ROBOTICS SEMINAR

LESSONS IN JAPANESE INDUSTRIAL PRODUCTIVITY

OCTOBER 28, 1981

STUDY SYNOPSIS OF REPORT ON
"PRODUCTIVITY, AUTOMATION, AND
ROBOTICS IN JAPANESE MANUFACTURING"

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PRODUCTIVITY, AUTOMATION & ROBOTICS IN JAPANESE MANUFACTURING

STUDY SYNOPSIS

Prepared For Robotics Seminar

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TABLE OF CONTENTS

LIST OF EXHIBITS

PRODUCTIVITY, AUTOMATION AND ROBOTICS
IN JAPANESE MANUFACTURING

STUDY REPORT SYNOPSIS

1. PRODUCTIVITY, AUTOMATION, AND ROBOTICS: THE JAPANESE CHALLENGE

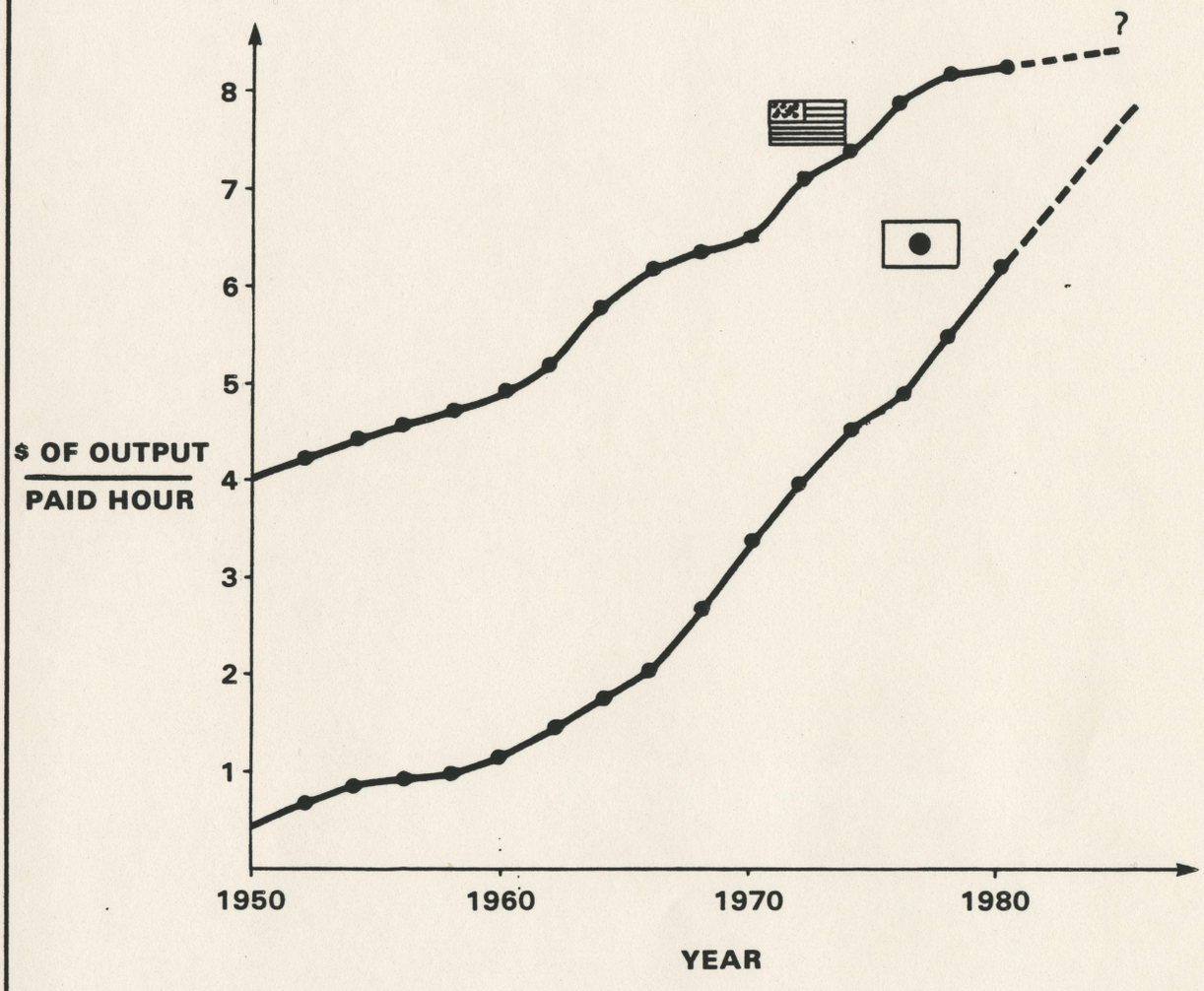
In the last few years, productivity has become one of our major concerns. Newspapers and articles have identified it, books and reports have discussed it, managers are increasingly directing activity based on it. Productivity has reemerged into the national economic consciousness with a power unmatched since the days of Frederic Taylor in the early 1900s. People comparing productivity growth here and abroad are becoming uneasy and consequently are paying more attention to the warning signals.

Why are shrewd businessmen, government leaders, and insightful academics reacting this way? It seems simple enough on the surface: productivity's ratio of output per hour worked indicates the state of health of the broad spectrum of national economics. It means the ability to competitively price on the micro economic scale. It means prosperity and employment on the macro economic scale. And it means international competitiveness and a favorable balance of trade on the international scale. Productivity is the harbinger of economic well being and demands our attention--for our own good.

What has brought this factor back to prominence? While for years America had a comfortable lead worldwide in national productivity, in recent times the aggressive challenge of the Japanese is becoming disturbingly obvious. Exhibit 1 shows one reason: Japan has improved its productivity 1300 percent over the last thirty years versus a mere doubling in the U.S. We see this impending challenge every day when we see Sony TV sets flickering in the shop windows and Datsuns "trying to make it to empty" on the highway. The

EXHIBIT 1

US/JAPAN PRODUCTIVITY COMPARISON



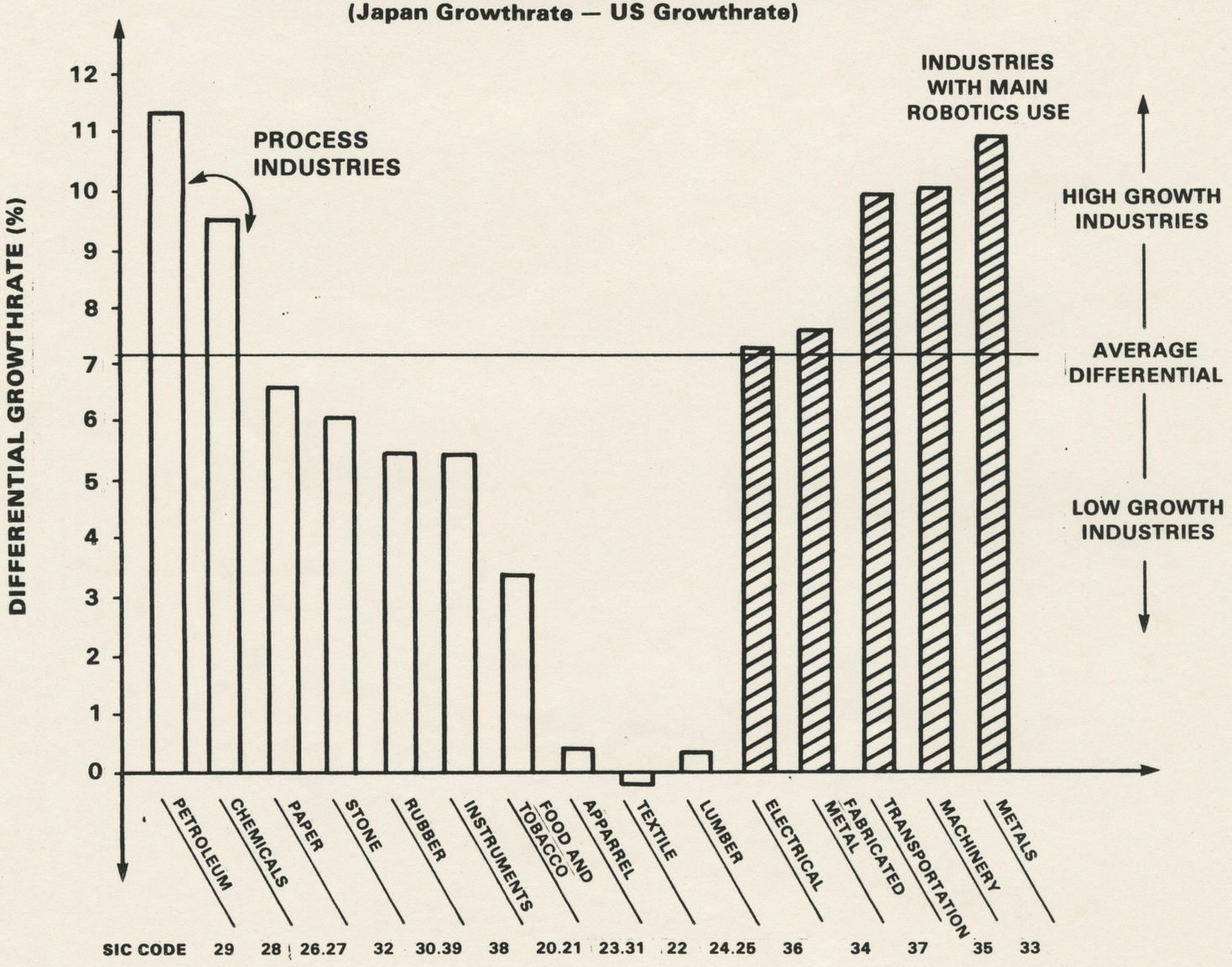
Japanese workers are already outproducing American workers in automobile and steel production by a factor of over two to one. America has long prided itself as being the most productive nation in the world, but the seemingly innocuous extrapolation in Exhibit 1 suggests otherwise.

