CAD AND PRODUCT DEVELOPMENT IN THE US AUTOMOBILE INDUSTRY

Based on Visits to Chrysler, General Motors, and Ford in the summer and fall of 1993, plus other public sources.

The report consists of a general section followed by separate sections on each company.

Introduction

This report deals with one aspect of a large and complex industry, namely some of the design methods and computer aids used to create concepts and details of automobiles by America's Big 3. Some of the organizational issues are included, including recent reorganizations of the design process by all three companies. These are compared to ongoing changes in Japanese firms which are being studied by other researchers. Material for this report was obtained from visits to the companies plus publications in the vernacular and research literature.

The report begins with a discussion of the objectives and methods of researchers who study this industry, followed by a short description of the car design process. Then follows a section about design problems common to all the companies.

Research Methods and Challenges

Research Methods

The car industry has been the focus of intense research for many years. This research has been carried out mostly by academics interested in the managerial issues. The methods used in this research are on-site interviews and survey questionnaires. The underlying intellectual basis of the research often is statistical analysis of the survey results that yields correlations between practices observed and various metrics that hopefully measure performance in some larger sense. It is understandably difficult to make convincing arguments from these correlations that lead to secure cause-effect relationships. This kind of research might be called "industrial anthropology" in the sense that the researchers aim to understand another culture, its "religion," and its "carvings."

Survey research is usually called "descriptive," meaning that it observes what is happening without rendering value judgments. Descriptive research can be contrasted to "normative" research which tries to indicate whether what is observed is as good as it ought to be in some sense. One would think that, to be useful, industrial anthropology should aspire to be normative, and to some degree discussed below it can do this. But even if it remains descriptive it has a powerful role to play. Good descriptive research is better than mere statistical mining of survey data in the same way as good history is better than mere chronicles. Good history converts a chronicle into a story with structure, interpretation, and linkages to the past, permitting us to see important patterns.[1]

Industrial anthropology has some pitfalls, however, because researchers often are unable to get to the heart of the technological issues that underlie some of the more visible features. Some "evidence" is found but a deep explanation is hard to construct. Sometimes the evidence is counter-intuitive, as in the case cited by [Ward, Christiano, Sobek and Liker]. These researchers discovered that Toyota apparently conducts less communication with suppliers of complex subsystems than it does with suppliers of simpler components. A possible explanation is that subsystem suppliers are in fact very capable of carrying out their own design given well-constructed specifications. The implication is that Toyota is good at basic system engineering and constructs subsystem specifications carefully.[2] More research like this that connects observable data with underlying methods is needed.

The reader has probably concluded that descriptive research has a degree of the normative in it. One cannot always say what is the best way to do something but one can find out what the different methods are. If one can define clear and quantitative ways for comparing the methods, then companies can use the results to compare their performance with that of others. Such comparisons involve the definition of "metrics."

Development of Metrics for Design and Manufacturing

A major task for researchers and managers alike is to develop metrics by which the statistics can be converted into useful statements about performance. In the realm of manufacturing, common metrics include the size of the area set aside for rework at the end of the assembly line (smaller is better), the amount of unplanned downtime (less is better), or the amount of

---

[1] Current readers are familiar with the Gulf War and the Iranian revolution. Those interested in history should read The Prize [Yergin] where they will find that the Gulf War is only one in a series either in or aimed at the Middle East's oil. They will also learn that the Mullahs in Iran were against western influence and ownership of Iranian oil reserves as far back as the 1920s and threatened the kind of revolution then that they carried out in 1979.

[2] Support for the systems engineering interpretation may be found in [Fujimoto] who gives a history of "black box" parts procurement in Japan. He gives examples of apparently complex items (climate control systems) that are procured by the black box method and apparently simple ones (door weather seals) that are not. Weather seals cannot be judged for quality independently of doors whereas climate control systems can be made and tested indepentently and will work as expected after installation.

equipment maintenance done by the line workers themselves (currently believed to be better if larger). Definition of metrics becomes more difficult when there is no obvious more/better trend, or where there are inherent conflicts. For example, in operating expensive machinery, some companies try to run the machines as fast as possible for as many hours as possible in an effort to reduce unit cost. Others reduce the speed, believing that this will reduce tool breakage and other maintenance problems, thus increasing uptime and reducing unit cost. They also tend to run the machines only when there are orders for parts (Just in Time manufacturing), reducing inventory cost.

Another recently cited example [BW] involves one of the many couplings between design and manufacturing. It has been observed that Japanese car companies can change over from one model to another in as little as a weekend, while US firms can take months. During changeover there is little or no production, causing serious sales losses. Even after changeover is complete, ramp-up to full production takes less time in Japanese companies than American. One recommended remedy is to force product designers to limit their designs to what the old equipment in the factory can manufacture. This policy could well shorten changeover but it could also strangle adoption of new manufacturing technology, new materials, or new labor-management arrangements. Other remedies offered include leaving space in the factory next to the existing line for new workstations to be brought in and tried out, then quickly shifted into the line. But past studies of assembly plant productivity have penalized plants for having too much space. [Krafchik and MacDuffie]

There is no general agreement on which of these alternatives is the best, and attitudes tend to cycle over periods of ten or more years. The companies are often well aware of these differences in policy[3] but are not usually able to articulate reasons except tradition. Conflicting metrics do not help, indicating that additional research is needed to clarify what to measure and how to interpret the results.

