggards”. Note, however, that it is not obvious how Hitachi GST can use the early entrant market share advantage because other hard disk drive suppliers' time-to-market decisions are uncertain. Marketing analysts at Hitachi GST state that they collect market intelligence regarding when another supplier may qualify and enter the market. Such
information is primarily gathered through trade shows, analyst reports and past competitive behavior.

![FIGURE 1: Percentage Market Share During Product Life Cycle](image)

For generic hard disc drives, the customer often dictate prices, leaving little profit margin for Hitachi GST. In hard disk drive industry, the profit margins are small and prices decline by 7-10% per quarter on average. To be profitable, suppliers focus on reducing production costs. On the other hand, for custom hard disc drives, Hitachi GST enjoys larger profit margins and can set prices “optimally” to some extent. But the marketing group knows very well that they need to keep an eye on competitors pricing strategy.

Demand for a hard disc drive during its life is uncertain. Most customers require Hitachi GST to build to stock. In other words, Hitachi GST owns inventory until customers pull the hard disk drives from Hitachi GST’s distribution hubs. Hence, Hitachi GST bears excess inventory and shortage costs. The accounting group estimates that shortage cost is 10-15 times more than holding an extra unit at one of its hubs. In such an environment, effective production and inventory planning is particularly important for profitability.

From the manufacturing perspective another challenge is to improve manufacturing yields. The qualified suppliers are required to deliver components that meet the customer’s specifications. Each hard disc drive is fully inspected before being assembled into the final product. To exactly meet the customer specifications, Hitachi GST often manufactures more than one unit per unit of demand due to imperfect yield. Yield may improve over time prior to market entry through better process design that allow faster assembly, less manual labor, fewer parts and lower overhead costs, which is referred as learning-before-doing. The yield also improves during production because accumulated experience in manufacturing processes reduces costly errors. This concept is known as learning-by-doing. As the yield improves, unit production costs improve as well. Figure 2 illustrates sample yield curves for a particular Hitachi GST product line. The curves increase during production due to learning-by-doing. The yield curves also shift downward for late entry, in agreement with the learning-before-doing concept. Hence, Clint and his organization often argue for more time to improve manufacturing yields and processes before
market entry. But he also realizes that delaying entry results in missed sales opportunities at high prices and possibly losing market share to other suppliers.

FIGURE 2: Percentage Yield During the Product Life Cycle as a Function of Market Entry

**Hard Disk Drive Industry**

A hard disk drive is the component of computers that stores and retrieves data. There are two main parts of a hard disk drive: the head stack and the electronic board. The head stack includes the disk to store data; the head to read and write data, and the slider to move the head. The electronic board includes the circuits that send and receive data between the disk and the computer processor. When the computer processor requests data, the slider of the hard drive moves to the appropriate position on the disk, reads the data and sends it to the processor through the circuits of electronic board.


The hard disk drive industry is characterized by rapid technological improvement and short product life cycles. When the first hard disk drive was introduced in 1956, it was a 24-inch drive that housed 50 24-inch disks, had an access time of 600 milliseconds, and a capacity of about 5.0 megabytes. Today, a hard disk drive with capacity of 6 gigabytes could be as small as 1 inch with access time of 8 milliseconds. This is made possible by fast technological breakthrough that
allows more information to be squeezed onto the recording disk. A key measure of hard disk drive technology is areal density, which is the amount of data storage capacity per square inch on the disk. Areal density has increased approximately 60% per year during 1990s. An immediate consequence of these advances is the shortening of product life cycles and more frequent new product introductions. This reduction in size also allowed hard disk drives to be used in many consumer products, such as hand held personal data assistants (PDAs) and mobile phones. The last decade has been dubbed as the 4\textsuperscript{th} era for the hard disk drive industry.

![FIGURE 4: Evolution of Hard Disc Drive](image)

Rapid technological advances in the hard disk drive market result in a fierce technology competition. To remain technologically competitive, suppliers initiate development for a newer generation towards the end of the development cycle for the previous generation. Suppliers that release products later than competitors often have difficulty capturing market share and revenue. Under such pressure, suppliers tend to introduce products before production processes are fully understood, ending up with yield and ramp-up problems throughout the product life.

Competition also results in severe price erosion. The average price per megabyte has decreased from almost $2200 in 1965 to less than a half of a penny today, with average rate reduction over 25% per year. As this paper was being written, Hitachi GST announced the first terabyte drive to be sold at 399 USD in the first quarter of 2007. This translates to 0.4 cent per megabyte. To survive such price pressure, suppliers need to constantly reduce unit production costs. This competitive landscape put many firms out of business. The number of hard disk drive suppliers in the industry has declined from 83 in 1984 to 9 in 2002.