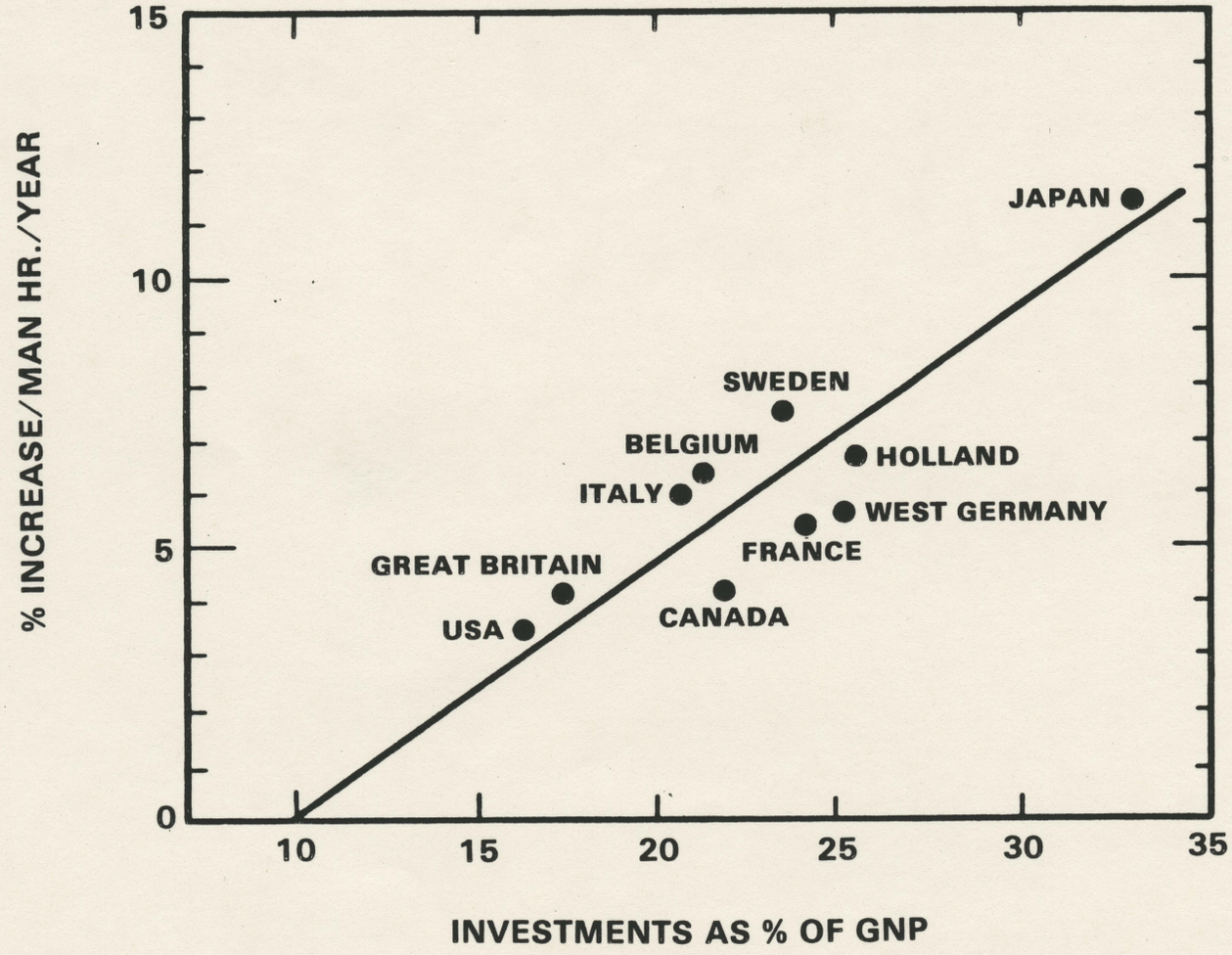
The picture looks even grimmer as we examine the productivity growth rates in individual industries. Exhibit 2 compares these growth rates over the last twenty years. The reference line in the middle shows us that the productivity of these Japanese manufacturing industries has been growing an average of 7 percent faster than the same industries in the U.S. More significant, however, is the fact that this growth is especially driven by the industries of the future: petroleum and chemicals, consumer electronics, fabricated metals, transportation equipment, machinery, and primary metals. Furthermore, all but the highly automated petroleum and chemical industries have been successfully integrating sophisticated forms of automation, including revolutionary industrial robots, into their lines to achieve this edge in productivity growth. Only in the food, apparel, textile, and logging industries, where American manufacturing has been particularly strong, has Japanese/American difference in productivity growth been less than the 7 percent average. Currently, this growth is presenting a challenge to U.S. industry; however, if we anticipate these trends to continue along a logical extrapolation they should more reasonably be viewed as a forewarning.

In an attempt to pinpoint the reasons for improved productivity, we must examine the link between the use of automation, particularly computer-based automation or robotics, and productivity increases. In order to study this effect, SAI compared the national productivity growth rates of seven large industrial nations with the population of robots normalized to the national GNP. While the data have some scatter, a distinct upward trend of productivity gain correlated with robotic usage is found. Exhibit 3 shows the relationship: the faster countries introduce robotics the better their overall productivity. America, the home of the industrial robot, and still the second largest producer and user of robots needs to respond. On the basis

EXHIBIT 2

JAPAN/US PRODUCTIVITY GROWTH DIFFERENTIAL
(Japan Growthrate — US Growthrate)





PERCENT INCREASE IN OUTPUT PER MAN HOUR PER YEAR, AVERAGED OVER THE LAST 10 YEARS, VERSUS CAPITAL INVESTMENTS AS A PERCENT OF GNP, FOR SEVERAL INDUSTRIALIZED COUNTRIES

EXHIBIT 3

of a dollar of GNP, Japan has a significant edge over the U.S. and Western Europe. These figures also show that robotics are not the whole story. France with a lower population of robots exceeds the annual productivity growth of Italy. Nevertheless these figures indicate a trend, one that we will follow to the conclusion.

2. PREPARING THE AMERICAN RESPONSE

These trends exist. Their continuation in the short run is a fact of economic life. Critics of their significance argue that much of Japan's astounding growth can be attributed to normal development efforts to recover from post-World War II destruction and accelerated efforts to return to an industrial norm. This cannot be discounted, but the subsequent conclusion that their growth will level off as their institutions come to full effectiveness must be questioned. The Japanese approach to industrial growth is significantly different from that in the U.S. The basic assumption, therefore, is <u>not</u> true.

We base this belief on our recent first-hand visits to Japanese factories, management offices, and research institutions. This view is confirmed by our experience with the exigencies of effective manufacturing, and our in-depth research (and that of others) into the significant impact that new, high-technology forms of automation are having in making production lines more productive.

The composite of these perspectives is the basis for a very interesting, and complete picture of the current state of Japanese manufacturing: what it is doing well, where it has improved, and how it has overcome significant barriers which are still bogging U.S. productivity increases. Past attempts at providing this information have been either too cursory, such as the standard coverage in popular literature and trade journals, or too narrow, such as books directed to Japanese management strategies for instance: either approach provides the U.S. readers with

information on the Japanese competition, but these discussions only give us a look at one part at a time without seeing the interlocking whole. This study brings these pieces together in one place so the reader can assess their potential impact and interrelation. After examining these interwoven strands, the reader can establish priorities for individual organizations and identify areas for further study. More detailed sources can then be used as needed.

The focus of the following report is on a clear documentation of the major factors which have contributed to Japan's astounding productivity increases--the story behind the standard story of productivity. It documents the current state of Japanese automation and productivity. It is a roadmap to the difficult-to-assess area of manufacturing technology, hard and soft automation, and robotics. It provides a basic reference for business and government leaders wanting to size up the Japanese competition and determine where Japanese approaches can contribute to overcoming productivity barriers at home.

Some of the highlights of this study are given in the following summary.

3. FACTORS IN JAPAN'S SUCCESS STORY

We can look at the story behind the story of Japan's success by viewing Japan as a first-time traveler. We will take a figurative tour of Japan noting similarities, differences, and perspectives. Travel with us to the end where we can draw some conclusions with our guide.

This tour begins as we fly into Japan for the first time. Even with a wealth of background reading or even with interviews of Japanese who have visited the U.S., we still have no practical experience. Flying in, even on the cloudiest of days one can hardly miss the unique form of Mt. Fuji with its regular conical shape spreading from a narrow summit in an ever expanding mass

of ore and rock to blend with the expansive contryside beneath. One's first reaction is that of a sightseer comparing it to Mt. Rainier or Mt. Washington in the States. But by the end of the trip, one will be able to equate that shape and cohesivness as an analogy appropriate to many significant aspects of the Japan story.

Upon landing, our first perspective is one of the people themselves: juxtapositions of business and diligence, energy and patience, kindness and restraint. Tokyo itself is a place of millions of people who seem to exist shoulder to shoulder with little of the friction inherent in Western cities. We see this extended quite literally in the factories where for eight hours a day workers perform their duties sometimes in very close quarters, completely unfazed. One sees clean, brightly lit workplaces decorated with hand-drawn posters created by the workers themselves. In the interactions between people throughout the social and business hierarchies, there is a strong sense of mutual responsibility between individuals, small circles, each forming part of a larger group. This seems to be the cement which holds the society together.