The problem of metrics becomes even fuzzier when one considers design. Here one is interested in time to market, cost of the design effort, cost to manufacture the product, and the ability of the product to satisfy the market (sometimes called quality). Hewlett-Packard has tried a series of metrics in an effort to improve product development. [House and Price] First it tried pure time to market, but discovered that too many poorly designed

---

[3] Ford, for example, runs its machines hard while Toyota and Yamazaki run theirs more slowly. Each knows exactly what the others are doing. Toyota's machines are often smaller than Ford's. I have observed this in both engine block machining and cylinder head assembly. People at each company simply say "That's our way of doing things." A challenge for the researcher is to find out the underlying advantages of one policy or another.

products were reaching the market quickly. H-P then developed a metric called break even time, which measures the time required for the product to earn back its development cost and finally turn a profit. This metric specifically recognizes the inherent conflict between design time and design quality by providing computer tools that help managers predict market losses caused by development delays. Efforts are also made to predict market benefits that might come from delaying while the design is improved.

Companies also are unsure about how best to organize large numbers of people engaged in a complex design project. Fifty or more years ago products were simpler; fewer engineers with more general knowledge could apply it to broader aspects of the design. As products became more complex, the natural response was to specialize. As specialties multiplied, so did the number of specialists. An executive at Ford told me, "Once we hired engineers. Now we hire mechanical engineers, structural engineers, electronic engineers, etc. We have Ford-ized the design process, making it into an assembly line with very high division of labor."

These engineering specialists were organized into departments with functional specializations and deep technical capabilities, such as chassis, engine, body, climate control, and so on. Each functional department was responsible for developing or obtaining the infrastructure it needed to carry out its work, such as test labs, design methods, material property data, computer facilities, and so on. Product design management was difficult and often consisted of trying to get these functional departments to assign people to work on one product program rather than another.[4] Product design took a long time and was characterized by poor communication, poor design for manufacturability, and poor coordination of designs across product line families.

Clark and Fujimoto [Clark and Fujimoto] studied product development in Japanese car companies and found a different pattern. Their research indicated that product development was undertaken by teams led by strong program managers with almost absolute authority to command resources from functional organizations. Team members worked on at most two car programs at a time and owed their allegiance mostly to the programs rather than to functional groups. In addition, design work did not proceed step by step but instead involved overlapping the steps, starting subsequent ones before prior ones were finished. This process encouraged communication between engineers involved in the respective steps. Engineers on such

---

[4] [Keller] describes GM's problems but similar problems occurred at other companies.

projects often had varied experience in both design and manufacturing and could see ahead to problems in the factory.[5]

Two important metrics emerged from Clark and Fujimoto's work. First, during the period studied, namely the mid to late 1980s, Japanese car companies spent fewer engineering hours on design than either US or European companies. Second, design in Japan was finished in fewer months. Some of these differences are due to better design management while others are due to the Japanese practice of letting suppliers do much of the design. All of these findings had profound effects on US car makers, who undertook to improve their design methods. These changes are discussed below, along with problems that are emerging with the new methods.

In concluding this section, one last problem facing researchers has to be mentioned. It often takes two to four years to carry out definitive research of the type described here. In the meantime, companies change their methods, the market changes, laws and regulations change, and the companies become different. A Vice President at Toyota's US transplant recently said to me, "If you come back here in 6 months, things will be different. If they aren't, then we aren't doing our job." He was referring to Kaizen, the practice of continually looking for better ways to do things, even very small changes.

A Sketch of the Car Development Process

In this section, a brief sketch of the car development process is given, based on Figure 1. The process is similar at all car companies although it differs in important details as mentioned above. The process falls into roughly three phases: concept design, product design, and process or factory design. Each phase comes to a formal end with major decisions regarding styling or engineering feasibility, but a great deal of intercommunication between the phases is necessary.

Phase 1 is concept and styling design. These are separated into two phases at some companies. Concept design may begin before there is corporate committment to build the car. The task is to determine a market need and see if a suitable design can be genrated that could be priced competitively for the target market. Styling attempts to capture this concept in computer or clay models that represent the shape of the car as well as its aerodynamics. At the same time, a process called packaging seeks to fit everything and everyone inside the exterior shape. A power train must be selected (or else a design for one has to be launched) that will provide the required performance and be able to participate in shielding the passengers from a head-on collision.

---

[5] See reports on Japanese companies by Whitney in previous ONR publications where detailed examples of these practices are given.

