Visit to Nippondenso, July 29-30, 1991[1]

Background

Our hosts for this visit were Mr. Fukaya, General Manager of the Production Engineering Department, Mr Tsuchiya, Fukaya's R&D Manager, a young engineer Mr Harada, and at dinner Mr Ito, the Executive Managing Director of Production Engineering.

Nippondenso Co Ltd. is a former subsidiary of Toyota Motor Co. that makes a wide variety of automotive components, such as alternators, motors and actuators, air conditioning systems, engine components and controls, radiators, dashboard displays, brake control systems, and so on. It has manufacturing plants worldwide to satisfy many automotive manufacturers. Handling the wide diversity of product models and responding to the Just in Time ordering system philosophy have heavily affected how Nippondenso designs and manufactures products.

Nippondenso is a high technology company. Basic and applied research cover materials, vacuum apparatus, semiconductor fabrication methods, ceramics, robotics, vision systems, factory automation software, simulation systems for testing driver reactions, and CAD/CAM. Major design thrusts over the past 10 to 15 years include "managing diversity," designing new products faster, overlapping design tasks while managing risk, and dramatically reducing the size and weight of products while increasing quality and performance.

The company has 41000 employees. Of these, about 5000 are design engineers, 1500 are production engineers. At the new R&D center where the visit took place there are currently 150 researchers. A major characteristic of Nippondenso , which I have noted in many previous reports dating back to 1977, is that it makes much of its own automation equipment and nearly all of its 3500 robots. This commitment to manufacturing equipment excellence is one part of its commitment to manufacturing excellence in general.

The typical working year at Nippondenso and in Japan generally is 2200 hours, compared with 1800 in the US. The government is trying to get this reduced to 2000 by 1994 and 1800 by 1996. Each Japanese company is attempting to reach this target, facing various problems.

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[1] I published a paper on this company that contains information from this visit and others going back many years: "Nippondenso Co. Ltd., A Case Study of Strategic Product Design," Research in Engineering Design, (1993) vol 5, pp 1 2 20.

Nippondenso characterizes its products as follows:

- Quality first
- Wide range of product variety
- High speed mass production
- Mixed production (several varieties in one place)
- Just in Time production method
- OEM sales mainly

These conflicting characteristics (especially variety, mass production, and mixed production) have driven the company into a variety of design and automation methods. These are covered below.

Automation and Product Development Techniques

An important feature of Nippondenso is an obvious long term enterprise-wide strategy for how to grow the company into a master of manufacturing products with these characteristics. Nippondenso has evolved a systematic approach to managing design processes, designing carefully to support JIT operations, and developing larger and larger systems of automation. In the 1950's they had "spot" automation (what we would call islands); in the 60's they had lines; in the 70's "areas," meaning presumably several lines of the same type or several lines connected; in the 80's and early 90's "cube" or "totality." Such increasing automation creates serious dangers for a company whose customers switch specifications, alter model production volumes, demand instant response to orders, and increase variety of products.

Nippondenso has only gradually realized how deep the dangers can be and has instituted several procedures for combatting them. These include simultaneous product-process development, a classification of levels of necessary flexibility in production, and a classification of degree of innovation in design projects.

Classifying Flexibility

Nippondenso's classifications are as follows:

Flexibility for Product Variation - configuration, size, model, and type are levels of variability within the product itself that are increasingly difficult for the automation system to accommodate

Flexibility to Design Change - minor changes are often easy to accommodate, model changes are harder, and the next generation of the product usually requires a new factory

Flexibility to Production Volume Change - total volume fluctuation requires reassigning manufacturing systems to different products; gradually increasing volume normally requires buying more capacity; fluctuations among product types require reassigning production capability between the types.

In response to these needs, Nippondenso has utilized several strategies, beginning in the 1960's: (See Exhibit 1)

- FMS-0 - Use specialized automation with no flexibility and make rigidly standardized products; an example is little control relays - Mr Fukaya notes that strong efforts at standardization occur even when automation at levels 1, 2, and 3 below are adopted. Furthermore, FMS -0 is the preferred approach and is used wherever possible.