What gives these interactions shape and form are the influences of tradition as it has interacted with rapid changes coming from the west. Exhibit 4 lists some of these major comparisons between Japan and America. The first is that the Japanese nation, and all elements thereof, is manned by a very homogeneous population which thrives on the value of shared experience. Not only is this a homogeneity of race, but in the factories there is a further homogeneity of experience. Implied life-time work contracts for most workers in major firms is a manifestation of this fact. These ties of commonality provide a mechanism for evolutionary change. Direction is uniform along lines of familiarity. This type of reaction to management by workers is often mistaken for wholesale collaboration rather than a reflection of common goals, which is closer to the truth.

EXHIBIT 4

CONTRAST OF AMERICAN AND JAPANESE CULTURES

AMERICA	JAPAN
HETROGENEOUS RAPID IMMIGRATION MUCH OF IT IN PAST 100 YEARS	HOMOGENEOUS SLOWLY EVOLVING POPULATION SINCE RECORDED HISTORY 2000 YEARS FORBID OR RESTRICT FOREIGNERS
DEMOCRACY FOR OVER 200 YEARS	FEUDAL, IMPERIAL STATE FOR HUNDREDS OF YEARS, DEMOCRACY SINCE 1950
GROWTH TO CONQUER FRONTIERS POPULATE LAND	GROWTH RESTRICTED DUE TO LAND LIMITS
EMMENSE NATURAL RESOURCES	FEW NATURAL RESOURCES
RAPID ACCEPTANCE OF NEW IDEAS REWARDS TO INNOVATORS	SLOW ACCEPTANCE OF NEW IDEAS
INDIVIDUALISM	COLLECTIVISM

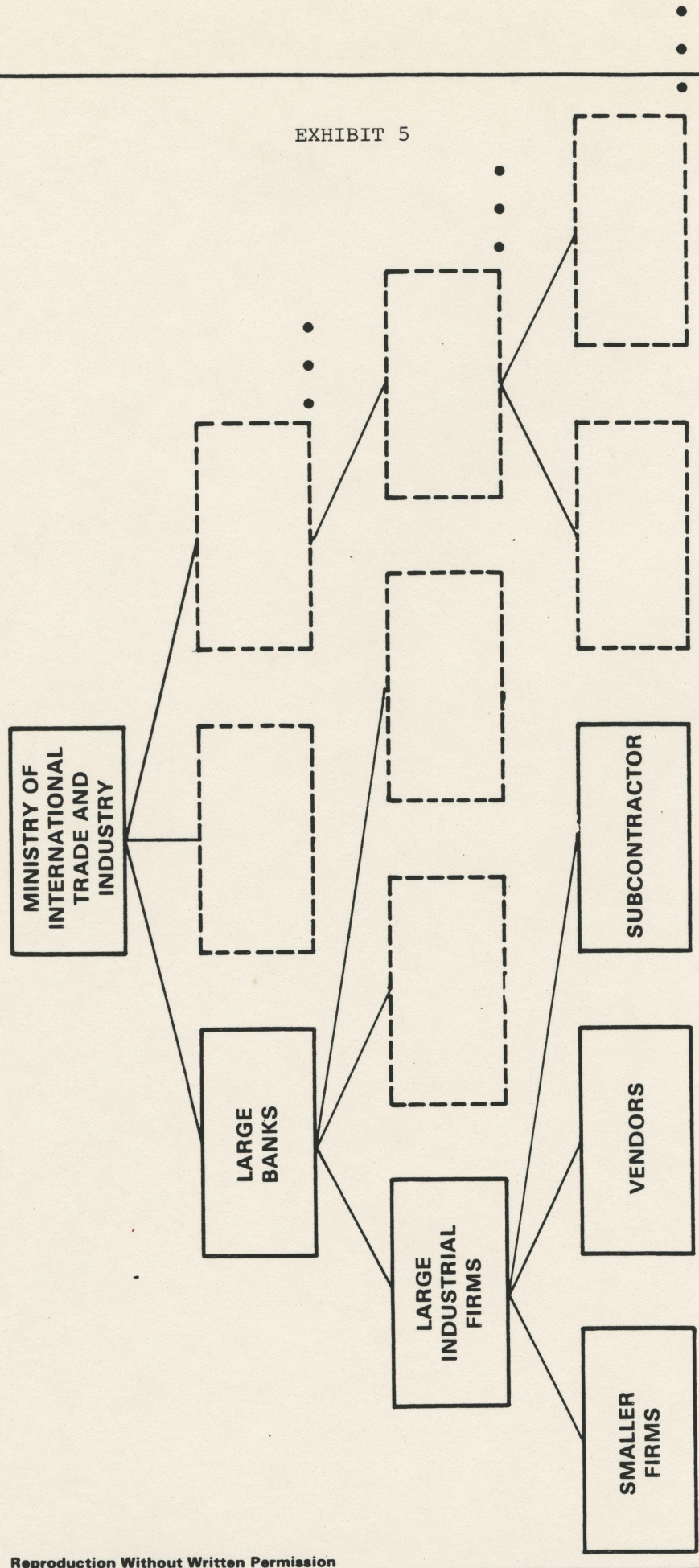
Another of these important aspects is the effect of restriction. Japan emerged into the modern world as a country constantly confronting restrictions. These restrictions included land, living space, domestic markets, and especially natural resources. The Japanese ameliorated these restrictions through pervasive institutions. Growth was controlled to prevent waste of land and minimize pollution. Long established traditions governing the interaction of personal relations have been preserved. Government was organized to effectively allot natural resources and production capacity. Whenever short-term free market influences begin to conflict with democratically selected long-term goals, government, banks, and industrial management come to a consensus before proceeding.

Japan has organized itself around the oriental philosophy that one's well being is derived from being a part of a well defined collective whole. Western organizations are based on the notion that each person is first and foremost an individual.

As our trip proceeds and we become more familiar with the workings around us, the complex interaction among a wide variety of factors becomes apparent. It also seems that as the importance of an activity increases, so does the number of factors and the level of interaction. The most visible example of this complex interaction is the community involvement supporting the introduction of robots into manufacturing production lines. We will again be reminded of the Mt. Fuji analogy as we see the relation of these interactions outlined in Exhibit 5.

At the top we find MITI (The Ministry on International Trade and Industry). MITI is the prime government organization which has responsibility for directing the allocation of resources and furthering business development in general. This is typically done not by restrictive regulations, but rather by use of three effective tools, as a de facto carrot: loans and tax policy, direct research funding, and non-monetary support for trade and information associations.

EXHIBIT 5



At the next level are the large banks which coordinate the Japanese business structure. By their ownership and creditor relationships with a group of companies, they exert overall guidance and development strategies.

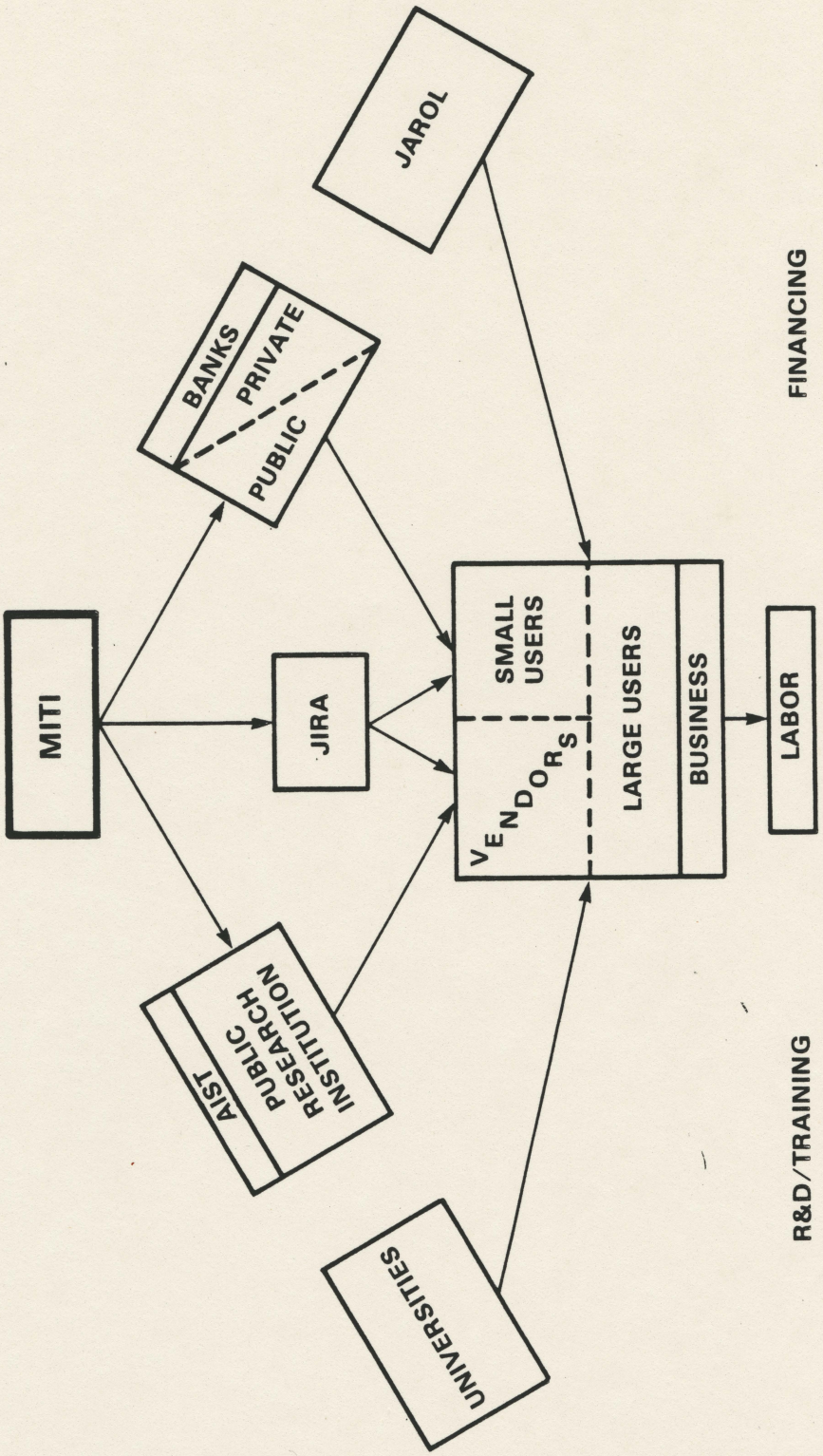
At the next tier are large manufacturing, financial, and service firms loosely associated, operating in separate sectors of the economy. Competition for a firm is from similar firms in another bank group. Supplying each large firm are a myriad of smaller firms, subcontractors, and vendors. These may be partially owned, or controlled by the parent bank, or be completely independent. Workers in the larger firms belong to company unions, which serve to increase their loyalty to the firm rather than acting in an adversary role.

