Visit to Toyota, September 6, 1991

Background

This visit was a followup to the one on July 31. Our hosts were Mr Kuranaga, Manager of Information Systems Div 1, Mr Takatoshi Negishi Manager of the CMM Group in Body Production Engineering, and Mr Yasuhiko Ichihashi, Project Manager in the Chassis Design Department. Other attendees were Mr Kato (CAD/CAM systems for suspensions), Mr Sasano (body engineering CAD), Mr Hatano, (engine engineering CAD), Mr Kobayashi (power train engineering R&D), Mr Shimizu (formerly engine design, now in CAE), Mr Yoshida (power train gear parts design), and Mr Iwase (Info Systems Div 1, planning new CAD/CAE/CAM systems). The general subjects were the overall vehicle design process and use of computers in engine and transmission design. Afternoon plant tours covered die design and manufacture, and Toyota's in-house manufacturing equipment building division.

Vehicle Design Process

Mr Sasano presented Toyota's car design methodology. He said that, overall, it takes 3 years from start of concept design to start of production. New technologies and power trains take longer. The concept, styling, and preliminary design takes the first year, detailed design, prototypes, and evaluation take the second year, and tooling design and production takes the last year. Later he amplified this breakdown with Figure 1, which shows that several of the processes extend over more than one year.

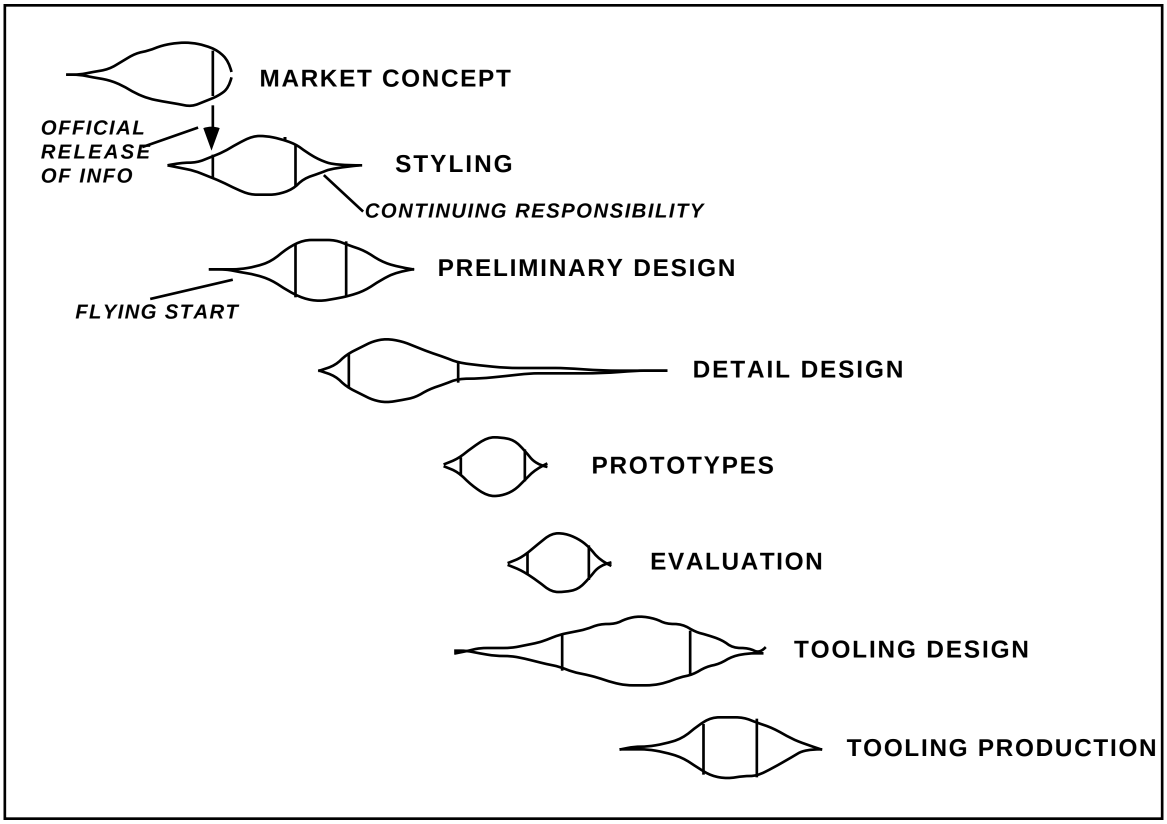

Figure 1. Overlapping Design Tasks

In this figure, the leftmost vertical line in each balloon indicates when official information is received from the previous balloon; the rightmost line indicates when official information is passed on to the next balloon. Preliminary information is released earlier than the official release so that the "flying start" can occur. Activity in each balloon continues after final release of information to take care of downstream problems ("continuing responsibility").

