92-F-15

Why Do Japanese Companies Automate Assembly Operations?

— A Survey in the Auto Industry —

by

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December 1992

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(Draft)

Discussion Paper for the Berlin Workshop on Assembly Automation

November 1992

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1. Research Questions and Overviews of the Issues

Why is Assembly Automation Low in the Japanese Auto Makers?

Assembly has long been a bottleneck of automation in the automobile industry. According to the survey of assembly plants in the world auto industry conducted by International Motor Vehicle Program (IMVP) at MIT, for example, average automation ratio in the sample final assembly line of the Japanese auto factories was as low as 1.7%, which contrasted the case of body welding (87%) and painting (55%) (Womack, Jones and Roos, 1990; Krafcik, 1988)[2]. Our study, conducted by JTTAS in 1992 for the 9 Japanese car makers, shows that the average automation ratio of the most automated processes at each company was by far the lowest (10%) compared with other processes such as welding (91%), painting (51%), engine machining (93%), engine assembly (55%), body stamping (94%) and so on[3].

Automation has historically been more prevalent in non-assembly areas of automobile manufacturing. In high volume metal cutting processes such as engine block machining, automation already has a half century's history, although Detroit-type hard

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[1] This paper is based on a survey conducted by the Committee for Research on Optimal Automation Systems in the Automobile Industry, which is chaired by Professor Koichi Shimokawa of Hosei University and is organized by Japan Technology Transfer Association (JTTAS). Professor Hisanaga Amikura of Chiba University and Mr. Takashi Matsuo, Doctoral Candidate at Tokyo University, were particularly instrumental in compiling the data. Mr. Seigo Onishi and the staff of JTTAS facilitated distribution and collection of the questionnaire. The author is grateful to the respondents of the survey, as well as the above people.

[2] Automation ratios were defined by number of direct steps automated.

[3] Note, however, that definition of automation ratio differs across companies and processes, so that they cannot be accurately compared across the processes nor with other studies such as IMVP.

automation with transfer lines has gradually been replaced by computer-controlled flexible manufacturing systems in certain areas that needed to handle a high variety of products or work pieces (Bright, 1959, Jaikumar, 1984, 1986). More recently, in body welding process, the Japanese auto companies achieved a high degree of automation by massive introduction of robotics. As far as spot welding is concerned, automation ratios of relatively advanced new plants (measured by number of welding spots) have been almost 100% worldwide as of the late 1980s.

In other industries such as consumer electronics, the Japanese makers were much more aggressive in automating assembly processes. Automation was instrumental to the Japanese TV and VCR factories in maintaining cost competitiveness despite appreciation of yen and catch-up of Newly Industrialized Countries. Rationalization of product designs (e.g., reduction of parts numbers, stack-up layout, etc.) was a key to the fast pace of automation. Overall, the Japanese outpaced the Western companies in introducing robotics, according to the industry statistics in the 70s and 80s, which was recognized as a source of competitive advantages of the Japanese manufacturing firms. This was not the case in automotive final assembly, though.

Across the regions, the IMVP study reports that average automation ratio of the Japanese sample assembly lines (1.7%) was, in fact, lower than that of Europe (3.1%), although it was a bit higher than the U.S. average (1.2%). This seems to be partly because some Europeans volume producers (VW, FIAT, and others) have been more aggressive in automating final assembly operations than most of the Japanese factories. In any case, there has been no evidence that the Japanese auto makers benefited from a high level of assembly automation in achieving higher manufacturing performance than the average Western makers during the 1980s.

The above evidences leave us at least two questions: First, why is the degree of final assembly automation of the Japanese auto makers relatively low compared with other processes and industries? Second, why wasn't it high compared with the Western (particularly European) competitors when the Japanese auto companies on average demonstrated a significant productivity advantage in assembly during the same era? To answer these questions, we have to examine both intrinsic natures of final assembly operations that make its automation more difficult, and factors specific to the Japanese auto makers that make them refrain from aggressive automation in final assembly lines. Let us first review the problem through some anecdotal evidences.

Assembly Automation and Competitiveness

In the case of final assembly, the relations between automation and competitiveness has not been clear. While automation played a major role in maintaining competitiveness in color TV, watch and others in Japan, the connection was less clear in the auto industry, particularly in assembly. Final assembly automation ratio and productivity have no significant correlation. For example, Toyota's Takaoka plant, known as one of world's most productive auto factories during the 1980s, had final assembly lines whose automation ratio was virtually negligible. Nissan is said to have been more aggressive than Toyota in welding and assembly automation since the 1970s, but it is generally known that Toyota is higher in labor productivity than Nissan (see, for example, Cusumano, 1985). Some highly automated plants built in the middle of 1980s by GM (e.g., Hamtramk) suffered from a high down time ratio and low efficiency. Assembly productivity of the European volume producers was on average lower than both Japanese and Americans despite slightly higher assembly automation ratio, according to MIT's IMVP study.

The lack of positive correlation between assembly automation and competitiveness may mean either that the Japanese firms did not emphasize automation as they did not regard it as contributing to competitiveness, and/or that there were some obstacles that hampered effective implementation of automation equipment. It appears that assembly automation has not been regarded by effective Japanese auto makers (i.e., the lean production type) as contributors to overall competitiveness.

Abernathy, Clark and Kantrow (1983) argued that it is not hardware (i.e., heavy investment in automation) but the microscopic infrastructure that explained the Japanese competitive advantages in this industry. In fact, Toyota, the master of lean production system, was apparently cautious not to implement automation for the sake of automation. With multi-skilled workers in the space efficient assembly lines, it was more difficult for the lean assembly system to justify automation investments, as robots and machines tended to increase manufacturing cost and consume space in this situation.