This pyramid of authority can operate together very effectively, as for instance in the introduction of robotics on the shop floor in Japan. A flow chart of the interrelations is given in Exhibit 6.

Through MITI low-interest loans can be extended through the banks to stimulate investment in desirable sectors, a mechanism used to extend the purchase of specific equipment, and provide special depreciation allowances directly to industry. Direct support is provided through the Agency of Industrial Science and Technology (AIST), an equivalent to a super National Science Foundation, to a wide variety of specialized public research institutions which specialize in development work. This agency emphasizes basic research in engineering programs and invests in applied research of industry's private engineering labs. There is also the non-monetary support provided by organizations such as the Japan Industrial Robot Association (JIRA) which acts as a clearinghouse of information among all the actors: technical, economic, social, etc. Labor unions assist in the introduction of new technology.

The focus of this support is directed to the corporate world where the machines are produced and used. A significant component of this effort is

EXHIBIT 6



managment's close cooperation with its labor force which reaps labor's loyalty and input in return.

These implicit relationships are impressed upon us wherever we travel in the land of the rising sun. Our research takes us to the ultra modern science city, the fabled Tsukuba City where Japan has stockpiled its latest and best research teams, facilities and equipment. We see illustrations of the common heritage and industry of the people, while traveling over 200 kilometers per hour on the Bullet Train, the Shinkansen. This technical marvel of rapid transportation took us past seemingly endless small plots of rice grown by the traditional ways. And we had time to ponder the paradox of Japan. Eventually, through closer examination, we were able to identify eleven separate but interrelated factors contributing directly to Japan's manufacturing success.

We find these eleven factors which are being excercised in the companies themselves are part of what has been impressed upon us during our tour: factors or approaches which play a direct role in increasing production and which contribute to efficiency and effectiveness in the manufacturing process. As we visit more factories and see these factors at work, we cannot help but note that these same approaches are common practice in the U.S. This is not a surprising observation since the elements of modern business operation were imported almost wholesale to Japan in the decade or so after the war. We find, however, subtle twists and unique implementations of these concepts which have made them an effective part of Japan's productivity increases of the last three decades. These significant factors we have identified are:

- Automation - the way to bring economies of scale, consistency, and speed to a manufacturing process. The recent introduction of robots has also introduced an element of flexibility

- Nationalism - the ability to organize a country's efforts behind previously identified and well defined societal goals

- Management of Resources - a method for using the material, energy and labor resource to greatest advantage. In the labor area Japan uses what we might call in the U.S. a form of cooperative management

- Labor Relations - the evolution of positive attitudes and loyality of workers toward their employer

- Quality Control - which establishes a reputation for consistently providing high quality and low cost products

- Inventory Control - the ability to have the right part at the right place in the production line at the right time

- Corporate Planning - the facility for adopting corporate goals and organizing the company's resources behind those goals

- Financial Business Arrangment - an environment in which manufacturing companies have easy access to capital by working closely with the banking community

- Product Design - the engineering sensitivity to the needs of both the manufacturing process and the consumers

- Export Market Development - the means by which companies can broaden their consumer base so as to be less sensitive to domestic economic fluctuations

- Product Pricing Strategy - the means by which products can exercise a competitive edge.

Most of these factors, though outgrowths of American business practice, have been radically overhauled by the Japanese and represent areas where the Japanese seem to be developing a distinct advantage over the U.S. These are the main reason we might expect productivity in Japan to have the potential of passing the U.S. as we suggested earlier.

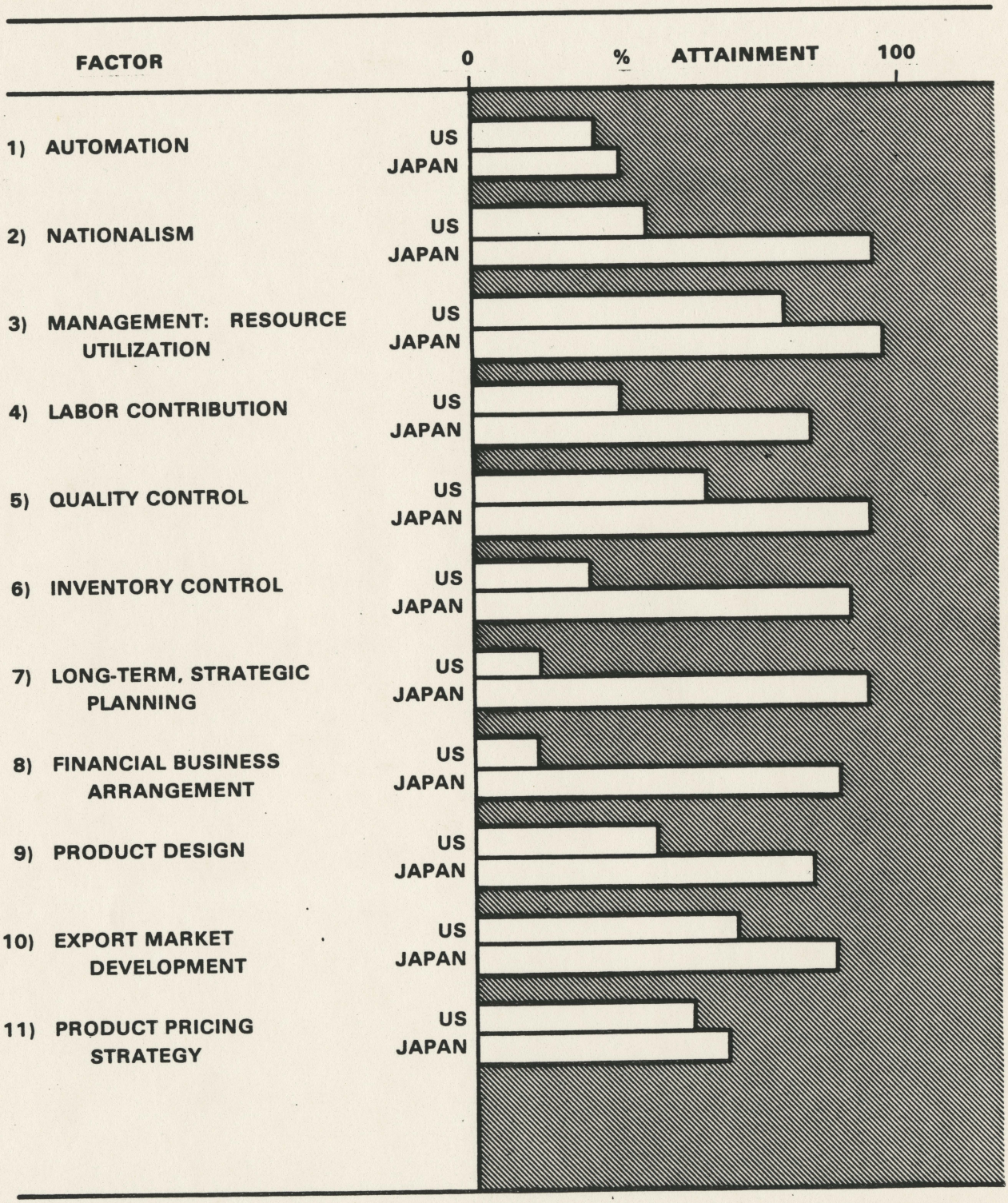
Exhibit 7 ranks the importance of these factors, gives a subjective, but reasonable comparison of their respective effectiveness attainments. Japan has achieved high attainments in all eleven areas and has been showing consistently higher levels of effectiveness in all these areas. All eleven factors are candidates for contributing to developing a significant competitive edge over the next decade.

The one factor which was most surprising in this respect was automation, for our background preparation has repeatedly impressed upon us that the sophisticated automation capability of the Japanese was in no way superior to what American companies have. Our tour of even the most advanced labs in Japan, like the Mechanical Engineering Lab supports the truth in this belief even with those complicated machines we classify as robots: Japan's industrial robots appear to have about equal intelligence and complex capability as those in the U.S.; however, when we tour the factories themselves we see scores and scores of robots where in the U.S. we would only see tens.

Furthermore, we discover that this development is only one step in a well coordinated, long-term project known as MUM (the Methodology for Unmanned Manufacturing) which is aiming for the development of a flexible manufacturing system capable of fully-automated, small batch production by 1985. The existence of this long term project to develop sophisticated manufacturing which would mean a quantum step in production effectiveness and the clear evidence of successful implementation of the necessary components, lead us to rank automation as the leading factor which could make a significant impact in the 1980s and 1990s.