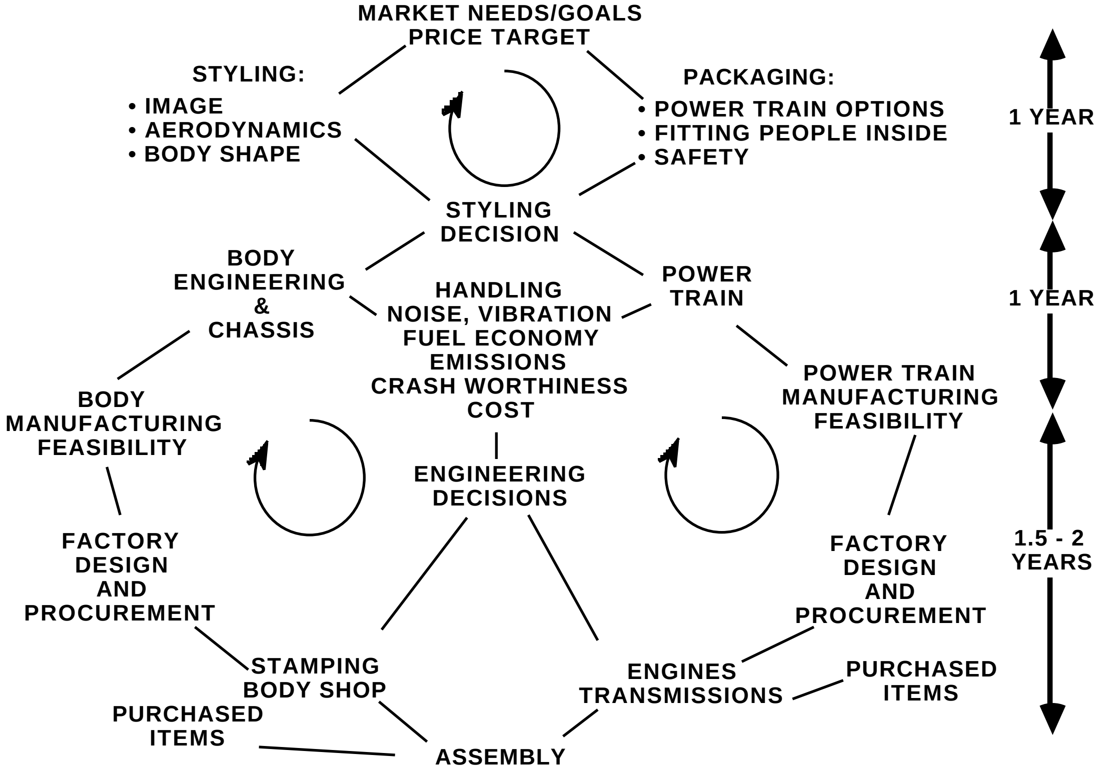

Figure 1. Outline of the Car Development Process

If the styling is approved by top management, major funding begins and a vehicle launch date is established. Serious engineering begins at this point. The computer or clay model of the exterior must be converted into sheet metal while the power train must be packaged to fit between the wheels and under the sloping hood. (Hoods are increasingly being sloped in order to improve aerodynamics to obtain better fuel economy.)

In body engineering, the designers' main job is to divide the given exterior shell into a set of individual panels. These comprise about 20 exterior panels such as fenders, roof, and doors, plus about 300 to 400 large and small interior panels. These inners are the bones of the body. They are thicker and stiffer than the outers and are responsible for giving the outers their detailed shape and fitup with each other. The challenge is to make all of these parts with good dimensional accuracy. The challenge is made more difficult by the fact that the outers in particular are very complex shapes which are hard to stamp from flat stock.[6] Predicting stamping problems is a major activity of the body engineers. Another major challenge is to design

---

[6] More detail on stamping is included in the report on GM. There it is estimated that as many as 400 dies may be needed. In Comeback: The Fall and Rise of the American Automobile Industry, the authors relate progress that Chrysler made in reducing the numbr of dies needed from 597 on the Sundance to 370 on the Neon, saving $42 million.

the body to withstand crashes. This work is supported by computer simulations using finite elements, but preparing the models can take months.

Body engineers also spend a long time ensuring that everything fits. This means ensuring that no two objects occupy the same space and that everything "inside" is really inside everything that is "outside." A particular challenge is door design. Doors must fit inside the exterior skin but not protrude into the passengers' space. The designers must pack a great deal of equipment and parts such as window glass, crash bars, latches and locks, motors, ventilation ducts, and mirror controls, into the available space.

Powertrain designers also face difficult packaging challenges. The most important is to arrange everything under the hood. The engine must be far enough forward that it can slide toward the passengers during a crash without penetrating the firewall. It also must be above the wheel centerline of a front wheel drive car so that the drive shafts can reach the wheels. If styling has created a car with a narrow spacing between the front wheels, then there is little space for the engine, transmission, drive shafts, suspension, and brake systems. Fitting all of these elements together is one of the greatest problems in car development.

Many secondary problems accompany the main packaging challenge. Foremost among these is noise-vibration-harshness (NVH). Japanese cars are known for being very quiet and smooth-riding. Reducing NVH has therefore become an important competitive element in design. However, NVH is a function of all the car's systems: drive train, engine and engine mounts, suspension, and body, as indicated in Figure 2.

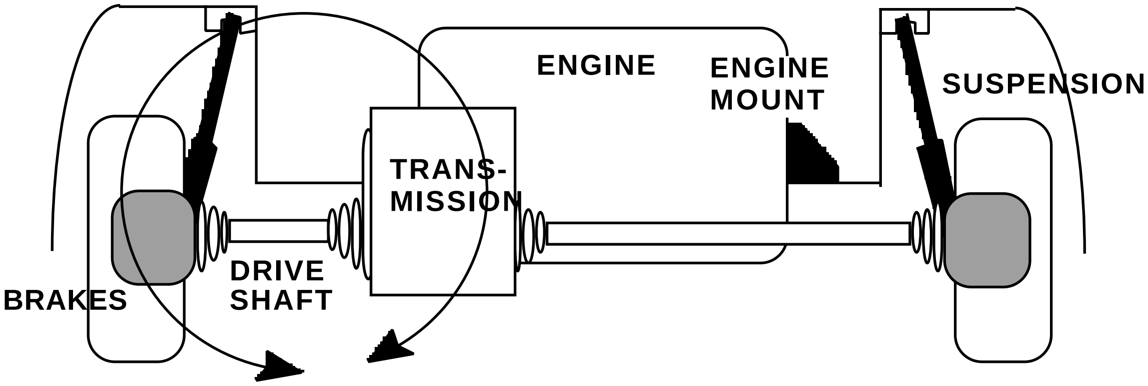

Figure 2. Illustration of the Interaction Between Items Under the Hood. All the elements within the arrow loop contribute to NVH: engine, engine mounts, body, suspension, wheel and tire, drive shaft, and transmission. Cooperation among most of the car's design constituencies is required in order to reduce NVH.

