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Knowledge Management across Firm and National Boundaries: Notebook PC Design and Development

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Executive Summary

The design and development of notebook PCs has the pattern of PC production, being outsourced to (mostly) Taiwanese suppliers and being relocated to the Asia-Pacific region. The actual process is very similar for all notebook PCs, whether they are designed and developed internally by brand name PC vendors or outsourced to Taiwanese original design manufacturers (ODMs). One of the striking characteristics of the process is its division into distinct sequential phases, with clearly defined "screens" or checkpoints that must be passed before moving on to the next phase. The nature of this process is clearly seen as the most efficient way to move a product from initial concept to full-scale production, given its ubiquity in the industry. More interesting from our point of view is how the design process influences the organizational structures employed within firms and the organizational boundaries between firms (i.e., which functions are handled internally and which are outsourced). These in turn influence the ways in which firms collaborate, where activities within the design process are located, and how they are coordinated across often large geographical distances.

The division of the process into distinct phases can be seen as a form of modularity and standardization, similar in some ways to the product modularity of the PC itself. As product modularity allows different components to be designed independently, as long as they comply with interface standards that allow them to work with the rest of the system, process modularity allows different parts of the design process to be separated across organizational or geographical boundaries. And as in the case of the modular product, there must be some coordinator with overall responsibility to make the system work. Traditionally, that has been the brand name PC vendors, but the Taiwanese ODMs are vying to take over this role for them in the interest of cost savings and time to market.

One result of the existing process is that firms have adopted a type of matrix organization. Design teams with a mix of skills and knowledge have end-to-end responsibility for individual products. Support teams consisting of functional specialists develop and share core technical knowledge (e.g., power management, software, materials, thermal dissipation) across all product lines. This structure allows core knowledge to be quickly applied to new products, and likewise, allows knowledge

[1] The Alfred P. Sloan Foundation is a philanthropic nonprofit institution established in 1934 by Alfred P. Sloan, then president and chief executive officer of the General Motors Corporation. The Sloan Industry Centers comprise a unique national network of 20 research centers, five of which focus on the computer and telecommunications industries. Together with partners in their industry, Sloan Industry Center researchers conduct field-based research, examining issues of innovation, technology, business processes, management, human resources and competitiveness that ultimately determine firm and overall industry performance. This Center, as its name suggests, focuses on the personal computing industry.

created in the development of new products to be shared across the company through formal and informal channels.

Given the clear breaks between phases, there are natural points at which to divide activities across organizations or geographies. For instance, one PC maker might do conceptual design in-house, outsource industrial design to an ID specialist, and outsource product development and manufacturing process engineering to an ODM. Another might do concept design in the U.S., product design in Japan and manufacturing processes in China, but all internally. However the processes are divided, the major PC vendors always maintain control over key issues such as brand image, quality and cost.

The nature of the design process and how it is organized by firms has important implications for the skills required and where different activities may be located. The initial pre-concept and concept stages involve understanding customer wants and needs, tracking technology trends and translating technological capabilities into products that meet customer needs at the right price. This requires a combination of market intelligence, product planning, financial analysis, high-level technical analysis, and the ability to communicate with both customers and suppliers. The major U.S. PC makers handle this phase in the U.S., and mostly in-house, as such a combination of skills is not yet available elsewhere.

Moving on, the product development stage is where the actual mechanical, electrical and some software development are done, with prototypes developed and tested. The required electrical and mechanical engineering skills are available in both Taiwan and China, but so far Taiwan's long experience in notebook design means that there are specialists with deeper functional knowledge than is yet available in China. In the future, there will likely be a migration of at least part of the development process to China, as Taiwanese engineers move to China to manage the process and as Chinese engineers gain more experience.

The manufacturing process stage requires proximity to the assembly line, and the availability of certain basic engineering skills. With most notebook production moving to China, and Chinese universities turning out large numbers of low-cost engineers, the mass production and sustaining engineering processes are already in China or being moved there.

To summarize, the modular standardized nature of the development process defines and constrains the possibilities for how the PC industry organizes notebook design, the skills required, and where different activities may be located. There are powerful economic forces acting on all firms in the industry favoring outsourcing to reduce fixed costs, and moving to cheaper locations, particularly China, to maintain cost competitiveness. The actual choices made by PC makers and the ODMs depend in part on strategic issues, internal capabilities, and existing relationships, but the need to cut costs means that these firms are finding ways to manage across firm and national boundaries.