RELATIVE RANKING OF MAJOR FACTORS CONTRIBUTING TO JAPAN'S SUCCESS

EXHIBIT 7



This final perception of Japan's active procedures to provide for the efficient introduction of automation, particularly programmable automation, or robotics, is an important realization in understanding why Japan can lead the world in advanced manufacturing.

4. THE POTENTIAL OF SOPHISTICATED AUTOMATION

On our return to the States, we go to our manufacturing staff to get a clearer idea of the potential of what Japan has done in sophisticated automation. Their analysis begins with the economic rationale for different kinds of labor--manual vs. automatic--and we can identify several compelling reasons why conventional automation at this point has barely penetrated the 70 to 80 percent of manufacturing which produces at less than 10,000 parts per year. Further, it is painfully obvious that the robotic mechanisms we saw in Japan have the potential to significantly and economically penetrate this region, based on the existence of a flexible system of machining, transfer, assembly, and control--a system exactly like the MUM project which has been under way in Japan for over a decade.

We begin this analysis with a look at the various types of automation currently available, and can classify them into two categories: hard and soft. Hard automation represents the conventional form, which has been around since the days of Henry Ford. All of the functions of the machine are contained within its mechanical construction. These machines are expensive, but can be justified for high-volume lines which have few model changes and allow the cost to be amortized over essentially the entire life of the machine without incurring the significant added cost of retooling and downtime.

We classify the other form of automation as "soft" because even though it is mechanical, the control of the mechanism is not by moving cams or mechanical stops which comprise the high cost and long downtime necessary for retooling conventional equipment. Soft automation uses computer control of

high precision electric or hydraulic positioning motors known as servos. The effect of computer control gives these mechanisms the ability to be "retooled" in the time it takes to change the electronic instructions--on the order of fractions of a second.

This type of automation was first developed in the late 1960s when industrial lathes and other machining centers were put under electronic or numerical control (NC) allowing automatic performance of an entire "turn" by numerically positioning the cutting tool. This development made it economical to bring "hard" equipment into the realm of smaller batch processes where they could be "retooled" with a quick, simple change of a magnetic tape, or even by just pressing a button.

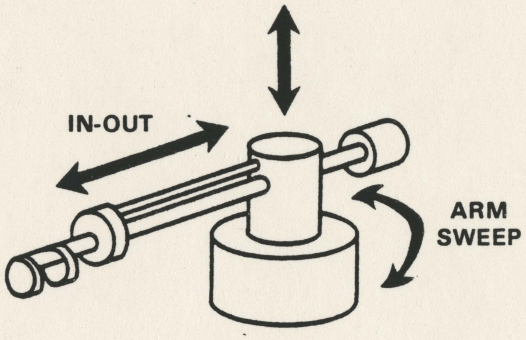
Another form of soft automation that began to emerge is the version we call robotic. This used the same concept of computer control, but the mechanism was completely different. The basic premise of its operation is that an electrically or hydraulically driven servo is attached to an "arm" which is in turn attached to another servo-driven arm. By putting these together in series, it is possible to set up a mechanism able to place the very tip of this series of arms in practically any orientation in three-dimensional space. Exhibit 8 shows the various forms of this type of mechanism which is capable of complex motion much like a human arm and can be almost "instantly" retooled like the NC machines.

The logical extension of these developments is to hook both the NC machining centers and robots up to a central computer so that the various steps in a production process can be jointly orchestrated. In this way, an entire line can be electronically "retooled" over a coffee break. Dangerous steps such as arc welding which formerly required manual labor are also feasible. More importantly, the computer can follow each item going through the production line, and "retool" each machine to perform the operation. Along with dynamic line balancing capability, this means a potential impact down to very small lots of 10 to 20 at a time. Herein lies the impact of the fully automated factory.

ROBOT DISTINCTIONS

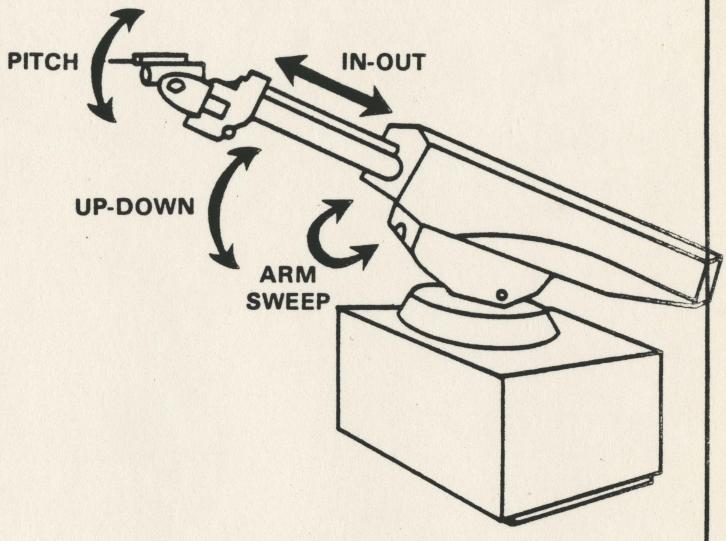
EXHIBIT 8

CYLINDRICAL: PICK-AND-PLACE



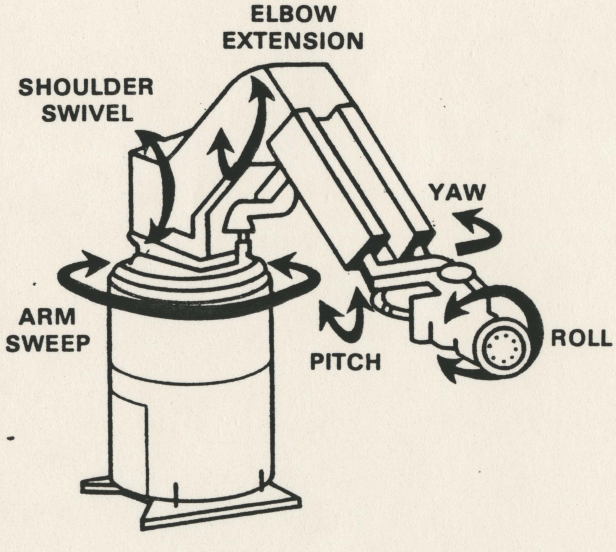
a, b, c, e CONTROL
2-3 AXES

SPHERICAL: UNIVERSAL



d, e CONTROL
3-6 AXES

SPHERICAL: ARTICULATED



d, e CONTROL
4-6 AXES

CONTROL OPTIONS:

NON-SERVO:

a) MECHANICAL STOPS
b) ROTATING CAM

SERVO:

c) PNEUMATIC
d) HYDRAULIC
e) ELECTRIC

The potential impact of this approach is shown in Exhibit 9. The conventional penetration curve of "hard" automation increases as the production rate, model inflexibility, and production simplicity go up. Adding "soft" automation and particularly robotics with flexibility and capability to handle even complex tasks like welding gives it significant impact down to very low production rates. The final curve represents the combined use of hard and soft automation and projects the potential for full-automation down to production rates of less than 1000 parts per year.

This analysis highlights the economies of scale that are possible through automation; high volume production economics can be made accessible all the way into the batch production region. Clearly, this is prefaced by the full development of these complex mechanisms in a factory setting and must also consider the need to relocate the manual labor force which will be directly displaced. At this point when one remembers that the Japanese have been confronting these two problems on both the company scale and the national scale for over a decade, one begins to appreciate the significance of the Japanese position.

5. ROBOTS IN JAPAN

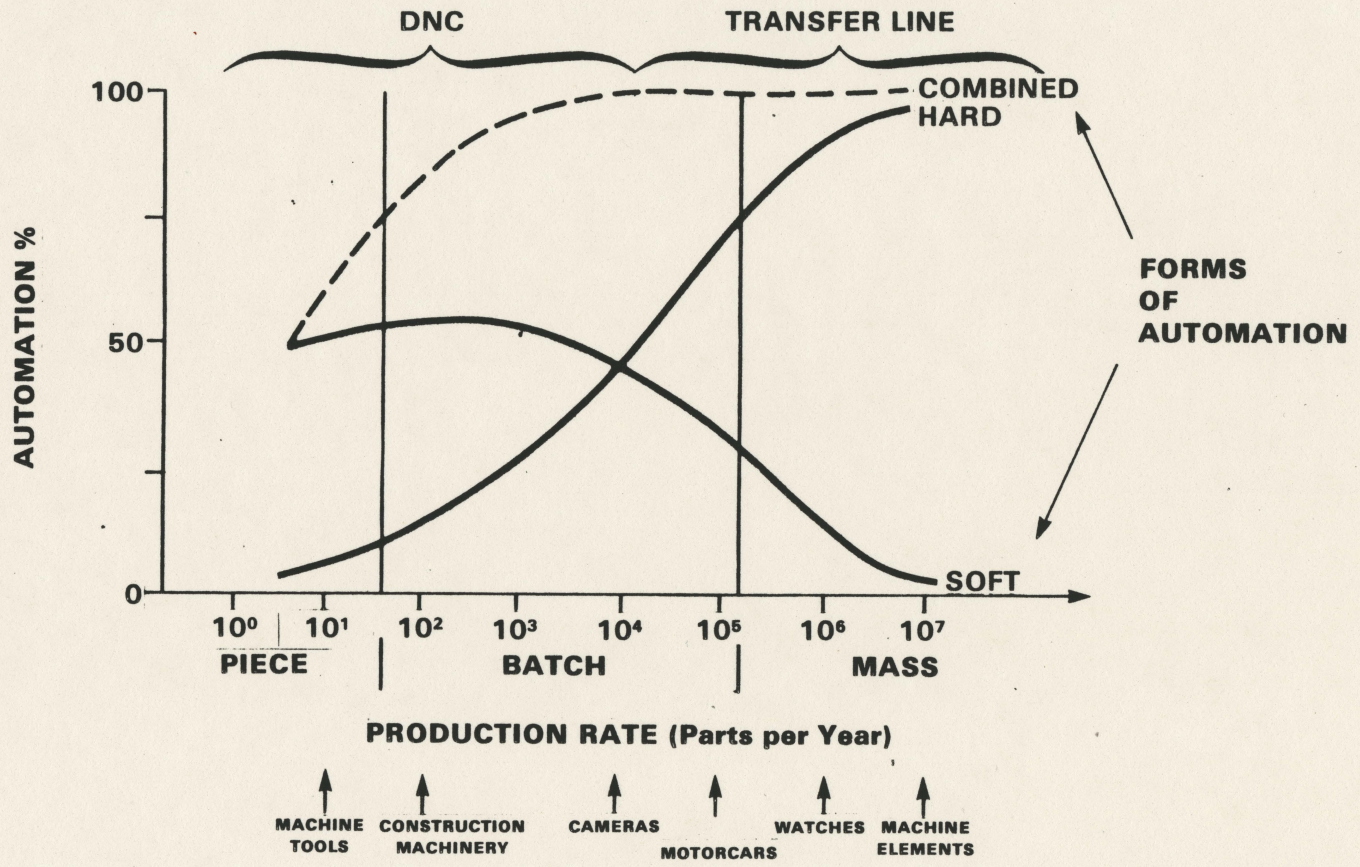
Item: A major TV network does a one-hour special on robots in the factory and extols the virtues of Japan's progress.

