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Strategies for Assembly Automation in the Automobile Industry

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ABSTRACT

The present paper describes and compares four typical strategies for assembly automation: *high-tech, low-cost, human-fitting,* and *human-motivating* strategies. It first argues that assembly automation strategies have to be analyzed and evaluated in the context of dynamic transition of total production systems in the world auto industry, which involves Fordistic mass production, lean production, Volvoism, neo-craftism, and so on. The paper then examines each of the automation strategies in more detail in terms of backgrounds, basic characteristics and performance. It is shown that the traditional Western mass producers tended to adopt the high-tech automation strategy, whereas the main Japanese makers (i.e., the "lean" producers) tended to pursue the low-cost strategy during the 1970s and 80s. Empirical data, which indicate that the Japanese makers shifted their emphasis from the low-cost to the human-fitting strategy, will be also presented. The connection between human-motivating automation, Volvoism and job-enrichment will be then discussed. Finally, the paper predicts that the main trend in the future of the assembly automation will be that of *convergence* at the basic level, *hybridization* through mutual learning across firms and regions, and *diversity* of the automation systems worldwide which includes many experimental assembly processes, which is typical at the transition period in the evolution of the world auto industry.

1. Introduction

The purpose of the present paper is to identify and analyze some of the alternative strategies for assembly automation from both historical and total system point of view. In order for the automobile manufacturers to form and implement assembly automation systems for the future, such strategies may serve as useful guidelines. The types of strategies that the present paper explores are, in a sense, ideal types, in that the pure form of each strategy may be hard to find in actual auto makers: In practice, they normally adopt hybrid or mixed strategies. It would be nevertheless useful to clarify the direction and shifts in emphasis in terms of basic objectives, philosophies and policies for constructing future assembly systems. This paper will describe and analyze four types of assembly automation strategy.

Total System Perspective

It is the author's belief that the future assembly automation system has to be discussed in the context of transformation of the automobile production system as a whole. In this sense, the 1980s - 90s has been a period of transition, in which the traditional Ford (i.e. American mass-production) system faced a competitive challenge from so called "lean" (i.e. Toyota-style) production system (Womack, et al., 1990). As the limit of the conventional Ford production system became obvious, various alternative production systems were proposed and experimented.

(1) Introduction of advanced automation technologies and computer networks into more or less traditional mass production paradigm was one direction that companies such as GM, VW and FIAT pursued in the 1970s and 80s. This approach, however, has so far failed to demonstrate significant international competitiveness in productivity and flexibility in the assembly area.

(2) Another proposals for an alternative to the conventional Ford system was the one known as "Volvoism," which attempted to make the assembly work more attractive by essentially abolishing moving assembly lines and returning to a modern version of stationary production. The Volvo system, while being reasonably successful in attracting and satisfying the workers, has not demonstrated its competitiveness in terms of productivity. Its main experiment sites, Volvo's Kalmar and Uddevalla plants, were both shut down in the early 1990s, although this may not mean the failure of the Volvoism itself (Berggren, 1993). Some elements of this system are still tested in

various factories (e.g. Mercedes' Rastat Plant), it is obvious that the major challenge for the Volvo system is how to improve its cost competitiveness.

(3) Neo-craft production system has also been tested at some of the mass-producing auto makers (e.g. Honda's NSX assembly plant). Although such experiments were praised as "craft renaissance" or antithesis against work alienation in modern assembly lines, its productivity was less than one-tenth of the "lean" production line. Thus, application of neo-craft system has been limited to extremely luxury models and custom cars.

(4) So called "lean" production system (i.e., the Toyota-style system) attracted much attention of the Western auto makers during the 1980s and early 90s because of its competitiveness in productivity, manufacturing quality and flexibility (Abernathy et al., 1983, Womack et al., 1990). Although the lean system can be regarded as a derivative of Fordism in many senses, it also had unique features in managing human resources, supplier networks, material flows, inventories, as well as productivity and quality. In fact, many of American and European auto makers have introduced a part of the system to catch up with better Japanese firms during the 1980s. However, the labor shortage and recession in Japan during the early 1990s revealed some weaknesses of the existing lean production system in attracting domestic work force and handling fluctuation of total production volume (Fujimoto, 1993a, 1993b). It is now obvious that the existing version of the lean system (i.e. lean-on-growth system) needs reforms in the long run. Direct assembly line work has been a particularly problematic area, as it has essentially been an extension of Ford-type moving assembly line and thus carried over the problem of lack of attractiveness that the latter had for years, despite the fact that the lean system added mechanisms for flexibility, self maintenance, self inspection and continuous improvements to it.

Thus, none of the existing alternatives to traditional mass production system have demonstrated clear long-term advantage over the others. However, as of the early 1990s, there is no sign that another totally new approach to automobile production suddenly emerges as a dominant production paradigm. Rather, many of today's auto companies in the world seem to be seeking for better solutions by fusing elements of existing alternatives (Jurgens, 1992). Thus, in the foreseeable future, the auto companies are likely to rely on "improved hybrid" production systems rather than entirely new production concepts. In other words, we will see various hybridization experiments by the auto makers of the world toward the twenty-first century.

In any case, it is my opinion that discussions on the future form of assembly automation needs to take the future of the automobile production system as a whole into account, as the former is one of the core subsystems of the latter.

Historical Evolution Perspective

Another assumption in the current paper is that history matters. In other words, the choice of the future assembly automation system for each company needs to take into account its evolutionary path of organizational learning and dynamic capability building (Teece, et al, 1993). Facing challenges from its environments (e.g. product markets, labor markets, competitors, etc.), it tries to acquire new capabilities, add them to existing managerial resources, and create a new set of core capabilities. Although some elements of old system may be abandoned or modified as new capabilities are acquired, other elements would remain in the new blend, making the capability building process cumulative. Whether the old and new elements collide or fuse with each other may affect subsequent performance of the total system (Fujimoto and Tidd, 1993).

This evolutionary view does not imply that there is only one deterministic trajectory or sequence of capability building. The evolutionary paths may be region-specific or even firm-specific. At the same time, it is the author's prediction that the overall trend of future assembly automation would be that of *convergence* and *mutual learning* across regions and firms at a basic level of the assembly automation strategies. In other words, the author believes that the future assembly automation systems would emerge as a result of *hybridization* of different automation strategies, rather than competition for survival among the pure strategies. Also, the very convergence may create *diversity* of the future assembly automation systems, as each company has to build a hybrid system based on each company's unique capability base.

With the total system and historical evolution perspectives in mind, the present paper will first explore some alternative approaches to assembly automation. Some details of each model will be then discussed with some empirical evidences. Finally, a scheme for analyzing and evaluating future assembly automation will be proposed.

2. Types of Assembly Automation Strategy

Let us now explore some types of strategies for assembly automation in the automobile industry. By assembly automation strategy we mean a coherent set of decisions on building and utilizing capabilities of assembly automation in order to improve manufacturing performance. It is a subsystem of overall manufacturing strategy that is associated with performance and capability of the total production system (e.g., Hayes and Wheelwright, 1984).

Figure 1 presents four major types of assembly automation strategies that the author have identified based on historical and comparative analyses of the assembly process of the auto makers. The classification is based on differences in the focus of performance that the automation systems are expected to improve[1].

The first criterion for the classification is what to improve. That is, the automation strategies may be classified according to whether it is targeted to product market performance or labor market performance. Product market performance, or competitiveness, measures how the products of the firm attract potential customers and satisfy existing customers. Labor market performance, on the other hand, means job attractiveness to potential employees and job satisfaction to existing workers. Although actual companies needs to satisfy both stake-holders at the same time in the long run, they may focus on performance improvements to a particular stake-holder group at a given time.

The second criterion of classification is how to achieve improvements in a given performance. One approach is an *element-focused* one, which assumes that superior performance of each element of the automation system, such as each individual automation equipment or work station, should add up to enhancement in total system performance. The other approach is a *system-focused* one, which argues that total system performance is more than a simple sum of element performance, and that basic design or conceptualization on the total system should precede element designs (Iansiti, 1993).

Based on the two-dimensional scheme, we can classify the basic strategies for assembly automation into four categories:

(1) High-tech Automation Strategy: This approach focuses on technological improvements of individual automation equipment, which is assumed to contribute eventually to such factors of product market performance as cost and quality competitiveness.