Jidoka and Low Cost Automation: The Total System Approach

What Toyota emphasized, in stead of aggressive pursuit of automation, was "Jidoka," in which human intervention was intentionally incorporated into the equipment to respond effectively to defects (See Monden, 1983, Schonberger, 1982, etc.). In Jidoka, machine stops automatically when defects are detected, but workers have to start it manually, giving them a natural opportunity to improve the process. In this way, Toyota emphasized the danger of mass-producing defects by fully automated equipment. When Toyota-type companies did automate the process, they tended to go for "low cost automation" to maintain cost competitiveness. To save equipment cost, such companies tended to develop automated or semi-automated equipment internally with limited functions just enough for the firm-specific requirements.

What is behind low cost automation and Jidoka seem s to be a total system approach to automation by some effective Japanese manufacturers. Whitney (1986), for example, argues that, "Robots are not mechanical people; they are parts of an integrated manufacturing system." He observes that relatively simple robots can perform the assembly operations repeatedly and reliably. According to Tidd (1989), the Japanese manufacturers tended to use simpler robots (e.g., SCARA type) than the case of the U.K.

factories to achieve the same level of flexibility and efficiency. This was partly because the Japanese tended to take a total system approach in that other elements of the robot assembly systems such as product designs and jigs were carefully adjusted to the robots to lower their workloads.

This kind of total system view is very important in analyzing the impact of automation on industrial competitiveness. Competitiveness seems to be a function of an integrated package that includes not only robots and automated equipment but also other factors including jigs, product designs, process designs, worker skills, maintenance organizations, etc. These elements surrounding the automation equipment may be called the infrastructure of automation. Without such an infrastructure, it would be hard to achieve competitive advantages through automation.

Avoiding Over -Automation for Competitiveness?

The anecdotal evidences shown above seem to indicate that effective Japanese manufacturers (e.g., Toyota) were carefully avoiding the risk of "over-automation" from the competitive point of view. The notion of "optimal automation ratio," above which further attempts of automation may decrease competitiveness, was apparently common in some Japanese makers. While the low degree of final assembly automation by the Japanese auto makers may be ascribed partly to the nature of the assembly operations, it may also be ascribed to reluctance of the Japanese auto makers to "over-automate" their assembly lines.

Here is a paradox. Normally it is assumed that manufacturers automate in search for competitiveness. In the current case, however, the effective Japanese firms apparently tried to avoid automation in order to maintain competitiveness.

Why Are the Japanese Automating Assembly Now?

It was argued that automation ratio was relatively low in final assembly of the Japanese auto makers during the 1980s, and that the relationship between progress of automation and improvements in competitiveness was somewhat ambiguous in assembly operations. An interesting paradox was found: the Japanese companies, which appear to have more abundant infrastructures to link automation to competitiveness, did not automate aggressively, while some Western auto makers, which did not have enough infrastructure to connect automation and competitiveness, still pursued aggressive automation strategy including assembly operations, and failed to improve competitiveness. In other words, the paradox was that those companies that were more conscious of competitiveness were, actually, less aggressive in assembly automation.

Since the end of the 1980s, however, the Japanese auto makers apparently started to accelerate their efforts to automate final assembly lines. In the latest assembly lines in Japan such as Toyota Tahara #4, Nissan Kyushu #2, Mazda Hofu #2 and Honda Suzuka #3, assembly automation ratios are significantly higher than that of the past generations, although it does not exceed 30%.

Why did this drive for assembly automation happen? One obvious reason was the economic boom in the late 1980s: the domestic auto market expanded rapidly, interest rates were low, and stock prices were increasing. In this situation, the Japanese auto companies could invest on new and automated production lines with very low cost of capital by using equity finance. This, however, is only a part of the story. We need further explanations on why the new generation of plants pursued higher automation in final assembly lines unlike the former generations. Technological advancement in robot and sensor technologies, as well as engineers' dreams for factories of the future, may explain part of the story, but they do not seem to be enough as far as the Japanese makers are still taking the total system approach.

How about competitive pressures after the appreciation of yen? Did the Japanese start to automate assembly in order to improve cost competitiveness against the Western and Asian competitors? However, it was the same Japanese makers that were apparently avoiding excessive automation for competitiveness. There do not seem to be any significant changes in the basic philosophies of the Japanese manufacturing management between the 80s and the 90s. Thus, competitive pressure does not seem to be a major motivation for assembly automation of the latest Japanese plants. As discussed in the next section, one of major motivations for the current drive for assembly automation seems to be the problem of labor shortage, rather than competitiveness per se.

From "Lean on Growth" to "Lean on Balance"

What is behind the drive for final assembly automation seems to be the forthcoming changes in the total manufacturing system in the industry. Borrowing the term from the IMVP study, I may summarize this change in the total system as that from *lean on growth* to *lean on balance*. The business environments surrounding the Japanese auto makers of the 1990s are changing. The trend seems to be a general shift from the sharp focus on competitiveness and customer satisfaction based on constant growth (i.e., lean on growth) to a more balanced approach that concerns about other stake holders than consumers, such as employees, suppliers, communities and stockholders (i.e., lean on balance).

When the lean production system emerged in some of the Japanese makers in 1950s through the 80s, high and constant growth of production volume was its precondition. The firms could concentrate on improvement in competitiveness and customer satisfaction without paying equal attention to other stakeholders. The focus on competitiveness, in turn, would result in the growth of production volume through expansion in global market share. This customer-focused approach might have de-emphasized and alienated the other stakeholders, but they were more than compensated by benefits from the growth: Workers might have had complaints about work conditions and high tension of the lean system, but they could also benefit from improvement in compensations created by high growth and competitiveness of the system; Suppliers might have complained about constant pressures from the assemblers for price reductions, but they could endure it as long as there was a constant growth in order volume. The above system worked well as long as production volume kept on growing.

In the 1990s, however, the growth in production volume slowed down, other stakeholders than consumers (workers, suppliers, stockholders, community, general society, etc.) became increasingly outspoken, and chronic shortage of domestic labor supply became a critical long-term problem to the auto makers and the suppliers. A particularly serious problem has been the lack of balance between continued popularity of the Japanese cars in the world product markets and a relative lack of popularity of the Japanese production processes in the domestic labor markets, as well as the lack of balance between its high flexibility to the variety of product market needs and inflexibility to the potential variety of the labor market (i.e., excessive dependence on homogeneous work force that consist mainly of young male workers in the past).

