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An Evolutionary Process of Toyota's Final Assembly Operations
——The Role of Ex-post Dynamic Capabilities——

by

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- The Role of Ex-post Dynamic Capabilities[1] -

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[1] This research was conducted with Takashi Matsuo, doctoral student at Tokyo University Division of Economics. The author is grateful for his research assistance in writing this paper. Some of the charts in this paper (figures 4,5,6,and 7) were jointly developed by Mr. Matsuo and the author. This research was partially supported by Monbusho International Scientific Research Program.

1. Introduction

1.1 Purpose of the Paper

This paper explores the evolutionary process and dynamic capability by which Toyota Motor Corporation reorganized its assembly operations in response to the changes in product and labor markets since the early 1990s.

Toyota's assembly process designs have been significantly modified since the late 1980s, while maintaining much of its core manufacturing capabilities, known as Toyota Production System or Lean Production System. The new system, which some industry observers call post-lean system, Toyotism II, and so on, tries to improve its attractiveness to the new generation of workers in Japan, where the number of young work force is decreasing in the long run, while trying to save its cash flow by making the plant and equipment design simpler and by avoiding excessive automation and capital investment. The authors call it "lean-on-balance" system, as the system tries to regain the balance between employee satisfaction and customer satisfaction, as well as the balance between lean production process and fat plant/equipment design (Fujimoto, 1994a, Fujimoto and Takeishi, 1994).

In a broader context, most of the Japanese automobile makers, facing the labor shortage and expansion of domestic demand around 1990, built a new generation of "human friendly" assembly plants, such as Mazda Hofu #2 plant (1990), Honda Suzuka #3 line, Nissan Kyushu #2 plant (1992), Toyota Tahara #4 line, and so on, with relatively high assembly automation ratios mainly for ergonomic purposes (Fujimoto, 1993). Such plants aimed at balancing customer satisfaction of their products and employee satisfaction of their work conditions. The assembly plants, however, suffered from high fixed cost due partly to assembly automation when Japanese domestic production started to decline due to post-bubble recession and further appreciation of yen since 1992. It has become clear that the Japanese auto companies have to readjust their basic designs of future assembly factories, automation and work organizations.

In this situation, however, Toyota seems to be the only Japanese company that has articulated and implemented the new concept of final assembly as a coherent system as of the mid 1990s, although it is too early to conclude that it is the best system to handle current problems. Miyata Plant of Toyota Motor Kyushu Inc. (called Kyushu Plant henceforth for simplicity), established in late 1992, is the first factory that materialized Toyota's new assembly process design as a total system. The new assembly concept has been diffused among the subsequent plants such as Motomachi RAV4 assembly line (renovated, 1994) and Toyota Motor Manufacturing #2 line in Kentucky, US (TMM II, new, 1994). Thus, one of our research questions is why Toyota could establish a coherent assembly process prior to its competitors in Japan. Although Toyota's market power and abundant financial resources might explain a part of the story, certain organizational capabilities, specific to Toyota, might also explain this fact. In other words, we are interested in Toyota's distinctive dynamic capability in this particular case of new assembly system.

The main theme of the present paper, however, is not only to demonstrate ex-post rationality of Toyota's new system, but also to describe and analyze how the new system evolved over time. In this regard, the authors hypothesize that the new system was created not simply by a rational and monolithic strategy planning process, but by a more complicated process of system evolution, which may involve not only ex-ante rational decision making but also trial and error, unintended changes, conflicts and coordination between different organizational units, complex organizational learning, and do on: a process of emergent strategy formation (Mintzberg and Waters, 1985). As Toyota seems to be the first company to reach an apparently feasible manufacturing solutions, we may regard Toyota as having "evolutionary capabilities," by which a firm can handle a complex process of new system evolution better than the others.

In order to analyze this process, the paper describes and analyzes recent constructions of Toyota's domestic assembly factories, including Tahara #4 and Toyota Kyushu Plant. The paper will try to show that Toyota's distinctive competence in manufacturing incudes not only its static capability of high quality-productivity-delivery performance and continuous improvements, but evolutionary (or dynamic) capability. It will also suggest that fundamental objectives at Toyota's manufacturing operations in recent years include not only customer satisfaction, which Toyota traditionally emphasized, but also employee satisfaction, which has become an explicit criteria in the 1990s. We will also try to challenge a rather stereotypical notion that Toyota is a monolithic organization where changes are made by one-shot rational decision making.

1.2 Conceptual Framework

In order to analyze dynamic and evolutionary aspects of the automobile assembly systems, the present paper applies a modified version of resource-capability view of the firm (Fujimoto, 1994).

Generally speaking, so called resource-based or capability theories of the firm has attracted much attention among business academics and practitioners in recent years. They illustrated a business firm as a collection of firm-specific resources, organizational routines, capabilities and competencies, which may explain inter-firm differences in competitiveness, as well as inter-temporal dynamics (i.e. evolution) of business enterprise systems[3].

Although the resource-capability framework has been used mainly for strategic analysis at the company-wide level, it can be also applied to rather detailed analyses of manufacturing issues (Fujimoto, 1994a, 1994b). In this context, production and product development capability of a firm refers to certain firm-specific patterns of productive resources and activities that results in competitive (or other) advantages over its rivals. Assuming that both competitive performance and capabilities change over time, we have to distinguish at least three levels of firms' capability (table 1; Fujimoto, 1994b): (1) *static capability*, which affects the level of competitive performance, (2) *improvement capability*, which affect the pace of performance improvements, and (3) *evolutionary capability*, which is related to accumulation of the above capabilities themselves[4]. While (2) and (3) both can be regarded as dynamic capabilities, they are different in that the latter is a non-routine meta-capability (i.e., capability of capability building).

In the existing literature of Toyota's production system, (1) static and (2) improvement capabilities tended to be emphasized as distinctive strength of Toyota's manufacturing operations. There has been historical analyses of the origin and evolution of Toyota, but they tended not to analyze it from dynamic capability's point of view. This paper, by contrast, highlights (3) evolutionary capability at Toyota. Our view is that Toyota's distinctiveness as a manufacturing form has to be analyzed at all three levels. The present paper is an attempt to apply this framework to the case of Toyota's new assembly system.

2 Toyota's New Assembly Factories: Elements and Functions

Section 2 focuses on ex-post rationality of the emerging Toyota assembly system. It is not the intention of the paper to demonstrate that this is the best assembly system to handle the current competitive and labor problems , compared with alternative assembly process designs (e.g., Volvo's Uddevalla concept). Instead, this section will describe how the new system at Toyota is recognized internally as a rational system after it was established.

2.1 Conventional Toyota System of Production[5]

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[3] For the concepts of resource, organizational routine, capability and competence, see, for example, Penrose (1959), Nelson and Winter (1982), Wernerfelt (1984), Itami (1984), Chandler (1990, 1992) , Praharad and Hamel (1990), Grant (1991), Leonard-Barton (1992), Teece, Pisano and Shuen(1992), Kogut and Kulatilaka (1992), Iansiti and Clark (1993), and Teece, Rumelt, Dosi and Winter (1994). For evolutionary aspects of the firm and its strategies and technologies, see, also, Dosi (1982), Nonaka (1985), Kagono (1988), and Mintzberg (1987).

[4] For further details of this three-level framework, see Fujimoto (1994b).

[5] The first half of Section 2.1 was adopted from Fujimoto (1994b).

Table 1 Three Levels of Development-Production Capability

	basic nature	influence on:	components
static capability	static & routine	level of competitive performance	productivity = efficiency of information transmission throuhput time = efficiency of information reception quality = accuracy of information transmission flexibility = redundancy of information stock
improvement capability	dynamic & routine	change in competitive performance	problem finding problem solving retention of solutions
evolutionary capability	dynamic & non-routine	change in capability	pre-trial capability: ex-ante rationality, entrepreneurial visions post-trial capability: ex-post rationality, retention and institutionalization

Overall Patterns in Manufacturing: Let us start with the Toyota's conventional system of production as an ideal type.

The typical volume production system of effective Japanese makers of the 1980s, particularly at Toyota, consists of various intertwined elements that might lead to competitive advantages. Just-in-Time (JIT), Jidoka (automatic defect detection and machine stop), Total Quality Control (TQC), and continuous improvement (Kaizen) are often pointed out as its core subsystems[6]. The elements of such a system include inventory reduction mechanisms by Kanban system; levelization of production volume and product mix (heijunka); Reduction of "muda" (non-value-adding activities), "mura" (uneven pace of production) and muri (excessive workload); production plans based on dealers' order volume (genryo seisan); reduction of die set-up time and lot size in stamping operation; mixed model assembly; piece-by-piece transfer of parts between machines (ikko-nagashi); flexible task assignment for volume changes and productivity improvement (shojinka); multi-task job assignment along the process flow (takotei-mochi); U-shape machine layout that facilitates flexible and multiple task assignment, on-the-spot inspection by direct workers (tsukurikomi); fool-proof prevention of defects (poka-yoke); real-time feedback of production troubles (andon); assembly line stop cord; emphasis on cleanliness, order, and discipline on the shop floor (5-S); frequent revision of standard operating procedures by supervisors; quality control circles; standardized tools for quality improvement (e.g., 7 tools for QC, QC story); worker involvement in preventive maintenance (Total Productive Maintenance); low cost automation or semi-automation with "just-enough functions); reduction of process steps for saving of tools and dies, and so on[7].

The human-resource management factors that back up the above elements include stable employment of core workers (with temporary workers in the periphery); long-term training of multi-skilled (multi-task) workers; wage system based in part on skill accumulation; internal promotion to shop floor supervisors; cooperative relationships with labor unions; inclusion of production supervisors in union members; generally egalitarian policies for corporate welfare, communication and worker motivation[8].

It is important to note that this system was not established by a one-shot rational decision, but evolved gradually through a cumulative process of capability building

[6] TQC emphasized clarification of quality goals, communication of the goals to the shop floor, involvement of all the employees, education of shop floor supervisors, diffusion of quality and cost consciousness, making good product the first time (tsukurikomi), cross-functional coordination, coordination with suppliers and dealers, smooth implementation of model changeover, and so on.

[7] For standard explanations of the production system at Toyota and other effective Japanese auto makers of the 1970s and 1980s, see, for example, Ohno (1978), Nihon Noritsu Kyokai, ed. (1978), Shingo (1980), Schonberger (1982), Monden (1983, 1993), Imai (1986), Toyota Motor Corporation (1987), Womack et al. (1990), and so on.

[8] For human resource management and labor relations of the post-war Japanese auto makers, see, for example, Koike (1977), Yamamoto (1981), Cusumano (1985), Totsuka and Hyodo, ed. (1990), Nomura (1993), Asanuma (1994), etc.

(Fujimoto, 1994b). It is largely a product of the post-war history of the Japanese auto industry.

Toyota's Assembly Process: Let us now focus on the final assembly process at Toyota's conventional factories. We can characterize it as follows.

(1) Toyota's volume factories adopt Ford -style moving assembly lines (typically chain conveyers). Thus there is nothing unique in body transfer mechanisms and basic layouts of Toyota's conventional assembly lines, except that Toyota's main assembly lines (typically about 1 km) tend to be shorter than those of US makers.

(2) The conveyer lines tended to be separated into three line segments: trim, chassis, and final. Different conveyer systems tended to be used among them. However, no buffer body was allowed between the line segments, so the assembly process was operated as if there were one long and continuous line.

(3) Unlike machining or welding, there have been few robots and automated equipment in traditional final assembly lines at Toyota. In fact, Toyota's assembly automation ratio tended to be lower than some European makers that adopted advanced assembly automation systems (VW, FIAT, etc.). In other words, Toyota has achieved the world class productivity in final assembly without relying on high-tech automation (Fujimoto, 1993).

(4) In order to achieve a high level of line-balancing, Toyota's assembly lines trained multi-skilled workers who could handle multiple tasks, assign a set of multiple work elements to each individual worker, and thereby reduced "muda" due to line imbalance. While such multiple work assignments raised productivity without increasing work speed, meaningfulness of the assembly jobs tended to be sacrificed: a mutually unrelated set of tasks tended to be assigned to each worker.

(5) One of unique mechanisms at Toyota's assembly line is so called "andon cord" (or switch), which assembly workers activate when troubles happen on the assembly line. If the worker and/or team leader cannot fix the problem within the cycle time, the entire assembly line stops. This is said to be an example of Toyota's Kaizen mechanisms, which reveal and dramatize the manufacturing problems and thereby facilitate the shop floor problem solving activities.

(6) Performance of Toyota's assembly lines have been traditionally evaluated internally in terms of efficiency and product quality, as well as safety. Quality of work environments had not been equally emphasized, though. There was an evaluation system that identify tasks that are potentially harmful to workers' health, but evaluation criteria for measuring work fatigue had not been developed in the past.

2.2 Changes in Product and Labor Environments in the 1990s

It is widely known that the basic system of Toyota's manufacturing capabilities had been established by the early 1980s. However, the environments had been changed significantly since then. Toyota's assembly system (as well as others) had to adjust itself to the new environments.

(1) Labor Market: By a combination of structural and cyclical changes in Japan's labor market, it became increasingly difficult to hire and keep sufficient work force for automobile production. As population structure changed, average age of automobile workers increased. It was expected that the population of 18-year -old youth would shrink by about 40% from the mid 1990s to 2010. Young people became less willing to work in certain manufacturing factories which they recognized as "3-D" (dirty, demanding and dangerous), including final assembly. One measure to alleviate this problem was to reduce work hours per year, but this meant further decrease in labor supply. On the demand side, expansion of domestic automobile production peaked in 1990 (13.5 million units), and created additional labor demands for the automobile industry. As a result, the Japanese auto industry suffered from severe labor shortage problems in 1990 and 91, which forced the auto makers to emphasize employee satisfaction aspects of automobile manufacturing (assembly in particular). Although the subsequent recession and loss of competitiveness due to high yen wiped out the labor shortage problem, and labor surplus problems surfaced instead, companies like Toyota still regards the lack of job attractiveness as their long term problem to be solved.

(2) Product Market: So called "bubble economy" era in the late 1980s was the final stage of the 40 years of continuous growth in Japan's domestic automobile production. In the early 1990s, domestic production started to decline from 13.5 million units (1990) to about 10 million (1995), which created financial burdens of high depreciation costs for those companies that had built new and highly automated assembly factories during the bubble era. Although this period of production shrinkage will be eventually replaced by that of fluctuation, a typical pattern in matured auto markets, it is clear that the era of continuous growth, which the traditional Toyota system enjoyed, is over.

(3) Financial Situations: The Japanese auto makers enjoyed relatively abundant cash flow in the late 1980s thanks to the bubble era. The companies also had expectation that, by issuing convertible bonds when stock prices were soaring, the companies could finance capital investments with negligible capital cost. Such atmosphere made the auto manufacturers make capital spending decisions without deliberate assessments. The situation changed completely in the early 1990s: stock market collapsed, the problem of cash flow shortage surfaced, and companies were forced to evaluate capital spending much more conservatively.

(4) International Competition and Conflicts: Appreciation of yen and reverse catch-up of Western auto makers since mid 1980s have virtually eliminated cost

competitive advantages of the automobiles built in Japan, if not overall advantages. Besides, trade friction against the US and Europe virtually restricted exports of completely built vehicles to such countries. The Japanese makers, in response to these problems, made adjustments in two main areas. First, the Japanese makers expanded local assembly and manufacturing of cars and components in the US, Europe, and Asia since the 1980s. Toyota, for example, now assemble cars at NUMMI (joint venture with GM), TMM I and II (Kentucky), and TMMC (Canada) in North America alone. Second, they made major cost cutting efforts for the products made in Japan. While a big jump in manufacturing productivity has become increasingly difficult since the 1980s (Fujimoto and Takeishi, 1995), the main contributor of the cost cutting in the 1980s has been simplification of product design itself, including product variety reduction, parts commonalty, value engineering, and so on (Fujimoto, 1994c)

(5) Production Technology: While final assembly has been known as the last area to be automated in automobile manufacturing, the 1980s witnessed significant progress in robotization of final assembly lines in some Western assembly plants, including VW's Hall 54, FIAT Cassino plant, and GM Hamtramk plant (Fujimoto, 1993). Although such "high-tech" assembly plants demonstrated progress in automobile process technologies, their overall productivity turned out to be lower than the best-practice assembly plants in Japan, whose assembly automation ratio was much lower.