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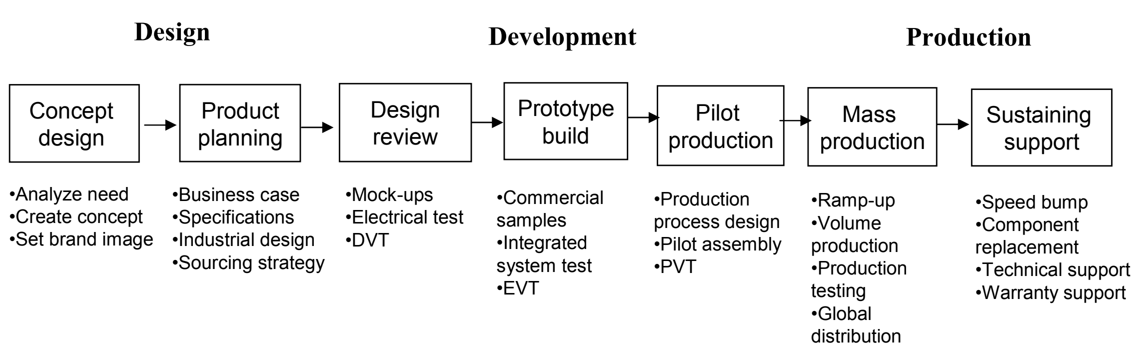
I. The Design and Development Process

The notebook PC development lifecycle consists broadly of three phases: design, development and production. These design and development phases take roughly a year for an entirely new product. Products may stay in production for about a year, and are under warranty coverage for 1-3 years. This means that there may be some type of knowledge work required for up to five years for a single product. Our focus is on the first year, from initial product planning through ramp up to full-scale production.

The design, development and production processes are highly modular with specific activities, outputs and gates to pass before proceeding to the next phase. This modularity has important implications for the organization and outsourcing of activities.

Wheelwright and Clark (1992, 1995), which some cite as the bible for product development, divide design and development into six phases with outputs and test gates specified for each. The six phases include: build knowledge and capability, idea generation, product definition, design and build prototypes, pilot production and manufacturing ramp-up. Each of the firms studied has their own definition and language, which can be generalized into two design phases and three development phases as shown in Figure 1 and discussed below.

Figure 1. Phases and activities in the product life cycle



[2] This report is based primarily on interviews conducted with companies that participate in the design and development process of notebook PCs in the PC industry value chain. The interviews included several major PC makers and leading original design manufacturers (ODMs). The interviews were conducted in the U.S. and Asia during the fall 2003. The interviews were supplemented by a review of secondary sources, such as trade journals and business press in the U.S. and Asia.

Design Phases

Idea generation and concept design. All PC makers engage in concept design, where an effort is made to define a new product based on market forecasts, technology roadmaps, and customer needs. Concept design is led by headquarters with a multidisciplinary team comprised of people from product marketing, market intelligence, industrial design (ID), and physical design (development) disciplines. The output is usually a design requirements document that identifies the target market, desired features (size, weight, battery life, screen size, components), industrial design language and resources required to develop the product.

Product planning. In this phase, a planning team translates the market data, user requirements and product features into a business case for the product with estimates for costs, units, price, revenues and margins. The industrial design language is translated into mock-ups of the product thru sketches, cardboard models or Styrofoam models. A least one firm uses computer-generated 3D models. Mock-ups of the components are placed within the chassis to determine physical feasibility and layout. Discussions are held with the development group regarding technical feasibility and potential development issues.

The output is a detailed product plan where, as one planner put it, "the project is nailed down from words to numbers." The plan presents the business case including segmentation by market and region, cost, margins and other financials. It includes a detailed product and marketing plan including product timing, resource requirements, and commitments of different functional areas, industrial design, detailed specifications, and bill of materials. And it includes a design validation plan to control the development stage. The outcome of this phase is a decision to build the product, which is made by the most senior executives in product planning, marketing and design/development. A product management team is then assigned to the product to manage the product through development, mass production and sustaining support.

Development Phases

Whereas design occurs mainly in-house, development is frequently outsourced. Regardless of sourcing strategy, development is tightly managed to ensure manufacturability and quality as they have huge implications for cost and customer satisfaction.

Design prototypes and review. Design review is conducted to test whether the concept design can be built physically. It involves creating a working motherboard and a working mockup of the product with its components and software drivers from the specified bill of materials. This is a preliminary test of viability of the mechanical components and of the electrical circuitry that is done outside the chassis but within a space equivalent to it. The physical chassis for the components and the display is built from the industrial design with attention to mechanical issues such as the display hinge strength and cover closure fit, and functionality issues such as input and output locations for ease of use. This is also the time when Intel might be consulted to assess heat dissipation and other issues for several processors, because most notebooks involve at least one “speed bump” to a faster processor during their product life. The result is a hand-tooled chassis and working mock-up of the electrical/mechanical/software system that will boot and operate as it should, but might not be stable. There might be one or more of these “engineering samples,” each involving different design tradeoffs to be evaluated by the product management team.