In parallel with all the engineering, estimates of the final cost are being generated. These costs include anticipated capital investment in new factories and machinery as well as labor costs. Frequently, it is found that the car will cost more than the anticipated market will bear. Redesign or relocation of the factory are often considered if this happens.

Another important parallel activity is specification and procurement of the many parts of the car that are made by other companies. Examples of such parts are: all wires and hoses, most trim items, seats, tires, glass, paints, and simple stampings. Items which may be made in-house or purchased include radiators, electrical items, engine controllers, instrument displays, air conditioners, radios, and so on. While engines and transmissions are usually made in-house, they include many purchased items. In the case of engines, nearly everything inside the block and head is made in-house except valves and little parts like valve springs and keepers. On the other hand, nearly everything outside is purchased, such as manifolds, wires, tubes, hoses, belts, pulleys, covers, etc.

The circulating arrows in Figure 1 indicate the ongoing discussions and revisions that are typically necessary in order to ensure that the design is feasible and meets performance, manufacturability, and cost requirements.

As the design begins to gel, the factory processes are designed and equipment is ordered. The major segments of the factory are powertrain, body shop, and final assembly. Often an existing engine and transmission are used, so preparation of their factories is a separate process.[7] Body manufacturing consists of a press shop were parts are stamped plus a body shop where they are welded together. Press lines usually consist of a series of large presses that stamp the parts between draw dies. Dies can now be changed in a few minutes, so only a few presses are required to make all the different parts.

Body shops consist of sets of welding machines or robots that weld a few parts into subassemblies. These subassemblies make up parts of the floor, the engine compartment, doors, hood and trunk lid, side panels, and roof. These are then brought together and tack welded in a few places in a process called framing. The framed car is then sent through a process called respot in which about 3500 spot welds are added by a long line of welding robots. Doors, hoods, and trunk lids are attached by screws. The welded body is then painted, after which the doors are usually removed. Since the doors were fitted individually to the cars before painting (by adjusting the hinge bolts), they are kept track of and reassembled to the same car they were painted with. The doors are removed for two reasons: to permit easy assembly of their

---

[7] Design of engines and transmissions and design and construction of their factories usually takes five or more years. Since this is longer than companies want car development projects to last, it is unusual for a car project to encompass power train design as well. At most, some modifications to existing powertrain elements will be included within the span of a car project.

internal parts and to keep them out of the way of final assembly tasks such as inserting the instrument cluster and the seats.

Final assembly is usually done by people who crawl in or around the car while adding a huge number of wires, tubes, cloth and plastic trim parts, lights, engine compartment parts, suspension and exhaust items, and so on. All of this must be done without scratching the paint. In addition, there are many variants to each type of car, due to presence or absence of options, and thus there are many kinds of brake lines, wires, interior trim parts and so on at each workstation. It is important that the wrong part is not added since this can be costly to correct, especially if it gets buried under other parts.

Common Problems in the Car Industry

Two issues common to all companies in the car industry world wide are product design management (mentioned above) and strategies for obtaining the "product realization infrastructure" (CAD software, manufacturing equipment, etc.) The work of Clark and Fujimoto made companies realize that quite different product design performance was being achieved by different companies. The work of Krafchik and MacDuffie indicated that the same was true in vehicle final assembly. So far no one has made a definitive link between these two domains of manufacturing performance, although I will offer some speculations here. First, each area will be discussed separately.

Product Design Management

Companies that had organized product development as hand-offs from one "functional silo" to another began to realize well before Clark and Fujimoto's work that there were distinct shortcomings to that method. The term "silo" is intended to evoke the vertical flow of management authority that is confined to each separate functional department. This vertical flow is contrasted to the horizontal flow of design and development as work is passed from one department to the next. Horizontal communication is essential to good design but it is impeded by the need to send requests and approvals up and down the vertical command chains.

Aoshima [Aoshima] points out that functionally (or vertically) organized companies tend to emphasize component excellence while project (or horizontally)-organized companies tend to emphasize system integration and product "coherence." Coherence is coming to be the preferred commodity, especially as car makers reduce their number of employees and farm out more work to suppliers. The remaining competencies at the car maker must then include pulling everything together. The challenge, discussed below and elsewhere, is how skillful companies can still be if they farm out most of the detailed work: can they keep ahead of technology, can they lead in designing their products to take advantage of new methods in design and manufacturing, can they tell what are the key issues to keep sight of as they integrate, and can they ensure that their suppliers have the requisite skills?

As far back as the late 1970s, both Ford and Chrysler developed focused teams as an alternative to the purely functional method. These teams were formed by energetic managers who needed to get a design done quickly or who wanted to break the old habits. Even though these efforts each were successful (in Ford's case the Taurus was the result), neither company adopted the method across the entire company or succeeded in making it permanent at the time.

The first company-wide effort appears to have been at Chrysler starting in 1989 with the LH car. Here the method was given the name "platform team" with the word platform indicating that the underbody, chassis, and major power line dimensions would be used repeatedly in a family of designs. In this case, a shortage of resources forced the team to be small, only 750 engineers, but management was convinced that this number would be enough if they were organized properly and had the right computer tools. (More details on this below.) A basic principle of the platform team method was that of the co-location. All 750 engineers were housed in their own section of Chrysler's new Technical Center.