- FMS-1 - Design the product with several versions of each part, capable of being intermixed: 3 fronts, 4 middles, 3 backs, total 36 types; an example is a panel meter gage, in which many varieties of one basic model are made minute by minute based on a stream of orders from Toyota [Nevins and Whitney]

- FMS-2 - Design the product with a common outer shell and interchangeable interiors, and provide robots and sensors as needed to make quick changes from one to another; several models of an air conditioner are made this way, all being essentially the same size

- FMS-3 - Design product and process so intimately that one can even change the outside shell's length and diameter without affecting the automation system. The Type III alternator (see below) is an example.

Flexibility means not only the ability to switch some important factors of the product but to switch rapidly. Nippondenso has worked over the decades to cut the changeover time from hours to minutes to seconds, while at the same time increasing the range of flexibility.

The size of the product is one of the most important factors in the design of an automation system. Supporting a later change in product size without rebuilding the system is almost impossible. Yet as cars become smaller and lighter, so must their components. Only the largest cars can take the largest components; even here, however, the manufacturers are pressing for smaller components which perform more functions. One can no longer simply reduce the capability of the product for use in a smaller car while keeping the outer shell the same. The shell must shrink, too. As more varieties of cars are made, more sizes of the same product are needed, each made in smaller production volumes than before. Lower production volumes mean less efficient automation unless some way can be found to make all sizes on one automation system. Thus FMS-3 is a very difficult but important level to achieve.

Summarizing, the ultimate factory can make any quantity of any item without any penalty for switching. The disadvantage of current automation systems is that they are too focussed on a small range of models of one product. If demand for one version of alternator, say, rises while that for another falls, the underloaded line cannot help the overloaded one. Instead, one must build more lines, resulting in overcapacity and wasted investment.

Several generic approaches exist to this long-standing problem: predict future demand perfectly, make super-intelligent manufacturing systems that can switch, or design the products and their manufacturing processes to contain a measure of alterability. I call the latter "smart products" below. It is probably the best of the three approaches, the first being obviously unavailable and the second beyond the current state of the art except in restricted but very useful situations. Nippondenso has adopted the smart products approach and showed some interesting examples.

Classification of New Product Development Efforts

This classification is as follows:

1. Innovative, totally new product (10% of design efforts); examples include active suspension or CRT dashboard displays

2. Strategic new product (called Jikigata); these are major, market-share-grabbing improvements of existing products such as radiators, alternators, and fuel pumps

3. Semi-new products; these are in fact minor improvements in performance of existing items; several such improvements come along between Jikigata's

The bulk of the visit focussed on the Jikigata for a new alternator.

The Jikigata Process

Jikigata efforts are directed at products which are mainstays of the company, feed a mass production requirement for a popular car, and face important competition, thus requiring strong innovation. On top of this, such products require timely and reliable delivery. These requirements have forced the creation of new design staff organizations and close involvement of top management. While CAD and CAE have played important supporting roles, the most important element of such developments is creation of new manufacturing methods to support the "smart" flexible design. This has meant making production engineering an equal partner in the design process.

Nippondenso , like many Japanese companies, maintains Production Engineering as a corporate level activity with a Director (equivalent to Executive VP) as its head. Thus the company was long prepared for the required organizational changes.

It is important to realize that this is a more sophisticated activity than mere "design for manufacture" or "design for assembly." A new level of automation / flexibility is being sought, and it cannot be achieved unless new manufacturing methods are created, methods which are *enabled*, not just *eased*, by the product design itself.

A Jikigata effort combines corporate production engineering and a product division's capabilities as follows:

Corporate Production Engineering	Product Group
System Section	Planning Center
Processing Section	Product Engineer
Materials Section	Manufacturing Department
Machinery and Tools Department	Quality Assurance

Product development begins after a launch decision by the New Product Development Council, which appoints a product development team (4 - 5 engineers) and a process development team (2 - 3 engineers). These teams work together to create the concept design specs. Each then splits into separate activities, enlarges to about 20 members each, and comes up with an action plan to meet the spec. Once the plan is approved it is condensed to a single sheet of paper and given to everyone. These 40 - 50 engineers stay with the product until the end of the project, later being joined by about 100 manufacturing equipment designers. The most specialized one third of the machines (by cost) are made in-house, while the more ordinary ones are built by contractors.