The gate for design review is a design verification test, or DVT. The design review might result in new specifications for components, functionality, software or physical layout because new technologies become available or system integration problems require changes. The chassis and mock-up are formally reviewed by the product management team and if any open issues can be resolved reasonably in the next phase, the product is moved to the next phase.

Prototype build. In this development phase, the chassis, motherboard, components, electrical system and software are put together into an integrated physical system and tested. This is when issues such as heat dissipation, power management, and battery life are tested and the whole system is “stressed” under extreme operating-like conditions related to running time, vibration, shock, and pressure in test laboratories. These tests indicate where key design changes are needed. The output is a small production lot (50-100) of commercial samples that represent a stable, reliable product for hands-on review by the development and product team members and prospective users. Another output of this phase is the tooling required for manufacturing of the chassis and mechanical receptors that will hold the components.

The gate for this phase is the EVT, or engineering verification test. The prototypes must pass reliability and quality criteria and the physical samples must meet criteria for fit and finish. These test data and samples are reviewed by the project management team at a gate meeting with the developers to determine whether the product can proceed to the next phase.

Pilot production. The final development phase involves preparation for mass production. The production process is designed complete with bar code readers for the BOM, pick lights for kitting parts (in the case of build-to-order production), electrical tests, downloads of the software image, control of burn-in, collection of statistics for shop floor management, and overall analysis of the production process. A pilot production line is set-up to produce around 500-1,000 units that will enable a test of the production process. There is also an out-of-box test of the quality of the units produced, wherein a sample of 100-200 units are taken out of the box and tested as if a user were setting up the system.

The gate for this phase is the PVT, or production verification test, where standards of quality, production time, and out-of-box reliability must be met before ramp-up to mass production. The PVT results are reviewed with needed changes and fed back to the manufacturing engineers. The final “go” decision on production is made jointly by the manufacturing, development and project management teams.

Production Phases

Mass production requires manufacturing engineers to plan and manage the production process and requires test facilities and quality engineers to continually improve product and process quality. Over time, these engineers come to know the product extremely well and are best positioned to provide sustaining engineering support that was previously provided by the original development teams. *Sustaining engineering* deals with changes that occur because of introduction of a faster processor, failing or end-of-life components, or improved components. Each change must be evaluated in terms of its implications for system performance and assembly and incorporated into the production process. The sustaining engineers also provide the highest level of technical support when problems occur during use during the product's 2-3 year warranty period.

II. Organizational Boundaries

The modular PC development process has led to a long-term trend from in-house design and development to either outsourcing or joint development with ODMs. The driving forces behind the shift are the competitive pressure to reduce costs, the growing capabilities of ODMs, and the perceived commoditization of notebooks. The notebook market may not be as price driven as the desktop market, and there are not thousands of white-box makers to contend with, but there is still intense competitive pressure and cost reduction is an imperative for all PC vendors. Given the lower cost structure of Taiwanese ODMs, and the fact that outsourcing reduces headcount and fixed costs for PC makers, there is a strong incentive to outsource product development.

The capabilities of the ODMs have developed to the extent that they have specialized knowledge in notebook design that only a few PC makers can match or exceed. Historically, companies such as IBM and Toshiba have used their internal design capabilities to differentiate their products and gain competitive advantage. However, there is a general belief expressed that the ability to use hardware design to differentiate in ways that matter to customers is waning.

There are three general ways in which design and development are organized between PC vendors and ODMs. First is in-house design, in which the PC maker uses its own design and development teams throughout the process, perhaps using an outside specialist for a specific task such as industrial design. Second is joint design/development, in which the PC maker develops product specifications, sometimes with input from an ODM, then works with the ODM in the development, testing and production engineering processes. The third approach is when the ODM designs a generic product and the PC maker simply selects the product off the shelf and sells it under its own name.

We have found no data at the industry level on this, but based on interviews and on market share of leading notebook vendors, we would estimate the following shares: In-house design and development: 30%; Joint design and development: 50%; and Off-the-shelf: 20%.This varies considerably by company, as only a few PC makers have in-house development teams, and those vary in depth of capabilities. It also varies by product line, as PC makers are more likely to outsource design of second generation or low-end products and more likely to buy off-the-shelf for a product they want to get to market quickly.