**Hitachi GST Products and Processes**

Hitachi Global Storage Technologies has a well-established place in the hard disk drive industry. It was founded in 2003 and was formed as a result of the strategic merger of IBM's global storage technology business. Hitachi GST produces hard disk drives for all three of mobile computer, desktop computer and server segments. In each segment, Hitachi GST has three to ten product families. Each product family had one to five product lines. Hitachi GST mainly manufactures two types of products: generic hard drives and custom drives. Generic hard drives
are sold to multiple customers, including manufacturers and distributors. Some of these customers require qualification tests, as discussed in the introduction. These generic drives are typically sold in larger volumes and require a larger work force, investment in raw materials, and production capacity.

Manufacturing yield is an important factor affecting Hitachi GST's production costs. Hard disk drives are difficult to produce with high yield for many reasons. They are sensitive to dust contamination and assembly inaccuracy. The head mechanism of a hard disk drive needs to be very accurate in order to locate information on a densely packed disk. When the head reads data, the distance between the head and the surface of the disk is 1 micro inch or less. Hence, a particle of dust on the disk surface can cause the head and disk to physically contact each other, which may cause the disk to crash. Therefore, hard disk drives are very sensitive to dust contamination and assembly inaccuracy. Such sensitiveness causes drives to fail during manufacturing, leading to yield problems. In addition, manual operations on very small components increase assembly inaccuracy. The head stack assembly operation needs to be handled manually because hard drive designs change considerably from generation to generation. The same automated machine cannot be used across generations. The only other option, manual assembly, is typically less accurate. The inaccuracy increases as the components of a hard drive become smaller with improving technology, making assembly harder to handle manually. Among the reasons of low yield, machine calibration problems, component quality issues of upstream suppliers, and problems with quality control equipment are also important.

To detect and rework the defective drives caused by yield problems, Hitachi GST has an extensive quality control system within its manufacturing operations. A brief overview of Hitachi's manufacturing operations is illustrated in Figure 5. In the first step, the head-stack assembly is carried out by assembling the disk, head and slider. This step is carried out in clean rooms to prevent dust contamination. Next, the electronic board and other components of the drive are assembled on the drive. Third, the disk is formatted in an operation called servo track writing. Finally, an overall test is carried out to ensure proper assembly. Various quality control tests are also carried out between these operations. The proportion of items that pass all tests without any rework constitutes the first-pass yield. Defective drives are reworked and fixed, if possible. The dashed lines in Figure 5 represent the rework loops. The percentages of non-defectives after the rework operations constitute various rework yield measures. The unit production cost is found by dividing the total costs of these manufacturing processes (including reworks) and input materials by the amount of non-defective items produced. Hitachi GST has an in-house built model that reflects the units costs based on first-pass yield and rework yields.

![FIGURE 5: Manufacturing Process and Rework Loops](image-url)
Yield improvement is very desirable since it reduces the amount of hard drives reworked or scrapped, decreasing production costs. Hitachi GST's yield improves via learning-by-doing and learning-before-doing. Learning-before-doing occurs due to product and process improvement prior to applying for qualification and possibly entering to the market. Electronic design changes, use of different material, or even changing a screw can allow for easier assembly of the product, leading to higher yield. A pilot production is carried out to address yield problems that can potentially occur later in mass production and avoid them before mass production is initiated. Specific first-pass yield and rework yield targets are set for the pilot production. Manufacturing issues such as machine breakdowns, slow set-ups, and quality problems of upstream suppliers are addressed. Once the yield targets are met and executives decide to enter the market, sample shipments are made to each manufacturer and the qualification process starts. Based on the outcomes of the qualification processes, Hitachi GST's customers are determined and transition from process design and development to actual manufacturing is initiated.

During the transition, every effort is made to replicate the pilot production assembly line in the mass production assembly lines. The goal is to initiate mass production with a yield that is equal to or higher than the yield achieved at the end of pilot production. To do so, a new product introduction team is formed which consists of development and manufacturing engineers who also monitor the pilot run. The engineers monitor the assembly line operations to ensure that the things learned from the pilot run are actually implemented and to resolve any issues quickly. As a result of these efforts, yield levels achieved during pilot production translate into equal or higher yield levels at the beginning of mass production. After initiation of mass production, yield continues to improve as problems with manufacturing are resolved and workers accumulate experience. This leads to yield improvement via learning-by-doing.

New Product Development Process at Hitachi GST

There is a well-defined, structured product development process at Hitachi GST. This process usually takes two years starting from conceptual design to initiating mass production. Annual, quarterly, monthly and weekly meetings are organized for progress review and planning. The stage of product development is summarized in Table 1.

