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MANUFACTURING AUTOMATION IN JAPAN: A TRIP REPORT AND OBSERVATIONS

INTRODUCTION

During February 1986, I visited Japan as a participant in an industrial study mission coordinated by the Technology Transfer Institute. Other mission members were from Ford, ALCOA, Hewlett-Packard, Litton Industries, and *High Technology Magazine*. The purpose of the study was to inspect and to discuss with Japanese technologists the implementation of computer-integrated manufacturing, flexible manufacturing systems, and robotics. The objectives of this article are to provide a picture of what manufacturing automation is like in Japan; to discuss how automation is practiced in Japan today; and to illustrate, by example, how the Japanese skills in manufacturing automation developed and how Japanese cultural characteristics help to make that development possible.

Japan and other Far Eastern and European countries are formidable industrial competitors of the United States. The Japanese have established a clear superiority in quality, reliability, delivery cycles, and the time needed to introduce new products related to automobiles, machine tools, video recorders, cameras, computers, industrial robots, semiconductor chips, fiber optics, steel, and microcircuits. My trip confirmed my concerns that the United States must take steps to regain the competitive edge it lost in the last 25 years or face serious economic difficulties.

DEFINITION

In its simplest context, "automation" is a technique by which processes are subject to control without human intervention. For example, the power source for the Industrial Revolution was steam. The steam engine had a governor; when the engines started to run away, the governor cut off the steam without human intervention. In the 1950s, I participated in the automation of the Ford River Rouge Engine Plant. That plant produced V8s at the rate of 3000 per day for Lincoln, Ford, and Mercury cars. The engineering design techniques applied were electromechanical. Thousands of relays and solenoids were used to operate mechanical linkages, controls, and conveyers; that type of production line is defined as "hard automation." It was set up specifically to build

V8s; if one switched to a slant 6 or a V4, it would take three to six months to retool the automated line.

Today, automation and flexible manufacturing systems provide important advantages:

1. They improve quality; unlike human operators, machines do not tire and are consistently accurate.
2. They cut the costs of material, overhead, and labor.
3. They provide flexibility in today's manufacturing requirements for short-batch production, catering to today's fleeting and constantly changing market whims. When the items produced have different colors, finishes, accessories, power devices, and shapes, hard automation does not work; the flexible manufacturing system is the modern practical solution.
4. They encourage the development of new and innovative products because they are easy to manufacture.

THE DEMING INFLUENCE

The Japanese attribute their approach to manufacturing and automation to the teachings of William E. Deming who visited Japan in 1950 and initiated a series of seminars on statistical quality control for managers and engineers. Deming's teachings, which were neglected in this country for 30 years, were based on 14 major points. I will list only seven:

1. We are in a new economic and technological age where we cannot accept delays, mistakes, defective materials, shoddy workmanship, and poor design.
2. We cease to depend on mass inspection to achieve quality; instead, we require statistical evidence that quality standards are built in.
3. We depend on meaningful measures of quality and price; we do not base procurement decisions on the lowest bidder or count on competition to take care of both quality and cost.
4. We drive out fear so that everyone can work effectively for the enterprise, and we break down barriers between departments and people.
5. We institute modern methods of training on the job for both workers and technically literate management.
6. We create constancy of purpose in top management and minimize the requirement for quick results and profits.

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7. We use the PDCA (plan, do, check, act) cycle relating to design, production, sales, survey, and redesign in order to maintain quality.

The Japanese took Deming's teachings seriously in the 1950s; by the early 1970s, they had developed an industrial technology based on automation and statistical concepts. In the United States, industrial and government leaders did not take Deming seriously until the early 1980s; now his principles are considered holy as we try playing catch-up with the Japanese.