Facing the long-term environmental changes described above, it became increasingly obvious to industrial observers and practitioners that the current lean system, which may be called "lean on growth" model, is hard to survive in the emerging environmental changes toward the 21-st century, and that some kind of "post-lean" system has to be developed to cope with the problems. The system that the Japanese auto makers are trying to develop may be called the "lean on balance" model: While it will try to maintain many elements of the current lean system that created competitive advantages of the Japanese auto makers in the past (i.e., continuous improvements by supervisors and workers, mechanisms to detect defects and non-value activities, training of multi-skilled workers, employee participation in problem solving, teamwork and communication, etc.), it makes the work places more flexible and friendly to a wider variety of work force including female workers, older people, handicapped people, and so on.

The other side of the coin is excessive adaptation of the Japanese products and systems to market needs, or the possibility that the Japanese auto makers try to attract and satisfy the current customers in such areas as product variety, component variety, model change cycles, and proliferation of peripheral functions even at the sacrifice of cost and wastes. While responding to the "real" consumer needs is still critical, it might have been the case that the makers were, in fact, responding to the illusions of consumer needs that they created themselves through the product planning process, which resulted in overshooting in product variations, model changes, product designs and so on. The Japanese auto makers finally started to consider this problem of over-adaptation to the market in the past few years. It is likely that model change cycles of the Japanese automobiles will get somewhat longer, product varieties at the option level will be reduced, parts commonality across the models will increase, and product designs will become more "lean" in the future.

In summary, the new manufacturing approach that the Japanese auto makers have to pursue toward the next century seems to be the "lean on balance" system, in which production processes become more friendly and human-fitting to the workers and suppliers, annual working hour is reduced, flexibility of the production process to involve a wider variety of work force is enhanced, contribution to communities is more emphasized, and excessive adaptation to the illusion of current consumer tastes is trimmed, while the high level of competitiveness and customer satisfaction that the current lean system enjoys is basically maintained. In creating such a system there will be much more opportunities to learn from the experiences and practices of the European and American companies, which would result in mutual learning between the Japanese and the Western firms[4].

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[4] Further details of the lean on balance system will be discussed in forthcoming papers by Fujimoto and Takeishi.

Assembly Automation for "Lean on Balance"

Following the total system approach to automation, the present paper argues that the current trend of higher assembly automation among the Japanese auto firms is based mainly on the total system changes from "lean on growth" to "lean on balance." Although competitiveness continues to be a key factor in planning and implementing automation, the major motivation of the Japanese auto companies for automating final assembly now seems to be their concerns about labor shortage and their relative lack of popularity in the labor markets. That is, while the "lean on growth" system did not include aggressive assembly automation as its element, the "lean on balance" system may create pressures to automate the assembly process. The automation in this case would be designed as a part of "human-friendly" manufacturing system.

The pattern of automation described above may be different from that of the American or European auto companies. This seems to stem from differences in motivations of the firms, as well as the total manufacturing systems to which the automation is incorporated. For European and American auto makers, to which the competitive threat of the Japanese makers continues, improvement in international competitiveness is likely to be the major motivation for assembly automation. The manufacturing system to which automation is applied is still based on single-skilled workers, which are typical in traditional Fordism. This may contrast with the recent Japanese case, where the major motivation is to make the work place more attractive to potential workers, and the assembly automation has to be adapted to the multi-skilled work organizations of the lean system. Generally speaking, the patterns and objectives of automation may be different depending upon the types of the total manufacturing system: When a craft system is automated, the main issue is likely to be de-skilling of job designs; When a single-skilled system (i.e. traditional Fordism in America or Europe) is automated, the major motivation may be reduction of work force; When a multi-skilled work systems (typical in the Japanese lean systems) has to be automated, the challenge may be how to introduce robots without fragmenting the job assignments to the workers and without getting back to the single-skilled work organizations. In summary, a total system view seems to be crucial in analyzing patterns of automation across the regions.

2. Empirical Results: Objectives and Obstacles

Outline of the Survey

The survey was conducted in July 1991 by the Committee on Optimal Automation Systems in the Automobile Industry at JITAS (Chaired by Professor Shimokawa of Hosei University). All of the 11 auto assembly companies in Japan participated in the survey, in which 9 were car makers (trucks otherwise). The questionnaire asked individual engineers of each company about their subjective judgment on motivations, expectations and obstacles of assembly automation. Thus, the answers do not reflect official stance of each company.

Objectives of Assembly Automation

The survey first asked about relative importance of objectives for, or expectations from, automating final assembly lines toward the year 2000. The respondents answered by selecting the degree of importance by 5 point scale (1 = unimportant; 5 = important) for ten potential objectives for assembly automation. The result on the average of the 11 firms is shown in figure 1.

Of the ten potential objectives, *quality improvements* (i.e., reduction of defects) and *reduction of workers* received a highest score (4.7). Their emphasis on quality is understandable considering their emphasis on TQC (total quality control). Reduction of workers also seems to be a quite natural objective of automation.

What is interesting is that the score of *cost reduction* (4.2) is not as high as quality and work force reduction. This is consistent with the prediction that recent thrust of assembly automation is not motivated primarily by pressures for cost competitiveness. What is more striking is that *improvement of work environments and reduction of workload* (4.6) was recognized as almost as important as the first two factors, and was significantly higher than cost reduction. A possible interpretation of the above result is that the Japanese auto makers no longer regard cost competitiveness as the primary driver for automation, and are now willing to invest on robot systems that make the work place more attractive and friendly to potential workers, even if it means cost increase. This story is, again, consistent with the trend toward the lean-on-balance system discussed earlier. Also, two additional motivations which were regarded as relatively important were responses to *aging work force* and *work hour reduction*, which are closely connected to the lean-on-balance argument.