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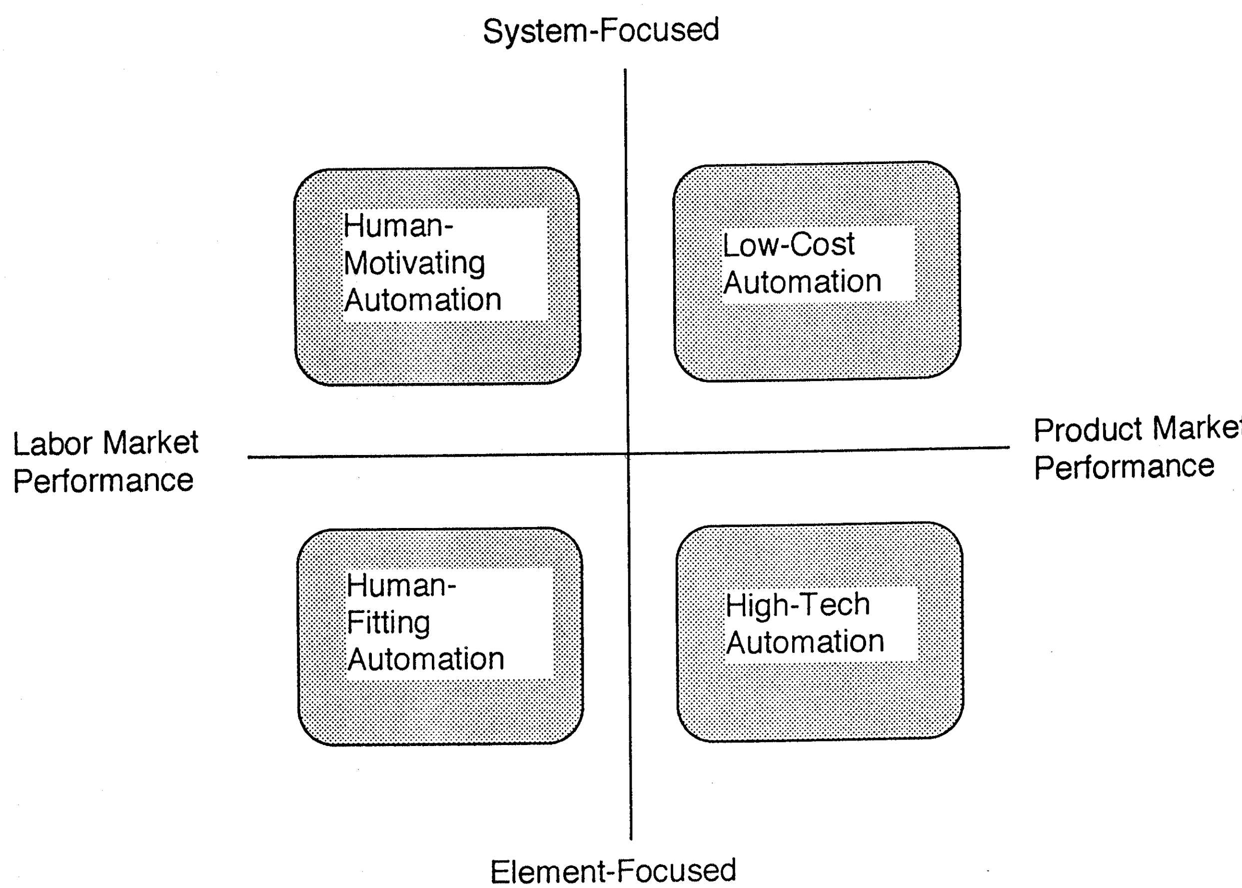
[1] Note that the four strategies are not logically exclusive against each other. That is, an actual company can adopt a mix of multiple strategies.

Figure 1 Four Types of Assembly Automation Strategies



(2) Low-cost Automation Strategy: This strategy directly targets total system performance. It aims at improvement in productivity, quality, delivery and flexibility with simple automation equipment in order to save total investment cost. If an introduction of advancement of automation is expected to cause decrease in total system performance, such automation will be deliberately avoided under this strategy.

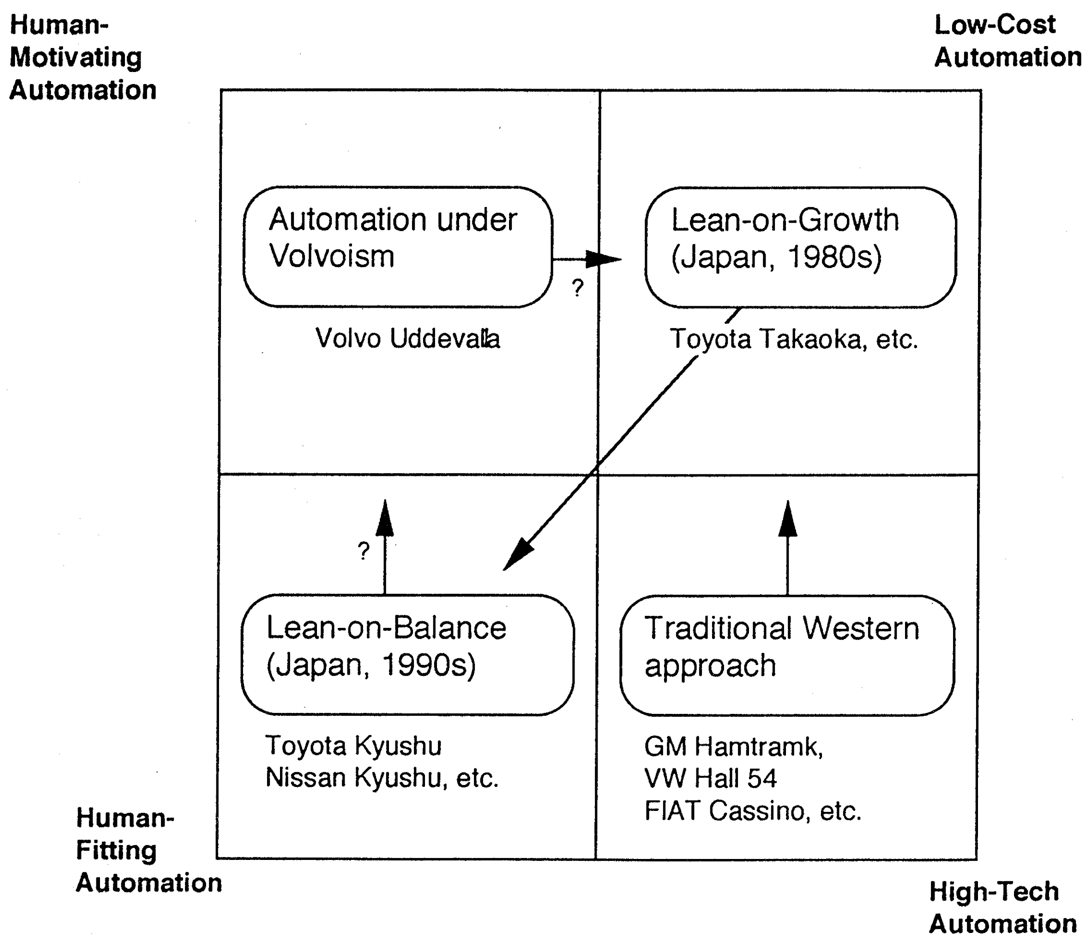
(3) Human-Fitting Automation Strategy: This strategy focuses on enhancement of attractiveness at each work station by replacing so called 3-D (dangerous, dirty and demanding) tasks with automated or semi-automated equipment. In other words, it tries to improve job satisfaction by eliminating dissatisfaction of individual workers at the physical or physiological level.

(4) Human-Motivating Automation Strategy: The last approach is oriented to total system designs for employee satisfaction and job attractiveness. It pays particular attention to the problem of job alienation inherent in the traditional Ford-style moving assembly lines, and tries to modify or replace overall production systems and work organizations. Or, alternatively, it may start with a highly automated assembly lines and try to blend repetitive task (i.e. residual work) and non-repetitive task (i.e. maintenance and engineering) into one job in order to alleviate stress and boredom of the former tasks.

The above automation strategies are not exclusive against each other. Besides, it should be noted that these strategic types are ideal types: Each of the actual firms is likely to adopt a mix of multiple strategies. However, the firms may focus, in relative terms, on a particular strategy at a given time, and the focus may shift over time as competitive pressures, labor situations and company performance changes.

The patterns of the strategic focus may also differ across firms or regional groups (figure 2). The choice of assembly automation strategies would be more or less linked to the transformation of the total production system concepts discussed earlier in this paper. For example, many of the Western mass-producers, such as GM, VW and FIAT appears to have pursued the "high-tech automation" strategy during the 1970s and 80s, but the strategy has been challenged by the "lean" production system in terms of its overall competitiveness. On the other hand, the prevalent strategy among the major

Figure 2 Typical Examples of Assembly Automation Strategy



Japanese auto firms, such as Toyota, has been the "low cost strategy," which seems to be an important component of Toyota-style production systems. The strategy contributed to competitive advantages of the Japanese firms during the 1970s and 1980s, but the companies shifted their emphasis to the "human-fitting" automation strategy as the existing strategy faced a problem of domestic labor shortage in the late 1980s to early 1990s. On the other hand, some European companies pursuing the Volvoism production concept have apparently attempted to introduce "human-motivating" automation (e.g. automation of material handling at Volvo Uddevalla plant), but have so far failed to demonstrate reasonably high performance in the market place.