2.3 Toyota's New Assembly Concept

In response to the new challenge from the environments, Toyota has modified its production system since the late 1980s. Final assembly has been the area where the change was most visible and significant. Reflecting the environments of the early 1990s mentioned above, the new assembly concepts aimed at improvements in employee satisfaction, as well as elimination of physically demanding jobs, with minimum capital expenditure. The new process also continued to focus on continuous company-wide improvements (Kaizen) in quality and productivity. To sum up, the new system attempts to preserve the strength of the conventional Toyota system in QCD (quality, cost, and delivery), while improving attractiveness of the assembly work both physically and psychologically.

The new system, as Toyota itself recognizes, consists of several subsystems, as summarized in table 2: (1) Functionally autonomous and complete process; (2) In-line mechanical assembly automation concept; (3) Ergonomics evaluation system called TVAL (Toyota Verification of Assembly Line); (4) Low cost equipment for better work environment and work posture; (5) Supporting HRM (human resource management) policies (Kawamura, et al., 1993, Toyota Motor Corporation, 1994; Kojima, 1994;

conventional	new	
Continuously moving conveyer line; about 1000 m	Unchanged	Autonomous-complete assembly process
Sort cycle time (1 - 3 minutes)	Unchanged	
Decomposed into three line segments (trim, chassis, final)	Decomposed into 5 to 12 line segments (trim, chassis, final)	
No buffer zones between segments	Buffer zones between segments	
A few work groups per segment	One work group per one segment	
Functionally unrelated tasks may be packed into jobs for a worker or a group	Functionally related tasks are combined for a worker or a group	
Group leaders play key roles in Kaizen and line management	Group leaders function was strengthened	
Automation for work load reduction	Unchanged	In-line mechanical assembly automation
Off-line automation: bodies stop	In-line automation: bodies move	
High-tech vision sensing for alignment	Mechanical devices or alignment	
NC (numerical control)	Simple sequence control	
Many industrial robots are used	Compact and simple equipment for assembly automation	
Process evaluation by quality, efficiency, and delivery (QCD)	Unchanged	TVAL for assembly process evaluation
Posture & weight score to avoid illness	Unchanged	
-	TVAL for quantitative assessment of work load	
Emphasis on low cost jigs and power assist equipment	Unchanged	Low cost equipment for better Ergonomics
-	A new generation of ergonomic devices: raku-raku-seat, wagon carts, body lifting mechanisms, etc.	
Basic human resource management policies at Toyota	Unchanged	Supporting HRM policies
Complete day and night shift	Continuous day and night shift	
Informal career plan for multi-skilling	Formal career plan for multi-skilling	
-	Other new HRM policies	

Ogawa, 1994; Kojo Kanri, 1994; Shimizu, 1995, etc.). Let us now examine main content and functions of the above subsystems.

(1) Functionally Autonomous and Complete Process of Assembly

Content: The autonomous and complete line has been implemented at Toyota Kyushu plant (1992), as well as Toyota's subsequent plant constructions and renovations. It consists of various elements, both physical and organizational, including the following (figure 1):

(i) The main assembly line is decomposed into 5 to 12 line segments, each of which is typically 100 meters or 20 work stations (process layout).

(ii) The shape of the assembly area is roughly square, so that the building can accommodate many short lines running back and forth (facility design).

(iii) Each line segments are linked by buffer zone, where up to about five bodies can be temporarily stored (process layout)[9].

(iv) A group of functionally related assembly tasks (e.g., piping) are assigned to one segment (job design). Toyota defined 108 sub-categories of assembly tasks, and changed the task assignment so that each sub-category is completed within a group of workers. Also, assembly of a given component is completed as one person's job[10].

(v) A quality check station is located at the end of each line segment (process design). Criteria for quality assurance were defined for each of the 108 task sub-categories.

(vi) Each line segment corresponds to a group (kumi) of about twenty workers, within which job rotation and training are conducted (organizational design).

(vii) The function and responsibility of group leader are strengthened (organizational design). Each group leader, now in charge of a semi-independent line segment, enjoy more discretion in managing the group's operations. For example, each segment can fine-tune its line speed within a certain limit.

(vii) Other supporting equipment for line control (line speed controllers, switches for planned line stops), information sharing (monitoring displays, Andon boards), and self actualization (Kaizen shops, training centers, rest areas) is set up for each line segment.

Overall, the autonomous and complete line differs from Toyota's conventional assembly line in that the main line (typically about 1000 meters) consists of semi-independent segments, each of which is functionally, physically and organizationally de-coupled from

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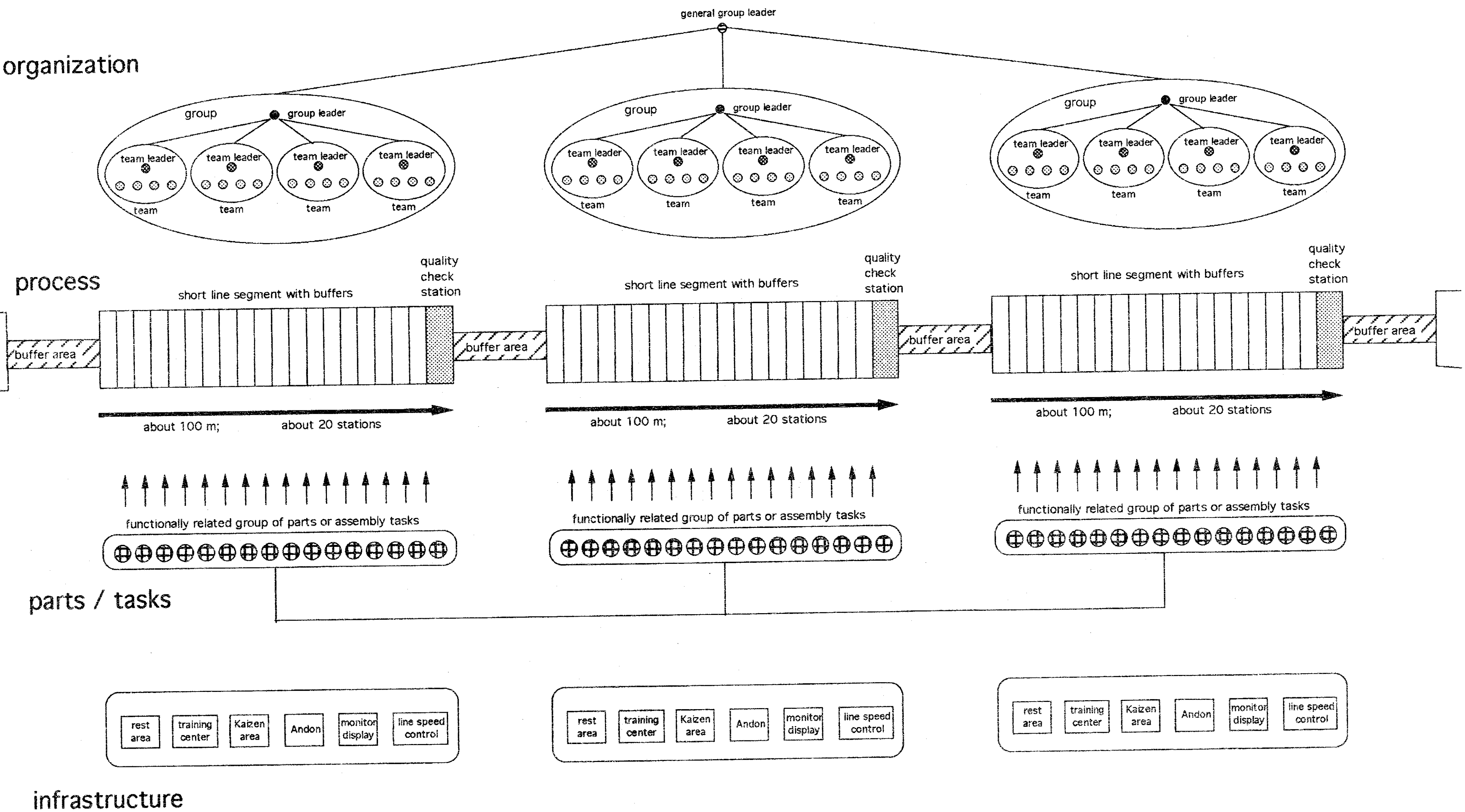
[9] Note that such body buffers between the line segments are essentially different from component inventories at the line side. That is, the existence of the body buffers does not necessarily mean relaxation of Just-in-Time principle.

[10] This is called "parts-complete" (buhin-kanketsu) assembly line. At Toyota, different assembly tasks for a given component (e.g., setting, bolting, etc.) were often assigned to different workers as a result of its efforts to maximize productivity by eliminating non-value time (muda) since the 1970s. Toyota's assembly line was originally following the parts-complete principle until 1960s. Thus, the re-establishment of parts-complete principle means a "back to the basics" effort for Toyota.

Figure 1 Autonomous and Complete Assembly Line Concept



the others. Each line segment is a short version of Fordist assembly line equipped with continuously moving conveyers, though.

Functions: Both quantitative and qualitative results have been reported in terms of initial performance of autonomous complete lines, which are generally consistent with what the process designers aimed at (Niimi, et al., 1994):

(i) Quality and Productivity: As each set of assembly jobs assigned to a work group became more meaningful and easy to understand, and as each group can self-inspect quality more effectively, productivity and quality of the autonomous-complete line was generally higher than conventional assembly lines, particularly at the start-up period (Niimi, et al., 1994; Okochi Memorial Foundation, 1994). Period for mastering a job was shortened to about a half. According to a survey of Toyota Kyushu assembly workers, over 70% of the respondents said they became more quality conscious, and that their jobs became easier to understand, compared with pervious assembly lines. Also, because the body buffer areas absorb the impact of line stops at other segments, overall down time decreased (Kawamura, et al., 1993)[11].

(ii) Morale: Also, as the assembly job became more meaningful, morale of the assembly workers increased. In the survey mentioned above, about 70% of the respondents found their job more worth doing than before. According to our interview with group leaders and team leaders, they tended to become more proud of their job as instructor and Kaizen leader, as their tasks shifted from day-to-day trouble-shooting to Kaizen, supervising, and training. In the past, they tended to be swamped by the complexity and confusion on the line. Some first-line supervisors were feeling psychological pressures due to their increased responsibility, though.

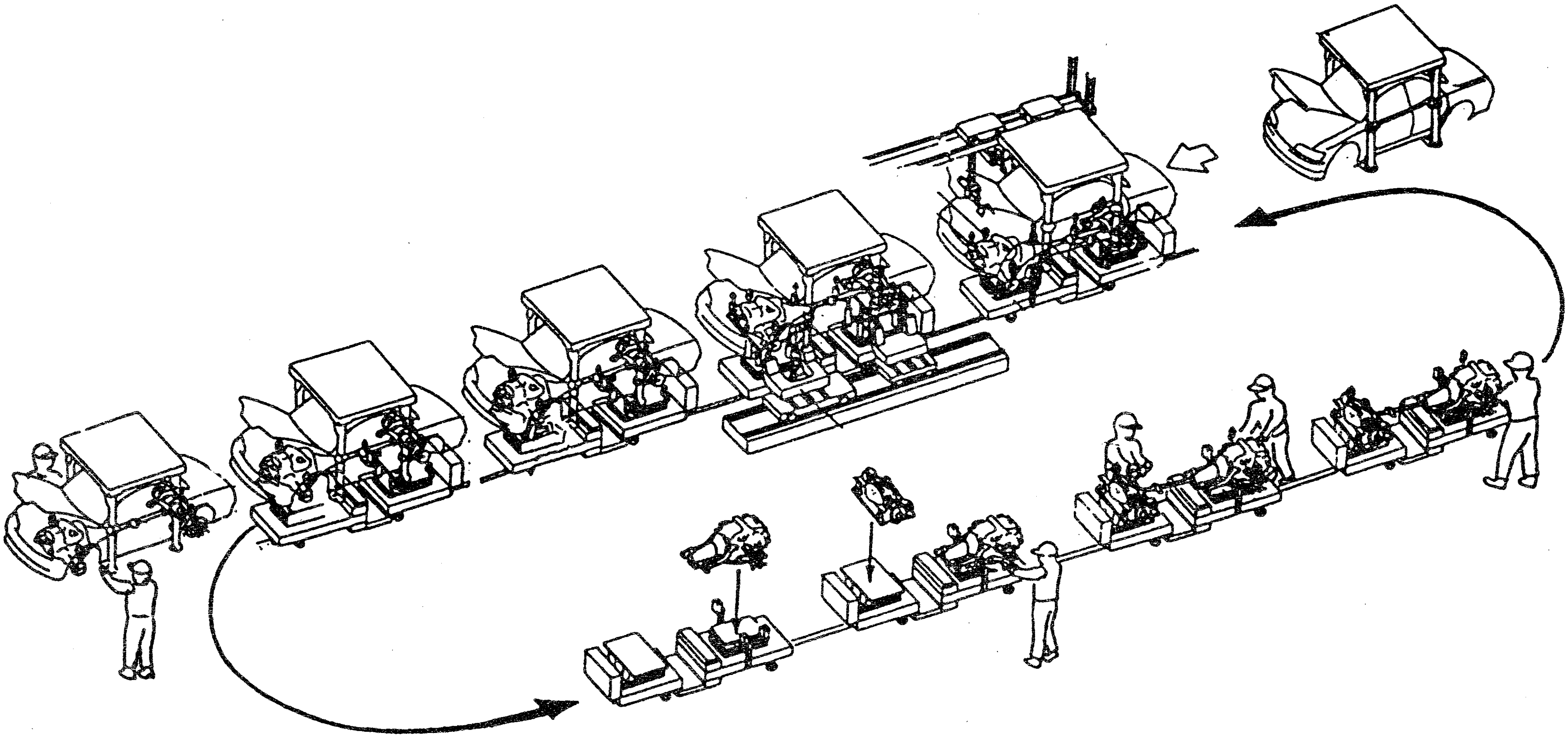
To sum up, the autonomous and complete assembly line concept aimed at balancing customer satisfaction (quality, cost and delivery) and employee satisfaction (job meaningfulness, self-esteem, sense of growth) on the assembly lines, which has been generally achieved so far. It should be noted, however, the autonomous-complete lines have to carry over both strength and weaknesses of Fordist conveyer lines with short cycle times.

(2) In-line Mechanical Assembly Automation Concept

Content: Toyota's new assembly lines adopt the concept of "in-line mechanical" automation, which consists of several elements (see figure 2, an example of engine / transmission / suspension decking) :

[11] Another impact of the body buffers, according to a Toyota executive, is that the buffers lower psychological pressures for the workers to stop the line, as they do not have to stop the entire line (typically one kilometer) but stop their line segment only (typically twenty stations, one hundred meters). A plant engineer at TMCA (Toyota's Australian subsidiary) witnesses that the number of line stops actually increased after the buffered sassily line was introduced there in 1994, apparently because of the reduction of the psychological pressure. This means revealing more problems and facilitating more Kaizen.

Figure 2 Process for Engine and Chassis Mounting



Source: *Report of Okouchi Memorial Prize* (1994)

(i) Both automation equipment and component jig-pallets are synchronized with bodies that move on the conventional continuous conveyers, as opposed to stopping the body for automated assembly.

(ii) The automation zone and the manual assembly zone coexist on the same assembly line. This contrasts with the idea of separating automated zone and manual zone. A groups of assembly workers on the line, rather than off-line maintenance staff, are in charge of operating the equipment.

(iii) Mechanical methods of alignment between bodies, jigs, equipment and component, which tend to be inexpensive, simpler, easier to monitor and easier to fix, are used as much as possible. This contrasts with highly sophisticated and expensive ways of alignment that use electronic vision sensing technologies.