The LH was not the only platform team, because in short order three more were formed. These cover Jeeps, minivans, and small cars like the Neon. As time goes on, each team will return to design another vehicle on the same platform, justifying the name platform team.

It was soon realized that the teams needed access to functional expertise. At first Chrysler attempted to borrow people from the functional departments but soon discovered that loyalty to the team was an important ingredient of success, so elements of the functional departments were transferred to the team's operating area. Each platform team assumed responsibility for one important functional area (engine, body, etc.) and shared that resource with the other teams in return for access to their functional focus area. Management later realized that this approach cut the functional experts off too much from the source of their deep capability and their career path, both of which lay in their functional home departments. These problems are common to companies that seek to use "matrix management," the method of assigning experts temporarily to projects.

Another generic problem with design teams is that upper management tends to lose sight of common problems, issues, or needs. These crop up in each team separately; each team attempts to solve them independently, unaware that they exist elsewhere. Management does not realize how big the issues are since only a small team is experiencing them at any one time.

In Chrysler's case, one solution is the Technology Club, an arrangement by which experts meet, exchange ideas, and review technical knowledge obtained from outside. This approach has been in place for about two years but it is too soon to tell if it is working. One manager told me that the choice of name "club" made it sound like management was not serious about it. The LH and Neon platform teams both produced their designs in record time and both cars are enjoying market success. A detailed analysis of Chrysler's product development management strategy may be found in [Scott, 1994a].

At Ford, the management of product development has evolved to a mix of dedicated teams and functional organizations. Ford has observed the concentration of talent in Chrysler's teams and has decided not to go that far. The company has also recently announced a wholesale reorganization of its world-wide design and engineering facilities and methods in an attempt to reduce duplication in styling as well as functional areas like engines. This reorganization was announced so recently (April, 1994) that it has not fully taken effect and its results will not be known for some time.

Independent of the reorganization, Ford has for several years been carefully analyzing its design methods at the technical level, seeking to identify all the relevant information flows, decisions, knowledge bases, and computer tools. These are discussed below. A detailed assessment of Ford's product development management strategies may be found in [Scott, 1994b].

At General Motors, a major reorganization occurred in the Spring of 1993 with the creation of the Vehicle Launch Center. The VLC reversed the organization created in 1984 in which separate divisions were set up called Buick-Oldsmobile-Cadillac and Chevrolet-Pontiac-Canada. In 1984 "decentralized was good;" now "centralized is good," one GM manager told me. The separate divisions were supposed to become closer to their customers, but one result was proliferation of parts, design methods, and manufacturing capabilities. Each program manager had the power to modify procedures as he saw fit.

The VLC brings together many disparate and dispersed activities into a coordinated and co-located activity on the grounds of the GM Technical Center. It is intended to standardize development processes and to focus certain core competencies in engineering, advanced development, and manufacturing, making them available uniformly to all car programs and increasing the use of coherent practices. One hope is that manufacturing facilities will become less unique, permitting some production load shifting in response to changes in demand. A major change is that the Tech Center's Manufacturing Staff has been given line responsibilities for supporting specific car programs. Gary Cowger, former head of North American Manufacturing Operations, said that his responsibilities united for the first time at GM all of the steps from advanced manufacturing development to deployment of equipment on factory floors.[8]

Very recently, (February, 1995), GM announced that it would assign "heavyweight project managers" to each car platform, increasing the identity and continuity of design in each market.

Japanese companies, however, have recognized that the co-located independent team method has drawbacks that need to be addressed. The all-powerful project leader tended to re-invent basic vehicle components rather than make use of developments going on in parallel projects.[9] A new pattern has begun to emerge. Nobeoka and Cusumano [Nobeoka and Cusumano] studied 223 new product introductions by 21 companies and showed that a mix of platform team and functional organization was being used in conjunction with a variety of strategies for reusing results from past or ongoing projects. They identified four types of development strategy: new designs, concurrent design transfer (from one ongoing project to another), sequential design transfer (from a finished project to one starting soon after), and design modification. Concurrent transfer permits faster introduction of cars with more recent design elements than sequential or modification, and it costs less than a complete new design.

A hybrid functional/platform team style was also identified, in which the most critical or highly engineered elements like engines or bodies are developed uniquely by platform team members whereas design of less unique elements like exhaust systems or trim is shared across more and more designs and is provided by functional organizations.

It may be that just as the US companies are evolving toward more unique platform teams, the Japanese are moving beyond that form to something different. The GM VLC could well evolve in a way similar to that observed by Nobeoka and Cusumano.

Development of the Product Realization Infrastructure

By "product realization" I mean all of the steps required to design and produce a product. This term is less ambiguous than "manufacturing" although it really means the same thing in the largest sense. By "infrastructure" I mean all the supporting technologies that are needed for product realization. This infrastructure can be divided into two broad classes, namely hardware and software. On the hardware side are robots, machine tools, conveyors, and other factory equipment. On the software side are

---

[8] Presentation to MIT Leaders for Manufacturing Research Committee, May 19, 1994,

[9] I was told at Volvo that a similar problem had been recognized there.

computer-aided design software (CAD), product data management systems, project management tools, factory scheduling, inventory control, and so on.

The key question is how companies obtain these infrastructure elements and put them together into an effective design and manufacturing organization. Opinions and strategies differ surprisingly widely. The term "core competence" is often used to call attention to capabilities that companies feel they really need to have in-house. Discussion of this topic was given a boost by a Harvard Business Review article by Prahalad and Hamel, who said, "Core competencies are the collective learning in the organization, especially how to coordinate diverse production skills and integrate multiple streams of technologies."... "Management trapped in the strategic business unit mindset almost inevitably finds its individual businesses dependent on external sources for critical components. ... But these are not just components. They are core products that contribute to the competitiveness of a wide range of end products."