The trend reported by the companies and outside observers is toward greater use of ODMs, but mostly through joint development. The ODMs might prefer to design their own product and be able to sell to multiple customers, but this part of the market will probably remain limited to a few low-end products, or to smaller PC vendors who lack any design capabilities.

Division of Labor

The PC maker usually does pre-concept planning in-house, then works with internal or external industrial designers and sometimes ODMs in the concept phase. The final result is a design language that is passed on to the development team, either in-house or at the ODM. ODM does detailed design and qualification including the hardware schematics and mechanical drawings.

Once the design is finalized, it moves on to a production engineering team for ramp-up and taking out costs until mass production begins. After some period of mass production, the product is moved on to a sustaining engineering team. Sustaining engineering is increasingly being handled by the ODM in support of whatever products they develop and manufacture.

ODMs are said to be capable of architecture design, mechanical and electrical engineering, and component selection, but the PC maker needs to protect its brand, product look and feel, and procurement leverage, which can be done by retaining industrial design, product management, high level architecture and test monitoring. Quality control is very important for a product that is very light, thin and complex, yet takes a lot of abuse ("no one calls us and says they left their desktop on top of their car and drove away"). So PC makers oversee this closely. They also work with Intel and some other suppliers for strategic procurement decisions. They want to control which components are used across the different series and models within each series to reduce cost, reduce complexity, and provide for serviceability.

Interaction of Firms

As one PC maker put it, there is a lot of room for finger pointing in the design process, between the ID firm, PC maker and ODM. Ideally they try to get the ODM and ID firm involved early to get everyone on the same page. There is a lot of tacit knowledge involved that can't be codified and handed off easily, so some face-to-face interaction is needed.

Throughout development, the PC maker may be involved to various degrees in overseeing the process. All PC makers audit the design implementation, but ODMs say that some PC makers are much more hands-on than others. PC makers themselves all say they oversee the process closely, and sometimes claim their competitors are more casual in their oversight.

The extent of oversight in the process also declines over time as a relationship with the ODM develops. One PC maker said that when working with inexperienced ODMs, they have to spend about 1 month working with them early on and also assign an engineer full time on site. When working with experienced ODMs, they only need to visit them at check points for entry and exit, perhaps 4-5 times over the 12 month development process.

Since most of the cost in a notebook PC is in the components, an important issue is procurement, i.e., who selects the suppliers and negotiates prices. Larger PC makers have enough volume to get the best prices on major components such as microprocessors, memory, drives, panels, batteries and graphics chips. They also want to be able to control the relationship with key suppliers. Smaller vendors might allow an ODM to negotiate, since the ODM has a much larger production volume than the PC maker. For less critical parts such as resistors, cables, fans etc., the ODM is more likely to handle procurement since it sits close to the supply network in Taiwan or China.

There is not a consensus as to the value created from in-house development or the relative ease of working with in-house teams versus ODMs. One PC company that does both in-house design and works with ODMs says the process is very similar either way, with the exception that the ODMs tend to try to please you more as the customer. Another PC maker that uses ODMs for all design argues that the results are similar to in-house design as long as the process is closely controlled.

III. Worker Skill Levels

The public discussion of skills and the location of knowledge work often is limited to broad data such as the number of engineers produced by Chinese or Indian universities each year, or the average salaries in different countries. These figures may be of interest at a high level, but are not adequate to predict shifts in knowledge work. Looking at notebook design, we find that each phase of the design/development process requires a different set of capabilities that involve formal training, experience, and familiarity with specific market characteristics. In addition, different work styles are appropriate for different activities. The availability of these combinations of capabilities and work styles varies widely by location, and while wage differentials create strong economic pressures, the need for specific capabilities, and the differences in productivity in different locations, may create a "stickiness" that prevents the relocation of design and development to the place with the cheapest, must abundant engineers. Looking at the major phases of notebook design and development, we find the following:

- *The idea or concept stage* requires people who know markets and customer demand, as well as engineers who understand technology trends. There also is a need for people who can talk to the marketing people, then talk to the technologists and see how customer demand and technology trends converge. These are highly skilled people, but the skills are not necessarily specific to notebooks. They may be marketing people or engineers who moved into planning. They generally have both experience and advanced degrees (e.g. MBAs).

- *At the product planning and specification stage*, PC makers have technical program managers who work with development teams and industrial designers to coordinate the process. Other skills needed are industrial design, procurement, product planning.
  - In one company, the program managers are highly technical engineers who used to do actual development, e.g., board layout; now they manage the ODM. They have to be able to look at an ODM's drawings and internal development schedule and tell them where it's wrong, or be able to help them solve a technical problem.
  - For industrial design, there are general skills taught in universities, but there are also different aesthetic sensibilities for different markets. Chinese industrial designers are said to lack that sense for colors, lines, bends, needed for US or European markets, so they're used for low level design if at all.