(iv) Automation equipment, including robots, tends also to be simple, compact, low power, and easy to maintain so that it can coexist with assembly workers on the continuous conveyers. Jigs are also designed to be compact and inexpensive.

(v) Automated equipment is adopted selectively by taking cost, performance and ergonomics into account, rather than aiming at the highest assembly automation ratios that are technically possible.

In-line automation is applied to such assembly tasks as engine / transmission / suspension installation and tire bolting, which are physically demanding because of the weight of the components, high torque for bolting, and work posture. This concept of assembly automation is significantly different from another type of assembly automation, or "off-line" automation with visual sensing, which many of Western and Japanese auto makers adopted in the late 1980s and early 1990s (figure 3). In such cases (e.g., FIAT Cassino plant, VW Hall 54, Nissan Kyushu #2 plant, Toyota Tahara #4 line), automation zones equipped with large jigs, sophisticated robots and electronics vision sensing devices, are installed separately from conveyer lines, and bodies are stopped for accurate alignment.

Functions: Compared with the off-line type, the in-line mechanical automation tries to reduce negative impacts or side effects of assembly automation, rather than making the operations more sophisticated. The negative side of conventional off-line automation includes the following points (Kawamura, et al., 1993):

(i) Large automation equipment tends to interfere the manual assembly area and disjoint the teamwork there.

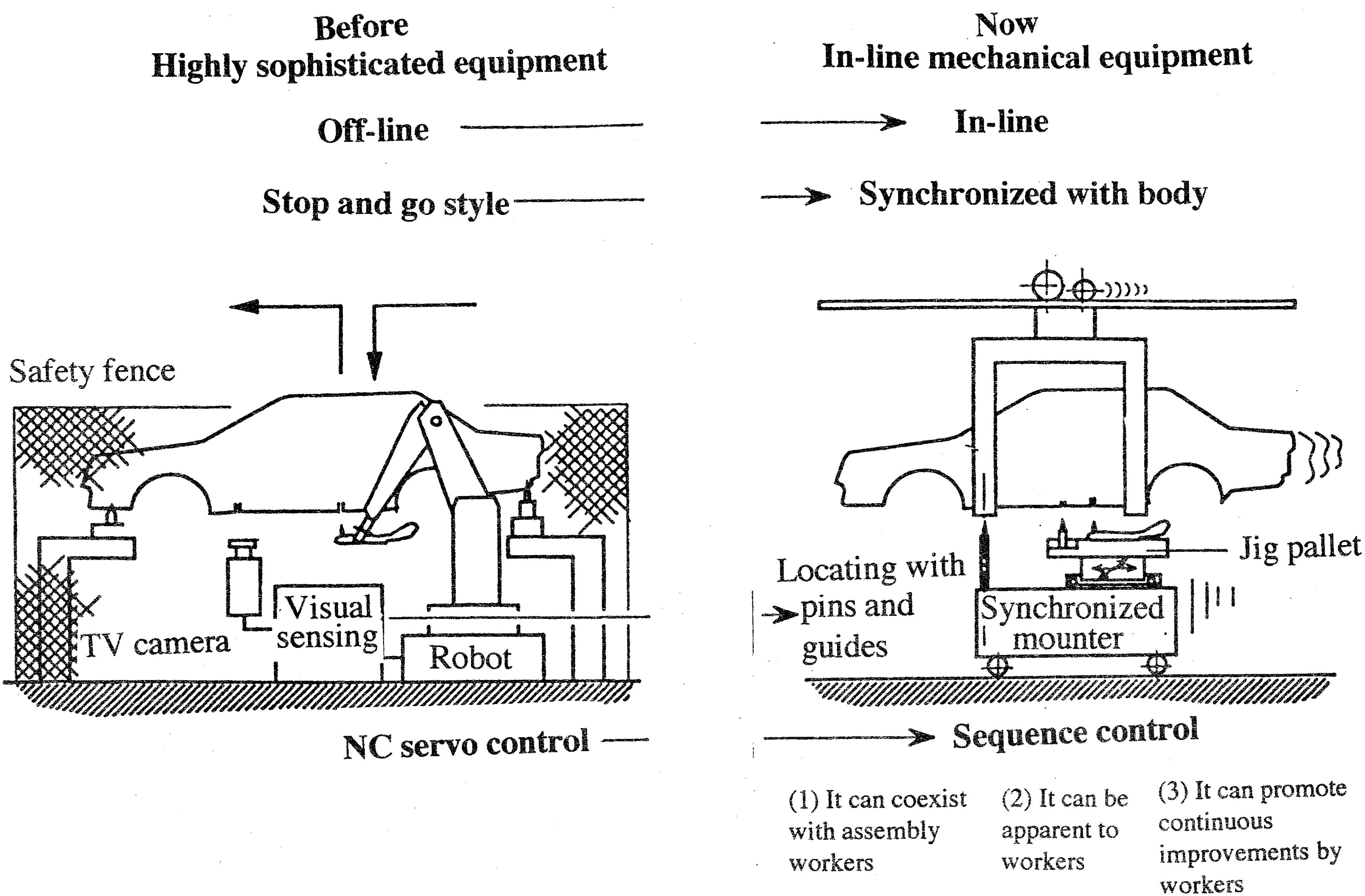
(ii) Assembly automation in separate areas tends to create "residual work" (Jurgens, et al., 1986), which are monotonous and meaningless to the workers in such areas.

(iii) Highly sophisticated equipment tends to become a black box from direct workers' point of view. The job of teaching, operation and maintenance of such equipment tends to be dominated by maintenance workers and engineers.

(iv) As complete automation tends to alienate human being, continuous improvements of the process become difficult to attain.

(v) Off line automation usually needs a large extra space for jigs and robots, as well as buffer stations before and after the process.

Figure 3 In-line Mechanical Assembly Automation Concept



Source: *Report of Okouchi Memorial Prize* (1994)

(vi) Large automation equipment tends not to be flexible enough to model changes.

By alleviating such side effects, in-line mechanical automation for assembly lines aims at reducing manufacturing cost by saving depreciation cost, decreasing machine down time, and promoting continuous improvements (Kaizen) by workers. It also tries to improve employee satisfaction of assembly workers by letting them control and maintain the equipment as much as possible, promoting a sense of ownership among them, minimizing "black box," and keeping the assembly process visible from the workers' point of view. In short, in line mechanical automation, just like the autonomous complete line concept mentioned above, attempts to balance employee satisfaction and customer satisfaction.

(3) TVAL (Toyota Verification of Assembly Line)

Content: TVAL is an indicator that measures work load of each assembly job quantitatively. Based on existing physiological studies, TVAL score is defined as follows (Shibata, et al., 1993):

$$TVAL = 25.51 \log (t) + 117.6 \log \{f (K, W)\} - 162.0$$

where t = task duration time

K = work posture

W = weight of parts/tools

Based on experiments, Toyota developed a table for calculation of $f (K, W)$. Using this table, Toyota measured TVAL score of all final assembly jobs in the company.

Function: TVAL was developed by Assembly Process Engineering Division in order to help the company make the assembly work friendly to all kinds of people regardless of age, sex and other individual differences. By using TVAL, assembly process planners can identify physically demanding jobs in an objective manner, prioritize the work stations to be improved, and concentrate efforts for improvements (e.g., automation, power assist devices, work design changes) on the work stations with high TVAL scores. Thus, TVAL was developed as a tool for improving physiological aspects of employee satisfaction (making assembly jobs less demanding) more efficiently and effectively.

(4) Low Cost Equipment for Better Work Environment and Work Posture

Content: There are various tools and equipment designed for making manual assembly jobs physically less demanding and less dangerous. This category include the following examples:

(i) Height-adjustable conveyers or platforms with variable body lifting mechanisms for achieving the best work posture for assembly task.

(ii) Wide floor conveyers that are synchronized with car bodies, so that workers do not have to walk while performing assembly tasks.

(iii) "Raku-raku" (comfortable) seats that eliminate crouching work posture for assembly tasks inside cabins, which is physically demanding. Each in-cabin job is conducted by a worker sitting on a seat attached to an arm that can be reached inside the car body. An alternative way to reduce crouching work posture is certain work design changes that aim at shifting in-cabin tasks to those performed outside the car bodies.

(iv) "Wagon carts" synchronized with car bodies, which carry parts and tools. This reduces walk distance of each worker. Another way of reducing walk distance is the "door-less" assembly method, in which doors are detached at the beginning of the final assembly line and re-attached at the end of the line.

(v) Simple power-assist equipment that reduce weight of the tools and components that workers carry.

(vi) Easy-to-see job instruction sheets attached to the hood of the car bodies. The instructions are printed out for each segment of the process, so that each sheet is simpler and easier to understand.

(vii) Better lighting, air conditioning, low-noise power tools, low-noise roller-friction conveyers, and other equipment for improving work environments.

Functions: These devices and equipment are mostly aiming at physically less demanding assembly work (i.e., achieving low TVAL scores), rather than productivity increase. Some of them need basic process design changes (e.g., choice of conveyer types, door-less methods), while others can be implemented through regular Kaizen activities (e.g., raku-raku seats, wagon carts, power assist). Generally speaking, they are aiming at improving work conditions with reasonably low equipment cost.

(5) Supporting HRM Policies

Continuous Two Shift: There are some human-resource policies that have been recently adopted for improving employee satisfaction and morale on the shop floor. Two examples are examined here. First, continuous two shift system, in which day shift and night shift are conducted back to back so that the second shift ends at midnight, was introduced in Toyota's assembly plants in 1995[12]. Compared with complete day and night shift that Toyota had adopted previously, continuous two shift enabled female workers work on two shift assembly lines on rotation basis (midnight work by female workers are banned by law), and made assembly work more friendly to aged workers,

[12] Toyota Kyushu Miyata plant had adopted this shift pattern from its inception.

whereas it reduced flexibility to production expansion through overtime and made maintenance work more challenging.

Formal Career Plan for Multi-skilling: Although multi-skilled workers were the core element of Toyota's manufacturing capability, there had been no formal system of career plan for each individual employee in the manufacturing area. In order to give the employees better sense of individual growth and clearer goals for individual skill building, Toyota introduced formal system for certifying their skill levels since the early 1990s: expert skill certificate system for team leaders (EX), group leaders (SX) and assistant managers (CX), and work life plans for production employees in general. The latter gives workers and leaders certain certificates starting from C and moving up to B, A, and S, according to the variety of skills that they acquired.

3. Evolutionary Process of Toyota's Assembly System

Section 2 described Toyota's new assembly system as a rational response to the changes in the environments. In other words, the foregoing section made "ex-post" explanation on the functions of the completed system. However, as the evolutionary view of the firms assumes, such ex-post rationality of a given system does not necessarily mean that the system was built by ex-ante-rational decision making (Fujimoto, 1994b). It may be a result of certain trial and error processes, pure luck, or, most importantly, ex-post capability of the firm. In order to assess Toyota's evolutionary capability (capability of capability-building), we have to analyze how the new assembly system emerged since the late 1980s by looking into historical and dynamic aspects of Toyota's assembly organization.

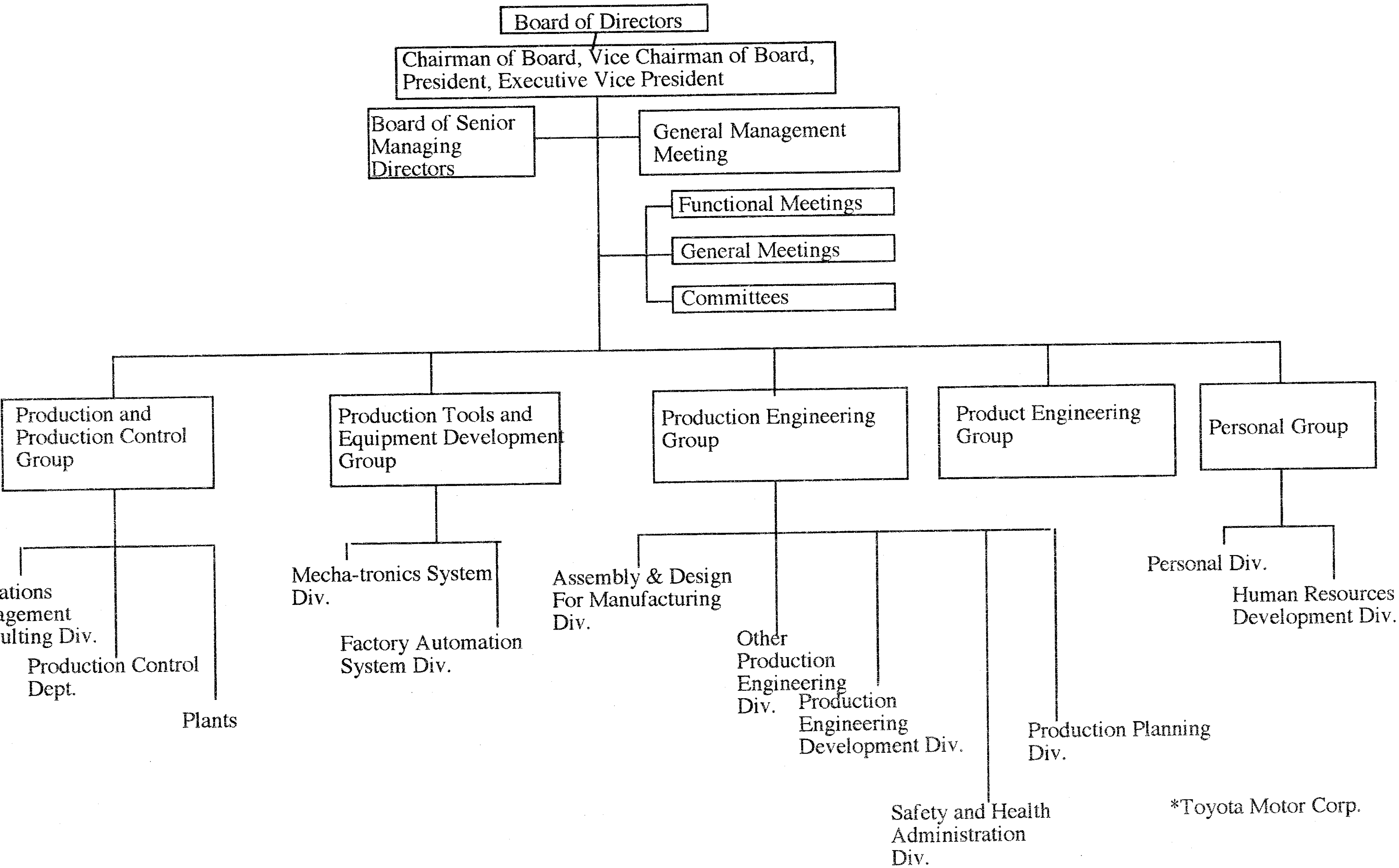
3.1 Production Organization at Toyota

First, let us briefly describe various organizational sub-units that are related to Toyota's decision making in manufacturing process designs (figure 4). As mentioned above, the present paper does not regard Toyota as a monolithic decision making unit, which tends to be a stereotype image of Toyota, but analyzes it a collection of various sub-units with different skills, missions and cultures, whose perceptions of environments and evaluations of alternatives need to be coordinated.

(1) Assembly & Design for Manufacturing Engineering Division (Sharyo Seigi-bu)

Production engineering (process engineering) group consisted of about ten process-specific engineering divisions, each of which specialized in a certain process, including assembly, welding, stamping, machining, foundry, etc., as well as Production Engineering Development Division (advanced production engineering), Safety & Health Administration Division, and so on. Assembly process engineers were organized as

Figure 4: Organization of TOYOTA (1994)



*Toyota Motor Corp.

Assembly Process Engineering Division They tended to be regarded as "conveyer specialists" but did not take enough initiatives for assembly process designs in the past. As an assembly engineer admits, final assembly was a process in which shop floor experiences were recognized as more important inputs than engineering in process designs, unlike machining, forming, etc. Managers and leaders on the shop floor tended to dominate assembly process design as a cumulative result of day-to-day Kaizen.