Item: A national news magazine does a cover story on Japan's economic strength and credits 50,000 robots working non-stop for the lions share. The story goes on to say that there are more robots in Russia than in the U.S., and something has to be done about this.

Item: A large industrial corporation launches an advertising campaign with the theme of learning from Japan's manufacturing success.

EXHIBIT 9

AUTOMATION POTENTIAL vs. PRODUCTION RATE



These are the stories. But what is the story behind the story? Can we replicate the Japanese success? Are robots the answer? Will our labor unions allow the unemployment? Where are the answers?

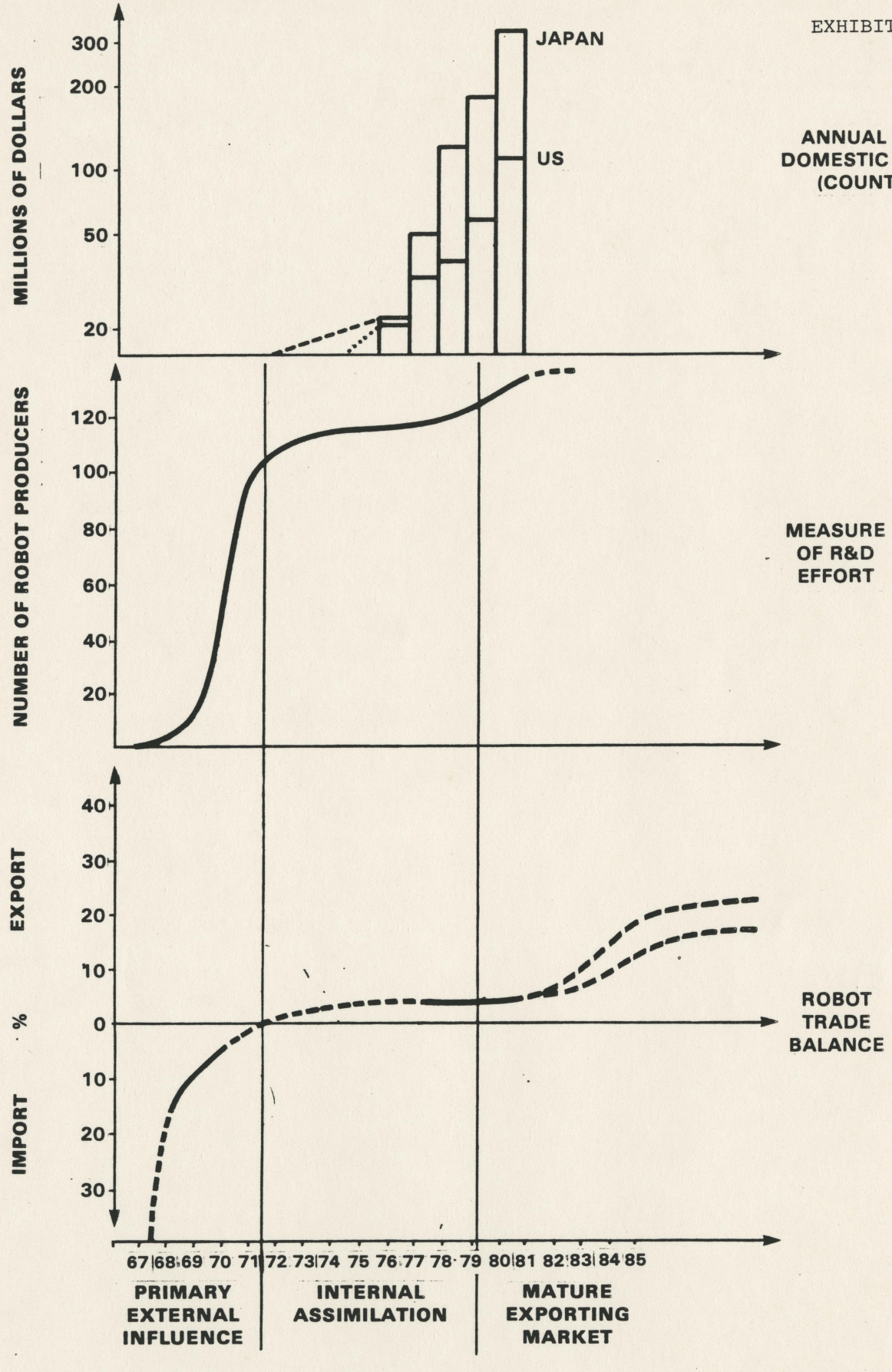
The answers are these. Yes, Japan does use robots more extensively than any other industrialized nature. They have over 10,000 industrial robots (not the 50,000 figure which includes many non-computer controlled manipulators). This four to one advantage over the U.S. still leaves many Japanese factories without any or too few robots. Yes, the Japanese are ahead but the race is far from over.

The labor area is one where traditional Japanese practice serves to Japan's advantage. Worker's jobs are virtually guaranteed. The fact that workers can be retrained and moved to other sectors of a business or national economy has been shown, for example, when automation was introduced into the lines of Nissan motor company and also when workers were relocated from the faltering shipbuilding industry to the car industry. This was the result of cooperative effort by Japanese labor, management, and the government--specifically MITI. We find this same cooperative effort expended on a smaller scale whenever industrial robots are being introduced in the workplace.

We see that the use of NC machinery and computer control play crucial roles in the move to flexible manufacturing systems; however, we note that these elements do not require a significant redirection of effort on the production lines themselves as do robots. We, therefore, need to examine specifically the data and accumulation of robotic operating experience to determine the status, significance and persuasiveness of their role in the flexible manufacturing concept that is being diffused through Japanese business thinking.

Exhibit 10 summarizes some of the crucial aspects of annual production, R & D effort, and the degree of internal use. 10(a) shows the dramatic difference between the way U.S. companies and Japanese companies