It should be noted, however, that there is a sharp polarization of opinions about the cost reduction factor, which made the average score relatively low. In fact, six out of the eleven companies regarded this factor as important by choosing point 5, while four of them chose point 3. This may imply that there still is a significant disagreement among the Japanese auto makers on whether cost should be the primary driver for automation.

How Much to Pay for Automation

In order to check if the Japanese auto makers became more willing to invest on automation even at the sacrifice of cost, a subsequent survey conducted in the late 1991 asked about the upper limit of automation investment that is equivalent of one person per shift. The result shows that, on average, the upper limit increased remarkably from about 7 million yen in 1986 to over 18 million yen in 1991[5]. Back in 1986, virtually all the companies ranged between 5 million and 10 million yens, which was roughly equivalent of one year wage and benefits per worker, a very conservative criterion. This seems to

[5] One company answered that there was no limit in both 1986 and 1991, which was excluded from the summary statistics here.

indicate that there was a consensus among the companies on their strong orientation to "low cost automation".

In 1991, however, the upper limits ranged much wider between 8 million and 40 million. As figure 2 illustrates, there were some companies that apparently maintained the principle of low cost automation, while there were others which clearly departed from the past criterion by raising the limit upward dramatically. This data seems to be consistent with the observation mentioned above that there is a disagreement among the Japanese auto makers on whether cost should be given the first priority in investment decisions for automation.

Obstacles against Assembly Automation

The next question was on the obstacles against assembly automation. The respondents were asked to select 1 (unimportant) to 5 (important) for 23 potential reasons for not automating the assembly operations. Based on the total system view, the potential obstacles were classified into five major categories: product and component characteristics; worker-related issues, robots and equipment; jigs/fixtures on the body side; process layout. The result is shown in figure 3. The obstacle most seriously considered, on average, was *excessive variety of parts* (#5). This is quite typical in the Japanese production system, where flexibility to deal with product variety is emphasized to an extreme. The variety factor is followed by *limits of space* for main and sub-assembly lines (#23 and #24), reflecting the compactness of the Japanese assembly plants. Thus, it is possible that some factors that have been regarded as strength of the traditional lean system (flexibility and space efficiency) become obstacles for further automation.

Other obstacles that were taken relatively seriously included *insufficient flexibility of equipment* for mixed model assembly (#15), *bulkiness of consuming equipment* (#14), which were simply the other side of the two factors mentioned earlier.

Also, *physical properties of parts* (complexity of shape, softness, difficulty to grip) (#1), *difficulty in parts' orientation* for assembly (#2) were regarded as equally important obstacles, which may imply that there is a large room for further improvements in product designs for automation. Another constraint against assembly automation was *high prices of equipment* (#9). Thus, despite the argument that cost reduction is no longer the primary driver for assembly automation, reduction of unit equipment cost may still be one of keys for introducing more robots.

Compared with the above factors, those related to the workers (# 6 to #8) and the body side (# 17 to #21) were not regarded as very serious obstacles. In these categories, continuous motion of bodies (typical in conventional conveyer systems) (#18), lack of flexibility of jigs (#20 and #21), and high cost of jigs (#17) received slightly higher scores on average. By contrast, the factors related to lack of alignment accuracy (#3, #4, #13, #19), as well as such technological factors as insufficient speed (#10), insufficient degree of freedom (#11), and insufficient intelligence of equipment (#12) were not taken seriously as major obstacles.

Expectations to Overcome the Obstacles

The next question was the extent to which improvements are expected on each of the 23 obstacles mentioned above within the next 5 years. The result is shown in figure 4. Generally speaking, expectation was high in technological improvements in automated equipment (#9 to #16), particularly in sensor technologies and intelligence (#12) and size reduction (#14), followed by price reduction (#9), alignment accuracy (#12) and flexibility (#15).

In the group related to parts' characteristics, expectation for modification of shapes/materials of parts (i.e., design for assembly automation) (#1) is relatively high. Expectation for reduction of parts variations (#5) is somewhat low, however, considering its importance mentioned above. The score is rather low in plant space expansion (#23,

#24), which may indicate that there are not many plans for assembly plant renovation in the next five years (It would be difficult to expand the assembly area using existing buildings). On the space problems, therefore, size reduction of automated equipment, mentioned above, was recognized as a more promising solution. Finally, expectations for improvements are generally low in the factors related to jigs and others on the body side (#17 to #21), which may imply that much efforts have been already made by the Japanese auto makers in this area.

By combining the scores on importance as obstacles and expectations for improvements (figure 5), we find that concerns and expectations are both high in such factors as size reduction of equipment (#14), shapes and materials of parts (#1), price of equipment (#9), and flexibility of equipment (#15). On the other hand, a relatively problematic factor where expectations were somewhat low compared with the level of concerns, where the bar chart significantly exceeded the line chart in the figure, was variation of parts (#5), which may imply that production engineers were still a bit pessimistic in reducing variation of parts for assembly automation, considering the constant pressures from the market and the marketing group. It should be noted that, after this survey was completed, many of the Japanese auto makers announced their plans to reduce the total variation of parts by roughly 20 to 50%. Thus, engineers may have become a bit more optimistic on this issue. Other relatively problematic factors were space (#23, #24), which was mentioned above, and part's orientation for assembly (#2). The latter may indicate a subtle trade-off between manufacturability (i.e., easiness to assemble by robots) and marketability of a product design.

3. Summary and Future Agenda

This paper explored the issue of assembly automation at the Japanese automobile industry in terms of motivations and obstacles. The paper started with the fact that the automation ratio in final assembly line of the Japanese firms was relatively low compared with other production processes, and was lower on average than the Europeans. The first part of the paper discussed the issue based on anecdotal and historical evidences. It was argued that the issue of automation has to be analyzed from the total manufacturing system's point of view. Based on this framework, a hypothesis was proposed that the Japanese avoided over-automation of assembly in order to maintain competitiveness of the total system under the "lean on growth" mode, but that they decided to accelerate efforts to automate assembly as they shifted from "lean on growth" to "lean on balance" system.