In early 1990s, however, an effort to make the final assembly process design "real engineering" started. Accordingly, Assembly Process Engineering Division was strengthened both quantitatively and qualitatively. The number of assembly engineers in this division was doubled in this period. Process engineers from other production divisions (e.g., equipment development, die development, machining, welding, electronics process engineering, etc.), as well as Plant General Managers, were added.

In 1994, Assembly Process Engineering Division was restructured to Assembly & Design for Manufacturing Engineering Division With this reorganization, the mission of the division was also changed from that of simple assembly process engineering to integration of all production engineering divisions from total vehicle's point of view. Also, a new position, Assembly & Design for Manufacturing Engineering Shusa (manager), was set up in this division. Each of the VPE Managers is in charge of a particular model and work closely with Product Manager of the model on the product engineering side, coordinating requests from various production engineering divisions, and propose VPE Manager Vision to the product development team as a representative from the process engineering group. In the past, each production engineering division coordinated with the corresponding product engineering division (e.g., Body Production Engineering Division versus Body Product Engineering Division), but the product-process coordination from total vehicle point of view was not as active as expected. The new Assembly & Design for Manufacturing Engineering Division tries to improve this interface by taking a dual role of specialist in assembly process engineering and integrator of process engineering divisions.

As assembly process specialists, some managers in VPE Division insist that they are committed to process optimization rather than equipment technologies. That is, in planning and designing assembly lines, the Assembly and Design for Manufacturing engineers tend to start with optimizing process designs, and then move on to selection and design of automated equipment. Equipment is regarded as means to achieve process optimization. They evaluate the assembly lines in terms of efficiency of the entire process, as opposed to advancement of equipment technologies or automaton ratios per se.

(2) Mechatronics Systems Division (formally #1 Machine Making Division)

Separate from production engineering divisions (since 1990), there is a Production Tools and Equipment Development Group, which consists of Mechatronics

Systems Division and Factory Automation (FA) System Division, and s on. They are in charge of developing and constructing production equipment and FA systems. As discussed later, Mechatronics Systems Division (formerly called #1 Machine Making Division) played an important role in designing and developing in-house equipment in Toyota's early assembly automation experiments. Reflecting its central mission as an in-house equipment supplier, Mechatronics Systems Division is more equipment-oriented than Assembly & Design for Manufacturing Engineering Division, which is more process-oriented. In other words, the approach of Mechatronics Systems Division to assembly automation was rather "technology-push" than "demand-pull."

(3) Operations Management Consulting Division (Seisan Chosa-bu)

Operations Management Consulting Division is an organizational unit unique to Toyota. Established in 1970 by Taiichi Ohno (known as father of Toyota Production System) as a staff office in Production Control Division, Operations Management Consulting Office has been in charge of maintaining, diffusing and educating Toyota Production System (TPS) both inside Toyota and at Toyota Group parts suppliers[13]. Whereas each of the Process Engineering Division, as well as plant engineers, are specialists in each process technology, Operations Management Consulting Office is in charge of generic TPS principles that are commonly applied across different processes and plants. Also, while production engineers take charge of planning and construction of new or renovated plants, Operations Management Consulting Division is in charge of practical improvements after the start of production.

The current missions of Operations Management Consulting Division include the following. (1) Educating Toyota Production System; (2) Implementing TPS principles on the shop floor in collaboration with TPS instructors (shusa) who belongs to each plant; (3) Participating in Voluntary Problem Solving Studies (Jishu-ken) by the plants; (4) Helping factories and suppliers manufacturing solve problems when requested and / or approved by Toyota's executives in production. As for education, there is a rotation arrangement by which plant engineers and production engineers are dispatched to Production Restart Division for a few years. The Division is strengthening TPS education to production engineers in recent years.

Operations Management Consulting Division, because of its historical background, tends to be recognized in the company as Ohno's disciples, guardians of TPS concept, or auditors of production processes from TPS point of view, although they do not have official line authority over the plants. In any case, in accordance with the TPS concept, the Operations Management Consulting Division staff tend to be customer-oriented, and emphasize cost reduction for the purpose of customer satisfaction.

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[13] The concept of Toyota Production System is said to have been formally established in 1970.

(4) Production Control Division (Seisan Kanri-bu)

Production Control Division is in charge of product allocation among the plants, as well as making production plans for levelization (heijun-ka) and assuring logistics to achieve such plans. Production Control, Production (plants), and Operations Management Consulting are grouped together at Toyota's organization charts since 1991, indicating their close relationships. Production Control Division does not have direct influence on the design and construction process of assembly plants, though.

(5) Assembly Plant

There are several assembly plants at Toyota. Toyota's assembly plants are headed by Plant General Managers, who are often directors in manufacturing. There is an Assembly Division Head for each plant, below whom there are section heads (Ka-cho), assistant managers (general group leaders; Ko-cho), group leader (Kumi-cho), and team leader (Han-cho), and team members (workers), as figure 5 shows. The first-line supervisors up to assistant manager are union members. Maintenance Section and Quality Control Division, as well as Plant Engineer Office and other administrative staff functions are separated from the line organization. Let us now examine selected functions and positions related to final assembly lines.

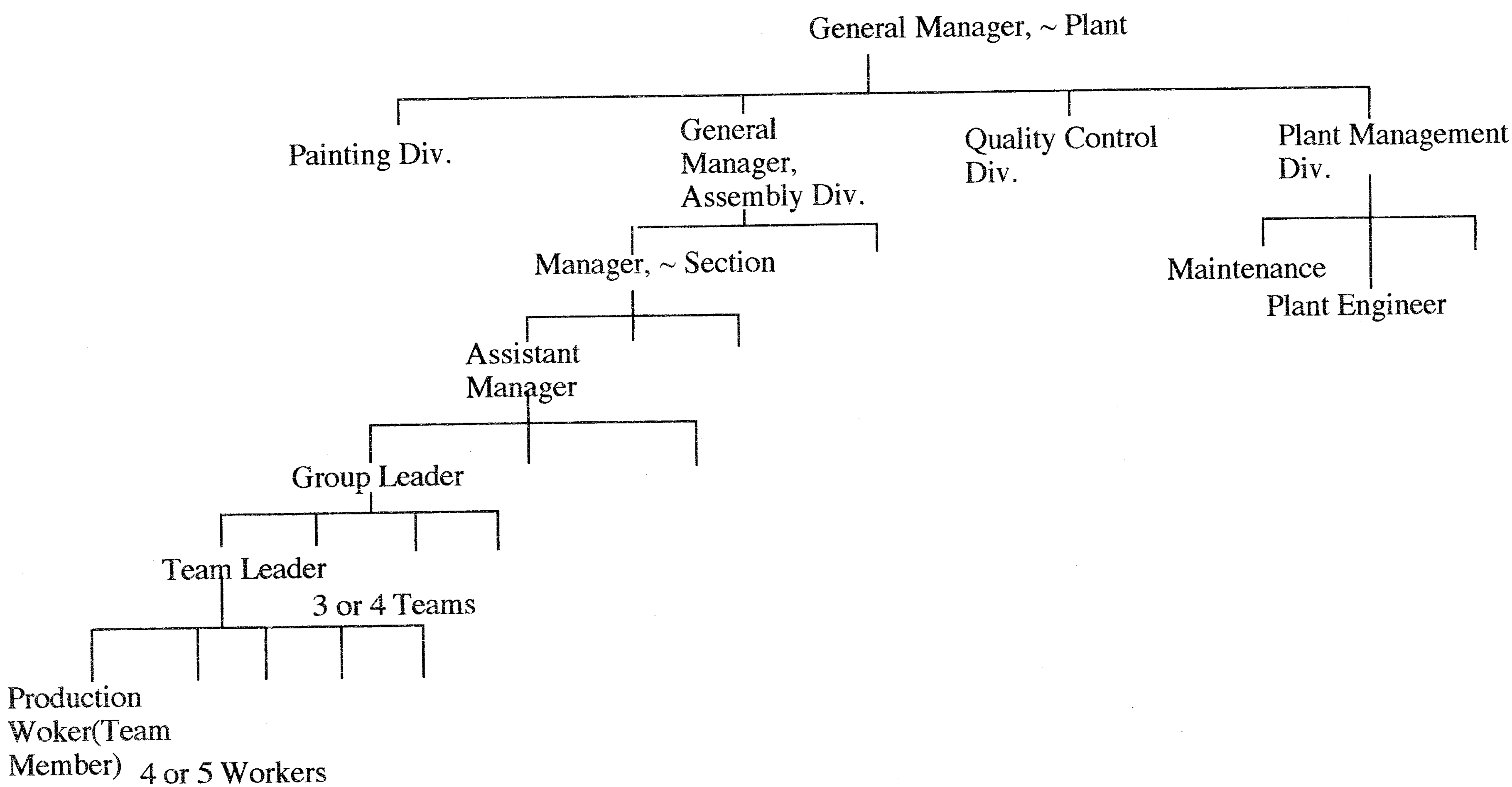
Production Worker (Team Member): There are typically several hundred workers in one assembly line, who rotates between day and night shifts. In two-shift rotation process, workers at Toyota have been almost exclusively male partly because of the labor law constraints prohibiting female midnight work. Average age of blue color worker is about XX, but those on the final assembly lines tend to be younger. Average length of work experience at Toyota is XX years. Annual turn over ratios of production workers are generally low (around 5 percent), but those for the first-year rookies (mostly high school graduates) tend to be much higher (often aver ten percent). The ratio of temporary workers is at most about 10 % in recent years. Both turn-over ratios and temporary worker ratio increased significantly at the peak of the bubble economy era, reflecting the labor shortage and changes in the mind set of the young people. Permanent employees are trained as multi-skilled work force.

Team Leader: In assembly lines, team leader (han-cho) is normally the head of a team of about five members. They are union members, and essentially "playing managers," who function as "relief" worker replacing absent team members, deal with line stops and other troubles, take initiatives in Kaizen activities, and do certain administrative jobs.

Group Leader and Assistant Manager: Called "kumi-cho" or "shoku-cho", a group leader in final assembly is typically a head of a group of twenty workers, or four teams. Group leader is the lowest-rank job as full time supervisor, who do not do direct

Figure 5: Organization in Plant at Toyota

Source: Toyota motor corp.



assembly work. They report to Assistant Managers (ko-cho), each of whom is in charge of a few groups. Group leaders and assistant managers are regarded as playing a pivotal role on the shop floor in day-to-day supervision, trouble-shooting, revisions of standard operating procedures, coordinating Kaizen activities, and so on. Their performance are evaluated in terms of efficiency, quality, etc. of their group.

In the case of final assembly, a labor intensive process where general engineering principles were not necessarily well established in the past compared with other processes, assistant managers and group leaders tended to be very influential not only in continuous improvements (Kaizen) but also assembly process designs[14].

Maintenance: The maintenance organization was centralized as separate section at each plant, but there is a tendency (e.g., Toyota Kyushu plant) to decentralize at the process level (e.g., press, welding, assembly). Also, maintenance people used in charge of maintenance and operation of automated equipment, but direct workers are now trained to handle minor fix and preventive maintenance of their own equipment under the TPM (Total Productive Maintenance) arrangement. In this way, maintenance function and direct workers are increasingly integrated in recent years.

Plant Engineer: There is a plant engineer office (gijutsu-in shitu) at each plant. Plant engineers are in charge of major improvements and major maintenance of production equipment.

TPS Shusa: TPS Instructors (shusa) are stationed at each plant. They make sure that the principle of Toyota Production System is implemented properly, in close collaboration with Operations Management Consulting Division

(6) Personnel Division / Human Resource Development Division

There are two personnel-related divisions at Toyota: Human Resource Division (jinji-bu) and Human Resource Development Division (jinzai kaihatsu-bu). The latter is in charge of recruit, education, and performance appraisal, whereas the former deals with labor relations and other communication inside the company, including that between management and employee, management and union, employee and union, supervisors and subordinate and so on. Communication is regarded as critical for maintaining and improving employee satisfaction, as well as active organizational cultures.

(7) Labor Union

Toyota's labor union (Toyota roso) has maintained cooperative relationships with the management since the 1950s, when there was a series of large strikes. It keeps regular communication with its members and the management. The union tires to listen to

[14] Assistant managers (general group leaders), group leaders and team leaders are normally selected from veteran workers. Section leader (Kacho) may be also from the shop floor leaders, but they are more likely to be college graduates. In any case, section leader is the highest rank to which blue color workers are promoted in most cases at Toyota.

the voices of its members, including team leaders and group leaders, articulate them, and make concrete requests through quarterly labor-management meetings (roshi kyogi), as well as other sub-meetings. Such meetings are held at not only the company level but also plant level.

Once an agreement is reached on new policies or systems (e.g., introduction of continuous two shift), union and management, through their respective channels, try to persuade the shop floor people to accept the new proposal. The key people in this situation are first level supervisors (group leaders, team leaders, etc.), who are at the bottom of the management hierarchy, member of the union, and opinion leaders of the shop floor organizations at the same time. At Toyota, a general practice is that a new policy is not implemented until a consensus is built at the shop floor organizations, even when union leaders and management both agree with it.

(8) Product Engineering

Product engineers are not directly involved in the production process design, but they coordinate with production functions through simultaneous engineering and design for manufacturability, and so on. In recent years, product engineers and production engineers are also conducting joint reverse-engineering of competing products, which serves as an important opportunity for mutual understanding of both groups.

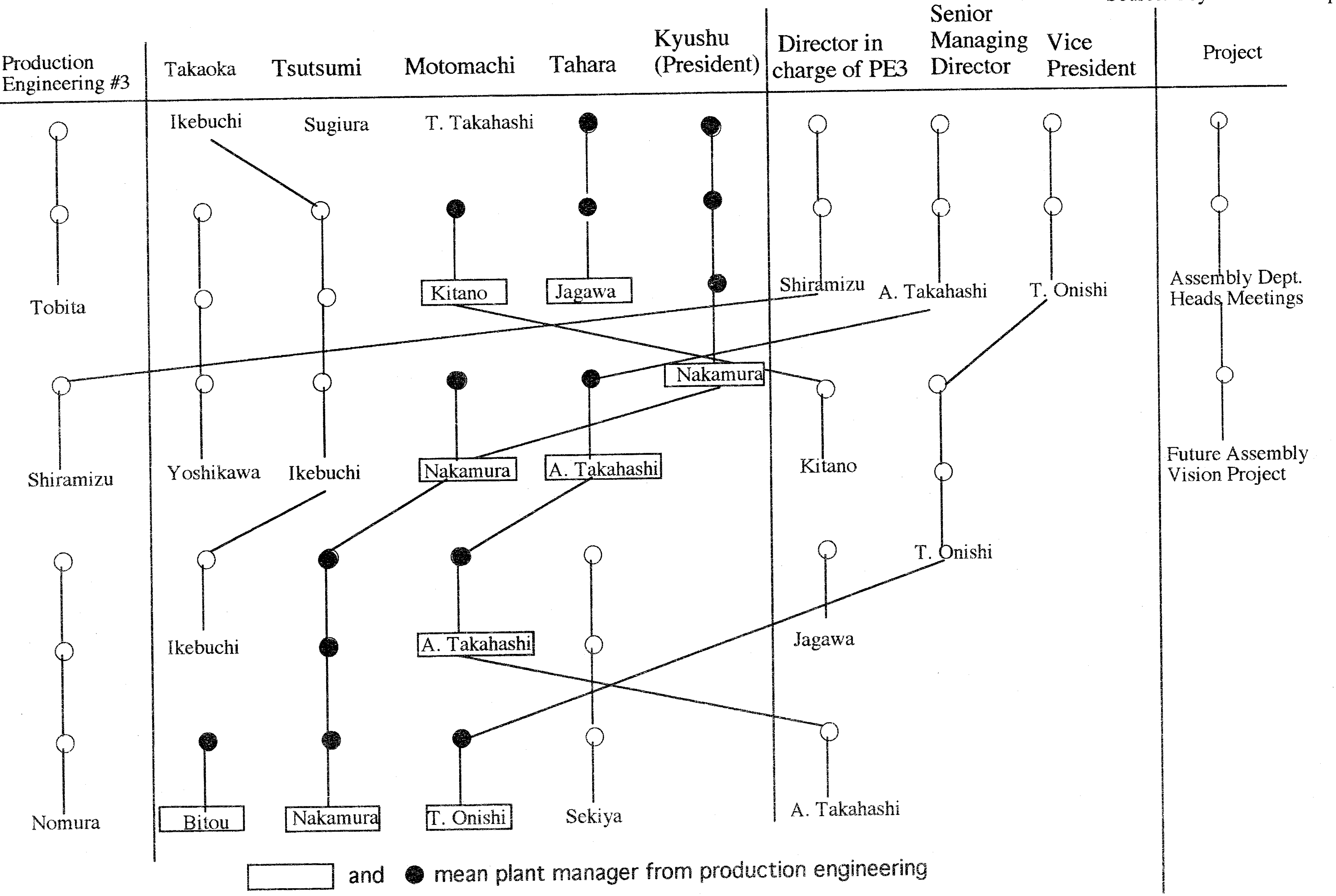
(9) Directors from Production Engineering

Finally, let us briefly examine the executives from the production area. Toyota in recent years has appointed disproportionately many executives (director level or above) from production engineering area, which indicates that the company recognize production engineering as a key function. Those directors are often nominated to be heads of assembly plants at the same time.