Thus, although the auto companies in different regions tended to follow different paths, none of the above strategies for assembly automation, as a pure form, seems to be dominant in the global market at this point. In the author's opinion, again, the recent trend in this regard seems to be that of convergence and hybridization of the automation strategies, rather than competition for survival among different approaches. Before examining this trend, though, the subsequent sections will first look at each of the strategies in more detail.

3. High-tech Automation Strategy

Characteristics and Background

High-tech automation strategy has been a prevalent approach in many of the Western auto makers, and has also influenced some of the Japanese auto makers. The main (internally consistent) elements of the high-tech automation strategy seems to be as follows[2].

(1) Contribution to advancement of automation technology. Motivation to production engineers.

(2) Technological optimism, or "automation for the sake of automation" mind set.

(3) Tendency to rely on expensive equipment that may have excessive functions from total system point of view.

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[2] Note that, in this context, the descriptions of this strategy may be biased toward the negative side.

(4) Tendency to de-emphasize robust equipment design that take into account future improvements.

(5) Tendency to buy equipment from outside specialist suppliers rather than making it in-house.

(6) Top-down equipment design and improvements by specialist production engineers.

(7) Emphasis on technological "great leap forward" by introducing big automation systems.

While the intended goal of the "high-tech" strategy is to enhance product competitiveness in the market place through advanced technologies, the backbone philosophy behind this strategy seems to be a technological optimism or progressivism, or the notion that advancement of automation technology will almost automatically result in improvements in overall competitiveness of the production systems. Thus, although the firms pursuing this strategy certainly contributed to advancement of automation technology itself, they tended to end up in pursuing "automation for the sake of automation" regardless of its overall competitive performance. Also, they tended to introduce individual high-tech equipment to the assembly lines without changing the basic concept and design of conventional mass production processes.

Also, the internal logic of technological advancement is emphasized. Such technology-oriented notions as "the higher the automation ratio, the better," "the more intelligent the robots, the better," or "the closer to unmanned operations, the better" tend to be taken for granted regardless of their competitive consequences. Therefore, this strategy tend to overshoot to an extent that excessive automation is pursued beyond the optimal level in terms of overall productivity or quality performance.

There seem to be at least a few philosophical reasons why the high-tech automation strategy has become prevalent in the Western auto makers. First, the Western mass production factories have tended to pursue a higher degree of functional-horizontal specialization than the Japanese counterparts, which might have created a certain divisional parochialism: The production engineering group might have pursued its divisional goals for technological advancement even in favor of company-wide goals for competitiveness. Second, vertical specialization between engineers (i.e. system builders-improvers) and workers (i.e. system operators) was more prevalent in the Western auto makers, which tended to nurture the former's preference to technological "big jumps" by "big systems" rather than company-wide efforts for continuous improvements of equipment. Third, lack of trust between workers and managers in some of the conventional Western factories might have fostered the notion that workers are inherent sources of defects and line stops and thus have to be eliminated altogether by way of automation as much as possible. Conversely, the post-war Japanese auto makers, de-emphasizing horizontal and vertical specialization while trusting the potential of workers as human resources, had philosophical reasons why they did not pursue high-tech automation approach too an extreme.

Performance

As far as assembly operations are concerned, competitive performance of the factories pursuing "high-tech automation" has not been impressive. According to the report of IMVP (International Motor Vehicle Program), for example, European auto makers, some of which seems to have adopted the high-tech approach (e.g. VW's Hall 54 and FIAT's Cassino plant), showed somewhat higher ratio of final assembly automation on average than the Japanese, but their average assembly productivity was much lower than that of the Japanese counterparts (Womack et al., 1990).

In the USA, GM invested about 40 billion dollars during the first half of the 1980s to construct a new generation of high-tech assembly plants, which culminated at its Hamtramk plant, which started up in the mid 1980s. Although Hamtramk plant contained an ambitious level of factory automation, it suffered from a very high level of down time due to frequent machine stops and slow recovery from them. GM toned down its automation strategy in its assembly plants during the late 1980s (e.g. Wilmington and Linden plants), but the company is still said to be the lowest in assembly productivity among the big 3 as of the early 1990s. Ironically, some of the Ford assembly plants (e.g. Chicago and Atlanta plants producing Taurus), despite lower automation ratio, is sad to have demonstrated productivity levels nearly as high as better Japanese assembly plants.

Finally, let us take a brief look at the comparative study of Japanese and British assembly automation systems in the automobile and consumer electronics industries by Tidd (1989). According to his study, the sample British factories on average tended to use more expensive and sophisticated robots, but the Japanese demonstrated a higher level of flexibility of overall automation system (see, also, Jaikumar, 1984, 1986). As shown later, the Japanese firms tended to improve other factors of the manufacturing system such as product design (i.e., design for automation), jigs, and work design before introducing robots and other automated equipment (see, also, Whitney). Consequently, the Japanese system achieved a high level of flexibility with relatively simple and inexpensive robots. British factories, by contrast, tended to introduce relatively sophisticated robots without redesigning the overall production system. The British case seems to be a typical example of high-tech automation.

4. Low-Cost Automation Strategy

Characteristics and Background

Low cost automation has been an important subsystem of the "lean" production system in the 1970s and 80s. This strategy has had the following characteristics[3]:

(1) Focus on Overall Competitiveness: Automation is recognized as means to achieve improvement in competitiveness of the total production system. The problem of "automation for the sake of automation" in the high-tech approach is thus carefully avoided. This approach tries to achieve a given level of total system performance with the simplest, most reliable, and least expensive automation equipment.

(2) Total System Optimization: Automation is regarded as just one of the total manufacturing system that includes product design, jigs and fixtures, materials, work design, process flow design, and so on. These factors are simultaneously optimized from total system's point of view, as opposed to designing automation equipment alone without changing the other factors.

(3) Simple Automation: In order to save investment cost, automated equipment tends to be designed to have "just enough" functions (e.g., flexibility) for the target operations. If semi-automation or power-assist devices are estimated to be more cost-effective, advanced automation technology is deliberately avoided. Thus, as opposed to the notion that "the higher the automation ratio, the better," the concept of "optimal automation ratio" is widely accepted in the low cost strategy.

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[3] Contrary to the case of high-tech automation, the following description of he low cost strategy may be biased toward the positive side of the system, because the author emphasize the link between the low cost strategy and high competitive performance in the effective Japanese auto makers of the 1980s.

(4) Robust Design: Although the automated equipment may have just enough functions for the current operations, It also adopts robust design in that it is easy to modify or add functions for future changes or improvements.

(5) In-house Production of Automation: The low cost automation strategy tends to result in higher ratio of in-house design/fabrication of equipment. Standard equipment purchased from outside specialist vendors tends to have excessive functions for the target operations. The user company may estimate cost saving by eliminating excessive functions to be larger than economy of scale effect of the outside vendor. Equipment designed and made in-house may also be also easier to improve and maintain for the in-house engineers, supervisors, maintenance workers, as well as operators.

(6) Incrementalism: Rather than trying to introduce a big and advanced automation system at a time, the low cost strategy tends to emphasize incremental approaches of making islands of automation and gradually expanding or connecting them.

(7) Compatibility to Continuous Improvements: The low cost automation needs to be compatible with the core elements of Toyota-style production system, or the organizational problem solving mechanism. The equipment may deliberately designed to automatically reveal manufacturing problems, and allow human intervention in response to the contingency. The concept of "Jidoka" (semi-automated equipment that automatically detects defects and stops operations) is a typical example. The equipment is jointly maintained and improved by production engineers, plant engineers, supervisors, team leaders and operators, with the supervisors playing a pivotal role. Total Productive Maintenance (TPM) is also built into the system.

Although the above list is, again, a description of an ideal type, many of the actual automobile and auto parts makers seem to have adopted automation strategies that were more or less similar to the above model. The description of the Japanese makers reported by Tidd (1989), as well as the case of Nippondenso by Whitney (1992) seems to be generally consistent with the above model. Also, According to the author's survey, the Japanese auto makers in the mid 1980s had set a very conservative upper limit to automation investment: 5 to 10 million yen for automation equipment equivalent of one person per shift, depending upon the companies (Fujimoto, 1992). Other empirical researches on the automation at the Japanese auto makers during this period seems to be generally consistent with the above description of the strategy.