The second part of the paper presented a preliminary result of the questionnaire survey conducted in 1991. The result generally indicated that at least some of the Japanese auto makers started to emphasize improvements of working conditions and job designs even more than cost reduction. Product variety and space constraints were cited as serious obstacles against automation. Overall, the data were generally consistent with the idea that the shift from the "lean on growth" to "lean on balance" is changing attitudes of the Japanese auto makers toward assembly automation.

The paper is still exploratory in nature, however. We have to elaborate our surveys thorough questionnaires, interviews and direct observations. The results on subjective judgment by the auto makers presented here have to be linked with data on what they are actually doing. The author, as well as the colleagues in the Japanese study group, is collecting and analyzing data on the Japanese auto makers on this direction.

We also have to introduce international perspectives. The recent experiences of the Japanese auto makers may be somewhat unique in that assembly automation was first implemented in the existing lean production system with multi-skilled workers and efficient space utilization, and that recent thrust for automation is motivated in the context of the "lean on balance" system. This may be a different pattern from the case of Europe and North America, where assembly automation was implemented in the context of traditional mass-production system with single-skilled work force, together with intense competitive pressures from Japan and/or labor situations that are different from Japan. Jurgens et al. (1986), for example, report that German auto makers increased the degree of automation in its assembly lines (e.g., Hall 54 of VW) as their work organization started to depart from the traditional mass-production system to a new one emphasizing group work and job enrichment, which the labor union and works councils have demanded. A comparison between the recent German and Japanese experiences may be an interesting topic to both sides.

Notwithstanding the international difference in the patterns of automation, there is also some signs of convergence in that the Westerns firms are learning from the lean production system, whereas the Japanese started to learn from the West as they started to move toward the post-lean system. International comparison of the patterns of assembly automation would become very important in this situation. Thus, one of the future agenda in this field would be to conduct international studies that facilitate mutual learning and understanding between the European, American and Japanese researchers and practitioners. An ideal form for studying this kind of multi-national phenomenon may be a multi-national team of researchers conducting international joint projects.

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Figure 1 Objectives for Assembly Automation

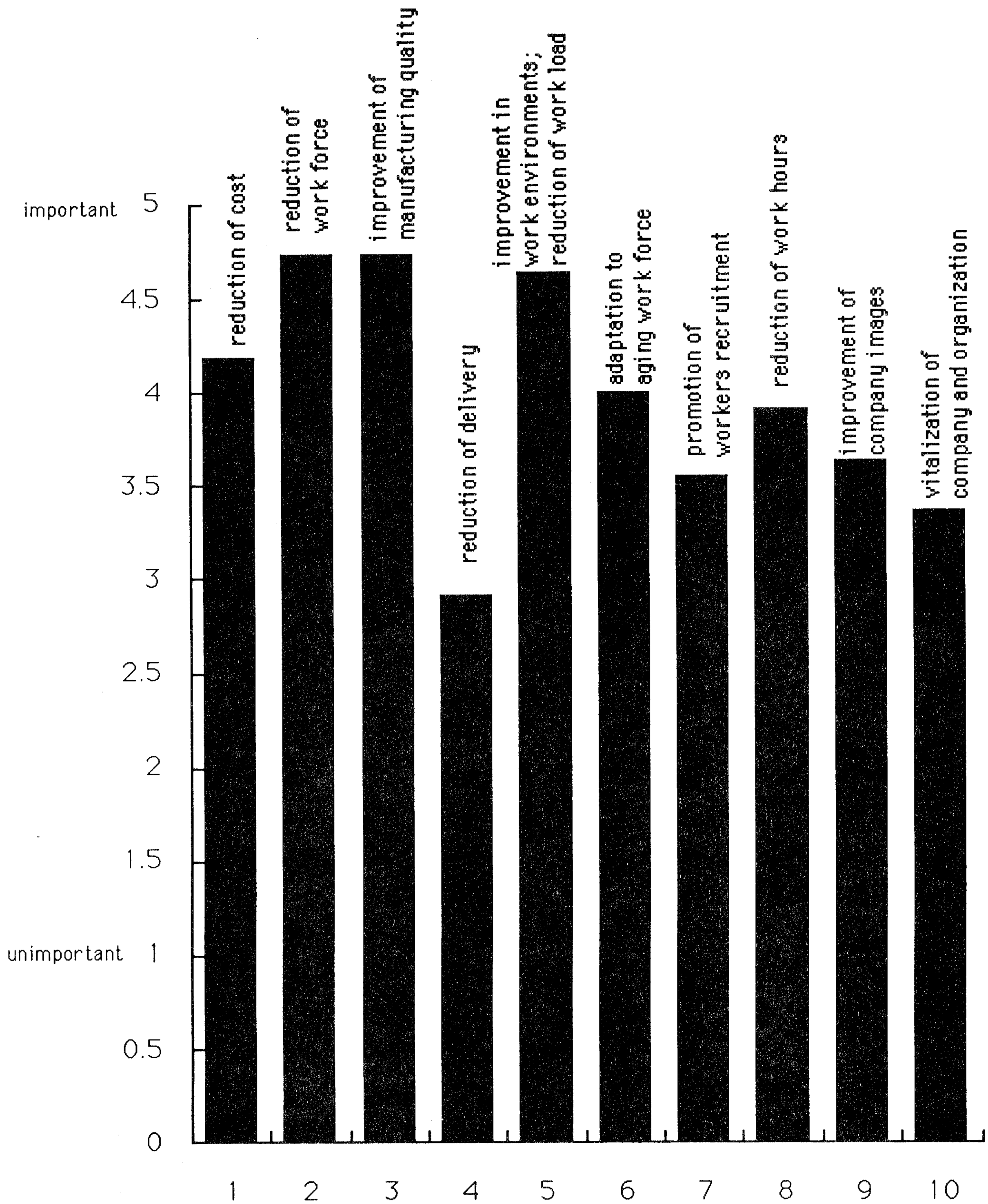
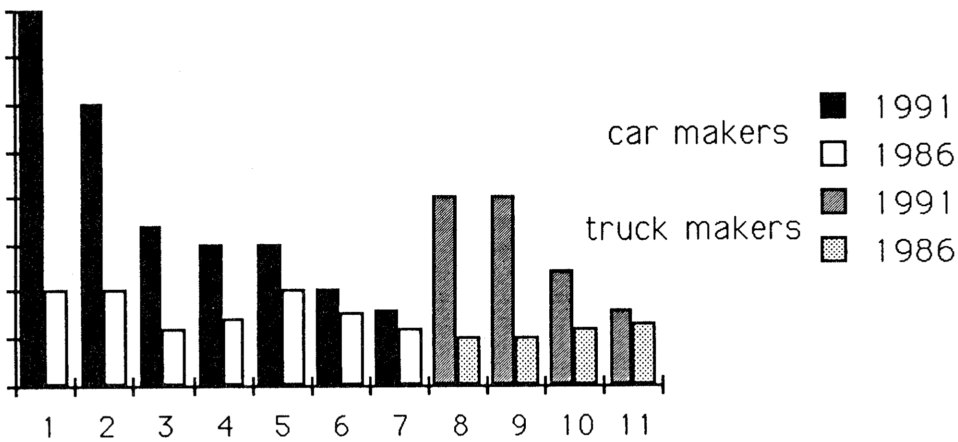