VISITS

Waseda University, Tokyo

We met with Professors Yukio Hasegawa and Seinosuke Narita of the Systems Science Institute. The robotics research activities at Waseda are impressive. Some of the projects deal with touch sensors for three-dimensional curved surfaces; touch sensors for breast cancer; self-propelled arc welding; off-line programming systems using computer-aided design for program checking; carbon dioxide gas laser cutting; sensors to ensure that painting robots remain perpendicular to the surface; robots that move with an assembly line; precision arms for moving electronic assemblies; hand and tool changers; voice control; fiber-optic sensors; three- and five-finger hand actuators; shape memory alloys; bakery cake decorators; concrete sprayers for tunnel construction; fireproofing installers in buildings with high ceilings; underwater construction; fast food service and restaurant automation; robots for nuclear power plants and other hazardous applications, some of which use multiple legs, climb stairs, walk on soft or rugged terrain, and climb ladders; and robots for the assembly of printed circuit boards and harnesses.

One of the most impressive programs was Wabot-2 (Fig. 1), an organ-playing robot that was developed at Waseda to realize such "soft" functions of robots as dexterity, speediness, and intelligence. Following are five sophisticated characteristics¹ of Wabot-2:

1. The limb control system consists of human-like limbs and their control system. When musical-note information is supplied, the movements of the four limbs are determined automatically, and the fingers of both hands strike the upper and lower keyboards of the electronic organ. The left foot works on the bass keyboards while the right foot operates the expression pedal.
2. The vision system is designed to recognize immediately, with the charge-coupled device camera, any printed music score commonly found on the market.
3. The conversation system is designed to enable as natural a conversation as possible between man and robot. This system is divided into two main parts, one for speech recognition and the other for the production and control of the sound.
4. The singing-voice tracking system determines the pitch and duration of musical notes from a singing

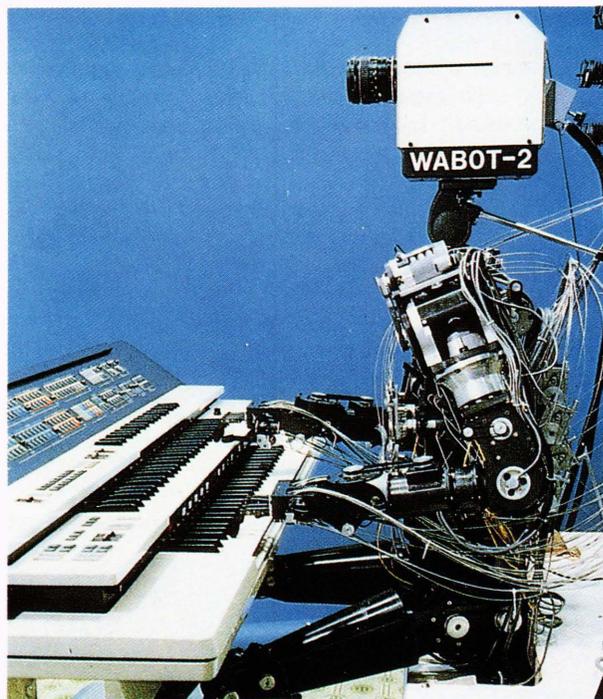


Figure 1—Wabot-2.

voice and compares them with the original score. The deviation is made to the supervisory system, creating accompaniment in tune with the singer's pitch. This means that Wabot-2 is adaptable to human behavior.

5. The supervisory system performs the interconnections between each of the subsystems and forms the nucleus that enables them to function as one robot system. Fifty-three microprocessors control the approximately 50 degrees of freedom involved in Wabot-2, a good example of parallel processing.

While Wabot-2 may be considered a toy by some, it is a serious demonstration of the application of artificial intelligence, vision sensors, and high-speed micro-processing techniques. It also illustrates the relationship between government (the Ministry of Trade and Industry) and industry (the Japan Electronics Industry Development Association), using academia to develop concepts that are, in turn, demonstrated with full-scale hardware and that eventually find their way into a product line for industry. This may explain why Japan continues to develop new and better products demonstrating a high degree of innovation in the use of state-of-the-art technology.

In addition to robotics, we received a briefing by Professor Narita about the number of computers installed in Japan (based only on Japanese-manufactured computers). Using 1984 statistics, there were more than 5000 mainframe computers and 13,270 microcomputers installed in various industries and educational facilities for use in agriculture, forestry, fisheries, communications, utilities, general service, etc. The Japanese make maximum use of computers in almost every endeavor

and are probably the most computer-literate nation in the world today.