He used Figure 1 to make the point that European and US car makers take longer to design cars because of a different attitude toward "responsibility and competence." In Toyota, designers have responsibility for their own designs, updating them where necessary due to the needs of downstream processes like tooling design. Mr Sasano thinks that in Europe and the US the downstream designers take over responsibility and can change the design. It is not clear why this should make the process take longer but clearly Toyota's method will cause the designers to learn downstream problems and avoid them next time.

The two important features of Figure 1 are the "flying start" and the "continuing responsibility" or downstream followup. Flying start involves two processes: an essentially free check of the design by the tooling people, and a costly/risky early start on design and construction of the tooling itself. The vertical arrows in the figure denote official drawing release but there are clear cases where flying start extends back almost to the beginning of the previous task or even two previous tasks.

Flying start information is not informal and is not transferred freely "among friends" (my terminology to indicate unsanctioned transfer). He was very firm on this point and it seems to contradict Prof Fujimoto's description of a process that depends on long-term personal contacts. According to Mr Sasano, there are various levels of approval, but all information transfer is approved. Final release has top management approval, but intermediate release of incomplete information can be done with departmental approval.

"Incomplete" can mean preliminary and subject to change, or it can mean that main structure is shown but details are omitted. How is the timing and content of these intermediate transfers worked out? What was the history of its evolution? "Difficult questions." The answer was typically Japanese: Our engineers are highly educated and have universal experience (i.e., they do not have a few narrow skills). They must harmonize with their job environment. Sometimes information is offered, sometimes it is requested. The correct action is a common subject of discussion among themselves.

Die design, power train design, and chassis design all utilize similar principles. The whole process is controlled by the Chief Designer (what Prof Fujimoto calls the Heavyweight system). He is responsible for launching the effort and deciding all the tough technical issues.

Among these is allocating space for wheels, engine, and transmission in a front wheel drive car. Styling sets the spacing and the power train people fight it out for the space between. To catch problems early, Toyota starts engine compartment layout as soon as early styling sketches are available because many of the "hardpoints" (fixed dimensions like wheelbase) are determined at that time. A special cross-functional working group chaired by the Chief Designer is formed to handle this problem area. Wireframe 3D computer data are used to aid the decision process. Often its meetings are short because design consists of choosing an existing engine-transmission pair. When a totally new engine and transmission are used, car design can take longer than the three years cited above.

Computer Support for Concurrent Engineering

Mr Sasano showed a chart (Table 1) delineating the two most important issues: databases and communication, showing the present status and future goals. For current data representation, there is a CAD model of the car in the form of a 3D wireframe or surface model, plus some parts that are modeled in a hybrid of wireframe and surface representation (the latter for complex surface regions). Communication is currently supported by data conversion software and by means for distributing data electronically to downstream processes. No mention was made of communication upstream. Since electronic data now consist mostly of geometry, a lot of attribute data are still issued on paper. Therefore, Mr Sasano seems to think that electronic data representation is merely a change in media. Several of us in the meeting disputed this and he relented.

	NOW	FUTURE
DATABASE	• CAD MODEL OF STRUCTURE: -3D WIREFRAME, SURFACE, OR HYBRID	• CAD MODEL • BILL OF MATERIALS • PART ATTRIBUTES* • DOCUMENTATION
COMMUNICATION	• DATA CONVERSION • DISTRIBUTION TO DOWNSTREAM PROCESSES	• UNIVERSAL COMMUNICATION NETWORK

Table 1. Computer Support for Concurrent Engineering
*Attributes include weight, material, thickness, spot weld locations and their tolerances, and other tolerances

Mr Hatano pointed out that in fact only body data are in 3D while all the rest are in 2D. The result is a lot of conversion to 3D to permit interference checking. This is painful and in fact the checks are done semi-manually. Multi-color wireframe computer drawings are projected onto a big TV screen in a meeting room and everyone talks them over. It is an awkward process and Mr Kuranaga asked them if they plan to switch to all 3D in the future. Their answer is the typical one, namely that 3D takes too long and the designers like 2D.

In the future, Mr Sasano says that the database will be a combination of CAD models, bill of materials, part attributes, and documentation like process instructions. The future communication system will comprise a universal communication network. This will create "integrated engineering."