Most discussion of core competencies deals with product issues, namely the ability to design and produce elements of the product itself. Far less often does the discussion include the ability to create the infrastructure.[10] The alternative to having either capability in-house is to buy it. All car makers now buy tires, for example, but some make their own machinery for manufacturing engines and write their own CAD software. Figure 3 illustrates the issues schematically. It shows three sets of supply chains providing product, hardware infrastructure, and software infrastructure. Figure 4 shows different shapes of this pattern to illustrate different degrees of in-house competence, with longer sections indicating more in-house capability. As a first cut, one often finds Japanese companies adhering to one pattern, US companies to a second one, and European ones to a third, although this observation is based on anecdotal evidence only, not a valid statistical survey.[11]

---

[10] At one US car company I was bluntly told "CAD/CAM is not considered a core competence here. Furthermore we have no corporate level forum in which to discuss such things."

[11] In the Spring of 1994, the CAD/CAM director for a large European car company told me of visiting Japanese car firms earlier that year and observing their astonishment when he said his company felt comfortable using commercial CAD.

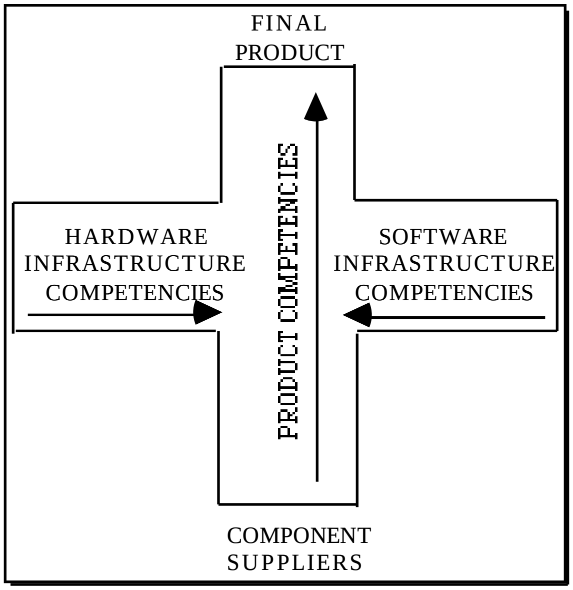

Figure 3. The "Core Competence Profile." Product competencies are in the vertical chain while infrastructure competencies are in the horizontal one.

In Japan, not only do the car companies tend to adhere to this pattern, but companies in many other industries do the same, such as consumer electronics, disk drives, printers, cameras, and so on. A detailed discussion of this feature of Japanese companies can be found in [Whitney, 1993].

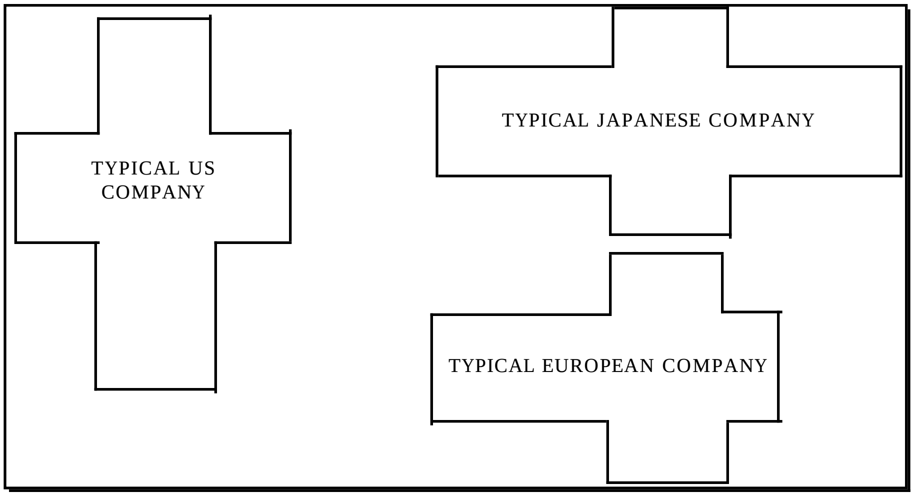

Figure 4. Different Core Competence Profiles Often Exhibited by US, Japanese, and European Car Companies

The different patterns can be interpreted (not explained) as follows: US car firms tend to buy both kinds of infrastructure and keep in-house the design and manufacture of product components. There are important exceptions, however, that will be discussed later. Briefly, Chrysler outsources an estimated 70% by value of its components, Ford about 50% and GM about 30%. Also, Chrysler decided in 1989 to discard its in-house CAD system and use CATIA for all body and mechanical design, whereas both Ford and GM have for years supported body engineering CAD in-house. GM has recently begun to do its mechanical design on Unigraphics, a commercial CAD system developed in the aircraft industry and recently purchased by GM's EDS. division.

Japanese firms were shown by Clark and Fujimoto to derive a considerable amount of their design efficiency by outsourcing a large portion of their car product components, retaining as most car firms do only drive train, suspension, and body engineering design and manufacture. However, these firms strongly support in-house CAD development as well as that of key manufacturing equipment. Such equipment may include robots, machines that cut stamping dies, sensors used in manufacturing, and assembly equipment. Firms in consumer electronics have moved even more strongly into assembly robots and now can assemble impressively complex mechanisms very rapidly and dexterously. The pattern in Figure 4 applies to semiconductor manufacturers as well. Most major Japanese firms in this industry make or at least develop some advanced processing equipment, while most US firms buy all of theirs, usually from Japanese suppliers.