The first stage in product development is concept development that involves planning of product technology. Annually, the strategic planning department within the marketing function of the company organizes a meeting with company executives, development engineers and marketing strategists. In this meeting, development engineers provide input on where they believe the hard drive technology is headed. Strategists make long-term sales forecasts based on historical data and their expert opinion. Based on this input, executives decide on what technology development to invest in and development is initiated. Monthly meetings are held to review (1) the technological changes in the market, (2) the state of the economy and accordingly, sales forecasts, and (3) progress of concept development activities. Based on these reviews, the company decides on design modifications to better match market potential. This development process usually takes two to six months.
Approximately 18 months ahead of product introduction, the company begins *initial planning* of manufacturing processes. In this stage, components of the hard drive are known. Based on the demand forecasts, production planners determine component needs (e.g. head, disk, PCB) and negotiate with suppliers. Planners also decide on which Hitachi GST plant will assemble the components into hard disk drives. Being a global manufacturer, Hitachi GST has ten different plants in the Philippines, China, Thailand and Singapore. The objective in this planning is to ensure supply at the lowest cost. The product design continues to be improved in parallel to these activities. Monthly meetings are held to review design progress and resolve potential issues.

In the next stage, the *product readiness* stage, the product design and manufacturing processes go under detailed review in order to resolve any issues and prepare the product for market entry. Two tracks of reviews are carried out. One track focuses on the product design and the other track focuses on the manufacturing processes. There are various checkpoints on each track, which are strictly followed by the review teams. At the end of each review, results, action plans, target dates, and staff responsible for executing each plan are documented in the process control database. Based upon the data and information presented in the review meetings, the review team may make one of the three recommendations: proceed as scheduled, hold for issue resolution, or proceed as scheduled with additional targeted action plans. Review results will also be reviewed with senior management.

As product design and manufacturing processes mature, more frequent, weekly meetings are held to ensure *launch readiness*. Final revisions are made before market introduction. A cross-functional checklist database is filled out to ensure that proper progress is made in all aspects of product and manufacturing process design and qualification readiness. Two types of tests are carried out in this stage: small volume and large volume. In small volume tests, product design is tested for manufacturability and performance. Prototypes of the product are produced in small volumes and tested for any assembly issues. On the performance side, issues such as noise level of the hard drive are addressed so that customer qualification is more likely. Thousands of hours of testing are performed to ensure low corrosion and vibration, high stability and performance in the long term. In parallel, a high volume test, *pilot production*, is carried out to test manufacturing processes. Issues such as machine breakdowns, slow setups, quality problems of upstream suppliers are addressed.

During testing, a business analysis team makes scenario analyses to support the introduction timing decision. Given deterministic sales trajectories corresponding to different entry decisions, marketing analysts project profit. Financial analysts project return on investment. Uncertainties in qualification outcome, competitor entry times and demand are not included in this analysis. Manufacturing engineers determine yield curves according to the outcome of the tests discussed above. Cross-functional meetings are held where marketing and manufacturing teams present their analysis results. Based on these meetings, company executives decide on the timing of the
qualification application. This timing decision impacts the supplier's profit in multiple ways, creating multiple challenges.

Next, Hitachi GST applies for qualification at the customers and makes sample shipments of the product. Customers have extensive qualification processes which involve testing the product, investigating the plant that the hard drive will be assembled in, and checking whether Hitachi GST has enough capacity. Frequently, customers ask for minor changes in the product during the qualification process. A team of engineers and business analysts from Hitachi GST standby to ensure fast response to customer requirements. Because of the extensive nature of this process, customers do not accept secondary qualification applications from a failed supplier.

Downstream manufacturers also need to introduce the product in a timely manner. Hence, each manufacturer sets a qualification time window in which Hitachi GST needs to qualify. Hitachi GST tries to plan the aforementioned design and development activities so that the qualification time window falls within the launch readiness stage. However, if the qualification time window falls within a much earlier stage of Hitachi GST's development processes, Hitachi GST can decide to stop developing the current generation of products if the managers determine that it is inevitable to miss the qualification time window. They may also stop this process if applying for qualification and hence possibly entering the market too late leads to losses.

**Production Planning Process at Hitachi GST**

Once the qualification process is completed successfully, then the supplier initiates mass production to meet customers demands. The mass production stage usually extends 12-18 months, followed by production ramp down. The production system is capacity constrained. During the earlier stage in the life cycle of the product, the capacity is often lower. Depending on the projected demand forecast, Hitachi GST starts to allocate more capacity to the new product overtime by allocating more resources to these new production lines. For a custom product sold to a single customer, capacity is not a concern because the volume requirement for a single product is very small compared to available capacity. However, for a generic product sold to multiple customers, capacity turns out to be an important consideration.

A material requirement planning system is in place to carry out production planning during mass production. Planning is carried out as follows. Sales people in the marketing department weekly receive firm orders and 13-week-ahead forecasts from customers. These forecasts are passed on to the customer volume planners (CVPs) who are responsible for ensuring that specific customers receive orders on time. CVPs make volume plans considering the demand uncertainty and capacity constraints. Next, production volume planners aggregate the volume plans of CVPs and make aggregate production plans at the hard disk drive level. These plans are disaggregated by component and passed on to supply chain planners who make component level production plans and give orders to suppliers. Once the components are received, assembly is produced according to the plans at the hard disk drive level.
Appendix 1

Disk Drive Industry Average Gross Margin