Performance

The low cost automation strategy that the Japanese auto makers adopted during the 1970s and 80s is believed to be one of the contributors to the competitive advantage that the main Japanese makers enjoyed during the same period. Although the Japanese automated welding operations more aggressively than the Western counterparts, they were rather conservative in automating final assembly operations, as the IMVP report indicated (Womack et al., 1990). Thus, ironically, the low cost automation strategy, applied to the final assembly area, meant keeping automation ratio low and avoiding excessive automation both quantitatively and qualitatively in order to maintain overall competitiveness. In other words, Japan's world class auto makers had apparently estimated optimal assembly automaton ratio to be nearly zero.

According to the author's survey, the Japanese auto makers pointed out that (i) many product variations, (ii) limit of space, (iii) shapes and materials of parts, (iv) existence of tasks inside the body, and price of the automated equipment were main constraints against automation in final assembly (Fujimoto, 1992a). It is also believed that, unlike certain consumer electronics goods, aggressive pursuit of "design for automation" tends to result in deterioration of design quality of the product. Thus, the companies focusing on overall competitive performance tended to be rather conservative in automating final assembly in the past.

Overall, empirical researchers have not found any correlation between automation ratio and overall competitiveness in the final assembly area. For example, Toyota's Takaoka plant, which industrial observers believe is one of the most productive assembly plant of the world during the 1980s, has had virtually no robot in the final assembly area. The NUMMI plant (Toyota-GM joint venture), which is believed to be one of the most productive in North America during the same period, had also adopted very low level of automation (Krafcik, 1988). By contrast, none of the highly automated assembly plants of the day, such as VW Hall 54, FIAT Cassino plant and GM Hamtramk plant, came close to the productivity levels of the above "low-tech" assembly plants.

5. Human-Fitting Automation

Characteristics and Background

Human-fitting automation strategy has attracted attention of the Japanese auto makers in the late 1980s to early 1990s, as labor shortage had become a serious limit to the continued growth of the Japanese auto makers. The strategy is characterized as follows:

(1) Worker-Oriented: Performance in the labor market (i.e., ability to attract and satisfy workers) gets higher priority than that in the product market as criteria for automation decisions. For example, if introduction of a robot assembly cell significantly improve attractiveness of the work place but increase unit product cost at the same time, a company adopting this strategy would still introduce this cell.

(2) Element-Focused: Individual work stations, rather than the entire assembly system, is the focus in improving attractiveness of the assembly operations. While the traditional Ford-style moving assembly lines remain basically unchanged, the firms following human-fitting automation strategy break down assembly tasks, evaluate them individually, and try to automate the most unattractive work stations.

(3) Physical Improvements: The definition of "attractiveness of the work place" is physical or physiological, rather than psychological or philosophical. That is, the human-fitting approach emphasizes elimination of 3-D (dangerous, dirty and demanding) tasks by automating them. Another bog issue of assembly work, or work alienation and boredom on the traditional assembly line, is generally outside the scope of this strategy. In other words, the human-fitting approach aims at motivating workers to join the assembly lines by satisfying them at the bottom levels of Maslow's hierarchy of needs (i.e. physiological and safety needs) (Maslow, 1954).

There are some reasons why human-fitting strategy of assembly automation became a focal point among the Japanese auto makers in the early 1990s. First, direct assembly work of Toyota-style (i.e., lean) production system has essentially been the same as that of traditional Ford moving assembly lines, although the former trained and deployed multi-job (multi-skilled) workers rather than Ford-type single-skilled workers. Typical tact times (1 to 2 minutes) are also the same between the two systems. Although there is a debate on whether Toyota-style system is more demanding to the workers than the Ford style mass production lines of the same production capacity, it would be hard to prove that Toyota's assembly lines are significantly less demanding physically than typical American or European assembly lines. It is true that the Toyota-style system has had various policies emphasizing potentials of workers as human resource, such as worker participation in continuous improvements, job enrichment and enlargement through multi-skilling program, and corporate welfare programs. However, such human-oriented policies mainly off the assembly line coexisted with highly stressful work on the line. In other words, direct assembly work had remained physically demanding as of the early 1990s.

Second, as labor shortage became a serious long-term problem to the Japanese auto makers in the early 1990s, lack of popularity of the automobile assembly lines was recognized as a serious constraints for domestic automobile production. Although subsequent recession temporarily alleviated the labor supply crunch, the problem still seems to exist in the long run (Fujimoto, 1993a, 1993b). Thus, the Japanese companies started to see assembly automation as a means to make the assembly work less demanding and more attractive, rather than a means to improve competitiveness.

Third, the period that the Japanese auto makers faced the labor shortage was also the time when perceived capital cost was very low under the bubble economy. As the companies believed that they would be able to use equity finance such as convertible bonds for building highly automated plants, they became less conservative in investing for automated equipment.

In short, the nature of assembly lines under Toyota-style system, emerging labor shortage, and low level of perceived capital cost all affected the Japanese auto makers shifting their strategic focus from "low cost" strategy to "human-fitting" strategy. In a sense, this shift was linked to the change from "lean-on-growth" to "lean-on-balance" system at the higher level.

However, it should be noted that the "human-fitting" approach, in its pure form, does not answer the question of how to solve the long-discussed problem of work alienation inherent in the Ford-Toyota-style moving assembly lines.

Empirical Evidences

A survey that a study group including the author conducted in 1991 seems to indicate some circumstantial evidences that are consistent with the Japanese shift of strategic emphasis from low cost to human-fitting automation[4].

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[4] The three empirical studies described here were all conducted in a study group called The Research Committee on Optimal Automation System in the Automobile Industry, chaired by Professor Koichi Shimokawa and sponsored by ten Japanese motor vehicle manufacturers. The author appreciates cooperation of the participating companies, administrative efforts of Seigo Onishi and Akimasa Kawata, as well as assistance in data analysis by Professor Hisanaga Amikura (Chiba University) and Takashi Matsuo (doctoral program, University of Tokyo).

(1) Upper Limit of Investment: A survey on the upper limit of investment on assembly automation equivalent of one worker (figure 3) shows that about half of the Japanese auto makers studied increased the ceiling significantly. Thus, at least some of the Japanese auto makers might have departed somewhat from the low cost strategy between 1986 and 1991 (see, also Fujimoto, 1992a) .

(2) Motivation for Automation: The same survey in 1991 also asked about relative importance of objectives for, or expectations from, automating final assembly lines toward the year 2000 (figure 4. See, also, Fujimoto, 1992a)[5]. Of the ten potential objectives investigated, "quality improvements" and "reduction of workers" received a highest score (4.7 point). What was more striking, though, was that the score for "improvement of work environments and reduction of workload" (4.6 point) was recognized as almost as important as the first two factors, and was significantly higher than "cost reduction" (4.2 point). This result seems to indicate that, although competitiveness (particularly that of quality) remained an important motivator of automation, improvement in physical conditions of the work place increased relative importance as a motivator, and that the companies had shifted their focus somewhat from the low cost automation strategy to the human-fitting strategy by the early 1990s.

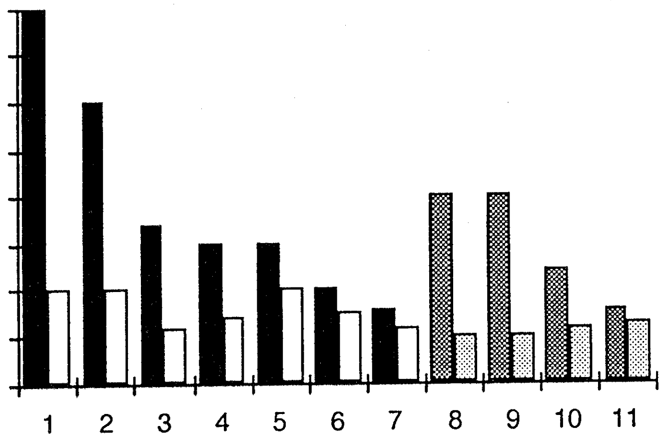
(3) Task Characteristics and Automation Installation: Another survey by the author's study group in 1992 indicated that actual patterns of robot installation on the relatively automated assembly lines in Japan was generally consistent with the above results on the motivation for automation.

First, the survey selected 35 major work stations in the final assembly process, and asked the respondents (production engineers representing ten Japanese auto makers) which work stations they have installed robots and automated equipment in the case of their most automated line. The responses were averaged for constructing "automation installation ratio." The results are summarized in figure 5 (For further details, see Fujimoto and Matsuo, 1993).

Second, the survey asked the respondents' subjective judgment on characteristics of each work station. For each of the 16 task characteristics such as "parts are heavy," "parts are complex in shape," "work environment is bad," "dangerous task," they were asked whether each description fitted each of the 35 work stations (1 or 0). Then, by averaging their responses by work stations and characteristics, "task characteristics indicator" was constructed (table 1).