Besides the top level executives in charge of production (e.g., Mr. Onishi, Executive Vice President), there are several people at the director to senior managing director level, as of the mid 1990s, who made significant influence on the evolution of Toyota's new assembly system, including Mr. Takahashi (former Motomachi and Tahara Plant General Manager), Mr. Jagawa (Tahara Plant General Manager), Mr. Kitano (former Motomachi Plant General Manager, currently heading TMM), and Mr. Shiramizu (former Tahara Assembly Division Head). What is common among them is that they originally came from production engineering area, and appointed to be head of one or more of Toyota;s newer (or renovated) assembly plants. Overall, over a half of recent assembly plant General Managers were from production engineering group (the rest being from plant operations) in recent years (figure 6). As for Toyota Kyushu Plant, Mr. Kato, current head of the plant, was former head of Assembly Division at Motomachi plant.

Figure 6: The Heads of Assembly Plants and Executives from Production Engineering

Source: Toyota Motor Corp.



and ● mean plant manager from production engineering

Interviewing with these executives, we found that they tend to have unique individual characters and ideas, rather than uniformity as technocrats, but have shared understanding about Toyota's core capabilities and philosophies in manufacturing (Mono-zukiri).

3.2 The History of Toyota's Assembly Process Concept

Having described main actors of the evolutionary process, let us now illustrate a brief history of Toyota's assembly system in the late 1980s and the early 1990s (see figure 7).

(1) Overview

The main opportunity of experimenting and adopting new assembly concepts is, naturally, new construction or renovation of assembly plants. Most of Toyota's assembly plants were built in the 1960s to 1970s (Motomachi: 1959; Takaoka: 1966; Tsutsumi: 1970; Tahara #1: 1979). In the 1980s, the main part of new constructions and renovations of major assembly plants occurred outside Japan: NUMMI (US, joint venture with GM, renovation, 1984), TMM (US, new, 1988), and TMMC (Canada, new, 1988), reflecting the trade friction and yen's appreciation. The construction of domestic assembly plants during the 1980s occurred only at Tahara: #2 plant (1981) and #3 plant (1985).

In the 1990s, though, another wave of assembly plant constructions and renovations have begun both in japan and overseas. This generation includes (1) new domestic plants with new assembly concepts (Tahara #4, 1991; Toyota Kyushu, 1992), (2) new overseas plants (TMUK in the UK, 1992; TMM #2 in the US, 1994; TMCA in Australia, 1994, etc.), and (3) renovations of domestic plants (new Motomachi #2, 1994). There are further plans for the cases (2) and (3) in the late 1990s. It is said inside Toyota that, as the number of assembly plant constructions and renovations increased, relative power and influence of production engineering group in Toyota's organization has increased.

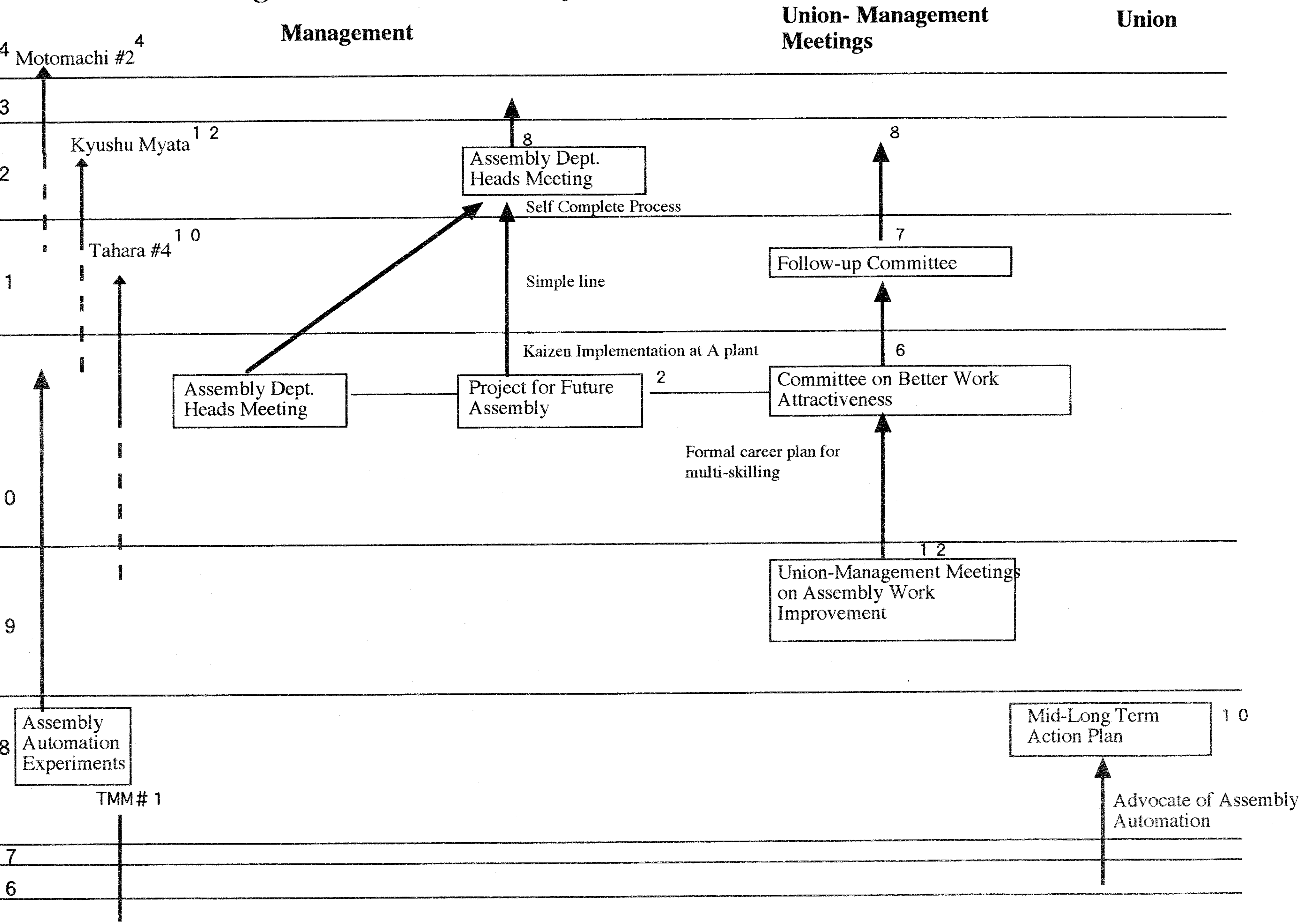
(2) Process of Assembly Plant Construction at Toyota

Before examining the recent history of Toyota's assembly plant construction, let us look through the generic process of assembly plant planning and construction. In the case of new construction, it normally takes Toyota a few years from basic plant planning (e.g., layout) to conveyer design, conveyer installation, equipment installation, overall try out, pilot runs #1 and #2, and to plant start-up[15]. Basic plant planning takes roughly a

[15] Typical plant planning and construction lead time is said to be roughly two years, but it varies widely depending upon the cases.

Figure 7: Time Chart (Toyota and Toyota Union)

Source: Toyota Motor Corp.



half year. The lead time is significantly shorter in the case of major model changes at existing plants. Note also that conveyer installation always precedes equipment installation.

Plan and construction of an overseas plant take a half to one year longer than the domestic case, on the other hand, because of extra activities needed only in the overseas cases: The planning and fabrication of major equipment are made in Japan up to the first pilot run, and then the equipment is shipped to the overseas construction site, where equipment installation, second pilot run, quality confirmation and start up are conducted. Because of this time lag, for example, basic plans for Tahara #4 plant (1991) and TMUK (1992) were in fact made almost at the same time, and so were those for Toyota Kyushu (1992) and TMM #2 (1994).

(3) <u>TMM: Transplants in America (1988)</u>

Toyota Motor Manufacturing U.S.A., Inc. (TMM) is Toyota's first full-scale assembly plant in the U.S. based on sole investment. Plant construction in Kentucky was announced in 1985, and production of Camry started in July 1988. Basic plant design of TMM replicated that of Tsutsumi, its "mother" plant producing also Camry, in order to make the training of TMM's maintenance and assembly workers at Tsutsumi efficient. Since the search process of Toyota's new assembly automation concept started roughly in 1988, it is clear that the basic design of TMM #1 plant still belongs to that of traditional Toyota plants. Toyota's tradition of combining paint and final assembly areas in one building was also replicated[16].

There was something new in TMM's plant layout because of the fact that the plant was located in the U.S. Since both U.S parts and Japanese parts were purchased, the final assembly building was designed such that US parts come from north end, while the Japanese parts come from south end of the building. The interface between the two receiving docks and the assembly line was designed to be long for better logistics of in-coming parts from the docks to the line side. As a result, the final assembly area, became closer to square than Toyota's traditional layout. Accordingly, the main assembly line was broken down into 8 segments running back and forth (3 trim, 3 chassis, and 2 final line segments, excluding the inspection line and the door sub-line). TMM's main line was 1.3 times as long as that of Tsutsumi, though.

These eight segments were linked by buffer zones. Thus, the physical aspect of the autonomous - complete line (i.e., many short segments with buffer zones) was already there. Unlike the subsequent assembly lines, however, this physical layout was not linked to the spirit of the autonomous-complete assembly process. TMM's final assembly layout was driven mainly by parts logistics mentioned above. Also, buffer

[16] Exceptions in Japan include, in fact, Tsutsumi Plant, Tahara #4 Plant, and Toyota Kyushu Plant, where the paint building was separated.

zones were used subsequently for reducing overall down time, but autonomy of each group was not recognized as the benefit of such buffers.

(4) Experiments for Off-Line High-Tech Assembly Automation (1989 - 92)

It was 1988 when Toyota started to consider experiments of advanced assembly automation technologies. One of the major motivation was completion of VW's new Hall 54 assembly plant, which soon became famous for its ambitious assembly automation concept[17]. Stimulated by the new wave of assembly automation in Europe, some of Japanese news media launched campaigns advocating future potentials of assembly automaton technologies. Encouraged also by the bubble economy, some other Japanese makers also announced construction of highly automated assembly plants (Nissan Kyushu #2, Mazda Hofu #2, Honda Suzuka #3, etc.).

Facing such pressures from outside for promoting assembly automation technologies, Toyota's managers decided to start experimental development of assembly automation equipment in 1989. #1 Machine Making Division (now called Mechatronics Systems Division) took charge of developing an experimental assembly automation line, which eventually consisted of about thirty automated stations, in a research building of Production Engineering Group. The experiments alone cost Toyota millions of dollars. If realized fully at commercial plant, the line would have achieved higher assembly automation ratio than VW's Hall 54, one of the world's highest.

The equipment development engineers at #1 Machine Making Division predicted that the effective assembly technologies would need corresponding changes in vehicle architecture (e.g., modularization of the product design) and assembly process configuration, which was the case with VW and FIAT. They approached to product engineers and assembly process engineers and asked about this possibility, but no clear answers came back. Therefore, the equipment engineers at #1 Machine Making Division decided not to wait for the architectural changes on the product-process side, went ahead and developed experimental automation equipment, in the hope that such changes would occur in the future. Thus, the motivation of the experiment was essentially "technology-push." With this policy, various element technologies for assembly automation, including installation or bolting of engine / transmission, tires, front window, and instrument panel, etc., as well as detaching doors, were developed at the first phase of the experiment and received a rather favorable feed-back from Toyota's management.

The second phase experiment, which got another management review in 1991, targeted practical application of the equipment to a commercial-scale assembly line at Plant

[17] FIAT's Cassino plant, another new and highly automated final assembly line, was another plant that Toyota paid much attention. Some of Toyota's production engineers also paid some attention to the experiments of Volvo (e.g., Uddevalla plant), but they did not adopt this concept at this point because they were not convinced of its competitive potentials in terms of productivity.

A's assembly line in 1992[18]. However, the engineers of the automation experiments could not persuade product engineers of Corona to design its vehicle structures for effective assembly automation: only one-tenth of the design change proposals by the former were approved by the latter. Besides, the process layout of Plant A, designed originally for manual assembly only, did not fit assembly automation. After all, a part of the automated equipment developed in this experiment was installed at Plant A's assembly line in 1992, but it was subsequently modified based on Toyota's new assembly automation concept (discussed later) by the mid 1990s. Separately, certain automated equipment that was based on the concept of the experiment was selectively introduced at Tahara #4 line in 1991.

The result of the second experiment revealed some problems of the assembly automation concept of those days. The equipment tended to be too large to install for existing assembly lines; Assembly automation had to be done "off-line," or outside the manual conveyer line; Workers tended to be alienated from the off-line automation processes as they could not access to the automation zone, making Kaizen by assembly workers impossible; The automaton system tended to be too expensive to be cost-competitive; Product cost was expected to increase if the product architecture was modified in order to accommodate this type of assembly automation.

As discussed later, however, a refined version of the equipment developed in the experiment was subsequently introduced to Toyota Kyushu, Motomachi #2, etc., as an element of the in-line mechanical automation system. Thus, the experiment contributed to the evolution of Toyota's new assembly concept at least partially.

(5) Tahara #4 Assembly Line: Implementation of Assembly Automation (1991)

Basic layout of Tahara #4 plant was developed at the end of 1989, and production started in 1991. Because of the timing of plant planning (the peak of the bubble economy, labor shortage, assembly automation in Europe), Tahara #4 line aimed at (i) reduction of the number of necessary work force by automation, (ii) increase in work attractiveness by reducing work load, (iii) exploration of technological frontier in assembly automation. As for the third point, some production engineers admit that there was a desire to show off the capabilities of Toyota's production engineering by building a show case factory. Budget constraint was not emphasized there. Considering the timing, it is also likely that its plant design was influenced at least partially by the assembly automation experiments between 1988 and 1991.

Tahara #4 adopted a main assembly line layout that consisted of 8 segments (excluding sub-assembly lines and inspection lines)[19]. There were already buffer zones

[18] Plant A is one of Toyota's existing assembly plant in Japan.

[19] More accurately, the main assembly line at Tahara #4 was cut into 13 segments with buffer zones, because five of the 8 lines were cut in the middle into two segments. Three of them were cut because of

between the segments at Tahara #4. This is physically similar to the layout of TMM (Kentucky), which also has 8 segments, but motivation for the multiple segment layout was different: TMM's multiple segment layout was motivated mainly by component logistics, as mentioned before; The off-line assembly automation was a main driver for Tahara's assembly line segmentation, as manual assembly segments and automated segments had to be physically separated with buffers for off-line automation[20]. At the same time, it should be noted that there was already an early and partial trials for the autonomous-complete assembly at Tahara #4. The concept was not fully articulated at this point, though.