European firms often display a hybrid pattern, being more comfortable developing hardware than software. Both Renault and Volkswagen made their own welding robots for years before transferring the technology to outside firms recently. But only Renault had a strong program in body CAD and that was terminated years ago. Today, just as 20 years ago, a European machine tool or robot maker will sell "naked" machines to manufacturers whose manufacturing and tooling engineers will do all the applications engineering (fixtures, grippers, programming, part feeders, installation, checkout). In the US, such suppliers must do nearly everything.[12] This is called delivering a "turnkey" system. However, in some cases the supplier has to keep turning the key, providing maintenance and upgrades.[13]

The Example of CAD/CAM

An important case is that of CAD/CAM software strategy, which differs in important ways at each of the Big 3. Chrysler abandoned its in-house

---

[12] "We include all that hand-holding in our bid," said one machine tool marketing manager.

[13] In some process-driven industries such as paper, the tables are turned. The customer modifies the equipment to greatly enhance its productivity, keeping these changes secret from the original supplier.

CAD/CAM in the late 1980s in favor of the aerospace CAD/CAM system CATIA. Little was lost and much was gained in end-to-end capability. Chrysler was able to bank on IBM's support for CATIA as well as its track record in aerospace. To make up for the lack of automobile-specific design support, Chrysler and a software contractor have spent the last few years developing a wide range of capabilities ranging from specific engineering calculations to an overall product data management system that helps control the entire design process, including bill of materials and cost and weight estimates.

Chrysler has a different CAD/CAM strategy from either Ford or GM. Ford, a pioneer in CAD/CAM[14] , has a highly developed in-house system called PDGS (Product Design Graphics System) which was developed by and is used by sheet metal body and internal structure designers and engineers, as well as for some mechanical design. It has hundreds of features that they need for this kind of design. In the last few years Ford has made several moves to make PDGS easier to use and improve. These include making it UNIX compatible and qualifying four workstation vendors to support it. Suppliers can adopt PDGS at a low entry cost. The open architecture is also being defined with an applications protocol interface (API) so that 3rd party software can be written and interfaced easily. The ACIS geometry kernel will be adopted soon, giving PDGS a common basis that will permit further integration of outside software. Ford's central strategy is that data is king and tools are to be obtained from wherever the best can be found.

Ford's power train and chassis departments also use PDGS, but in addition use commercial CAD systems (Aries and Computervision) that do well with mechanical parts. It appears that the vision of "CAD/CAM the master" has not yet been realized across both body and mechanical design. The separate systems now in use will be difficult to unify. Chrysler says that while CATIA has been most thoroughly adopted in body design, it is also penetrating power train and proving to be successful there.

GM has evolved through several stages of CAD/CAM development starting from the early 1960s when it developed a pioneering CAD system called DAC. Later it developed CGS (Corporate Graphics System) which supports both surface and solid modeling. However, GM has decided to use Unigraphics for its mechanical and tooling design. Both systems are continually being augmented with in-house and third party software. In the mid 1980s GM attempted to unify all of the company's design and engineering under one program called C4 (CAD, CAM, CAE, CIM) but this effort has been sharply scaled back. Its major accomplishment was to provide

---

[14] See "Analytic Surfaces for Computer-Aided Design," by Johnson, Sanders, and South (SAE Paper 660152, 1966) which defined Ford's vision for "CAD/CAM the Master."

a backbone infrastructure for communication plus some standardization on hardware and software.

It is not likely that either Ford or GM will move completely toward either one in-house system or one commercial system for all design and engineering. They have too much invested in existing software, augmenting programs, facilities at suppliers, and user familiarity. Chrysler had a much smaller investment in its own software , so the switch was easier.

Which Way to Go?

The arguments for and against having in-house control of the infrastructure are the same for both hardware and software. The argument against is simply that someone else will have more expertise, being able to concentrate on being excellent in that one specialized area. Demand is also highly cyclical, so leaving the infrastructure to someone else leaves the layoffs to him, too. The argument for is more complex and hard to justify because it seems to involve intangibles. The Japanese say that design processes are carefully nurtured technical and cultural structures that depend heavily on software. That software must support the company's "working style." CAD software is deliberately grown to be an integral part of the company's culture. No commercially available software is presumed capable of doing this.

Similarly, if one develops one's own manufacturing equipment, one knows its capabilities and can design to stay within them. Both individual workstations and whole manufacturing systems have characteristics that designers need to know about or have the opportunity to influence. What tolerance range can be supported? What kinds of flexibility in manufacturing is it capable of, or what flexibility attributes should we ask for? How sensitive is it to variations in raw material properties? Can we tailor it just so, to take advantage of some other piece of equipment or feature of our design? Can we teach our people how to fix it? A Japanese engineer said to me "You learn by trying, not by buying." A US engine production manager said "We tend to push complexity down onto the factory floor. Toyota knows what each machine can do and designs for that. Then the factory can just concentrate on becoming more efficient." The savings Toyota reaps in reduced direct and indirect labor on the factory floor can be considerable. In addition, "leaving the layoffs to someone else" has often led to the outright disappearance of some suppliers, leaving the manufacturers with fewer options, many of them offshore.

Finally, there is the problem of evaluating the suppliers' designs and bids. "We make billion dollar decisions all the time on no quantitative basis," said one manager.