Prof Kimura says he has heard Toyota people talk about this future dream system before but he feels they are still debating its details. It appears to be less developed than the ideas outlined by Mazda. Neither company seemed to have made explicit provisions for passing information back upstream. The issue came up at Toyota during a discussion of assembly planning. I had given an example of alternate assembly sequences for automatic transmissions, indicating that one sequence required mating several gears at once while another mated them one at a time, distinctly easier. The example was intended to show that there is more to DFA than just reducing part count.

Their reactions were several: first, manufacturing engineers work out the assembly process. They critique the detail design as well, pointing out opportunities to use existing tooling by recreating the hole spacing from a past design, or increasing spacing between holes so that all the bolts can be tightened at once. All this is based on past experience and data in people's heads. Second, so many meetings are held that 95% of all the assembly problems are discovered and eliminated. "Drastically speaking, our production engineers are our software," says Mr Kuranaga. This confirms Nissan's view that Toyota can throw people at a problem and solve it. It also supports the view that many Concurrent Engineering activities that we would account for individually have become second nature at Toyota, and no need for specific efforts or additional software is seen.

Toyota uses CAD models to check tool access during assembly. Models of both tools and human hands are available in the database. Also, designers of transmissions and engines take into account the need for chamfers on parts, that a worker has only two hands, that assembly should occur from one direction, and so on. Transmissions are assembled manually. However, engines are assembled by a mix of manual and automatic methods. No formal design methods are used for taking these different assembly techniques into account, as far as I could tell.

As a result of its many meetings and universally experienced engineers, Toyota has no use for traditional DFA and feels that companies that use it must have poor communication and experience. The fact that both GM and Ford have made much of their success using DFA only confirms to Toyota that their competition is weak. They are apparently unaware of the innovative uses that companies like Sony and Nippondenso have made of DFA methods, where communication is simply not the issue.

It is possible that Toyota makes too much of communication and, like Nissan during my first visit, felt that I was interested in how computers can support communication. Since few Japanese companies think such support is necessary, I usually hear at first that computers are not essential to the design process. Only later did it emerge at Toyota that Mr Iwase's new CAD project will indeed contain as much process engineering computer support as he can obtain or create, including that for assembly.

I also learned that Toyota is actively investigating new workstation-based CAD software, such as ProEngineer. Mr Negishi is quite impressed with it. However, all CAD systems he has surveyed, including ProEngineer and Ricoh's Design-base, are unable to represent the complex fillets he wants for modeling connecting rods and other similar parts. While I originally thought CAD vendors' boasts about their filleting capabilities were self-indulgence, this remark by Mr Negishi shows that some weight-critical parts can be essentially all fillets. Thus filleting can be crucial in certain situations.

A final point: my hosts at both Toyota and Nissan were CAD support people responsible for providing computer capability to engineering. The computer people are distinctly ahead of the engineers in their thinking, and often propose capabilities or practices that the engineers see no need for. However, the history is that the capabilities are eagerly used as soon as they are made available.

Computer-Aided Engineering in Power Train Design

Apparently the typical CAE applications are in use, including their own software for supporting engine and transmission design. No software is available for setting tolerances, nor is there any support for selecting the style of transmission design. "An experienced person does it." Not enough detail was obtained to make possible an interesting report on this complex and rich topic. Another visit should be arranged.

Tour of CAD/CAM of Stamping Dies at Motomachi Plant

The CAE of dies was covered briefly in the first visit report. The tour covered the CAD facilities and the machining area. Exhibit 1 of the first Toyota report illustrates the elements of die design and manufacture. Our hosts for CAE and CAM were Mr Muta and Mr Amano.

CAE of dies has been forced by the huge growth in diversity of cars and the short design cycle. Many more dies are needed much sooner than before. As long as ten years ago Toyota forsaw needing many more skilled people and more of their time than could be provided, and therefore launched the CAD / CAE / CAM effort.

The CAD facilities are centered on a large UNISYS mainframe and many terminals. Data on die shape come from body engineering. In this area, die design is completed by the addition of details, clamp surfaces, cutters, and so on. Extensive software written by Toyota then determines the tool paths so that all the die's details can be cut, usually with a 1" diameter ball end mill. Smaller tools are used only when necessary.

CAM consists of two rows of four large NC machines each. The first row was built by Toyoda Machine Tool Co. in the early 1980's and consists of 5 axis machines. These yield die accuracy in the ±50μ range. Toyota decided during the mid 80's that this was not accurate enough and developed the second row of machines, which were installed in 1988. These are 3 axis (a surprise) and yield accuracy in the ±20μ range. Three axis NC has the advantages of being more rigid and of having a smaller tool socket size, reducing interference problems between machine and die. On the new system a die stays on one machine 20 to 40 hours while it receives all the necessary cuts. The shop runs 3 shifts and runs unmanned over the weekend.