- *At the product development stage*, a variety of engineering skills are required, primarily in mechanical and electrical engineering. Specialized skills are needed in thermal, EMI (emissions), shock and vibration, power management, materials, radio frequency, and software. These require a combination of formal training and experience working in a particular specialty.

There are differences between U.S. PC vendors and Taiwanese ODMs in terms of the types of skills that are sought, at least according to one U.S. firm. To work for Tier-1 PC vendors, engineers need core analytical skills gained through formal training, not just hands-on experience. Analytical skills allows engineers to sit down with counterparts at Intel and other component suppliers and influence standards. On the other hand, Taiwanese companies are said to use engineers with mainly hands-on experience in implementing design specifications.

Skill levels vary significantly in different locations.

- In the U.S., even new engineering graduates are said to understand practices such as managing cross-functional teams and project management. There are capabilities available in the U.S., such as market intelligence, brand management, product planning that are hard to find elsewhere. There are also industrial design teams that can make products for U.S. market, although interestingly, a leading industrial design house used for notebook PCs is in Milan, Italy.
- In Japan, there are industrial designers that are very good at designing for the Japanese market, but also can create products for the U.S. market if they interact with U.S. marketing people. Japanese design and development teams have great depth of skills in all design and development areas.
- In Taiwan mechanical and electrical engineers are available with strong hands-on experience. Taiwan is developing more analytical skills, but a U.S. person fresh out

of school is much more dynamic according to one U.S. company. Taiwan universities produce industrial designers, but they don't get much practical experience during their education.

- Chinese mechanical and electronic design engineers are well-trained, but lack the hands-on skills that come largely with experience. Industrial design is weak.
    - The college education of engineers in China and Taiwan is about the same according to one company, but another says only about 10% of Chinese graduates are good enough to hire.
    - According to one interviewee, China's engineers "work perfectly at doing what they have been told, but cannot think about what needs to be done; they lack both creativity and motivation. They are good at legacy systems, but not new things; they can't handle 'what if' situations."

Availability and Cost of Engineers

- In Taiwan, there are not enough engineers available in some areas. Taiwanese firms recruit in China, but Taiwanese immigration laws makes it difficult to bring people in from China. Instead, firms are moving some processes to China to use Chinese engineers. They also try to bring high level engineers from the U.S. in some cases.
- In China, a large number of engineers are produced each year, but quality varies greatly by university. Engineers and other professionals from elite universities want to work for MNCs first, local companies second, and Taiwanese companies last. This is mainly because of salary differences.
- Engineers with a new college degree can get 4-5,000 rmb/ month ($800) at big multinationals like IBM, Motorola, Siemens, etc. Engineers with 6-7 years experience get 10,000 rmb/month ($1200) at MNCs. Similar engineers may get 2-3,000 rmb/month ($250-400) from Taiwan firms or local firms. As a result, Taiwanese companies hire engineers from all over China, not just elite universities.

Relative costs vary greatly among the countries. In the U.S. or Japan, an engineer or procurement professional might cost $120,000 fully loaded. In China it would be $40,000 for a senior person at an MNC, of which $20,000 is salary and benefits. Taiwan is somewhere between. Obviously there are strong economic advantages to moving to China, if productivity is even close.

Complaints about China

There were several complaints expressed by multiple interviewees about engineers, and workers more generally, in China. Most common was the high turnover rate. Engineers are said to stay about a year on average and then jump to another company, which is possible in places like Shanghai and Shenzhen where demand is high. The problem is more serious for the Taiwanese companies, who pay lower salaries than the MNCs.

Taiwanese companies claim that Chinese engineers only care about money, are not motivated by the nature of the work, and have no loyalty. This complaint was also heard in Japan. There could be some exaggeration, since it is Taiwan and Japan that are most at risk of losing jobs in this industry to China. On the other hand, it might simply reflect the abundance of job opportunities and rapid economic transition taking place in China, as contrasted to the more mature Taiwanese and Japanese economies.

IV. Knowledge Creation

Notebook PC design involves limited knowledge creation in the traditional sense as there is little R&D carried out by PC makers or ODMs. Component and software makers generally spend a much higher share of revenue on R&D than PC makers do, and much of the new knowledge embodied in a notebook PC is created by these suppliers. On the other hand, integrating these technologies into new products involves knowledge creation at the system level, a process that is quite complex given the nature of notebook PCs. Integrating numerous components and packaging them into small, light, rugged, power saving, user friendly notebooks involves many design and engineering tradeoffs where analytical skills, experience and tacit knowledge play a major role. The problem solving processes involved in each new model create knowledge that can be applied to future designs. In addition, some PC makers and ODMs have advanced R&D teams that focus on areas such as thermal diffusion, EMI emissions, materials, software, and power management. This knowledge can be applied across a PC maker's product lines, or across different PC makers' products developed by an ODM.