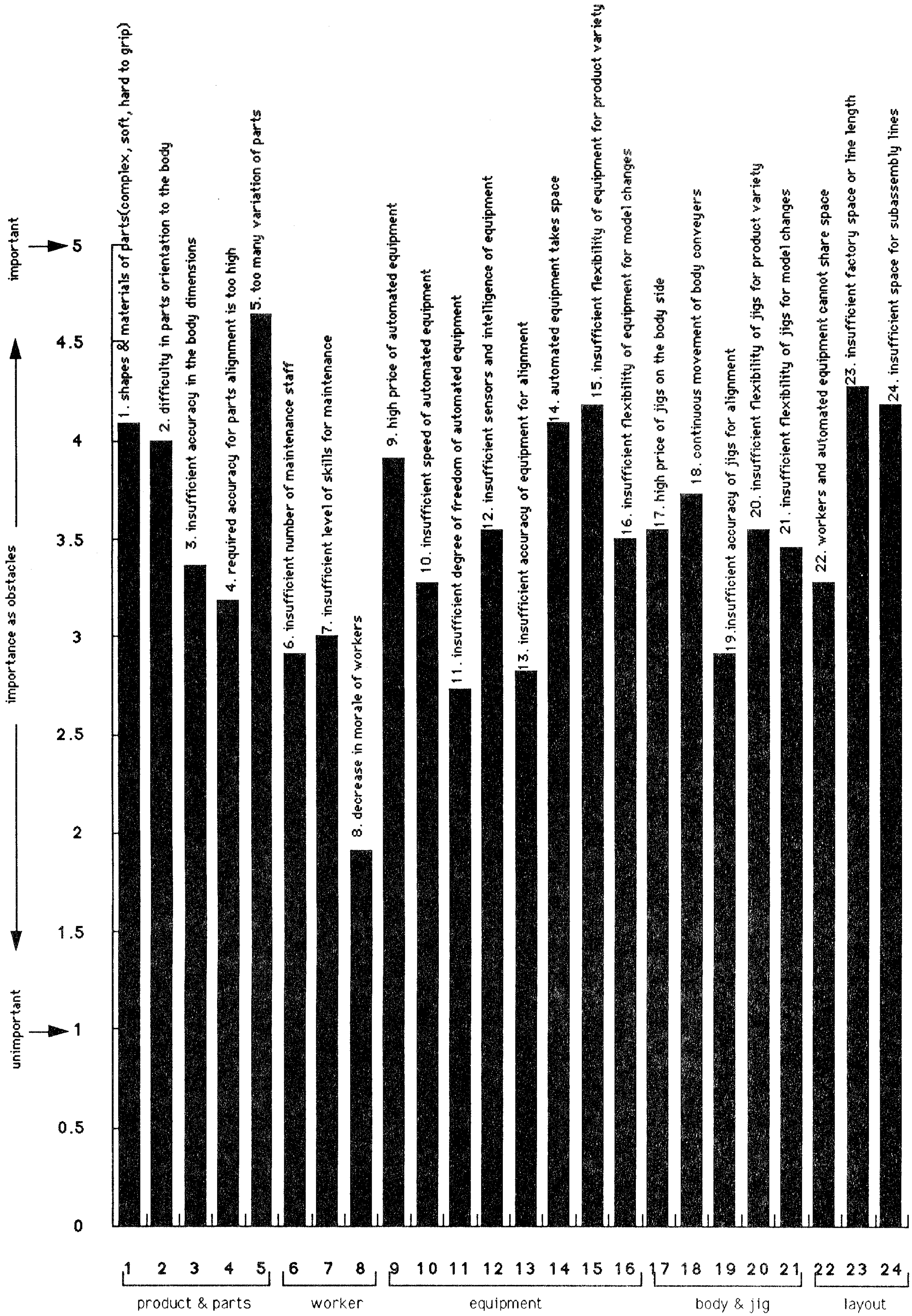
Fig.2 Upper Limit of Automation Investment