Waseda University is only one of the many academic institutions that participate in all aspects of Japanese manufacturing research and development. The Wabot-2 development at Waseda received financial support from Sumitomo Electric Industries, a company now involved in expert-systems development with Silogic Inc. in the United States. Through interface with the Ministry of Trade and Information, many Japanese universities have projects that are supported by both government and industry in the area of basic research related to automated manufacturing. For example, Kanazawa University works in surface metrology, displacement measurement, contour inspection, and cutting studies using scanning electron microscopes and other sophisticated techniques.

Yamazaki Mazak Corporation — Minokamo Plant

The Minokamo Plant, only one of Yamazaki Mazak's many machine-tool plants around the world, is a very modern facility. This becomes evident as soon as one enters the building and meets Tommy, the friendly receptionist (Fig. 2). There is no one else to greet you except Tommy, a robot consisting of a vision device, a cathode ray tube that provides the necessary instructions to the visitor by means of a menu with all the identifiers necessary for the visit. He asks such questions as, "Who do you want to see?" and "Who do you represent?" and, at the same time, can take your picture, transmit it to your host, and provide a badge. This may appear to be a gimmick, but many organizations need receptionists in their lobbies, and Tommy will probably appear shortly outside Japan as an additional export for Mazak.

The plant itself is a modern twenty-first century design that represents a serious attempt toward an unmanned factory. The production equipment consists of about 60 computer numerical control machine tools, 30 robots, and automatic ground vehicles, all under computer command and control. The system is connected to the computer-aided design and computer-aided manufacturing computer in a main plant 12½ miles away. The plant even has a solar energy system for efficiency and is surrounded by a park-like environment. It produces vertical computer numerical control lathes, both quick- and slant-turn, of various sizes and can manufacture horizontal and vertical milling machines.

The cleanliness and size of the operation are shown in Fig. 3. The line consists of a grouping of automatic ground vehicles to transport the work. There is an interline that takes the part—in this case a large shaft—to be machined, inserts the raw part into the machine, takes it out, puts it back on a conveyer, and then transports it to the next station. There are very few people on the factory floor. The simplicity of the computer-controlled area is emphasized by the control room (Fig. 4). The brains and the heart of the entire plant are concentrated in the computer area, which consists of a main computer, six subcomputers, and a system-monitoring panel.



Figure 2—Tommy, the robot.



Figure 3—The Mazak plant's interior.



Figure 4—The Mazak control room.

The panel displays the status of all system components and machine tools on the line that manufacture and assemble the subsystems and final products. The computer room is manned by one operator for both the first and second shift. The third shift is completely unmanned,

as are Sundays, when all the machine tools operate in the third-shift mode.

The plant employs about 300 people, 60 of whom are engineers. They produce 250 computer numerical control machines a month. The plant design and equipment are now exportable items; Mazak is building similar factories for corporations in both England and the United States. The average salary of the professional staff is about \$2000 per month plus quarterly salary bonuses based on profits and productivity; the average blue-collar salary is about 20 percent lower. The average age of the people in the plant is 26 years.

There is less than 3 percent downtime of the continuously operating machinery. Much of the software and the computer systems is of IBM origin and the program is CADAM (computer-graphics-augmented design and manufacturing). The delivery time for a machine tool has been reduced from about 90 to 14 days. This is practically an off-the-shelf item when compared to a U.S. machine-tool company's many-months delivery schedule. The plant manager stated that his break-even point is about \$10 million per year and that the plant is now comfortably doing about \$15 million worth of business per year. Costs to build the plant were estimated at \$40 million.

This machine-tool plant is a good example of the position Japan has achieved in the world of automation. The Japanese developed this technology after the 1960s and were already on-line in the 1970s with sophisticated automated systems. The West has yet to catch up with the technology. A major reason for our lag is that automation, as practiced by the Japanese, has only recently been integrated into the American industrial system, but in a less efficient way and on a smaller scale.

Seiko Ishioka Plant

This Seiko plant does not build small precision watches but rather alarm clocks and other quartz devices that are used in larger types of clock movements, such as children's, kitchen, and desk-type timekeepers. In addition, they also supply microprecision parts, plastic housings, and other components to factories elsewhere in the Seiko group.