The plan (Exhibit 2) must be challenging but reasonable. It must contain the total view and plenty of detail. It involves top management, who attend monthly follow-up meetings. Each goal has a responsible person and a list of risk-management actions. Each goal is classified as to its importance to the project and its level of risk. The importance levels range from "M" (for must have) to "W1" (want very much) to "W2" (want, but not so much). Risk varies from "A" (feasible today) to "B" (currently being studied for application to mass production) to "C" (under basic examination, not out of the lab yet). At each point in the schedule there is a "T" (target) date after which, if a risky process or design element has not been achieved, one of the prearranged alternates will automatically be substituted.

On top of all this, Nippondenso aimed at reducing the development time from the customary 6 years to 4, by overlapping product and process development activities. For the Type III alternator the development time apparently was 5 years.

Along with this elaborate planning process, Nippondenso has some "useful tools." These comprise the usual CAD/CAM/CAE software, plus value engineering, group technology, and variation reduction, plus Nippondenso's own design for assembly evaluation method, a variety of system engineering aids like discrete event simulation and process FMEA, and quality management methods (design reviews, QC techniques, and the Taguchi method). Calling these "useful tools" reveals Nippondenso's priorities: get the methodology in place first, then support it with tools.

All of the debates and tradeoffs involved in these efforts are carried out by experienced people. When there is a major problem a top executive decides. Design is vulnerable to change, often forced by the actions of a competitor. In alternators and air conditioners, where Nippondenso dominates, competitors' actions are less disruptive of the design schedule, but in brake systems where Nippondenso does not dominate, the schedule is more vulnerable. The availability of top management and their willingness to take the responsibility and make decisions quickly is crucial. In this sense, Nippondenso is like Nissan and other companies who organize to absorb change during the design process rather than try to resist it.

Note, too, that Nippondenso is willing to use the overlapping tasks method even on projects with lots of technical risk. Overlapping brings the risk of more change, but Nippondenso and Nissan both feel that changes forced by outside pressures such as competitors' actions are more severe. This fact slightly counters Prof Kimura's feeling that only "understood" processes and products could be approached this way. Mr Fukaya was quite clear on this point, and said that Concurrent Engineering (joint operation of product and process design teams with monthly follow-up by top management) was the way to accomplish it. They all agree that it is based on human communication and experience, and wish for computerized versions of CE. I did not hear them suggest any ways to create them.

Nippondenso's production engineering people are also sympathetic to the idea that computer aids will help this process and fervently wish for such help, but they do not see it becoming available soon and do not think it will be a dominant feature of their success. Yet they are developing several effective computer tools and see where others might be introduced. See below for a summary of these.

Development of the Type III Alternator

The main components of an alternator are the stator, the rotor, the two-piece cast outer case, and the rectifier assembly. The goals of the redesign were to produce an alternator that could be made in several lengths and diameters on the same fabrication and assembly equipment. Important changes in the design of all four components were required. Some were relatively easy, such as cutting different diameter grooves on different size cases. Redesign to permit assembly from one direction was also not too difficult to achieve. Others required considerable innovation, such as making different diameter stators. This was done by coiling stator laminations stamped from long strips of steel (Exhibit 3) rather than stamping rings from steel sheets and stacking them up. (The amount of scrap material is also drastically cut this way.) The wire windings for the stator are formed separately from the stator itself and pushed radially outward into the grooves in the stator rather than being wound in place in the stators. Changing the diameter of the windings is easier this way. Most of the size changes can be made almost without stopping the manufacturing equipment.