[5]The respondents answered by selecting the degree of importance by 5 point scale (1 = unimportant; 5 = important) for ten potential objectives for assembly automation

Figure 3 Upper Limit of Automation Investment



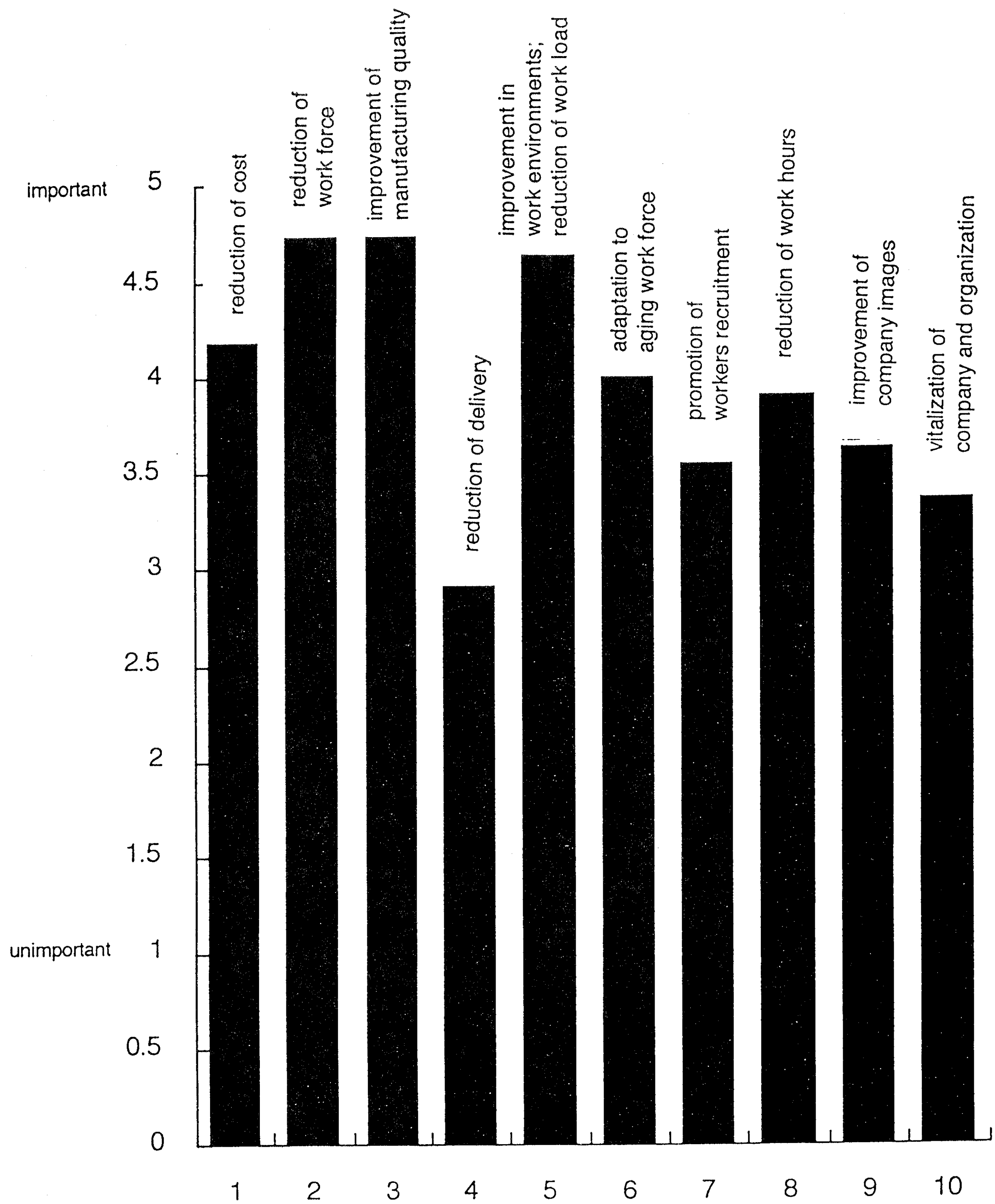
NOTE: average of all makers

1991	17.72	million yen
1986	7.17	million yen

car makers
- ■ 1991
- □ 1986

truck makers
- ▩ 1991
- ▨ 1986

Figure 4 Objectives for Assembly Automation



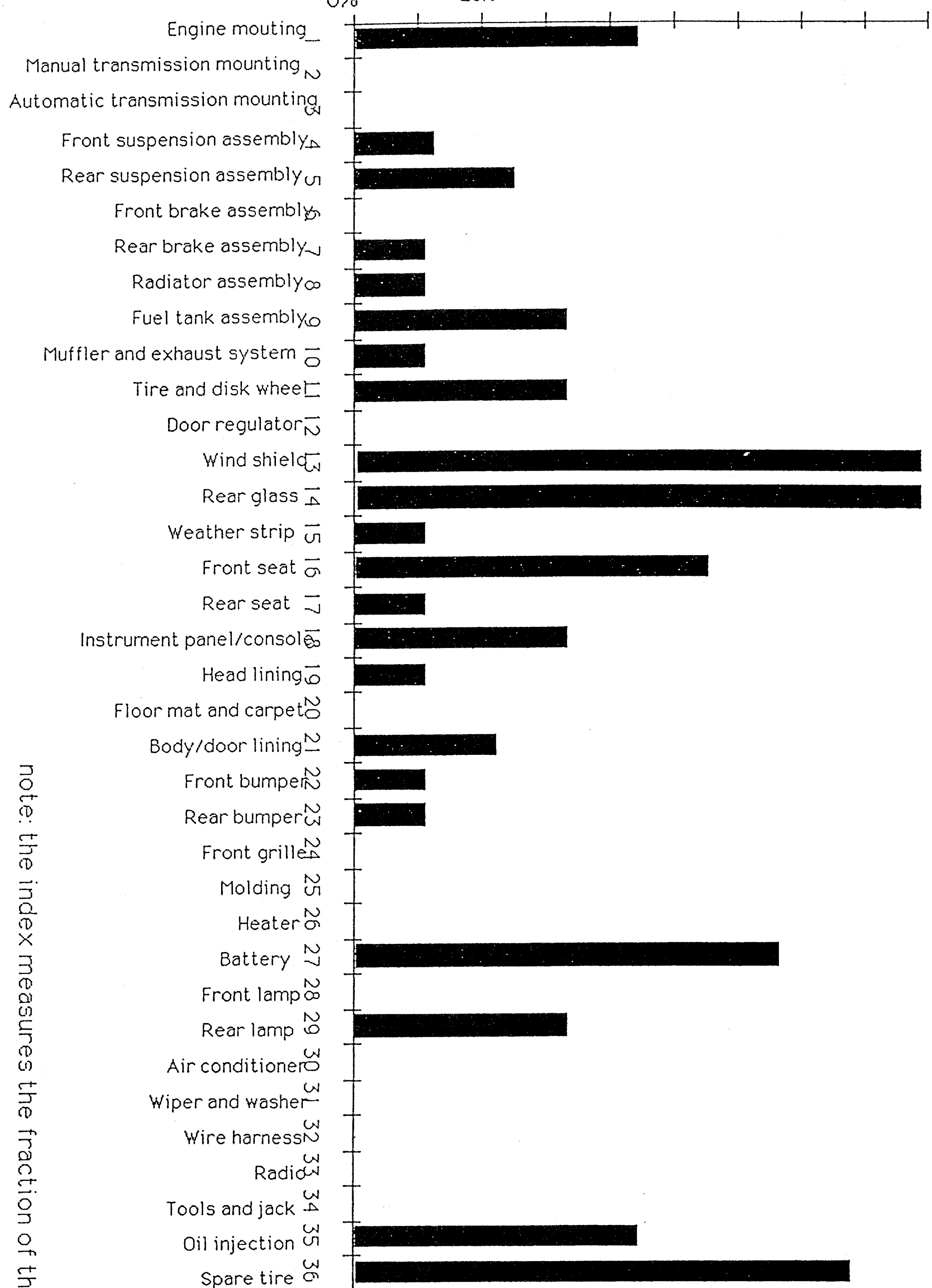


Figure 5 Robotization Index by Work Stations

note: the index measures the fraction of the companies

Table 1 Task Characteristics Indicators by Work Stations

	Engine mounting	Manual transmission mounting	Automatic transmission mounting	Front suspension assembly	Rear suspension assembly	Front brake assembly	Rear brake assembly	Radiator assembly	Fuel tank assembly	Muffler and exhaust system	Tire and disk wheel	Door regulator	Wind shield	Rear glass	Weather strip	Front seat	Rear seat	Instrument panel/consol
viness of ts	100	100	100	100	78	33	33	67	100	78	100	11	89	89	0	100	78	78
kiness of ts	67	50	50	63	56	56	67	56	67	100	56	0	67	67	33	67	78	67
nplexity of ts'shape	78	38	38	63	67	56	56	11	33	78	11	56	0	0	22	33	33	78
tness of ts	0	0	0	0	0	11	11	11	11	11	11	0	0	0	89	56	67	56
mber of -parts	67	0	0	25	33	22	11	11	22	11	11	0	0	0	0	33	22	67
riety of ts	56	25	13	38	33	67	67	44	56	44	67	0	44	44	0	56	56	78
embly ide the ia	33	0	0	13	11	11	11	44	11	11	0	67	0	0	13	67	78	67
gament ween body l parts	78	13	13	38	44	22	22	67	67	78	22	33	33	33	67	44	56	56
ficult tions	89	50	50	75	78	33	33	89	89	100	67	22	22	22	56	100	100	89
or work ironment	33	13	13	13	11	0	0	22	11	22	11	11	44	44	22	11	11	0
ngerous s	56	38	38	25	22	0	11	0	22	11	22	0	22	22	0	11	0	0
h skill uirements	78	38	38	25	33	22	22	22	44	44	33	78	44	44	44	11	11	56
quirements many rson-hour	22	13	13	38	33	11	22	0	22	11	0	22	0	0	33	0	0	33
tical parts vehicle ety	78	63	63	88	89	100	100	11	67	0	67	0	22	11	0	22	0	0
k of mis- embly in nual rations	0	0	0	0	0	11	11	0	0	0	11	0	11	11	0	0	0	0
k of low ality in nual eration	22	13	13	25	22	11	11	0	0	0	11	11	78	78	11	0	0	0
tomation dex	44	0	0	11	22	11	22	22	33	11	33	0	89	89	11	56	11	33

	Head lining	Floor mat and carpet	Body/door lining	Front bumper	Rear bumper	Front grille	Molding	Heater	Battery	Front lamp	Rear lamp	Air conditioner	Wiper and washer	Wire harness	Radio	Tools and jack	Oil injection	Spare tire
aviness of rts	14	56	0	89	89	0	0	44	100	0	0	44	0	22	0	0	0	100
lkiness of rts	100	100	56	100	100	14	38	67	11	11	13	44	0	56	0	0	0	56
mplexity of rts'shape	0	44	33	56	56	0	38	56	0	33	50	44	56	78	0	11	0	0
ftness of rts	89	100	78	44	44	14	63	0	0	11	13	0	44	89	0	0	0	11
mber of b-parts	0	0	33	22	22	0	0	22	0	0	0	33	22	22	0	0	0	0
riety of rts	33	67	78	56	44	29	13	33	56	56	38	22	11	44	63	0	25	22
sembly side the bin	100	89	33	0	0	0	0	89	33	11	13	89	33	78	63	56	13	22
gament tween body d parts	78	67	22	56	56	14	50	22	22	11	13	22	33	56	13	22	13	33
fficult otions	100	89	33	78	78	14	13	89	44	22	38	78	44	56	38	56	13	56
oor work vironment	11	33	0	0	0	0	0	0	11	0	0	0	0	11	0	0	63	11
angerous bs	0	0	0	0	0	0	0	11	22	0	0	0	0	0	0	0	0	11
igh skill quirements	22	11	33	22	22	0	63	22	0	0	0	33	0	22	13	0	0	0
equirements r many erson-hour	0	11	11	0	0	0	13	11	0	0	0	22	11	44	0	0	0	0
itical parts r vehicle fety	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	25	11
isk of mis- sembly in anual erations	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	0
isk of low ality in anual peration	0	0	0	0	0	0	25	0	0	0	0	0	0	13	0	0	13	0
utomation dex	11	0	22	11	11	0	0	11	67	0	33	0	0	0	0	0	44	78

Then, using the above indicators in multivariate regression analysis (N = 35), it was examined whether the pattern of actual automation installation by work stations could be explained by certain task characteristics. Because putting all the independent variables (i.e. task characteristic indicators) in the regression model creates multicollinearity problems, the author tried, as the first cut, to find some models that may indicate why automation installation ratios at some work stations were higher than those at the others[6]. Table 2 shows some models with reasonably good fit (standard errors in parenthesis).

As the table shows, the automation and robot installation ratio tended to be positively correlated with both competition-related indicators, particularly in quality (e.g. "defects occur if manual operation," "quality assurance is difficult if manual operation"), and job-related indicators (e.g. "parts are heavy," "dangerous job"). The automation ratio was also negatively correlated with the complexity of the parts' shape.