The parts-fabrication portion of the operation is largely automated. Metal parts are produced by automatic lathes, which are machine tools designed and built by the plant (Fig. 5). The lathes operate 24 hours per day, seven days per week. The few people involved are used occasionally for tool changing and general surveillance.

Figure 6 shows the plastic-injection machines, which also are largely unmanned operations and which operate continuously. The assembly of the quartz-crystal movements into the casing is not highly automated (Fig. 7). The movements assembly line is semiautomated, with an occasional operator to monitor the performance of what appears to be a very simple type of automation. However, the final assembly into the casing is done manually. Seiko considers it profitable to automate an operation if it will replace one operator per shift per year, a saving of about \$150,000 in salaries and benefits.



Figure 5—Seiko's lathe line.



Figure 6—The Seiko plastic-injection line.



Figure 7—Seiko's manual assembly.

The plant employs about 700 people on three shifts, seven days a week. Each month they produce about 800,000 units; of the 60 percent exported, the United States receives about 30 percent. While the plant is not a demonstration of Japanese advanced technology, it is impressive from the standpoint of its automated systems and the fact that it operates with only 60 engineers and technicians who not only design the products but also design and maintain the machinery. Several of these

unique machine tools are now available on the open market. This is another example of the development of a new machine-tool product line as a result of automating their plant for clock manufacture.

NEC Yokohama Plant

NEC is a large electronic organization that operates plants all over the world. It is an example of an organization that has captured a great deal of the world's electronics market including video cassette recorders, satellites, ground control stations, antennas, receivers, and communication equipment of all types. The emphasis in this discussion will not be on products or automation but on the business aspects of a typical large Japanese operation.

Figure 8 identifies domestic and international sales, in dollars, of the Yokohama plant, a \$750 million per year operation. Government sales comprise 16 percent. The private sector in Japan absorbs only about 30 percent and the remaining 54 percent is exported, which is typical of other major enterprises. The Japanese must export to survive, a precarious situation because international competition continuously threatens exports, and the rising value of the yen is an economic threat to their economy.

The plant plays a major role in the area of receivers and ground stations for satellites. During my visit, my host—Kiyoshi Emi—mentioned that just within the past 24 hours the plant had received an order from the United States for 27,000 mini ground stations for satellite communications. They have a working arrangement with

Hughes Aircraft to manufacture components for the many satellites that Hughes produces in the communication field. They also are building navigation and earth-measuring satellites for the National Space Department of Japan and are the prime contractor for the satellite that obtained data on Halley's Comet. Ten percent of sales are committed to research, development, and engineering.

NEC Yokohama is an innovator and not just a packager of the western world's technology. It represents stiff competition, especially in VLSI/VHSIC devices, in the mass production of electronic ground-control equipment, and in innovative scientific areas. (NEC is dwarfed by Hitachi, which does about \$30 billion per year of business in state-of-the-art products and invests \$1 billion in research and development at 21 research laboratories.)

Nissan/Toyota Automobile Plants

The reports of visits to Nissan and Toyota have been combined because of the similarities in their automotive production techniques and plants (Fig. 9), which are large, modern, and highly automated.

The Nissan plant is about 25 years old. It produces several models of cars such as the Sentra, Micra, Volaro, and a line of Datsun forklift trucks. The trucks were originally designed for use in their own facilities but have now found a worldwide market. The plant is populated by many types of robots, especially in the body assembly line where about 200 welding robots produce about 3000 spot welds on each car. The painting line is also highly automated, with additional assembly capability using robots in the engine and power-train assembly area. However, there are numerous manual operations in the final assembly line. Attempts have been made to introduce robots for installing instrument panels, windows, seats, batteries, and wheels, but the design of the assembly automation has not yet been worked out. During the briefing, we were told that the Nissan Murayama plant produces 50,000 cars and 2000 forklifts per month.