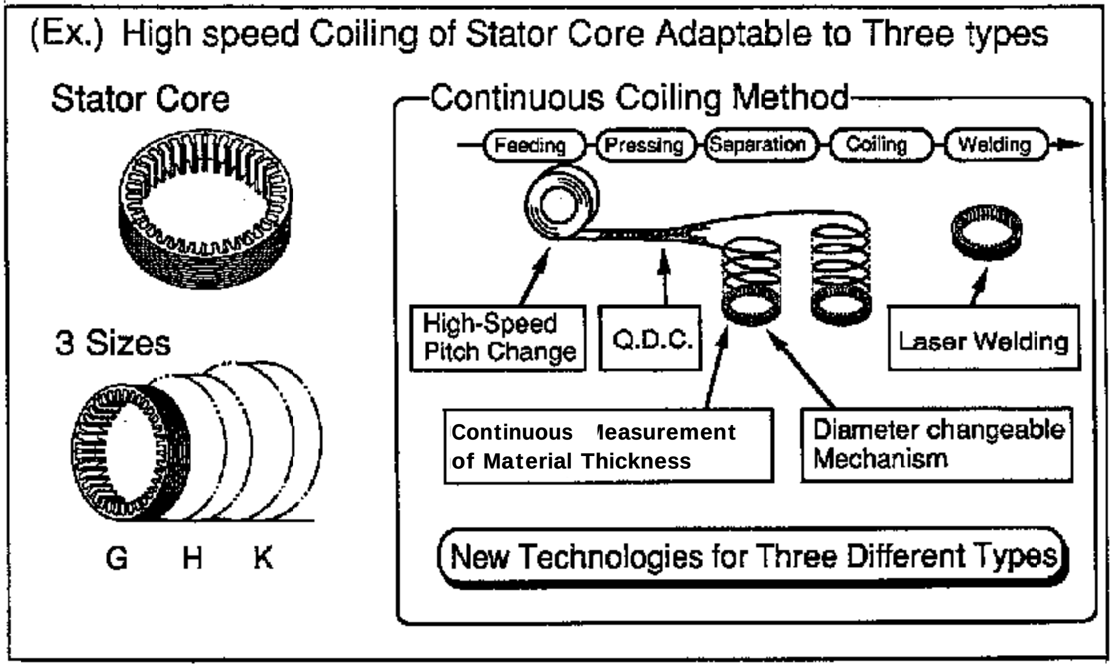

Exhibit 3. High Speed Coiling of Stator Cores in Three Diamaters and Several Stack Heights

Altogether 74 new manufacturing technologies were developed. This project occurred in the early 1980's.

The resulting design comes in three main sizes with capacities ranging from 35 to 80 amps. Within each size there are about 250 variations.

These alternators are assembled on automated assembly lines that use mostly specialized automation for the assembly moves themselves plus robots to feed the parts from trays to the assembly stations. A few simple fixture changes, accomplished manually, support changes in product model. Nippondenso built these lines in 1987 after seeing a film in 1980 made in 1977 by our group at Draper demonstrating complete robot assembly of Ford alternators.

The spirit of these innovations can also be seen in the way Nippondenso redesigned radiators a few years earlier. [Ohta and Hanai] A major feature was machines that could switch sizes of components in a few seconds, plus a snaptogether assembly method that eliminated the need for fixtures in the different sizes. The cost of the fixtures was saved but more importantly the time required to switch from one size set of fixtures to another was eliminated. Some of these techniques were pioneered by General Motors Harrison Radiator Division but not put in place as completely as at Nippondenso .

Radiators and alternators are clear examples of "smart products," being designed so that the challenging manufacturing strategy of conquering variety could be achieved without basic advances in manufacturing knowledge. Innovative manufacturing methods were indeed made, however. Deciding how to partition the problem into product innovation and process innovation clearly required a single team working together from the start of the project. Success would have been unlikely if process engineers had merely critiqued the product engineers' design, and would have been impossible if the process equipment had been merely purchased from vendors after product design was complete.

Use of Computers in the Design Process

Nippondenso has a large CAD/CAM/CAE activity, combining their own software development and use of commercial software. The system they have developed is similar to several commercially available "frameworks" in the sense that it supports many application programs as long as they respect certain data conversion protocols, but there is no true common data base. In addition to this core system, there is the typical array of CAE plus a range of software that supports production preparation and production control.