As for assembly automation, it is true that automated equipment that adopted the concept of the experimental line was introduced in engine / transmission / suspension installation (so called "decking") and tire bolting. It should be noted, however, that Tahara #4 line adopted the results of the automation experiment line rather selectively: Tahara decided not to automate door disassembly, which the experimental line automated, for example. The plant did automate air conditioner unit, battery, instrument panel, window shield, etc., but their method of automation was different from that adopted in the off-line assembly automation experiments mentioned above.

In any case, Tahara #4 plant became a symbol of Toyota's new generation factories that emphasized employee satisfaction and advanced automation technologies when it started production in 1991. After the bubble era ended, however, the plant became criticized for its high capital investment cost, which caused high fixed cost burden to Toyota when utilization ratio decreased due to the post-bubble recession.

(6) Labor Union Initiatives and The Committee on Better Work Attractiveness (1988 - 92)

Let us now turn to the union side. It had already recognized the "assembly problems" by the time when Toyota Motor Worker's Union (Toyota Roso) announced its mid-long terms action plan (Chu-choki Katsudo Hoshin) in October 1988. The assembly problem was not recognized as the central issue at this point, though. The Action Plan endorsed the following policies: (i) Reducing annual labor hours; (ii) Strengthening functions of various union-management meetings; (iii) Promoting stable shop floor unit that can respond flexibly to demand fluctuation; (iv) Programs for the issue of aging labor force; (v) Programs in response to then introduction of microelectronics technologies on the shop floor; (vi) Programs in response to internationalization of business; (vii) Others, including mental health care problems,

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assembly automation, but two of them were cut in order to separate functionally different parts (e.g., carpet and brake).

[20] Also, TMM's assembly line segments were much longer, as overall length of the main assembly line was about 1.3 times as long as that of Toyota's domestic assembly lines.

improvement of work environments. Although policies (iii), (iv) and (vii) are potentially related to the assembly issue, it was not featured as a central issue[21].

At the level of detailed programs, however, the union had already been an advocate (not an opponent) of assembly automation. Under the policy (iii), assembly automation was recognized as a means to the alleviate labor shortage problem, which the union had already predicted then, and thus respond to the upswing of production volume. The union had aimed at 20% assembly automaton ratio by 1993 and 30% ultimately.

Following the action plan, a Union-Management Meeting (Roshi Kondan-kai) on Manufacturing Issues was held in April 1989. The main agenda there were: (i) Short term measures to cope with production expansion (hiring and subcontracting); (ii) Long-term issue of making work place more attractive; (iii) Improvement of assembly process in terms of work load, work posture, job attractiveness, and aged workers; (iv) inter-plant transfer of workers. Thus, the assembly problem emerged as one of the central issue at this point.

Between December 1989 and May 1990, three additional meetings on "Assembly Work Improvement" were held between union and management. The list of agendas proposed by the union included: setting appropriate standard time and evaluation criteria; possibility of assembly automation; inter-plant transfer of workers de-stabilizing shop organizations; demanding nature of the assembly work; pressures to team leaders and group leaders due to "fire fighting" on the shop floor, and so on. Management promised to improve on the above issues.

The management became more actively involved in the "job attractiveness" issue by spring of 1990. Toyota chose "Creating Attractive Work Place" as an annual slogan of the company in 1990, and proposed a joint union-management Committee for Improving Attractiveness of Production Work in May 1990. The committee held seven meetings (June 1990 - June 1991) and five follow-up meetings (July 1991 - August 1992). Improvements of production work environment, as well as desirable assembly process design, was discussed. In 1991, Toyota articulated implementation plan for improving direct production work, including air conditioning, dirty jobs, dust, noise, and physically demanding jobs.

To sum up, the assembly problem had been addressed initially by the union between 1988 and 1989, and became a central issue to be discussed between union and management by 1990. Management started to take initiatives on this issue by spring of 1990, and it made certain action plans in a rather piecemeal manner by 1991. Toyota had not created a clear vision for future assembly processes at this point, though.

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[21] A leader of the union, in our interview (July 1995), said that it was recognizing the existence of the assembly problem when it was making the Action Plan between 1986 and 1988, but it did not highlight this problem at hat point.

(7) Project for Future Assembly Plants and Plant A's Experiments (1990-91)

In parallel with the union-management discussions mentioned above, plant managers and production engineers started to articulate concrete visions and action plans for better assembly processes. In Summer of 1990, Project for Future Assembly Plants was initiated under supervision of a high level executive in manufacturing. One of Plant A's trim lines was chosen as a "model process," where certain experiments were made. Plant A's Assembly Division, Assembly Process Engineering Division, Operations Management Consulting Office, Production Control Division, and Human Resource Division were involved in the project.

Reflecting the environment in the bubble economy era, the project addressed three background problems; labor shortage, stricter quality requirements, and impact of product proliferation (complexity) on assembly lines. Proposed solutions included improvements in shop floor organizations (e.g., strengthening functions of team leaders, group leaders and assistant managers), as well as improvements in assembly processes and work designs (e.g., simplification of job instructions, human friendly-work design).

The project continued until the end of 1991. Experiments at the Plant A's assembly line resulted in proposals on the new assembly concept aiming at (i) simper and more rhythmic job designs and (ii) better work environments (lighting, noise, ergonomics, etc.). The concept of "autonomous-complete assembly line" was not the main issue in this experiment at Plant A, though. It was discussed in another sub-group of the Project for Future Assembly Plants.

Overall, the Project for Future Assembly Plants was led mainly by the plant staff and plant engineers, while Assembly Process Engineering Division had not yet played an active role. After all, the results of the Plant A's experiments did not lead directly to the core concepts of the new assembly system at Kyushu (e.g., autonomous-complete assembly and in-line mechanical automation).

(8) Assembly Division Head Meetings (1992)

In parallel with the Project for Future Assembly Plants, Assembly-related Division Head Meetings (Kumitate Bucho Kaigi) were being held in close collaboration with the former. These Division Head Meetings, which continued after the Project for Future Assembly Plants was over, are likely to be the main arena where the autonomous-complete assembly concept (Jiritsu Kanketsu Kotei) was finally articulated at the company-wide level by 1992. At this stage, unlike the previous Project for Future Assembly Plant, Assembly Process Engineering Division, which had been significantly strengthened by then, played a leading role in developing the new assembly concept.

Motomachi plant also played a key role in shaping up this concept: There are some evidences that Motomachi plant, under supervision of Director Mr. Takahashi, had already tried a partial prototype of "complete" process deigns at one of its assembly lines in the late 1980s, where the line was not separated into short line segments, but job assignments and process sequence were oriented to parts-complete jobs for each worker, if not functionally complete ones at the group level.

(9) Toyota Kyushu: Establishment of the New Assembly Concept (1992)

Miytata Plant of Toyota Motor Kyushu, Inc. (called "Toyota Kyushu" henceforth for simplicity), Toyota's new subsidiary in Kyushu Island, is known as a place where the new assembly process concept was established as a total system. Toyota Kyushu Plant, which started production of Mark II series in December 1992, introduced (i) autonomous-complete assembly process; (ii) in-line mechanical automation for assembly; (iii) TVAL (systematic measurement of work load); and (iv) various tools and equipment for better work conditions, as a package.

In a sense, the lessons from the Tahara #4 plant fully reflected the design of Kyushu plant by the assembly process engineers[22]. Thus, there was obviously knowledge transfers from Tahara to Kyushu. Also, considering the timing of the plant start-up, and considering the fact that Motomachi (the former assembler of Mark II) was the mother plant of Toyota Kyushu, it is likely that the idea of parts-complete job designs, an element of the subsequent autonomous-complete assembly concept, was transferred from Motomachi plant[23].

As for physical plant layout, Toyota Kyushu succeeded the recent trend since TMM and Tahara #4, with 11 line segments (trim 3, chassis 2, and final 4, excluding inspection and sub-assembly lines) and buffer areas in between[24]. The building was separated from the paint shop, and its shape became closer to square, so that parts from Tokai area (the central part of Japan's main island) and those from Kyushu are received from the opposite side of the building (i.e., the TMM method). Functionally related set of tasks were concentrated in each line segment, and one group (about 20 workers) and one group leader corresponded to each segment for each shift. Continuous two shift was introduced for the first time at Toyota group factories (October 1993).

As for automation, the experiences at Tahara #4 line, both positive and negative, helped the assembly process engineers establish the in-line automation concept, which is also consistent with the philosophy behind the autonomous-complete process (see table 3 for comparing assembly automation equipment between Tahara #4 and Toyota Kyushu). Experiments for the in-line assembly automation were conducted at the same facility that was used for the off-line assembly automation experiment (1989 - 91) mentioned before.

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[22] Evaluation of Tahara #4 line had already started in spring of 1991 prior to its start-up, when basic planning of Toyota Kyushu plant was going on, according to Mr. Hisada, a leading process engineer for both Tahara #4 and Kyushu.

[23] For example, Mr, K. Kato, Plant General Manager of Kyushu Plant, was a former assembly division head of Motomachi plant when Mr. Takahashi was Motomachi Plant General Manager.

[24] It is said that basic layout of Kyushu plant was supervised by Mr. Jagawa, and then the task was succeeded by Mr. Kitano and Mr. Shiramizu in this order.

Table 3:

Process	Thara#4	Kyushu Miyata
Engine mount	Robot	In-line mechanical automation
Fuel tunk	Robot	Robot
Tire	Robot	In-line mechanical automation
Windshield	Robot	Robot
Rearshield	Robot	Robot
Front seat	Robot	Robot
Battery	Robot	In-line mechanical automation
Air conditionar	Robot	Robot

*From questionaire conducted by authors

Unlike the previous experiment, which was assigned to #1 Machine Making Division (i.e., Mechatronics Systems Division) as more or less a "show-case" model line, the in-line mechanical automation experiments were conducted by Assembly Process Engineering Division in a piece-meal manner. The equipment tested in this test site was introduced to Kyushu one after another.

Overall, The final assembly process design at Toyota Kyushu plant can be seen as a synthesis of pervious plants and experiments. Although Toyota Kyushu does not represent the ultimate form of Toyota's new assembly lines, it is certainly the first systematic outcome of the evolution.

Another important feature of Kyushu plant is that the system introduced to this plant took into account its transferability to the plant renovation cases, as well as new plant constructions. As Toyota's domestic plants need renovation one after another, adaptability to the renovation cases was much emphasized in the plant design of Toyota Kyuhsu.

(10) TMM II: Transferring the Concept to Overseas (1994)

The assembly concept established at Kyushu was partially transferred to some overseas transplant including the TMM's #2 line in Kentucky (1994) and TMCA's new plant in Australia (1994). TMM #2, whose basic planning started almost at the same time as the Kyushu Plant, adopted the same element of the new assembly system, but only selectively[25]. As for plant layout, TMM #2 was very similar to that of Kyushu: near square assembly building separate from paint shop; 12 line segments (trim 3, chassis 5, final 4) with buffer areas in between. It did not adopt most of the in-line automation equipment that Kyushu introduced, although space for future automation has already been prepared. The major reason for this decision, besides the constraints of capital equipment spending, was insufficient capability of TMM's maintenance people that results in higher down time than the case of Toyota's assembly plants in Japan, according to TMM's plant coordinators. When their capability increases to a sufficient level, it would consider introduction of more assembly automation.

The function of the assembly line layout is also different from the Kyushu case. First of all, although the line segments corresponds to work groups, capabilities of TMM's group leaders have not fully developed as of the mid 1990s, so that TMM cannot exploit the full potential of the multi-segment layout for higher group autonomy, according to Mr. Kitano, President of TMM. Thus the first thing to do is to develop capabilities and attitudes of the leaders for self-management of the groups.

To sum up, although certain physical aspects of the new assembly concepts were transferred to the transplants, deliberate modification and reinterpretation of the system

[25] Mr. Shiramizu took charge of the plant planning of both Kyushu and TMM II.

was necessary because of the difference in environment sand capabilities between the Japanese and overseas plants.

(11) Motomachi #2 Assembly Line: Application to Existing Plants (1994)

Toyota Motomachi #2 plant (producing RAV4), renovated in 1994, is the first case that Toyota's new assembly concept was applied to a renovation of the existing assembly plant[26]. As for the autonomous-complete concept, the Motomachi layout was less drastic than the Kyushu case, because the former had to use the existing building, which is long and attached to the paint shop: Toyota's traditional plant layout. Thus, Motomachi #2 line was separated into 5 segments (trim 1, chassis 2, and final 2), each of which is longer and corresponds to two work groups, not one.

As for in-line mechanical automation, on the other hand, the new Motomachi line shows some incremental improvements compared with Kyushu. For example, jigs, pallets, and automated equipment for engine installation have become even simpler and more compact at Motomachi. There were also some new applications of automation for better work posture (e.g., automated detachment of guide caps for tire installation).

Overall, the case of Motomachi shows an interesting combination of realistic approaches to cope with the constraints of renovations on the one hand, and continued evolution of the assembly technologies on the other hand. This pattern will be repeatedly observed in Toyota's other assembly plants, which will be renovated one after another in the near future[27].

3.3 Patterns of System Evolution

Having illustrated the historical events in chronological order, let us now analyze the patterns of organizational problem solving and learning. Following the standard framework of problem solving, we will first examine the process of problem recognition about the labor issue, then move on to generation and evaluation of alternative plans in several components of the new system (autonomous complete line, in-line mechanical automation etc.), and finally summarize the overall patterns.

(1) Problem Recognition

While the changes in the product market (the end of the growth era) and financial performance after 1990 was obvious to Toyota's organizational members, the changes in labor market was much more subtle and equivocal. We will therefore focus on organizational problem recognition of the labor issues.

[26] The new Motomachi #2 line is said to have been designed under supervision of Mr. Shiramuzu, and the handed over to Mr.Kitano, Motomachi Plant General Manager then.
[27] For example, Toyota's Motomachi Crown assembly line was renovated in the same spirit in 1995. Tahara #1 line is also under renovation as of 1995.

The problem related to attractiveness and employee satisfaction in manufacturing, particularly on the assembly lines, seems to have been recognized first by labor union in the late 1980s[28]. When Toyota Motor Worker's Union (Toyota Roso) announced its mid-long terms action plan (Chu-choki Katsudo Hoshin) in October 1988, reduction of labor hours, new policies for aging workers, and absorption of excess labor demand were clearly depicted, but "attractiveness of work" was not explicitly pointed out[29]. While quantitative aspect of labor shortage was much emphasized, the concept of assembly automation for better quality of work environment had not been articulated.

Attractiveness of the company and its shop floor, particularly in assembly process, was chosen as an agenda at the Union-Management Meeting (Roshi Kondan-kai) on Manufacturing Issues in April 1989, which was presumably the first official meeting where the "assembly line problem" (its attractiveness, work posture, and work load) was explicitly addressed. In the subsequent meetings on "Assembly Work Improvement" between union and management, the main issue was still quantitative labor shortage, but qualitative aspects of job attractiveness became an increasingly important agenda.

As mentioned before, Toyota's management became actively involved in the "job attractiveness" issue by spring of 1990, when it took initiative in creating the joint Committee for Improving Attractiveness of Production Work in May 1990. The Committee was coordinated by Human Resource Division, whereas Assembly Process Engineering Division, was not included in the main Committee[30]. Improvements of production work environment, as well as desirable assembly process design, was discussed.

Toyota's management side keenly recognized the assembly problem in 1990 to 1991 partly as a result of the alarming result of the opinion surveys that Human Resource Division had conducted bi-annually since the 1970s, as well as the turn-over record[31]. That is, turn-over ratio jumped up (particularly at the final assembly lines), and workers' subjective evaluation of job satisfaction and self-esteem dropped sharply. Thus, the early and qualitative information from the union, as well as subsequent quantitative data that Human Resource Division collected that were reconfirming the problem, triggered a consensus-building process on the work attractiveness issue.

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[28] The pressure of labor shortage itself had been recognized as a chronic problem for Toyota during the high growth era. Also, criticism against Toyota's assembly job is not new (See, for example, Kamata, 1973). Thus, it is likely that the problem was recognized by certain organizational members for a long time. This paper will, however, focus only on the process that such problems became issues to be discussed at the company-wide basis.

[29] The plan was prepared between 1986 and 1988.