While knowledge creation is important, notebook PC design and development mainly involve knowledge deployment and sharing. Knowledge about market demand, user needs and new technologies is integrated to create a product concept and plan which is then translated into a physical product through industrial design and engineering development. The primary engineering knowledge required is that of systems analysis, integration and testing. The systematic, engineering nature of the process with precise specifications, physical tests and formal gates that must be passed for each phase results in considerable codifying and sharing of knowledge and experience gained in the process.

Internal Coordination

The product and functional teams constitute the internal organization for knowledge creation and deployment in both the vendor and ODM organizations. The product management team is the central coordinating structure across design, development and production. One team handles a product from concept through the first 90 days of production, when the product is transitioned to sustaining engineering. The matrix organization of design and development teams facilitates sharing of knowledge across development phases, engineering disciplines and product platforms. Product teams handle single products throughout process, but coordinate with other product teams on things like selection of components to reduce procurement costs and simplify the task of supporting a number of product lines. Engineering teams coordinate across platforms and products on solutions to system integration issues.

The formal gates at the end of phases in the design and development cycle facilitate information sharing because they document key outcomes of the preceding phase. Design teams meet with development engineers before, during and after handover; development teams meet with manufacturing engineers; and manufacturing teams meet with sustainability engineers. All product/process reviews are mechanisms for both formal and informal collaboration and information sharing.

External Coordination

PC maker and ODM. The joint development process is very much like a PC maker's internal process. When using an ODM, a contract is executed with specifications, tests, timing and gates, and it becomes the framework for coordination. Vendors and ODMs agree that coordination tends to be more formal in these instances and is more costly than internal coordination.

Vendors and ODMs have formal meetings only 4-5 times over 8-12 month design/development cycle. Usually one meeting occurs during design, whereas the others occur at the end of each stage of development. However, there might be many more face-to-face meetings between individual designers or engineers to work out specific issues or problems. As put by one ODM, "there is somebody (from the PC maker) here about every two weeks throughout the design and development process. Sometimes it is product managers, sometimes industrial designers and other times electrical, mechanical or software engineers. The engineers usually stay a week and work closely with our engineers. Engineers also come to Taiwan or China to see production once it gets rolling. They want to be sure things are going OK and they want to see how things are being done in detail."

In new relationships the PC maker and ODM spend considerable time "educating" one another, but this declines with successful experience and development of trust. One vendor uses visitors from headquarters to convey management culture, engineering practice, or technical matters to their ODM. Another uses temporary assignment of ODM engineers to headquarters or to the development organization. ODMs complain that some PC makers do too much monitoring, thereby increasing the ODM's costs.

Management across cultures is always an issue as vendor and ODM frequently have different styles. One vendor described Taiwanese companies as wanting to have harmony, avoid conflict and look for alignment quickly whereas Americans are more comfortable with debate, conflict and negotiation. Communication also differs according to this vendor: "Americans hit the key point and then explain the details, whereas Taiwanese build the story and then get to the main point. We have to ask them, 'What's your one page slide?' We have started to use templates to get them to go through our process. We also have classes on conflict management and communication."

PC maker and component suppliers. Because the PC is a modular product with standard components developed by upstream suppliers, there is generally little formal input from PC makers in their R&D efforts. Intel is an exception because Intel sets hardware standards for the whole industry. Major PC vendors work with Intel in setting technology specifications or even details such as where to locate the pins on the chips for ease of assembly. Because PC makers build and sell the systems, they understand some issues better than Intel or other suppliers.

Both vendor and ODM development teams generally have good relations with local suppliers in Taiwan, Japan or elsewhere in Asia. Suppliers may have engineers located at the production site to deal with problems that arise and to develop knowledge that can be fed into design for manufacturability. As production has moved to China, there has been a need to bring suppliers to China or develop local ones.

When a new technology is being integrated into a notebook design, there may be more collaboration with technology suppliers. For example, in developing a new wireless mobile PC, one vendor coordinated with a key supplier in order to develop specifications for wireless WAN technologies; it then issued an RFI with several others to see which firms could qualify; and finally, it issued an RFQ with still more firms to obtain competitive pricing.