The Toyota plant is similar. An interesting aspect of final assembly in both the Toyota and Nissan plants is that there is not a great deal of quality control evident. As shown in Fig. 10, the cars come off the line, are driven to a dynamometer platform, and run for approximately five minutes; data are obtained from the test gauges. In a short test of waterproofing, water is sprayed

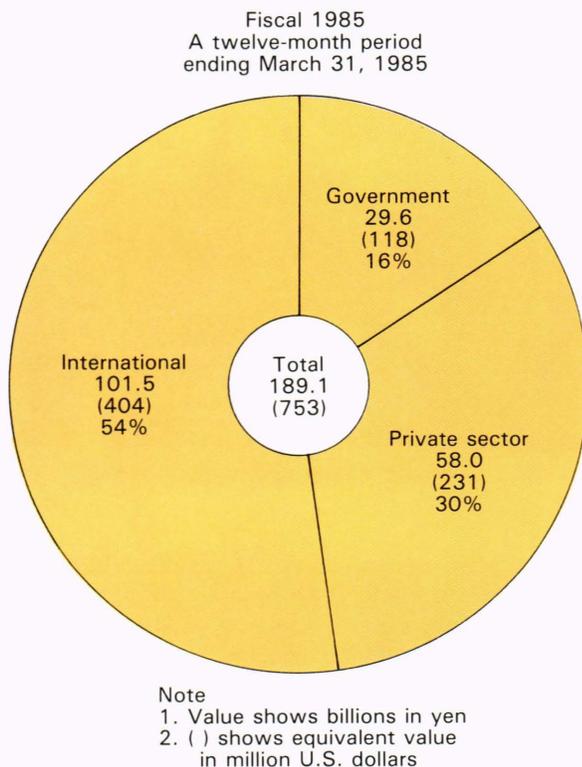


Figure 8—The NEC business chart.



Figure 9—The Toyota Honsha plant.



Figure 10—Toyota's checkout.

on the finished car, which then goes out the back door to be delivered. Apparently, quality is built into the car during the manufacturing automation design. There is confidence in this procedure. Following Deming's teachings, inspection costs are kept to a minimum, yet a quality product is produced.

GENERAL OBSERVATIONS OF JAPANESE CULTURE AND TECHNOLOGY

Japanese technology is closely related to Japanese culture; those who wish to adopt Japanese manufacturing automation techniques must consider the cultural aspects. Japan is a country that has a 2000-year history of survival with limited natural resources and comparatively little land. Yet it is now a world industrial and economic power. In order to overcome these adverse conditions, the Japanese appear to have developed special characteristics:

1. They are willing to work very hard and live under somewhat unfavorable conditions. Many Americans would not accept Japanese housing, for example.
2. They work six or seven days a week, if necessary.
3. They have a desire to contribute constructively to Japanese society.
4. They have faith in their nation and believe that

their fellow citizens are well disposed and cooperative.

5. They maintain pride in and loyalty to their companies.
6. They are frugal, saving about 20 percent of their earnings, compared to about four percent in the United States. Since they cannot get loans for housing, they have to save in order to buy a house. They have few retirement programs in place, so they have to save for their old age.
7. They emphasize and support a very good educational system and are a highly literate society. Ninety-three percent graduate from high school and 40 percent of the college-age group graduate from colleges or universities. Parental participation in their children's education is intense and comprehensive.

SUMMARY

Japanese automated manufacturing facilities in the areas cited in this report are very efficient. The United States is five or more years behind the manufacturing automation being demonstrated by Japan. The European Economic Community is investing heavily in modernization, automation, and technology. Two of their efforts, the European Strategic Program for Research and Development and the European Research Coordination Agency, cover information, telecommunications, robotics, manufacturing technology, lasers, and transport technologies. These efforts can be compared to Japan's "fifth-generation computer program" (and its other cooperative government/industry/university projects). Similar U.S. programs are not government supported or organized and thus are more chaotic and less productive.

The Japanese educational program is an important part of its technological strength. Engineering is a highly respected profession, and more Japanese engineers are graduated at the bachelor-degree level than in the United States, despite our larger population. The teaching of design for manufacture and on-the-job training are other sources of strength for Japan.

Regarding the future of U.S. manufacturing, our ability to become competitive again will depend on the ability of our product designers and manufacturers to relearn the principles of high quality, rapid product innovation, and reasonable cost.

REFERENCE

- ¹"Special Issue on Wabot-2," *Bulletin of Science and Engineering Research Laboratory*, Waseda University, No. 112 (1985).