NOTE: average of allmekers

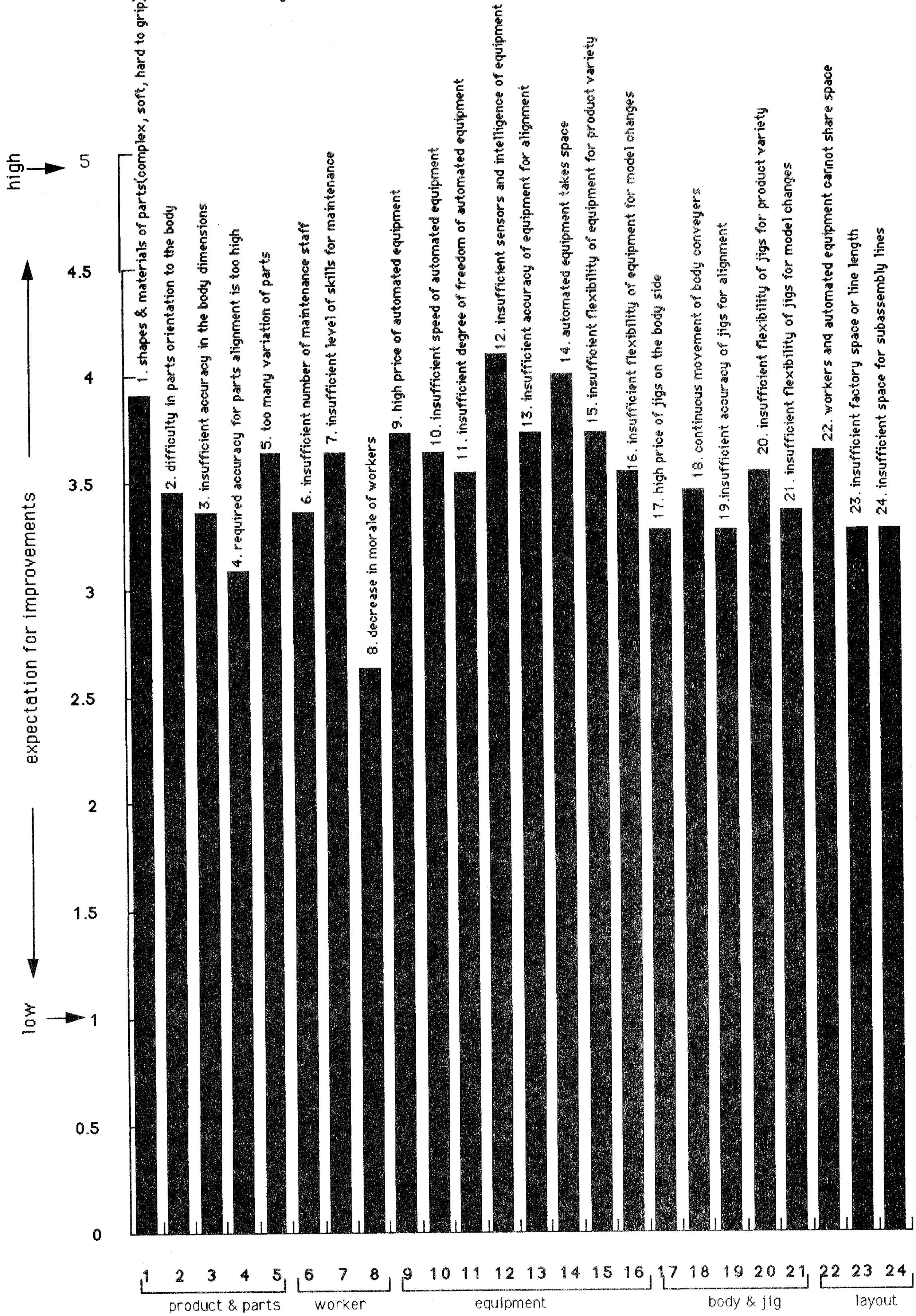
1991 17.72 million yen

1986 7.17 million yen



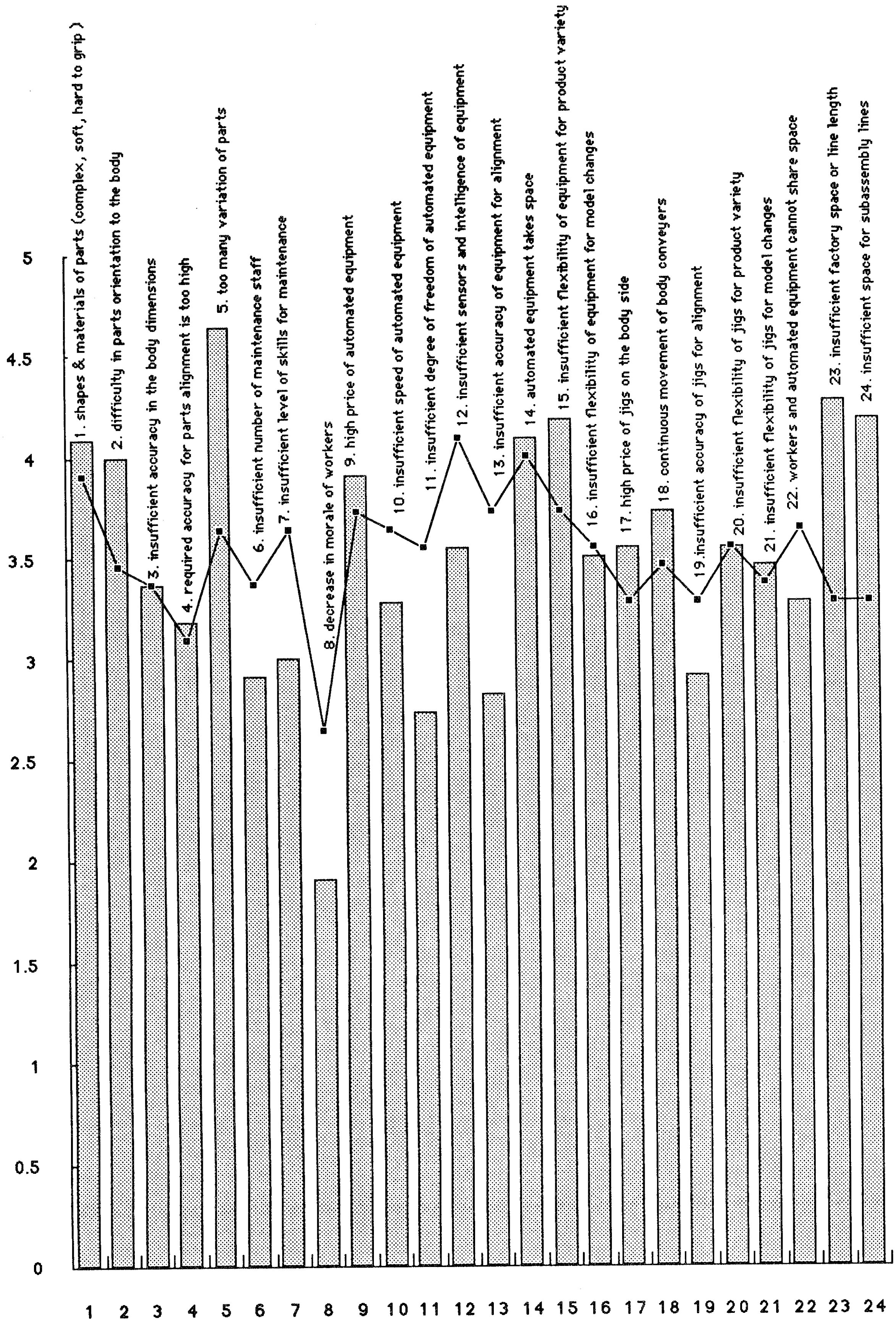
Note; Average of 11 Japanese Auto companies