There is no single correct answer to the question of how much in-house infrastructure capability companies need. It depends in part on their commitment to using design and manufacturing capability to help differentiate their products in the marketplace, perhaps with faster design cycles, better quality, lower warrantee costs, and so on. In the car industry, styling has always been the prime factor in attracting buyers.

The choice also depends on the strength of the commercial sources for such expertise. The record in the US in this area is spotty. A few excellent companies exist that deliver large complex factory systems direct to manufacturers. But most equipment and system vendors are small, short of technical expertise, and undercapitalized. Customers do not make progress payments, so the size of project they can undertake is limited by their credit line. One bid too low and such firms could be out of business, leaving their customers to figure out how to maintain and repair the equipment.[15] CAD companies, with a few exceptions, are also small and financially shaky, technically limited to programmers and mathematicians with little design or manufacturing knowledge. They must sell generic software to survive, but often find themselves stretched by one or another big customer who demands that the software be tailored to their needs.

A final area of competence is people. Chrysler is leading the way in becoming a lean (smaller) company that can still deliver complex designs and manufacture cars, but Ford and GM have also drastically downsized. Among the methods these firms use for managing cyclicality in demand for people is to hire "contractors" or "job-shoppers." These are professionals, usually without university educations, who work for employment agencies instead of the car companies. They move from job to job, car company to car company, staying a few weeks, months, or even several years. A very large percentage of what the car firms call "designers" (called draftsmen in other industries) are contractors. In practice this means that much of the detailed engineering and design knowledge is in the heads of people who are not permanent employees. "They walk out with knowledge of our car programs and all the CAD training we gave them." It also means that college educated engineers spend a lot of their time managing such contractors (and suppliers) rather than doing actual engineering themselves.[16] The technical content of the designs can suffer under these conditions. Improved CAD tools are a major weapon being sought by all the car firms against both deterioration of

---

[15] An automation company executive recently told me "You always have at least one incompetent competitor who bids too low. This sets a ceiling on everyone else's bid. The customer has no in-house capability and thus cannot tell that the low bid is incompetent. So for small companies in this business the downside risk is huge and the upside potential is small."

[16] A former student recently told me, "I spend more and more effort trying to avoid becoming a manager after only two years here. Most of my colleagues fight fires while the real technical work is done by consultants."

human skills and the loss of a permanent engineering workforce at the detail design level.[17]

The specific company reports that follow discuss how each of the Big 3 is dealing with the above issues: how to arrange and improve their design processes, how to use computers to aid those processes, how much in-house CAD capability if any to maintain, how to augment generic commercial CAD with in-house design tools, and so on.

---

[17] An informal survey indicates that in Japanese car companies the designers, including CAD system users, are fulltime university-educated employees. Engineers make their own designs and "designers" are not a separate category.

Chrysler Car Company

separate document

Ford Motor Company

separate document

General Motors

separate document

References

[Aoshima] Aoshima, Yaichi, "Inter-project Technology Transfer and the Design of Product Development Organizations," MIT Sloan School of Management Working Paper, December, 1993.

[BW] "Motown's Struggle to Shift on the Fly," Business Week, July 11, 1994, pp. 111-112.

[Clark and Fujimoto] Clark, Kim, and Fujimoto, Takahiro, "Overlapping Problem-solving in Product Development," in K. Ferdows, ed., Managing International Manufacturing, Amsterdam: North Holland, 1989. See also Chapter 5 of Womack, Jones, and Roos, The Machine That Changed the World, New York: Harper Perennial, 1991.

[Fujomoto] Fujimoto, Takahiro, "Development of the Black Box Parts Procurement Method in Japanese Car Industry," University of Tokyo Faculty of Economics Working Paper FP-1, December, 1993.

[House and Price] House, Charles H. and Price, Raymond L., "The Return Map: Tracking Product Teams," Harvard Business Review, Jan.-Feb., 1991, pp. 92-101

[Ingrassia and White] Ingrassia, Paul, and White, Joseph, Comeback: The Fall and Rise of the American Automobile Industry, New York: Simon and Schuster, 1994.

[Krafchik and MacDuffie] Krafchik, John, and MacDuffie, John-Paul, Chapter 4 in Womack, Jones, and Roos, The Machine That Changed the World, New York: Harper Perennial, 1991.

[Nobeoka and Cusumano] Nobeoka, Kentaro, and Cusumano, Michael, "The Influence of Inter-project Strategy on Market Performance in the Auto Industry," MIT Sloan School of Management Working Paper WP 3370-92-BPS

[Prahalad and Hamel], Prahalad, C. V., and Hamel, Gary, "The Core Competence of the Corporation," Harvard Business Review, May-June 1990, pp. 79-91.

[Scott, 1994a] Scott, Gregory, The IMVP Product Development Series: The Chrysler Corporation, IMVP working paper, September 1993

[Scott, 1994b] Scott, Gregory, The IMVP Product Development Series: The Ford Motor Company, IMVP working paper, May, 1994

[Ward, Christiano, Sobek and Liker] Ward, Allen, Christiano, John, Sobek, Durward, and Liker, Jeffrey, "Toyota, Concurrent Engineering, and Set-Based Design," to appear in Engineering in Japan: Organization and Technology, eds. J K Liker, J E Ettlie, and J C Campbell, Oxford University Press, 1995.

[Whitney 1993] Whitney, Daniel E., "Integrated Design and Manufacturing in Japan," Manufacturing Review, v 6 no 4, Dec., 1993, pp. 329-342.

[Yergin] Yergin, Daniel, The Prize: The Epic Quest for Oil, Money, and Power, New York: Simon and Schuster, 1991.