[30] Production Engineering Administration Dept. was included, instead.

[31] Some plant managers were apparently recognizing the problem earlier, though. A former assembly dept. head, for example, says he recognized the problem when the number of temporary workers increased in the late 1980s. Relatively low morale of the young temporary workers at that time made him realize that the mind set of the young generation is changing, and that assembly process has to be changed accordingly.

Also, the Project for Future Assembly Plants, which Assembly Process Engineering Division, Operations Management Consulting Office, Product Control Division, and Human Resource Division were involved, may have functioned as the mechanism through which the awareness of the assembly problem was diffused among different divisions. Assembly-related Division Head Meeting was another means for coordinating an exchanging information among different divisions[32].

The communication between the shop floor organization and assembly process engineers were also strengthened in the early 1990s, facilitating diffusion of the knowledge from the shop floor to engineering depts. In 1992, for example, core members (section head level) of the Assembly Process Engineering Division were dispatched to work on actually the assembly lines to gain direct experiences about the work load and fatigue on the assembly line. This helped the process engineers acquire tacit knowledge on the nature if the assembly work, which was used subsequently for development of TVAL.

To sum up, the problems in assembly lines, which existed at least potentially o the shop floor for a long time, was recognized as a main issue for the company first by labor union in the late 1980s, while the management side, interfaced by Human Resource Division, became increasingly concerned about the problem around 1990. This problem awareness was subsequently diffused to other sections through the Project for Future Assembly Plants, Assembly head Meetings, participation of process engineers in direct assembly work, and so on. Also, it should be noted that the focus of the issue shifted from quantitative aspect of labor shortage to qualitative (and more profound) aspects of the problem. Thus, organizational problem awareness itself evolved over time in terms of both width and depth.

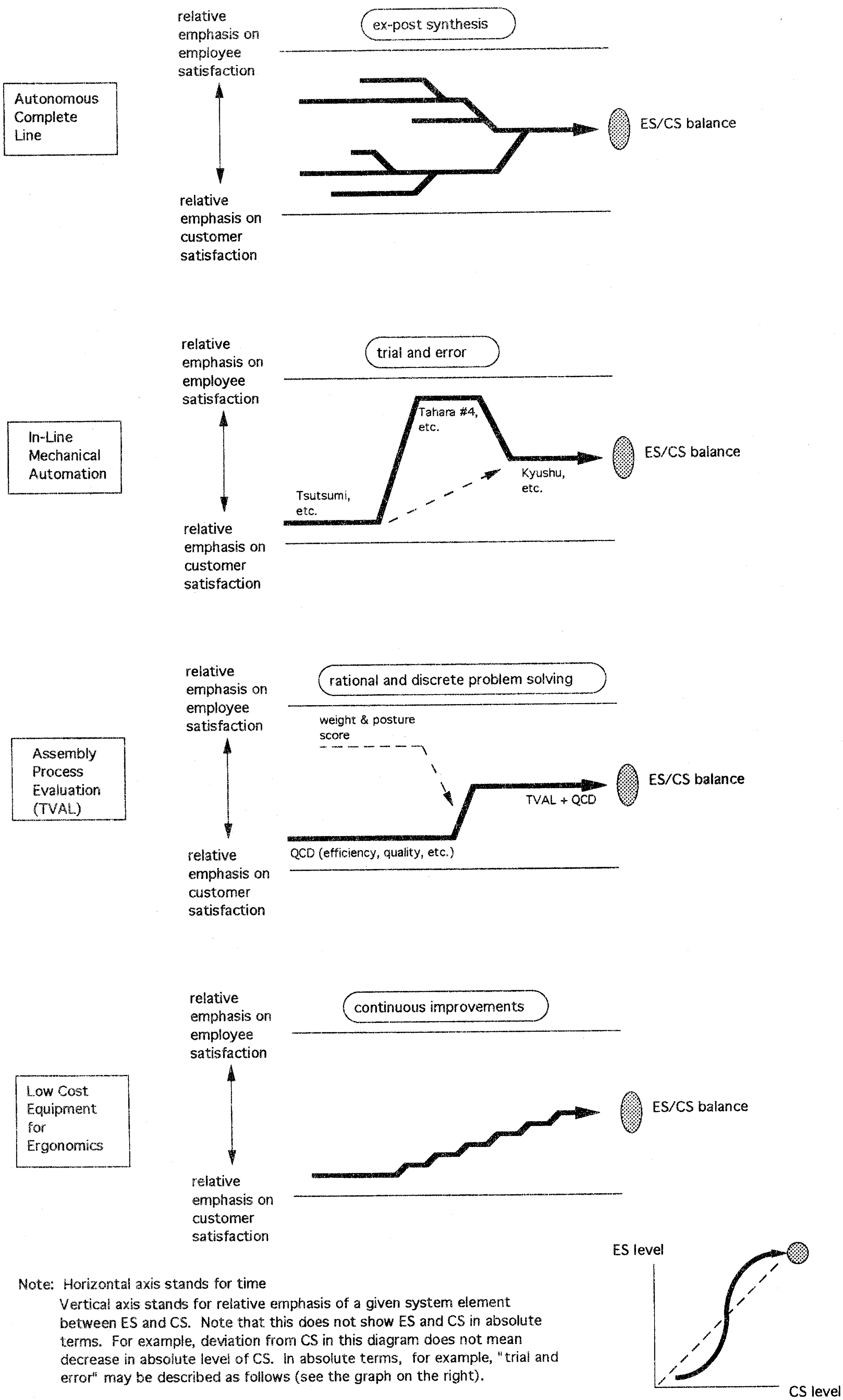
(2) Autonomous Complete Process: Ex-post Synthesis

The foregoing historical analysis of the new assembly concept indicates that there are various patterns of evolution (figure 8). Let us now examine different patterns in the cases of autonomous-complete process, in-line automation, TVAL, and ergonomic devices.

The case of the autonomous process may be summarized as "ex-post synthesis." That is, the system concept emerged as a result of synthesis of various elements, each of which were developed for various reasons. Some of the elements were not developed as components of the autonomous system, but were reinterpreted and adopted after they were developed. In this sense, the evolution of the autonomous-complete line appears to be "ex-post synthesis" (figure 8).

[32] Assembly Dept. Heads of seven factories, as well as heads of Human Resource Dept.. Assembly Process Engineering Dept., Safety and Health Management Dept.., Production Control Dept., and Operations Management Consulting Office were the members of the Assembly-related Division Head Meeting as of 1990.

Figure 8 Types of Evolutionary Paths toward ES/CS Balance



Note: Horizontal axis stands for time
Vertical axis stands for relative emphasis of a given system element between ES and CS. Note that this does not show ES and CS in absolute terms. For example, deviation from CS in this diagram does not mean decrease in absolute level of CS. In absolute terms, for example, "trial and error" may be described as follows (see the graph on the right).

For example, TMM in Kentucky already had multi-segment and buffered assembly lines, but it was developed apparently for logistics reasons, not as an element of the autonomous process. Tahara #4 line was also multi segment with buffer areas, but the concept of autonomous and complete assembly process was not linked to this layout (see figure 9).

In the Project for Future Assembly Plants, "short assembly line" concept had already been discussed and reported in summer of 1990. The discussion was headed by Mr. Shiramizu, head of Assembly Engineering Division Head then. By the end of 1991, the "Vision" Project was completed. "Complete Assembly Process" had already examined by then, but it was not the main concept yet at this point. Simplification of the assembly jobs to absorb variation proliferation seems to have been more emphasized.

As a part of the Project for Future Assembly Plants, Plant A's Model Line highlighted simple job designs to cope with increasing product variety and complexity, and it addressed the issue of group leaders and team leaders, but they did not articulate the autonomy-complete concept. The Motomachi experiment in the late 1980s did address the issue of "complete" job for each component at the level of individual workers, but it did not articulate the "autonomous" assembly line concept at the work group level[33]. The Motomachi trial was made on conventional assembly lines.

By summer of 1992, the concept of "complete assembly process", as well as its main functions (morale, self actualization, quality improvement) was articulated in the Assembly-related Division Head Meetings, as well as the plant design process for Toyota Kyushu by the Assembly Process Engineering Division For example, the word "complete assembly line" appeared for the first time in union document in August 1992, where management responded that "complete line" had been discussed at the Assembly-related Division Head Meetings[34].

After all, it was Toyota Kyushu plant (December 1992) that finally combined physical, functional and organizational elements of the new system and crystallized them as autonomous-complete assembly process. But there were many predecessors before the final synthesis occurred.

(3) <u>In-line Mechanical Assembly Automation: Trial and Error</u>

The evolutionary pattern of in-line mechanical automation was very different. Unlike the cumulative synthesis observed in the case of the autonomous line, this case looked more dialectic (figure 8). The trajectory started with Toyota's traditional "low cost automation" concept (Fujimoto, 1993), which did not pay much attention to employee satisfaction itself. Then it swung to human-fitting "off-line high tech" automation, which responded to the employee satisfaction issue, but created fixed cost burden to the

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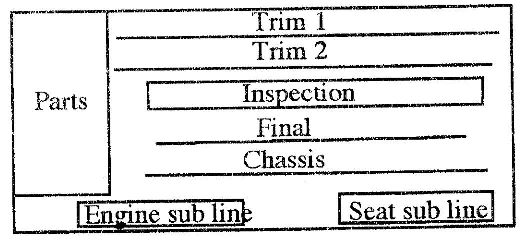
33 Note that the origin of the "parts-complete" concept and the "autonomous" concept are different.
34 Motomachi plant took initiative in this theme.

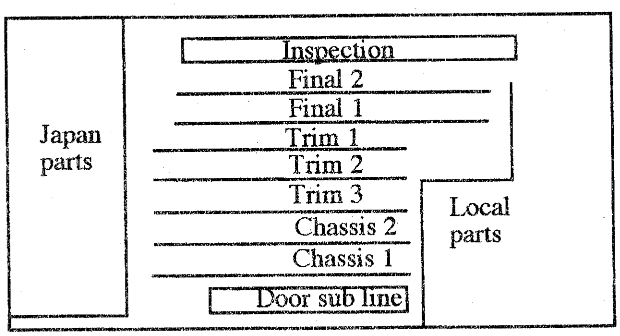
*Rough scale

Takaoka #1



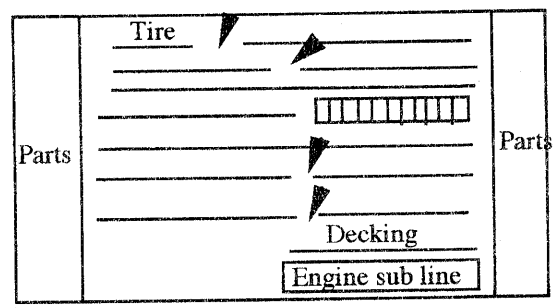
Parts are supplied from only left side.

TMM# 1



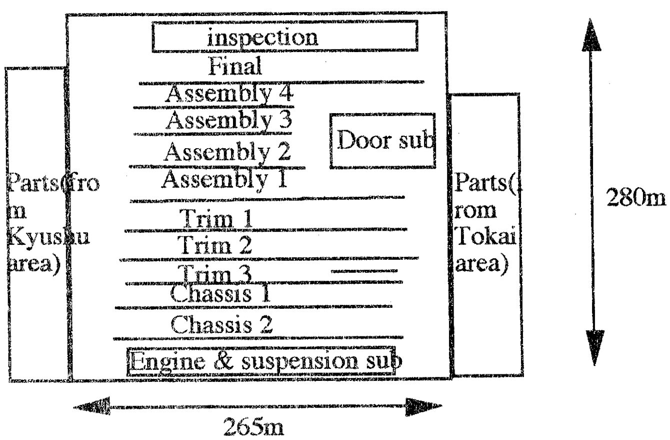
Parts are supplied from both sides.

Tahara #4

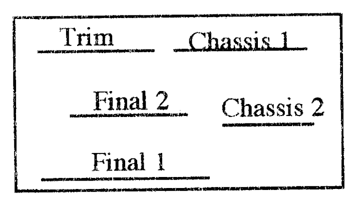


Lines are divided at ▲.
Parts are supplied from both sides.

Kyushu Miyata

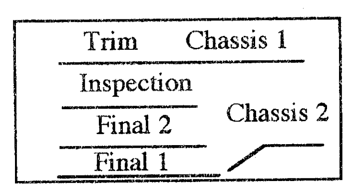


Motomachi #2 (new)



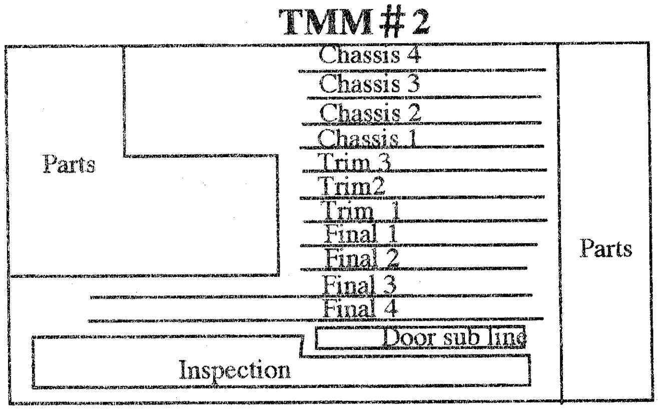
Trim and Chassis 1 are divided.
Inspection process is in other building

Motomachi #2 (old)



Trim and Chassis 1 are connected.
There is the inspection process in the building.

TMM#2



Source: Interviews, *Koujoukanri* (in Japanese, '*Plant Management*'), bulletin of Toyota company. Then there was another swing toward better balance between customer satisfaction and employee satisfaction: in-line mechanical automation.

There were at least two different motivations for the previous off-line automation concept which was pursued in the assembly automation experiment in 1988 to 1991. First, production engineers' desire to develop and implement advanced technologies, stimulated by the European cases of FIAT and VW, is often pointed out. Such a "technology push" approach may have also been promoted by the culture of Tools and Equipment Development group (#1 Machine Making Division; now Mechatronics Systems Division), which naturally tends to be equipment-oriented rather than process-oriented.

The second major motivation for drastic assembly automation in the experiment of 1988 to 1991 was to absorb excess labor demand that had been predicted then. In 1989, for example, Toyota predicted that it would need six thousand more employees in the next five years, and that it would have to absorb a half of this shortage by automation. Thus, the fear of labor shortage, both by management and by union, led to the idea of maximizing automation ratio at any cost. Favorable financial conditions of the bubble era also amplified this mood for maximizing automation. As production volume started to decrease and cash flow shrank, this motivation clearly retreated.

Assembly automation at Tahara #4 line has at least three origins: (i) rather small scale assembly automation developed gradually by Assembly Automation Division (e.g., gas tank, battery, air conditioner, etc.); (ii) large scale automation tested for the first time at the off-line automation experiment by #1 Machine Making Division (e.g., decking, tire, etc.); (iii) other sources such as foreign auto makers (e.g., wind shield sealer). The path (ii) tended to be emphasized, though.

As for assembly automation at Tahara #4, there are two different views even among production engineers at Toyota. The first view emphasizes discontinuity between Tahara #4 and Toyota Kyushu, regards automation at Tahara #4 as a deviation from traditional Toyota philosophy, and see the in-line mechanical automation at Kyushu as return to basics of Toyota's automation philosophy. The cases of engine installation and tire installation, gigantic off-line systems with expensive vision sensing for alignment, are often cited as examples of the sharp difference between Tahara concept and Kyushu concept. Thus, the first view tends to see Tahara #4 as a "straw man" while highlighting legitimacy of the in-line mechanical automaton.

The second view, by contrast, emphasizes continuity between Tahara and Kyushu, points out that Toyota constantly made trial and error in developing its production systems in the past, see the above case of engine and tires as just another example of Toyota's trial and error, and insists that the main stream of assembly process designs at Tahara were on the right track of evolution.