The goals of CAD/CAM/CAE are stated as

improving the efficiency of product development
shortening the lead time for new products
making it easier to design product variants
helping create smaller and lighter products

(Note that Nissan denied that a goal of its CAD was to shorten the lead time...) Design is supported by NADAMS (Nippondenso Advanced Design and Manufacturing System), which has been under continuous development since 1980. It is written in PL-1 with recent additions in C. Outside contractors wrote most of it under the leadership of an internal group of programmers. It runs on IBM 3090's and supports about 1000 terminals. NADAMS supports 2D and 3D wireframe models, surface freeform shapes using Coons surfaces and rational B-splines, and solid models.

All items designed in NADAMS are in one database accessible to the designers, including those who design production equipment. Casting and molding dies, NC machine operations, robot programming, operating models of parts and products, and simulations are example applications supported. There is an expert system to help devise cutting process plans, typical CAE for vibration, stress and thermal analyses, mold flow simulations to aid die design, and some fault tolerance analysis software that was not explained further.

For example, the mold flow program (IMAP, developed by Toyota Central R&D Laboratories, Inc.) helped Nippondenso reduce the weight of its air conditioner case and avoid having a hole develop during molding. The number of actual prototypes needed was reduced by 66%.

The metal cutting expert system is based on Metcut's data plus 650 rules provided by Nippondenso's process engineers. The rules comprise knowledge about how to process certain geometries plus formulas for calculating feedrates and tool wear, for example. The software chooses tool material and size, cut depth, feedrate, cutting speed, and cutter rotation rate. In a side-by-side test, process engineers provided process plans for a precision surface that varied by 4 to 1 in recommended cutting speed. Only one engineer recommended a cutting speed as high as the expert system did. This cutting speed was verified in a test. The system thus has the capability to solve three problems: lack of experienced process planners, non-uniformity of their plans, and unwillingness of planners to choose aggressive plans, thus costing time and money unnecessarily.

Tour of CAE Facility

The facility I toured was a training center. It contains a wide variety of workstations but mostly IBM 5080's. I saw two demonstrations: robot offline programming and supercomputer output showing FEM studies.

Robot offline programming is supported by a wireframe 3D modeler that permits a user to build up a model of a workstation from basic shapes. A primary function of the program is to predict and improve the cycle time of the robot workstation. The computer already has models of Nippondenso's various robots (which it makes in-house). I could not find out how the coordinate data were put in so that workpieces, fixtures, and teach points for the robot could be described. Collision avoidance is done by trial and error, using the modeler's intersection capability. Straight line paths are computed automatically as a first try and the user modifies them to avoid obstacles or improve cycle time.

Several FEM examples were available. These include fluid flow in plastic injection molding, turbulent mixing and heat transfer inside the air conditioner between cold and hot air, stress-strain, and flow inside a fuel manifold. NADAMS supports pre-and post-processing, and a commercial FEM package does the calculations on the mainframe.

Developments in Assembly Technology

Two interesting activities of the Assembly R&D group were presented by Mr Harada and Mr Sugito: Design for Assembly, and Assembly Technology. The Assembly R&D group has only 5 members and was begun in 1985. Its jobs include interacting with the research community at home and overseas, developing ways to simplify products using their own DFA methodology, and developing ways to assemble difficult products that can't be simplified.

Assembly Technology is divided into two parallel efforts: dexterous/intricate assembly and large variation assembly of simple items. (Exhibit 4) Engineering innovation is used on the first kind while economic approaches are used on the second because they are already technically easy but too costly to automate.

For large variation products, an economic analysis showed that cost of preparing and feeding parts grows much faster than other costs as the number of variations grows. Efforts are going into various "low cost" feeding and preparation methods, including an attempt at low cost bin picking. Bin picking is being used in only one factory application, however. Other applications are under development. Reconfigurable grippers and pallets are also under consideration, along with such approaches as molding groups of parts onto one backbone and cutting them off at the moment of assembly.

For technologically challenging assembly tasks, such as fitting unwieldy, flexible, and warped items together, Nippondenso long ago concluded that "intelligent, dexterous, and adaptable" robots were too expensive or unavailable. Instead, they decided to "utilize the characteristics of the product" as well as to redesign the product so that assembly could be accomplished. This is another example of the "smart product" approach.