Collaboration

The product plan sets the framework for internal collaboration and the development contract plays the same role externally. Both set up mechanisms for product/process reviews and information sharing. The modularity of the design/development process enables teams to set up entry and exit criteria for each phase and processes for collecting performance data, which facilitates entry and exit reviews against these criteria at major gates. These gate reviews involve large teams from both sides. The gate review prior to mass production involves executives from the highest levels in the company or business unit. Gate reviews and scheduled meetings are planned and documented in shared files that others can access.

Knowledge Management and Dissemination

The structures and processes for knowledge management include quality teams, design reviews, shared databases, engineering change requests and newsletters to disseminate knowledge. One vendor uses quality teams not only to ensure that quality is built into design and development, but to distill lessons learned from production and customer use that have implications for future design. Help center calls, critical customer situations and problems/solutions encountered during development and production are entered into a problem management database covering all active products. This database is culled by the quality team for lessons learned which are then disseminated via “lessons learned” newsletters, quality champions in product team, subsystem design teams (mechanical, electrical, software) and the manufacturing procurement organization. We did not determine how much the problem management database is used, but the lessons learned newsletter was described as a big success.

While it is not clear how much knowledge repositories are used, it is clear that product management databases are used throughout the design, development and early production phases, and passed on to sustaining engineering team. These databases contain documents, drawings, analyses and tests that are used on a daily and weekly basis throughout the process. They are the official record for confirming product specifications, engineering change requests, product review meetings and the stream of decisions that emerge from these activities. All product and functional teams contribute to them and use them in the course of their activities.

Information Technology

Design, development and production occur in different geographies and information technology (IT) plays a key role in coordination. Communication may be synchronous and asynchronous forms, but the latter is more frequent because of time differences.

All forms of IT are used for coordination: fax, scanners, email, instant messaging, telephone, collaboration tools such as Lotus Notes and design tools such as Cadence's suite for electrical, mechanical and board layout. Email is used on a daily basis both for messaging and for sharing files such as documents, open-issue lists, drawings, bill of materials, photographs, and 3D images. Weekly telephone conferences are used for updating and review. Person to person calls are used for urgent issues. One ODM uses NetMeeting internally, but not with customers. One vendor uses the Notes platform to create a shared file where all materials related to a particular product are posted throughout the full product lifecycle and available to anyone with access privileges.

The industry is reportedly becoming aligned on tools for design, with vendors and ODMs having either the same tools, or viewing capabilities for each others' tools (e.g., ViewLogic to view ORCAD). PRO-E is used for 3D mechanical and stress testing; Cadence's Allegro is used for electrical and board layout. ORCAD is used for schematics. One ODM feels that the tools increases productivity a little, but views them more as a necessary evil—something pressed on the ODMs by the major vendors rather than being a real need. The cost of a single seat for Cadence software, for example, can be $50,000 plus 20 percent annually for maintenance. Consequently, the ODMs may buy only a few seats, share the software among their engineers and not always implement the updates.

The extent to which 3D tools are used for industrial design is unclear as yet. One vendor indicated they do not use such tools, relying more on hand sketches of design features and scanned photos of physical mock-ups. The consider the latter a quicker and more flexible approach. Such 3D tools seem to be more appropriate for tooling and the design of plastic moldings and enclosures.

V. Risks and Benefits of Joint Product Development

Strategically, the vendors are outsourcing an activity that had been a source of product differentiation for some, but appears to be less so today. In doing so they gain cost savings that go directly to their margins. And, they can concentrate on high-level concept design where this is still opportunity for product differentiation through targeting the right markets, rapidly incorporating new technology and strengthening brand image.

In operational terms, there are few risks from joint product development. ODMs work under contract to meet product specifications and test criteria, and vendor product managers monitor their work to ensure they do. When problems occur, they work cooperatively to solve them. Some ODMs do not share all of their processes with notebook makers. One Taiwanese ODM indicated that they have their own tests and processes that they do not share with the vendors because it is proprietary technology that they see as a competitive advantage over other ODMs. They share the results so the vendor sees the advantage, but not the processes or test equipment.

The bigger potential concern is that an ODM will reveal information about one customer to another, since the major ODMs work for multiple PC makers. One vendor mentioned an ODM showing them a design done for a competitor, mainly out of pride in the design, but otherwise this was not mentioned as a concern. Another executive mentioned that he was able to learn quite a bit through interaction at industry events where people in the small community sometimes are quite talkative. Overall, the risk of joint development is probably reduced by the long-term nature of the relationships; if an ODM was seen as unreliable it would risk future business with existing customers, and probably with other potential customers given the closeness of the community.