EXHIBIT 10



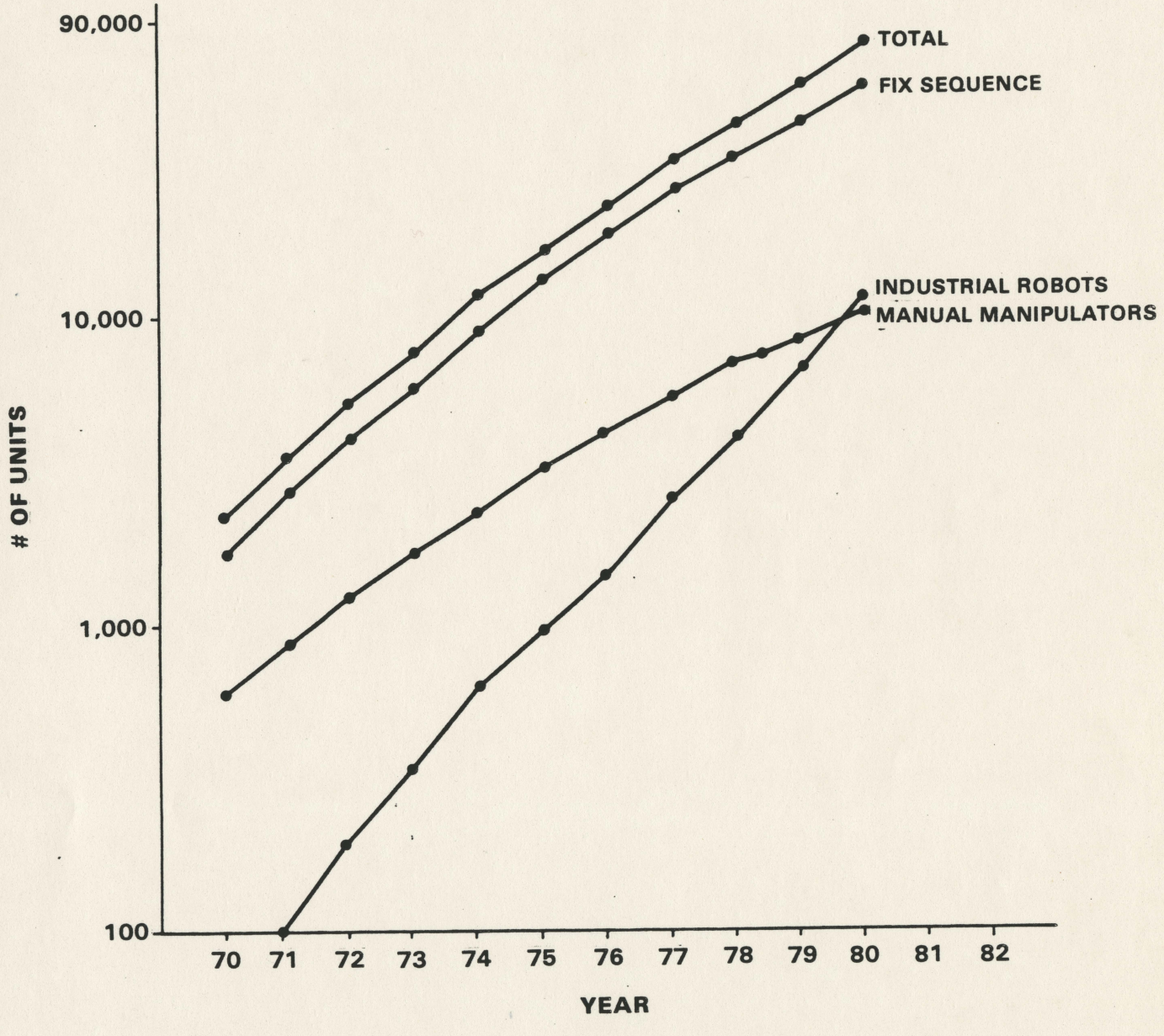
have embraced robots in their operations. By 1976, less than 10 years after robots were first introduced in Japan, the Japanese market had exceeded its American counterpart which had been in existence almost twice as long. 10(b) shows the speed and enthusiasm with which almost 100 Japanese robot producers came into the market within four years of that first introduction. Because these companies do the bulk of robot applications research, this also shows the diversity and longevity of interest over the last decade. Even in 1981 there are not even fifty robot producers in the U.S. Finally, as we can see in 10(c), these years of the '70s have been quiet exporting years in robotics mostly because Japan's feverish production has been going into their own factories. Note especially the dramatic increase in the exporting market during the last two years. This might indicate the Japanese have enough experience implementing and applying robots that they are not threatened by competition or productivity benefits which might be achieved abroad.

Cumulative sales since 1970 show the extent of this accumulated experience in Exhibit 11. The exhibit includes development of both what American industry terms industrial robots and two classes which are ordinarily excluded: manual manipulators, and fixed sequence. The reason we include these simpler machines is that the fixed sequence manipulators, mostly of the pick-and-place kind, are being extensively used as transfer mechanisms in fixed production lines. True, they are not easily reprogramed in these applications, but their presence represents a task which was not formerly done by machines. It is a significant indication of how the Japanese are accumulating practical experience.

The long-term use of simple manual manipulators is also significant. They are simple mechanisms with the capability of a robotic mechanism with four and five degrees of freedom and require only manual control of the motion parameters going into the control microprocessor. Even though they are not fully robotic, they are being used for complex and dangerous tasks such as removing forgings from a furnace by mechanical means. They also represent how the Japanese are accumulating experience in the factory.

EXHIBIT 11

CUMULATIVE SALES BY JAPANESE VENDORS



As the technology becomes more advanced and sophisticated enough to combine these operations, fully programable robotic units make their way into production application. The bottom curve shows the rapidity of this advance. In 1980 some 11,250 industrial robots were in use in Japan. That same year, despite the extra ten years of market activity in the U.S., only a quarter that number were being used in American factories.

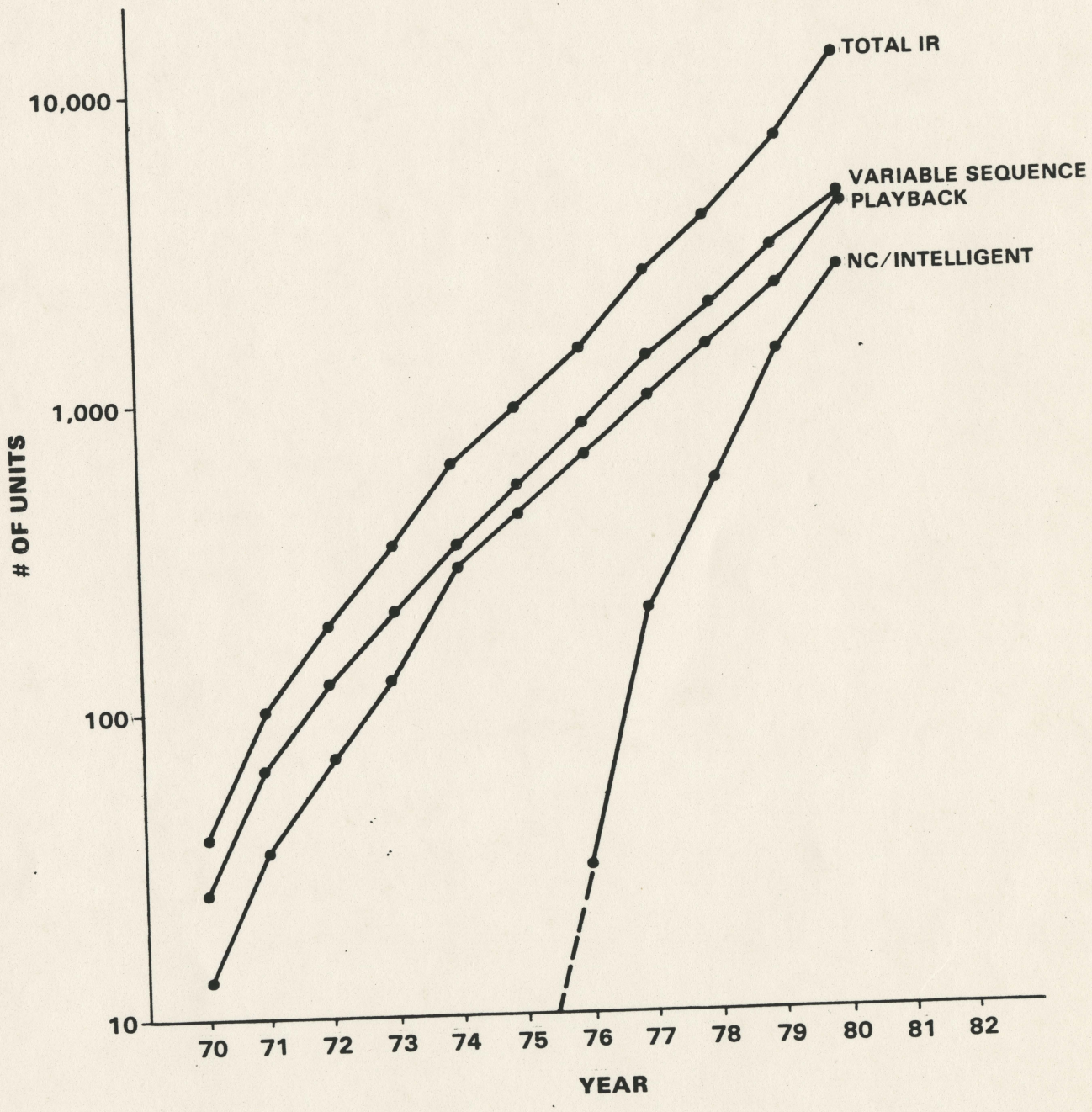
Exhibit 12 shows a similar trend. Building upon their accumulated experience with simpler devices, the Japanese began to produce the most sophisticated NC/Intelligent robots which can be directly integrated into the flexible manufacturing schemes. Simple variable sequence transfer machines and playback robots were improved as the technology allowed operations to be physically "taught" to the robot, so the robot executes these commands over and over. These playback robots have seen considerable use in spray painting and spot welding. As the control systems became sophisticated enough to be taught by direct numerical means (i.e., from a computer) or by external sensors (i.e., intelligent), these additional capabilities are coming into use. The continued explosive growth of these more sophisticated robots is the culmination of well laid research in sophisticated production schemes. These have developed along the path of experience laid by the simpler mechanisms. That the simpler mechanisms still form a significant part of the market further justifies their role in experience acquisition which is being used to diffuse this technology to all facets of Japanese enterprises under the direction of the government.

6. THE VIEW FROM THE JAPANESE FACTORY FLOOR

Some of the more extreme impressions circulating in America have every Japanese factory running with the latest automation, operating unattended, and having robots building

EXHIBIT 12

CUMULATIVE JAPANESE ROBOT PRODUCTION



more robots in a self perpetuating process. It is true that the Fujitsu-Fanuc Fuji plant is a modern marvel of automated warehousing, robotic transfer of parts, robotic machine tending, and automated assembly. It is probably the most advanced factory worldwide, but there is room for more optimal procedures. We reviewed about thirty factories in several key industrial groups in addition to the Fuji plant, this pinnacle of success. Exhibit 13 shows the list. The companies produced machine tools, automobiles, electrical and electronic components, construction machinery, and precision instruments. Each plant had different ways of going about automation, many "homemade." Each plant used all the eleven factors (though to greater or lesser extent) and did not rely on robotics alone. The results, however, are impressive. The productive ratios for each factory, that is the ratio of goods produced (in dollars) to employees, in these Japanese automated plants exceed those of the U.S. by factors of 2 to 3! Exhibit 14 graphically compares this productivity ratio for the U.S. and Japan.