The need for higher accuracy came from identifying quality problems in earlier cars. An example shown is surface waviness near the edge of a door. Accuracy of internal structural parts is just as important as accuracy of the outer panels. (For reference, there are between two and three times as many inner panels as outer panels. Since there are typically 30 outers, there are at least 100 total per car and some require several dies.)

The dies are machined using 5mm pitch cuts at first, then finished with about 0.5 to 0.7mm pitch. Very high feed rates (as high as 4 m / min, they claim) are used on the final cuts. The resulting dies look like they have been sand-blasted, with only a hint of linear tool marks about 15μ high. Before finishing, the dies are checked in a coordinate measuring machine (CMM) to be sure that the 20μ is obtained. About 15 to 20 hours of hand stoning and emery cloth polishing by three people then converts the die to a smooth, almost mirror finish.

Mating die pairs are checked with yellow transfer ink. Where a space equal to sheet metal thickness must remain, sheets of rubber are laid on the male die and then inked. These sheets have raised patterns of different heights in fractions of a mm with a different pattern for each height. From the pattern printed on the female die, the toolmaker can see how much material must be removed.

Why is this technique needed when 20μ accuracy is obtained? Apparently this was an embarrassing question. The answer was not entirely satisfactory: there are not enough high accuracy machines in the shop to make all the dies to 20μ. Either they are made on less accurate machines, or they are made by outside contractors to lesser accuracy, or the time is not devoted to a final cut at a fine pitch. More hand finishing is needed, adding error. Thus some dies must be hand-fitted.

Unlike any other shop I have visited that attempts work this accurate, this shop was not temperature-controlled or air conditioned in any way. The 20μ is clearly meant as a relative error limit, as we could tell by noting how the CMM was working. That is, it is only necessary to be accurate relative to the hard points on the two dies that bottom on each other at the end of the stroke. Most dies are too shallow for temperature excursions to make large changes in height relative to the hard points. Length and width were not being held to such accuracies.

It takes about 22 days (three shifts) to make a die, according to Mr Muta, of which about 3 to 5 are for tryout. These figures must be averages, since tryout of difficult dies often can take much longer. I was not able to find out how long it takes in such difficult cases, but Exhibit 3 of the first Toyota report shows tryout times in hundreds of hours, which is many days at 24 hours per day.

Visit to Teiho Plant

At this plant, Toyota designs and makes automation equipment, some of which it sells as well as uses internally. Mr Takano showed us local area network (LAN) equipment and associated controllers, cables, and connectors all designed to Toyota's own standard. These controllers were attached to a variety of Japanese computers, controllers, and robots. The data rate is 1.25 MB/sec.

We also saw a video illustrating several pieces of factory automation designed and installed by this division. These included beam-transfer handling systems for merging car bodies, chassis, engines, and axles, vision-aided robots for installing dashboards, and a system of three robots that (in a rather complex way) installed wheels on cars and then installed and tightened the nuts. The body-engine-axle merging system looks somewhat like what VW installed in Hall 54 in the early 1980's.

Mr Kuranaga noted that the dashboard being installed was empty, that workers later must lie down on their backs in the car and install the instruments and wires. "We do not install complete tested cockpits. In fact our weak point is that only 5% of our final assembly is automated." VW claimed 25% in Hall 54, and GM has been installing complete cockpits in some cars for several years.

A tour of this division's workshop turned up two cooperative robots programmed by mutual timing to open a beer bottle and pour beer, some AGV's being tested, plus several conventional assembly and machining lines under construction. The beer opening robot contained no sensors and operated in a very conventional way available to any commercial robot. I was told that in a factory, a similar pair is at work loading balls into constant velocity joints.

The other equipment was also conventional. One machine consisted of robots and transfer equipment intended to weld together three parts for the tube and brackets of MacPherson struts. These are simple parts and such struts are undoubtedly available from any number of vendors. Given the outsider's impression that Toyota buys conventional components, I was surprised to see this machine. No explanation was available.

However, I have heard separately that Toyota is beginning to bring as much as 10% of routinely procured parts in-house so that some idea of a fair purchase price can be determined internally. This includes not only simple parts like the struts but complex electronic items.

Concluding Remarks

These two visits obviously barely scratched the surface of one of the world's leading manufacturing companies. It is clear that use of computers in the design process is growing rapidly and that it is company policy to encourage this process. The priorities are focused on design-manufacturing integration of efforts that currently take a lot of time, for which accuracy is required, or for which human experience is needed and ways exist to augment this experience.