VI. Location of Activities

It is clear from the foregoing that each of the phases in bringing a new product to market has its own demands, and it is important to distinguish the phases when considering the location of activities.

- *Design* remains in the vendor's lead market, which is usually their home market, because of the strategic importance of branding and the need to be close to the market. The U.S. is the home to most leading notebook vendors and remains the leading world market, while Japan is home to several others and is the second largest market. China is becoming a major PC market, led by a local brand (Legend), but the notebook market remains small and local companies do not have their own design and development capabilities yet.

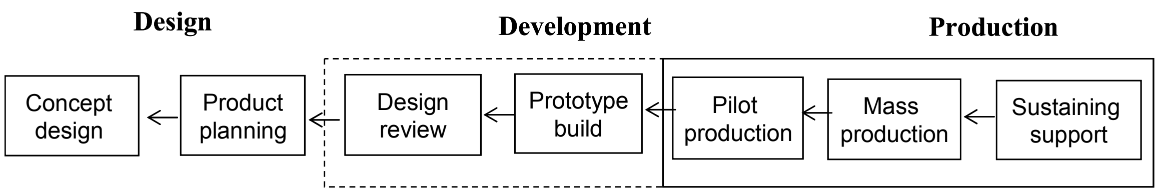
- *Development* is being outsourced to ODMs for lower cost. Although complex, the management structures processes for coordination and collaboration have become sufficiently codified that development can be conducted remotely.
    - Within development, *designing and building prototypes* involves experience, tacit knowledge and joint problem-solving and benefits from co-location of personnel from PC vendors and ODMs. As a result, at least two leading PC makers have set up design centers in Taiwan that work closely with ODM partners.
    - Given that notebook production is increasingly in China, *pilot production* is also moving to China. However, the *production verification testing* activity within pilot production is done in the development organization, which has the testing equipment and labs needed. In varying degrees, the companies expect that production testing will be transferred to the production site as the engineering

capability is developed there among local engineers. One notebook maker already has a test laboratory in China and Taiwanese ODMs are discussing such investments.

- *Sustaining engineering*, which traditionally was performed by engineers in the development organization, is now performed increasingly by engineers in the manufacturing organization. They have the necessary knowledge, and this frees up more highly-skilled engineers for new product development.

Some hypothesize that once production moves to a low cost location, it will pull development activities with it. We found some support for this view. As manufacturing engineers in production sites upgrade their capabilities, they are set up to pull other activities from the development organization if there are labor cost advantages. Given that production is increasingly in China, sustaining engineering was first to move, and is now being followed by pilot production. Not all vendors or ODMs have created test facilities or transferred know-how to engineers in China, but the upgrading process is underway and expected to move further up the product life cycle as illustrated in Figure 2 below. One source estimates that the entire development process could potentially move to China by 2006.

Figure 2. Production "pull" of development activities



VII. Implications of the Organization of Knowledge Work

Our conclusions about the implications of the global organization of knowledge work are preliminary and will be refined as we continue to analyze interview data and conduct further interview to fill in gaps in our understanding.

Fortunes of Firms

The notebook PC market has continued to grow at double digit rates even as desktop sales have declined. As long as the U.S., Europe and Japan remain the major markets, and common designs can be used across those markets, U.S. and Japanese vendors will continue to lead the industry. In China, the dynamics could be different, given the strong position of Legend and other local companies. By tapping the capabilities of the ODMs, Chinese companies are already offering cheap notebooks, and China is likely to be a market where low price is more important than distinctive design for many years.

There is a debate about whether the notebook is becoming so commoditized that one cannot differentiate products with hardware design. The vendors we interviewed believe this is becoming the case, but they also believe that differentiation is critical. Some believe that the opportunity to differentiate is shifting to software and services. Others believe the opportunity is in market segmentation. However, with new technologies continuing to be introduced and notebooks gaining much wider popularity in consumer markets, there may still be room to differentiate through design for some time. Less clear is whether in-house development teams are still a source of competitive advantage, or whether such differentiation can be achieved just as well through joint development with ODMs.

Fortunes of Countries

We estimate total number of knowledge workers (market analysts, product planners, project managers, industrial designers and engineers) in all phases across major vendors and leading countries in notebook design and development to be on the order of 7,500-10,000.

Some development jobs are moving, mainly from the U.S. to Taiwan and from Taiwan or Japan to China. Given the growth in the notebook PC market, the total number of development jobs is still growing, and the number actually moving might be small. While we do not know the number of jobs the U.S. has lost in development, we do know that it is retaining the high-end knowledge work so far. And with the notebook market growing, there might be growth in the jobs associated with the concept design stage.