Figure 4 Expectation for Improvements in the Next Five Years



Note; Average of 11 Japanese Auto companies.

Figure 5 Comparison of Obstacles (Bar Chart) and Expected Improvements (Line Chart)



Note ; Average of 11 Japanese Auto companies.

Appendix 1 Distribution of the Responses (fig 1: Objectives)

		important ←				→ unimportant
		5	4	3	2	1
1	reduction of cost	6	1	4	0	0
2	reduction of work force	8	3	0	0	0
3	improvement of manufacturing quality	9	1	1	0	0
4	reduction of delivery	1	2	5	1	2
5	improvement in work environments; reduction of work load	9	0	2	0	0
6	promotion of worker recruitment	3	6	1	1	0
7	adaptation to aging work force	3	1	6	1	0
8	reduction of work hours	3	5	2	1	0
9	improvement of company images	1	5	5	0	0
10	vitalization of company and organization	1	3	6	1	0

Appendix 2 . Distribution of Responses (fig.3: Obstacles)

		important ◄				► unimportant
		5	4	3	2	1
1	shapes & materials of parts (complex, soft, hard to grip)	4	4	3	0	0
2	difficulty in parts orientation to the body	3	6	1	1	0
3	insufficient accuracy in the body dimensions	2	2	5	2	0
4	required accuracy for parts alignment is too high	3	1	3	3	1
5	too many variations of parts	8	2	1	0	0
6	insufficient number of maintenance staff	1	1	6	2	1
7	insufficient level of skills for maintenance	0	3	6	1	1
8	decrease in morale of workers	0	0	4	2	5
9	high price of automated equipment	3	5	2	1	0
10	insufficient speed of automated equipment	1	4	3	3	0
11	insufficient degree of freedom of automated equipment	1	2	3	3	2
12	insufficient sensors and intelligence of equipment	2	3	5	1	0
13	insufficient accuracy of equipment for alignment	1	1	4	5	0
14	automated equipment takes space	4	4	3	0	0
15	insufficient flexibility of equipment for product variety	5	3	3	0	0
16	insufficient flexibility of equipment for model changes	4	1	2	2	1
17	high price of jigs on the body side	3	3	2	3	0
18	continuous movement of body conveyers	5	1	3	1	1
19	insufficient accuracy of jigs for alignment	2	1	4	2	2
20	insufficient flexibility of jigs for product variety	3	2	5	0	1
21	insufficient flexibility of jigs for model changes	3	3	2	2	1
22	workers and automated equipment cannot share space	3	2	3	1	2
23	insufficient factory space or line length	5	4	2	0	0
24	insufficient space for subassembly lines	3	7	1	0	0

Appendix 3. Distribution of Responses (fig 4: Expectations for Improvement)

		high ←		→		low
		5	4	3	2	1
1	shapes & materials of parts (complex, soft, hard to grip)	1	8	2	0	0
2	difficulty in parts orientation to the body	2	4	3	1	1
3	insufficient accuracy in the body dimensions	1	4	4	2	0
4	required accuracy for parts alignment is too high	2	2	3	3	1
5	too many variations of parts	3	3	3	1	1
6	insufficient number of maintenance staff	1	3	6	0	1
7	insufficient level of skills for maintenance	1	4	6	0	0
8	decrease in morale of workers	0	2	4	3	2
9	high price of automated equipment	3	4	2	2	0
10	insufficient speed of automated equipment	2	5	2	2	0
11	insufficient degree of freedom of automated equipment	2	4	3	2	0
12	insufficient sensors and intelligence of equipment	3	7	0	1	0
13	insufficient accuracy of equipment for alignment	3	3	4	1	0
14	automated equipment takes space	3	5	3	0	0
15	insufficient flexibility of equipment for product variety	2	4	5	0	0
16	insufficient flexibility of equipment for model changes	1	5	4	1	0
17	high price of jigs on the body side	2	3	3	2	1
18	continuous movement of body conveyers	2	4	2	3	0
19	insufficient accuracy of jigs for alignment	1	3	5	2	0
20	insufficient flexibility of jigs for product variety	3	3	2	3	0
21	insufficient flexibility of jigs for model changes	2	3	3	3	0
22	workers and automated equipment cannot share space	4	2	4	0	1
23	insufficient factory space or line length	3	2	3	1	2
24	insufficient space for subassembly lines	2	4	2	1	2