7. FOLLOWING THE JAPANESE LEAD

Because of the many accomplishments the Japanese have made in productivity advances on the general front and automation advances on the manufacturing floor, a number of their approaches should be examined and evaluated by U.S. manufacturers. The accompanying report details the specifics of these basic developments based on appropriate background material, provides detailed discussions of both the major factors and influences as well as the significance and approaches they have made in sophisticated automation, and finally discusses translations which might be appropriate for America.

Section 1 "Introduction to the Report," outlines the rationale and study methods used for our study, the significance of Japan's productivity efforts and the broad based approach of overhaulng and fine tuning all the mechanisms which affect the competitiveness of their manufacturing operations. This section also suggests the most powerful effect of these

EXHIBIT 13

List of Japanese Plants Reviewed

Machine Tools, Robotic Mfg.

Fujitsu Fanuc
Hino-Shi (Tokyo)
Fiji

Kawasaki H.I.
Akaski

Kobe Steel Ltd.
Kobe

Shin Meiwa Industry
Shin Meiwa

Toshiba Seiki
Kanagawa

Okuma
Aquchi, Nagoya

Automotive

Nissan
Muragama
Oppama
Zama

Mitsubishi Motors
Kyoto
Okazaki

Toyota
Kamigo (Nagoya)

Nippon Denso
Anjo
Takatana

NHK
Shiga

Mitsuba Electric
Niisato
Akagi

Construction Machinery

Komatsu
Osaka

Precision Manufacturing

Daini Seikosua
Takatsuka

Hydraulic Valves and Pumps

Kawasaki H.I.
Nishi-Kobe

Yamatake Honeywell
Sumakawa

Electrical, Electronics

Mitsubishi Electric
Kyoto
Muragama

Fuji Electric
Mie

Tokyo Sanyo Electric

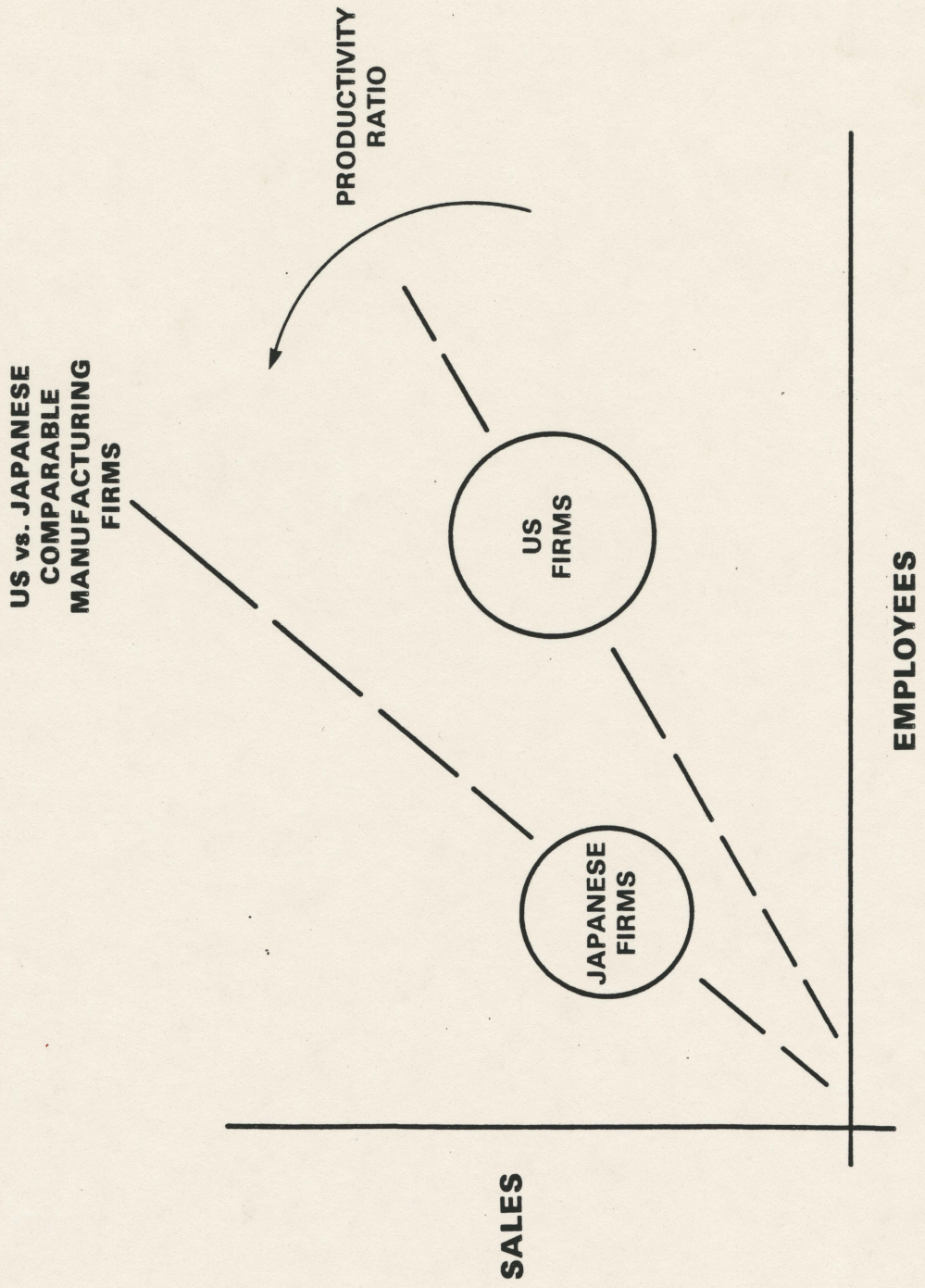
Government/Private

MITI - Ministry on International Trade and Industry
MEL TSKUBA
JPC - Japan Productivity Center

JRA - Japan Industrial Robot Association

Japan Marine Science and Technology Center

EXHIBIT 14



factors: that their synergistic action is allowing the realization of greater effectivness in all parts by their coordinated interaction.

Section 2 "Japan the Nation," details the historical and societal underpinnings of the current state of Japanese business. It is a necessary starting place, because these traditions are often hidden in the approaches business has taken to the productivity issue. It is especially important because it will flag those elements which readers must be wary of in making analogies with the U.S. It also provides guidelines for more profound changes in the structure of the workplace should they be applicable. This section discusses Japan's historical beginnings and development up to the end of WWII and the U.S. occupation.

Section 3 "The Japanese Business Environment Today," outlines the Japanese business environment as it has developed since 1950. It puts a realistic cap on the theoretical and philosophical trends introduced in Section 2. It also provides the basic information for understanding the scope of Japanese progress, and suggests areas where its strengths and weaknessess are hidden. Finally, it presents the themes which have spawned the Japanese movement to develop a fully automated factory.

Section 4 "Major Factors in Japan's Economic Success," discusses the eleven areas where Japan has made unusual strides in furthering the efficiency and effectiveness of their productivity programs. This is a crucial chapter because it presents the broad range of factors which contribute to the national symbiosis.

Chapter 5 "Defining Robots and other Forms of Automation," gives the background of automation and lays out the distinctions, advantages, and disadvantages which are coming together under the national program for a fully automated factory. It provides the basic information crucial to any understanding of these new technologies, and it gives the necessary perspective for discussing the status and impact of the Japanese robot program.

Section 6 "Robots and Automation in Japan," deals with the specifics of what Japan is doing with advanced automation and how robotic implementation is playing a significant role. One section describes the plans and progress in their project for Methodology for Unmanned Manufacturing, MUM. There is also a section on the significant patterns of development and use of robots. This section of course lists the major industries and applications where the implementation has been particularly heavy. A subsequent section describes the major government, research, finance, corporate, and labor institutions which have hastened this development. This section finally concludes with an accounting of Japan's robotic edge and what that can mean for future industrial competitiveness.

Section 7 "American Translations," details the various ways U.S. executives should confront this information as they make decisions about avenues for development in America. It covers government, management, labor, technological development and points out areas where the Japanese example might provide direct answers in the U.S.

Section 8 "Profiles of Major Japanese Firms," gives a final summation of the leading Japanese companies. Each profile identifies the company by name, its grouping, philosophy, use of automation and other features, and provides comments based on tours of the factories. It complies data on robot manufacturers and specifications for Japanese industrial robots and applications.

It is the intention of all those in the SAI Robotic Applications Center who worked on this study to present the data and information needed by executives to size-up the Japanese success story and prepare appropriate future plans for their organization. We believe the following book does just that.

8. STUDY METHODOLOGY

What has gone into this book is the compilation of many months of intensive research and first-hand visits and interviews in plants, executive offices, research institutions, and government offices by personnel with many years of experience in manufacturing technology. What follows in the body of the report is a detailed accounting of the crucial areas affecting robotic implementation.

Some of the basic themes which are presented are not new, but are the synthesis of earlier accounts in trade, academic, and popular literature put together to provide a complete picture of the field. To do this, we started with a data base search on robotics and Japan which netted thousands of entries from twenty data bases. Current reports and articles were also collected and added to our robotics library. The second stage was to abstract the important articles from these two sources--the latest entries as of this writing now number about 400 sources.

Another source for updated information was a study trip organized by the Society of Manufacturing Engineers to visit factories, government offices, and research institutions in Japan. The Center's director, Dr. T. M. Knasel, led the "B" Group of fourteen highly trained engineers through two weeks of intensive interviews and visits during late June and early July of this year. His insights and perspectives have been invaluable in the preparation of this book. A second trip to Japan to visit additional factories and attend the 11th International Robot Symposium and Exhibition in Tokoyo complete the findings.

Finally, efforts by the RAC staff and others in parent company, Science Applications, Inc., all contributed to the inspiration, research, and review of the final product.