Thus, a preliminary analysis indicates that actual patterns of automation installation in the recent assembly lines in Japan (e.g., table 2) were generally consistent with their intention in the motivation study (e.g., figure 4). That is, concerns about quality and those about demanding nature of the assembly work were identified as two main motivators for assembly automation in both cases. The above three studies combined seem to indicate that the Japanese firms of the early 1990s shifted their focus to human-fitting approach at least partially, while quality has remained as the most important criterion for automation investment.

6. Human-Motivating Automation

Background: From Human-Fitting to Human-Motivating

As mentioned earlier, the concept of automation that is "friendly" to human being became a focal point at the Japanese automobile assembly plants of the late 1980s to the early 1990s. Assuming that the labor shortage is a problem that the Japanese auto makers have to handle in the long run, despite the current recession in 1992 and 1993, the future automation concepts that they pursue would have to continue to take job attractiveness and employee satisfaction into

[6] For future investigation a combination of factor analysis and multiple regression analysis may be applied here.

Table 2 Selected Regression Results

Dependent Variable: Automation Equipment Installation Ratio by Work Stations

variables \ regression models	model 1	model 2	model 3	model 4	model 5
constant	0.8	0.3	1.2	1.5	2.2
The Component is Heavy	3.5 (0.8)	2.9 (0.8)		2.6 (0.8)	
Dangerous Task			7.6 (2.7)		7.0 (2.5)
Frequent Misassembly in Manual Operations	27.6 (7.8)		26,5 (8.8)	6.0 (1.7)	22.8 (8.3)
Difficult to Assure Quality in Manual Operations		6.5 (1.9)			
The Component Consists of Many Piece Parts				5.3 (2.3)	6.2 (2.5)
The Shape of the Component is Complex				- 5.0 (1.5)	- 5.0 (1.7)
R^2	0.50	0.49	0.37	0.63	0.51
degree of freedom	33	33	33	31	31
F-value	16.4	16.1	9.6	13.3	8.1

account. The "human-fitting automation" of their new generation assembly plants was the first step along this line, although their initial experiments might have cost them too much, judging from the fixed cost burden of the new factories that the Japanese makers are suffering from in the recession of the early 1990s.

However, the "human-fitting" approach is not the only way in which automation makes work places more attractive. The "human-motivating" automation, which assists alternative assembly systems to Ford-Toyota-style assembly lines, may also deserve serious consideration.

In this regard, the existing approach of the Japanese makers tended to focus only on physical or physiological aspects of the existing Ford-style assembly lines, or alleviating so called "3Ds" problems (dangerous, dirty and demanding jobs). Consequently, the existing human-fitting approach tended to be element-focused, in that it tried to automate 3D tasks at each individual work station while keeping the Ford-style moving assembly lines basically unchanged[7].

In retrospect, the traditional "lean" production system was, in a sense, human-oriented outside the direct assembly jobs as it promoted worker participation in continuous improvements through suggestion systems and small group activities, job enlargement through multi-skilling training, the stable employment policy, relatively egalitarian wage systems, as well as other company welfare policies, but its direct assembly jobs was based essentially on the concept of Fordistic moving assembly lines. In fact, critics of Toyota-style factories often concentrated on high-stress nature of their assembly lines (e.g., Kamata, 1973).

Characteristics of Human-Motivating Automation

Against this background, some companies have started to seek for alternative modes to the Ford-Toyota style assembly line concept. As mentioned earlier, Volvo and some other European makers have already started experiments along this line (e.g., Kalmar and Uddevalla), but so far they have not proven sufficient competitiveness vis-a-vis the "lean" assembly lines. The main idea of "human-motivating" approach is to use automation for alleviating the work alienation and psychological stress inherent to moving assembly lines, while

[7] Robotized work stations often stop the bodies and make the body transfer intermittent by disconnecting them from the moving conveyers in order to maintain accuracy of body alignment, but such automated stations tend to be "islands" in the middle of traditional moving assembly lines.

maintaining competitiveness in the international market. Rather than tackling the problem of physiological stress at each work station, the approach tries to improve psychological, social or philosophical aspects of assembly work by focusing first on the assembly system as a whole (i.e., system-focused). In other words, human-motivating automation attempts to make the work place more attractive by motivating people at the higher level of "Maslow's hierarchy": socialization, self-esteem, and self actualization (Maslow, 1954).