A fine example shown was fitting top and bottom halves of molded plastic air conditioner housings together. (Exhibit 5) These fit by tongue and groove around a large perimeter ("island"). Since the cases warp, the halves cannot just be pushed together. Fixturing could be used to force the halves into the correct shape but that would require costly fixtures and/or making the parts too flimsy.

The problem gets worse when the joint has a gap ("discontinuity") or two rather than covering the entire perimeter. The worst situation occurs when there are "intermediate parts" such as pivoted damper doors where one end of the hinge pin fits in a hole in one case half and the other end fits in a hole in the other half. Such doors are placed upright in the lower half but flop over to one side and the hinge pin will not line up with the upper half's hole.

People currently assemble these parts. They push and bang the case halves together, reaching inside to line up the damper hinge pins and the case holes. It is an obvious bottleneck on the production line and inherently difficult to automate.

The robot solutions have been demonstrated in the lab but not applied in the factory. They are elegant and involve a mix of robot angular maneuvering of the top part, redesign of tongue and groove shapes, and redesign of damper doors. This is the approach I called "smart product" above.

To fit a tongue-groove that covers the entire perimeter, the robot tilts the top half and mates the parts on one side. It then pivots the top half down gently by hinging at the initial contact point, and the tongue rolls into the groove.

When the joint has a gap, the above method is used, starting at a pivot point opposite the gap and rolling around so that the parts are mated at one end of the gap. A vision system is then used to find the top in relation to the bottom at the other end of the gap, and the robot pushes and slightly deforms the top half until the parts are aligned. Then the pivot-roll method is used to mate the parts while not disturbing the mate achieved at the first end of the gap. When there are several gaps, the one in the most flexible region of the case is mated first, then the next most flexible, and so on.

When there is one damper door, the robot pushes it upright with the top half of the case and catches the door hinge in the hole in the case. Then it repeats the tongue-groove method. The hinge pins on the damper are made extra long so that they do not fall out during the pivoting operation. When there are several doors, this process is repeated for each door, and the hinge pin of each door is designed to be longer than that of the next door so that the sequence of door mates can be controlled.

Whether this scheme can be applied reliably and at high enough speed in the factory is unclear at this time but given Nippondenso's past record, it will be. It is a pretty sophisticated approach and represents "design for assembly" as high art.

Nippondenso has also developed its own DFA evaluation method. Nippondenso s method is broader and more sophisticated than typical DFA methodologies, which most people agree focus too much on small parts. It contains 65 points of evaluation, such as how parts must be prepared for feeding, how many variations there are in parts and product, whether a part's feeding method supports variety, how difficult the assembly technique must be, and how many parts there are (the most important item). Production engineers perform the evaluations and give advice to the product designers.

An interesting redesign activity is called Variation Reduction. Its aim is to reduce the effect of multiple models on the assembly processes. Methods used include modularizing the product into fixed portions and variable portions, suppressing minor variations and using more common parts instead, and using the FMS-1 technique. This topic is a subject of ongoing research and Mr Harada is gathering more examples from around the company.

Twice a year they hold a DFA seminar to trade stories, hear advice from both product engineers and process engineers, and teach the method. Mr Harada's goal is to create a DFA program based on a solid modeler that will help product designers evaluate their own designs. Other companies I have asked about such an approach (a subject of my own research) say that they do not believe product designers will ever have the time or knowledge to do such evaluations themselves. Mr Harada will move to Nippondenso Technical Center USA, Inc. near Detroit and will survey research opportunities from there.

Prof Kimura noted later that both Boothroyd / Dewhurst and Draper Laboratory research on design for assembly and simplification of products have had a strong influence in Japan. The B / D method is very popular although its limitations are recognized.

Reference

[Nevins and Whitney] J L Nevins and D E Whitney, eds, Concurrent Design of Products and Processes, New York: McGraw-Hill, 1989, pp 54-58.

[Ohta and Hanai] K. Ohta and M. Hanai, "Flexible Automated Production System for Automotive Radiators," 1st Japan-USA Symposium on Flexible Automation, Osaka, Japan, 1986, Kyoto: Japan Assoc of Automatic Control Engineers, pp 553-558.