As the idea of using automation for new forms of assembly systems is relatively new, we have not identified full characteristics of this approach. The basic guideline may include the following, though:

(1) System-Focused: While the human-fitting approach tries to make each individual work station more human-friendly through automated equipment, this approach focuses first on the overall system level and tries to identify an alternative assembly work design that can attract and satisfy workers better than the existing systems.

(2) Motivation at Higher Levels: While the human-fitting automation tries to make the work place more attractive by eliminating physical work conditions that may create workers' dissatisfaction, the human-motivating approach emphasizes certain assembly automation methods that help the work organization motivate workers by overcoming work alienation, boredom of repetitive tasks, and psychological stress inherent in the traditional assembly line work.

(3) Automation as By-Player: Workers are still expected to be the main players of the alternative assembly system in the long run. Thus, this approach does not regard unmanned assembly operations as the ultimate goal of assembly automation.

Two Paths of Human-Motivating Strategy

There seems to be at least two paths in which automation is applied to the problem of work alienation and boredom in the repetitive assembly work. The first approach is closely related to Volvoism or neo-craftism discussed earlier: using advanced automation technology to non-Ford style assembly work systems to make their productivity reasonably high compared with that of Fordistic ("lean" style, in particular) assembly lines. The second approach is, while starting from a highly automated assembly line, to change training programs, modify work designs through job enrichment, and blend repetitive and non-repetitive tasks into one job for each worker, in the hope that the problem of the repetitive work may be alleviated by the nature and pace of the non-repetitive, non-routine tasks.

Automation tends to be applied to indirect tasks (e.g. material handling and parts picking) in the first case, while automation of direct assembly tasks is assumed in the second approach.

Automation and Volvoism: Although we have not seen many concrete examples of the human-motivation automation, the experiments of Volvo at its Uddevalla assembly plant may be an exceptional case (Berggren, 1993). At Uddevalla plant, each car was assembled by a team of workers in a booth, as opposed to the assembly line, while a kit of parts for each vehicle were picked up and delivered by automatic guided vehicles (AGVs). Thus, whereas the Uddevalla system was, in a sense, a return to the pre-Ford stationary assembly method, it used automation not for direct assembly work but for indirect material handling jobs, which was a major bottleneck of the pre-Ford assembly system. Also, the same kind of ideas might be able to be applied to the case of neo-craft production system.

Although Volvo decided to close its experimental plants (Uddevalla and Kalmar), this does not mean the end of the experiment itself. In fact, some of the recently built assembly plants, including Mercedes Benz's Rastat plant and Toyota's Kyushu (Miyata) plant, seem to have a small dose of Volvoism elements. The challenge of such alternative methods would be how to overcome the problem of relatively low productivity. Some forms of advanced automation technologies may be able to be applied for this purpose.

Job Enrichment at Highly Automated Assembly Lines: Another approach is to start from a relatively automated assembly line and try to alleviate the problem of work alienation. This type of job redesign for automated lines may be first implemented in other areas than final assembly, such as body welding and machining, which has historically been more automated than the final assembly area.

Generally speaking, when direct assembly job is robotized, two types of tasks may be created: the tasks of monitoring, teaching, maintaining, and improving the automated equipment on the one hand, and "residual" tasks that handles what the robots cannot do on the other hand (Jurgens, et al., 1986). The former tend to be non-repetitive and require new types of judgmental skills (Adler, 1983) or engineering knowledge; the latter tend to be repetitive, fragmented, and de-skilled. If the two types of tasks are carried out by different group of workers, automation may cause polarization of workers in terms of work alienation: those who control robots, and those who are controlled by robots. For example, while

Job classification of the Japanese assembly plants have been relatively simple with just two main categories (i.e., direct / semi-direct workers, and maintenance workers), introduction of robot automation may further divide the former category: "operators" doing teaching, monitoring, minor maintenance and so on, and other direct unskilled workers doing residual activities[8].

A potential danger of the work organization described above is that it is difficult to make the residual job meaningful to the workers doing just that. This is particularly the case when the robotized zone is clearly separated from the manual zone, since it means isolation of the "residual" workers in the automated zone. The problem is solved if the residual work for automation can be eliminated altogether, but this would be technically and economically difficult in the foreseeable future.

One way to avoid the work alienation of residual work might be to let the robot operators do the peripheral jobs through job enlargement and job rotations. Another possibility may be to combine direct assembly tasks and the residual jobs by locating robots and manual assembly workers adjacently to each other. In any case, it should be noted that assembly automation, if carelessly introduced, may aggravate the problem of work alienation for a certain group of workers. A new type of training programs, job enlargement / enrichment, and production process redesign would be required in order to avoid this.

To sum up, there seem to be at least two paths toward human-motivating automation: one is to start from non-automated assembly systems that aim at job attractiveness and make it more competitive by using automation; the other is to start from relatively automated assembly lines and try to make them more attractive through job redesign and training programs. In both cases, though, so far there have been relatively few explicit attempts for human-motivating automation systems. Further experiments would be needed along this line.

7. Future Prospect: Convergence, Hybridization, and Diversity

The Trend of Convergence and Diversity

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[8]In one Japanese company, operator's skill level is regarded as equivalent of that of team leaders in manual assembly areas. The operators have been formally trained through Off-JT programs and pilot plant operations at this company.

We have examined four types of assembly automation strategies, which are summarized in table 3. It should be noted again that each type of the strategies is essentially an ideal type, and that actual auto makers may choose mixed strategies rather than pure ones. Nevertheless, the present paper also indicated that a certain group of companies, normally clustered around a certain geographical region, have tended to emphasize a certain strategic type at a certain point in time (figure 2). This tendency seems to be natural, as a group of companies facing the similar competitive and labor environments would try to adapt their capabilities of assembly automation to the challenges from the environments. Thus, for example, some of main Japanese companies apparently had tended more toward "low cost automation," and less toward "high-tech automation" than average Western auto makers during the 1970s and 80s, but they then shifted their emphasis to "human-fitting automation" around 1990.

What about the future of the assembly automation? Are automation strategies going to converge to the extent that there will be only one best strategy in the world auto industry? Or are they going diverge, so that each auto maker chooses a certain pure strategy rather than being "stuck in the middle"? Neither seems to happen. Judging from the general trend of the total productions system described earlier, in which assembly automation is an indispensable subsystem, the global trend of assembly automation strategies in the auto industry appears to be a combination of both convergence and diversity.

First, as both product competition and inter-firm cooperation become global in the auto industry, it would be natural for the companies in different regions to start learning from each other's production systems. This will be the case both at the level of total production system and assembly system. For example, while the Western makers introduce some elements of low-cost automation in the process of learning the lean production system, the Japanese makers may find automation strategies adopted by some European car makers useful for solving their problems in the labor market.

Second, convergence in automation strategy would not mean that all the auto makers in the world start to follow one best way to automate assembly operations. Inter-firm and inter-regional differences will still remain. In fact, the early 1990s has witnessed that many auto companies in the world started to blend certain elements adopted from other firms and regions with the existing capability that the firms have accumulated for years. A natural result of such "hybridization" experiments would be a diversity at detailed levels of production

Table 3 Summary of the Four Types of Assembly Automation Strategies

	High-Tech Automation	**Low Cost Automation**	**Human-Fitting Automation**	**Human-Motivating Automation**
Main Objectives	Competitiveness through advancement of automation technology	Competitiveness through total system improvements	Improvements of physical work conditions at each work station	Elimination of work alienation
Key Measures	Advanced automation equipment for each work station	Total system approach to automation with low cost and limited functions	Automation of "3D" tasks despite increase in manufacturing cost	Automation supporting alternative systems to traditional assembly lines
Strength	Contribution to advancement of automation technology Reputation as high-tech company	Contribution to total performance in cost, quality and flexibility Compatible with continuous improvements of the lean system	Contribution to attractiveness of work place Reputation as "high-touch" company	Contribution to attractiveness of work place Reputation as "high-humanization" company
Weakness	Advanced automation may not contribute to quality and productivity increase Lack of trust between labor and management may be worsened	Assembly work place may not attractive enough to workers	Investment on difficult automation may result in loss of competitiveness through high fixed cost	Utopian pursuit of humanization may result in loss of competitiveness through low productivity
Typical Examples	US and European mass producers of 70s and 80s: GM Hamtramk, VW Hall 54 FIAT Cassino	Japanese mass producers of 70s and 80s Toyota Takaoka Honda Suzuka	Some Japanese producers around 1990 Nissan Kyushu Toyota Tahara	Some European makers under Volvoism influence Volvo Uddevalla Mercedes Rastat (?)

system and manufacturing strategy. Compared with Toyota's main assembly factories of the 1960s (i.e., Takaoka and Tsutsumi), form example, we tend to find more diversity among its new generation plants: Process deigns and manufacturing strategies at Tahara, Kentucky, and Kyushu (Miyata) plants appears to be considerably different with one another, although they still share the core philosophy of Toyota Production System. Above all, hybridization of traditional Toyota System and certain elements from European factories seems to make Miyata plant somewhat unique among the Toyota factories.

To sum up, a general trend of the future production systems and assembly automation strategies in the world auto industry seems to be a combination of *convergence* at the basic level, *mutual learning* across firms, *hybridization*, *experiments*, and growing *diversity* at the detailed level.

Future Research: Inter-Firm Comparison of Strategic Profiles

If the basic trend is that of hybridization, a relevant question for future researches in this field would be not so much how to classify each auto firms into a certain pure strategic type (i.e., into a particular cell in figure 1), as comparing and analyzing "profiles of automation strategy" of the auto firms. That is, each of the auto firms can be evaluated in terms of its efforts and achievements in the four automation strategies. It is theoretically possible for each firms to pursue more than one strategy at the same time, but actual firms may emphasize one strategy over the others at a certain point in time. In order to explore this issue of convergence, hybridization and diversity in assembly automation strategies on international scale, a series of comparative studies may be needed along this line.

For example, auto companies and its assembly plants may be compared and analyzed by using a set of variables that collectively form "profile indices" of the four strategic types. A preliminary example of such data for some of the new generation Japanese assembly plants is shown in figure 6. By aggregating the data with a certain weighting system, we can create the indices for assembly automation strategies and compare them across firms and plants, which may show the practitioners where they are and where they are going in the context of global and dynamic evolution of the world auto industry into the 21-th century[9]. Figure 7 shows examples of the strategic profiles derived from figure 6, which

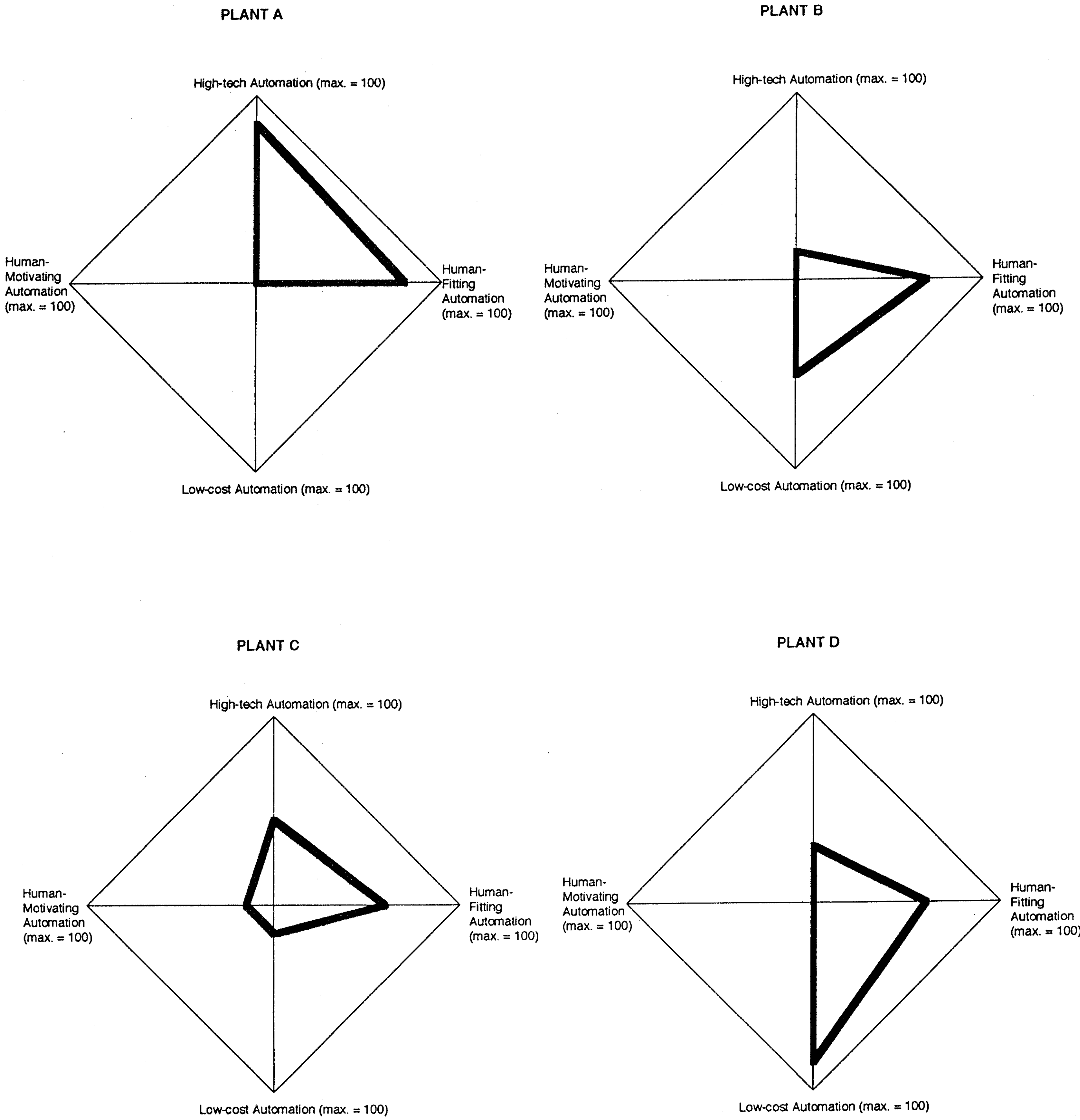
[9] A simplified version of indicators measuring system profiles is shown, for example, in Clark and Fujimoto (1991, Chapter 9 and Appendix).

		plant A	plant B	plant C	plant D
high-tech automation indices	Automation ratio >15%	●			●
	Many assembly steps (>150)	●			
	AGVs for body transfer	●			●
	Intelligent robots used		●		
	Average axes of robots > 5	●		●	
	Vision sensors used for alignment	●		●	
	Investment/capacity >1M yen/unit-month	●		●	
	total point (max. = 100)	86	14	43	29
low-cost automation indices	Upper limit of investment < 10M yen / person				●
	# of semi-automation equipment> # of robots		●	●	
	Mechanical methods used for alignment		●		●
	Average axes of robots < 4				●
	Inhouse robot development				●
	Investment/capacity <1M yen/unit-month		●		●
	total point (max. = 100)	0	50	17	83
human-fitting automation indices	Work environment more emphasized than cost	◍ even	●	●	◍ even
	Human fitting clearly stated in plant charter	●	●	◍	●
	Demanding (heavy parts) stations robotized	◍ 7/15	◍ 7/15	◍ 8/15	◍ 8/15
	Dirty (oil injection) station robotized	●			●
	Dangerous (engine mount) station robotized	●	●	●	
	total point (max. = 100)	80	70	60	60
human-motivating automation indices	Cycle time is long (> 10 minutes)				
	Small # of work stations (< 30)				
	Stationary assembly system adopted				
	Maintenance and assembly tasks merged			◍	
	total point (max. = 100)	0	0	13	0

Note: Plants A, B, C, D are all Japanese final assembly lines that were installed in the late 1980s to early 1990s.
In each of the four indices, equal weighting was used as the first cut.
The data were collected by the JTTAS study group (Fujimoto, Amikura, Matsuo).

● = affirmative (one point) ◍ = partially affirmative (half point)

Figure 7 Strategic Profiles of Four Japanese Final Assembly Lines



indicates that the strategy mixes of the recent Japanese assembly plants have been, in fact, significantly different from one another, despite the fact that they all emphasized the human-fitting automation strategy.

The measurement system for analyzing the strategic profile of automation is by no means perfect. The next step would be to refine the set of variables that better represent the strategic pattern of each assembly plants. Making the analysis international is another agenda.

The world auto industry of the 1990s is certainly in a period of transition. Strategies of assembly automation has to be evaluated in this context. Each company would have to decide how it accumulate manufacturing capability toward a desirable mix of high-tech, low-cost, human-fitting, and human motivating automation in order to cope with the dynamics of product and labor markets, while maintaining internal consistency of the total system. To the extent that the nature of this challenge is pre-competitive, there would be growing opportunities for the auto firms to learn from each other's experiences, visions and strategies.

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