In a sense, the first view is a "paradigm shift" hypothesis, while the second is a "progressive evolution" hypothesis. Both camps, however, appreciate the value of assembly automation at Tahara Plant #4 as precursor of the in-line mechanical automation at Kyushu plant. In other words, even those who are criticizing Tahara's automation concept normally admit that Tahara's automation experiments enabled the new automation concept at Kyushu and Motomachi.

In any case, the lessons of off-line high-tech automation at Tahara #4 line, which had been clear by spring of 1991, was fully taken into account in the basic design process of Toyota Kyushu's in-line automation by the assembly process engineers. Note also that the experiments for in-line assembly automation were conducted by the Assembly Process Engineering Division, as opposed to #1 Machine Making Division (Mechatronics Systems Division) that took charge of the off-line automation experiments, which may reflect the shift from the equipment-oriented (technology-push) approach to the process-oriented (demand-pull) approach for assembly automation at Toyota.

(4) <u>TVAL: Rational and Discrete Problem Solving</u>

The case of TVAL shows a smooth pattern of ex-ante rational problem solving, rather than ex-post synthesis (i.e., autonomous line) or dialectic trial and error (i.e., in-line automation). That is, TVAL was developed by engineers in Assembly & Design for Manufacturing Engineering Division in response to a clearly defined goal of developing a systematic tool for measuring work load from physiological or ergonomic point of view (Shibata et al., 1993)[35]. TVAL was also based partly on existing scientific knowledge in the academic community, partly on Toyota's existing measurement system (posture and weight scores), and partly on deliberate experiments that the engineers conducted. Although there may have been trial and error at the microscopic level, it would be possible to regard development process of TVAL as a cycle of ex-ante rational problem solving by process engineers.

In a broader context, development of TVAL may be regarded as an evolutionary path of Toyota's systems for measuring and evaluating assembly processes and tasks. In the past, Toyota's evaluation criteria were concentrated almost exclusively in the domain of customer satisfaction, such as efficiency, quality, delivery, and flexibility, as well as their improvements. It was argued that Toyota system was human-oriented, but this simply meant that value of human activities can be enhanced by reducing non-value activities (muda). Thus, reducing "muda" almost automatically meant increasing productivity and increasing human value at the same time in the tradition of Toyota

[35] Mr. Shiramizu, Dept. head and director in charge of assembly process engineering since 1992, took a clear leadership in development of TVAL. He insists that current TVAL, as of 1995, is only 60% complete, as it does not capture full aspects of assembly work load and fatigue. TVAL needs further development, according to him.

Production System. her was no independent criteria that measure employee satisfaction or job attractiveness.

In the final assembly area, also, efficiency was the most important criterion for evaluating shop floor performance. There was an index that measured work load for each task, called work posture and weight score, developed by Safety and Health Administration Division, but this was virtually a minimum standard from illness' point of view. In this regard, development of TVAL can be seen as the company's rational efforts to balance evaluation criteria for customer satisfaction and those for employee satisfaction in response to the changes in the labor market (figure 8) .

(5) Equipment for Better Work Posture: Continuous Improvements

Finally, let us examine the patterns of various low cost equipment and tools for better ergonomics, such as "raku-raku" seat, wagon carts, power assist tools, etc. The cases of recent human-friendly factories indicate that the framework of continuous and company-wide improvements (i.e., Kaizen), which is one of Toyota's traditional capabilities, can be directly applicable to the case of such tools and equipment for better work posture, better work environments and lighter work load (see figure 10 as example of Kaizen for better ergonomics). Based on the objective evaluation of each job and each task by TVAL and other measures, workers, team leaders, group leaders, maintenance workers, plant engineers, and so on, are individually or collectively create or modify systems for better ergonomics on continuous basis, just like Toyota's ordinary Kaizen for quality and productivity.

For example, Toyota Kyushu plant, after its production started in 1992, has continued improvements on this direction. In 1993, the plant started to introduce wagon carts, and solved an alignment problem at the tire automation equipment by Kaizen; In 1994, it introduced four raku-raku seats, and increased the number of wagon carts that are designed mostly the workers; In 1995, adopted two hour job rotation, and developed a tool for interior parts, both for ergonomic purposes. As a result of these and other efforts, the number of high work load jobs (TVAL score > 35 point) decreased gradually from 95 in 1993 to 89 in 1994, and to 85 in 1995.

In this way, low cost tools for better ergonomics help the assembly shop floor achieve a better balance between customer satisfaction and employee satisfaction through a path of incremental improvements (figure 8).

(6) Summary of the Evolutionary Process

We have analyzed the patterns of evolutionary paths for different elements of Toyota's new assembly system, including autonomous-complete assembly line concept, in-line-mechanical automation, TVAL for measuring work load, and low cost equipment for better ergonomics. Four different patterns of system evolution were identified,

* Toyota Motors Kyushu

IP ⑰

改善事例

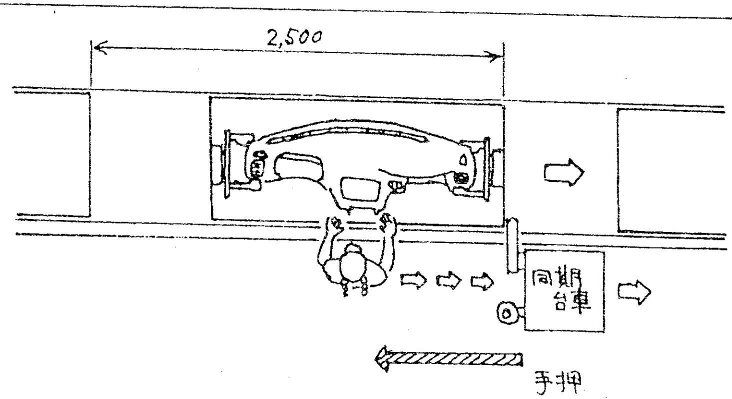
7年4月18日 総組立部

テーマ	同期台車の改善

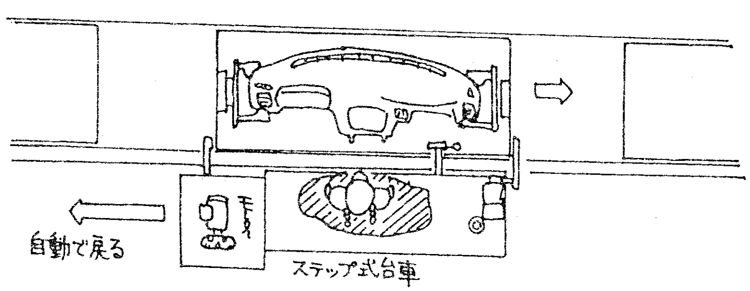
＊改善のねらい

歩行数の低減
女子工程の作業疲労度の軽減

改善前



改善後



効果	作業性・安全性の向上	投資額	部品 .万＋人件費 万＝計 万円

□品質 □安全 □原価

改善事例

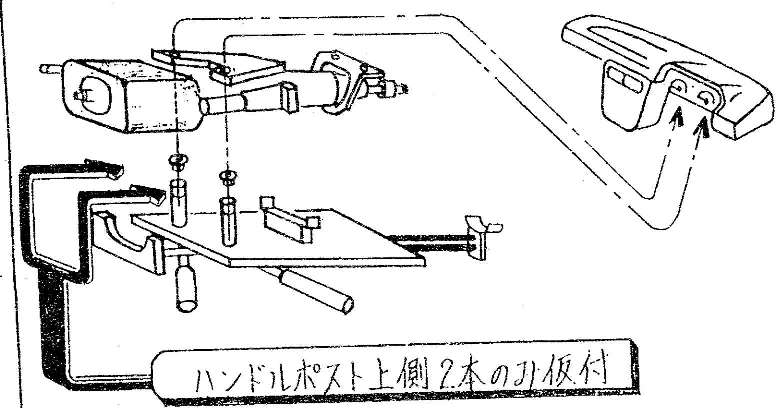
7年8月7日 総組立部

テーマ	ステアリングポスト 仮付補助装置の改良による作業性の向上

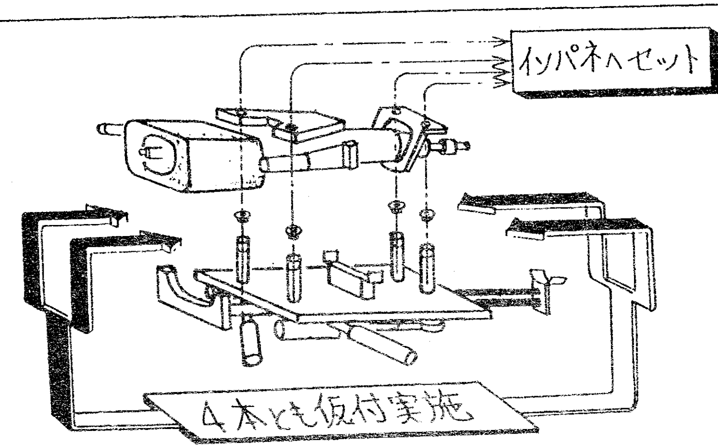
＊改善のねらい

① 下側仮付時 腰への負担大であった。
② 仮付しにくく作業性がとても悪るかった。

改善前



改善後



効果	① 仮付工数低減	投資額	

提案者： 組 氏名

corresponding to the four elements of the system: ex-post synthesis, trial and error, rational problem solving, and incremental improvements (figure 8). Thus, we can summarize the foregoing analyses as follows:

(i) Variety in the Evolutionary Paths: The first conclusion is that there is no single pattern that can summarize the emergence of the new assembly system at Toyota. We can infer from this pattern that Toyota's distinctive evolutionary capabilities do not lie in its specific way of controlling system changes. Toyota's dynamic capability in this case may be a more generic ability to harness various evolutionary patterns, including rational and discrete problem solving, continuous improvements, dialectic paths of trial and error, or more chaotic process of ex-post synthesis.

(ii) Consistency in Ex-post Rationality: Despite the variety of the evolutionary trajectories, the function of the resulting system seems to be quite consistent in that all the elements of the new assembly system are aiming at better balance between customer satisfaction and employee satisfaction. In a sense, they are coherent components of what the authors may call "lean-on-balance" production system (Fujimoto, 1994a; Fujimoto and Takeishi, 1994).

(iii) Export Capability is Key : What follows from the above discussion is that Toyota's evolutionary capability is ex-post capability (Fujimoto, 1994b). As explained earlier, by ex-post capability we mean the ability of an organization to integrate intended or unintended trials that have been already made, refine them or reinterpret them, and make a coherent and ex-post rational system out of them. The foregoing cases also indicate that Toyota has ex-ante rational capabilities (i.e., capabilities of making rational choices before it makes trials) in some cases, but it cannot rely on the ex-ante rationality in all cases. Ex-ante rationality is not a necessary condition for explaining ex-post rationality of a system, either. When we observe a variety in the paths of system emergence and consistency in the rationality of the resulting system, what matters is, after all, an ex-post capability of the firm.

3.4 Anatomy of Toyota's Dynamic Capability

We have so far identified various patterns of the system evolution in the case of Toyota's new assembly concept, and argued that what is essential in this case is Toyota's ex-post dynamic capability. By ex-post capability we mean firm-specific ability to build a certain system that are ex-post rational out of elements of various origins. In the present case, we have illustrated different patterns of evolutionary trajectories (ex-post synthesis, trial and error, ex-ante rational problem solving, etc.) in the case of different elements of the system (autonomous lines, in-line automation, TVAL, etc.).

A question that still remains, however, is what constitutes Toyota's unique and dynamic capability in this case. Although we need further empirical researches to answer this question, we propose some preliminary ideas here.

(1) Variety of Opinions inside Toyota

The foregoing description of the system evolution does not fit the stereotyped view that Toyota is always a monolithic organization. In many aspects of environmental perceptions, evaluation of alternatives, and interpretation of solutions, there seem to be significant disagreements inside Toyota. For example, the problem of assembly work attractiveness appears to have been recognized by different organizational units at different timings. The problem that assembly line work is not attractive enough (or even boring, tiring, meaningless, and self-alienating) apparently existed at least potentially or partially on the shop floor, but neither management nor union recognized it as a central issue until the late 1980s, when union leaders, through their direct channels with its rank-and-file members. Human Resource Division, through its communications with the union, as well as alarming results of its own surveys on employee satisfaction and turn-over ratios, recognized it as a critical issue. Most of the managers and engineers in other parts are likely to have lagged behind them.

There have been also disagreement in evaluation of the assembly automation at Tahara #4 line, even among production engineers, as described earlier. Some argue that the plant was a symbol of Toyota's mismanagement in production engineering, which was influenced by the atmosphere of the bubble economy. For them, Tahara #4 is a temporary, but significant, deviation from Toyota's manufacturing tradition, and was subsequently overcome by a newer assembly concept represented by Kyushu and Motomachi.

Others, however, insist that assembly technologies at Tahara #4 essentially belong to the main stream of Toyota's evolutionary trajectory. They insist that there were only a few cases of obvious over-automation, namely tire and engine / transmission installation, which they think were exaggerated. For them, such trial and error itself is nothing but the tradition of Toyota engineering.

Still another example of disagreement is found in the evaluation of the new assembly line concept itself. For those who emphasize continuity of Toyota Production System (TPS), the new assembly concept is just another variation of TPS. For them, TPS has always pursued both efficiency and human dignity, and so does the new assembly system. For those who emphasize discontinuity, however, the recent trend is a departure from traditional Toyota Production System, in that the new assembly concept identified employee satisfaction as an independent value from efficiency for the first time. One manager described it as "amendment of Toyota's constitution."

(2) Shared Views in Evaluation of the Result:

Despite the variety of views in various aspects of decision making for changing the assembly concept, we also found that the evaluation on the resulting assembly system has been strikingly uniform among different organizational units: All of those whom we interviewed, including Production Engineers, Operations Management Consulting staff, Human Resource Managers, Plant General Managers, Union Leaders, Plant General Managers, Groups Leaders, Team Leaders, said they liked the new assembly system, and highly evaluated it. Some may ascribe this to the Toyota's culture of strong group conformity, but then we cannot explain the existence of significant disagreements in other areas mentioned above.

There is also a striking conformity in the interpretation of the current labor environment among managers, engineers, and union leaders at Toyota: all of those whom we interviewed regarded the needs for attractiveness of the work places as a long-term objective despite recent recession and potential labor surplus. They all explained that the assembly line problem was revealed by the labor shortage at the bubble economy era, but the problem itself exists regardless of economic booms or recessions. Thus, managers, engineers and union leaders all share the long-term commitment to higher employee satisfaction.

In this regard, what we may have to explain seems to be the paradox that exists between disagreements in the system evolution process and agreement in the results of the process.

(3) Organizational Mechanisms for Convergence:

What is inferred from the above paradox of disagreements and conformity at Toyota is that this company may have an effective convergence mechanism that can quickly convert a variety of organizational elements into a coherent system. Although the this paper cannot present sufficient evidences, we identify at least three elements of this organizational capability: shared basic value, horizontal convergence, and vertical convergence.

(i) Shared Value and Evaluation Criteria: Toyota is often said to have a basic value shared by its members. Although it is seldom articulated, the basic value may be described as customer-orientation, cost-consciousness, spirit of manufacturing (mono-zukuri), and so on. It may be ascribed to the philosophy of Toyota's entrepreneur-founder Sakichi Toyoda or Kichiro Toyoda, or to the heritage of Ford Production System, or it may have been shaped up a result of day-to-day activities in TPS or TQC. In any case, it is likely that Toyota has a stable and commonly shared value that are deeply ingrained among many of its members, despite changes and varieties in specific opinions and practices on the surface (Mishina, 1995).

(ii) Vertical Convergence: Quasi-Market Mechanism inside Organization: Shared values may not be enough to explain Toyota's unique organizational capabilities in system evolution. We suspect that, in addition, there are certain strong "convergence mechanisms," both vertical and horizontal, at Toyota (figure 11). By vertical convergence we mean a "quasi-market" of new ideas that appears to exist in the production area. In this case, the shop floor organizations (seisan-genba), whose core part consists of group leaders (kumi-cho) and team leaders (han-cho), have ultimate legitimacy to choose new production ideas. The analogy that Toyota often uses, "the downstream process is your customer." is applied to the case of new production ideas.

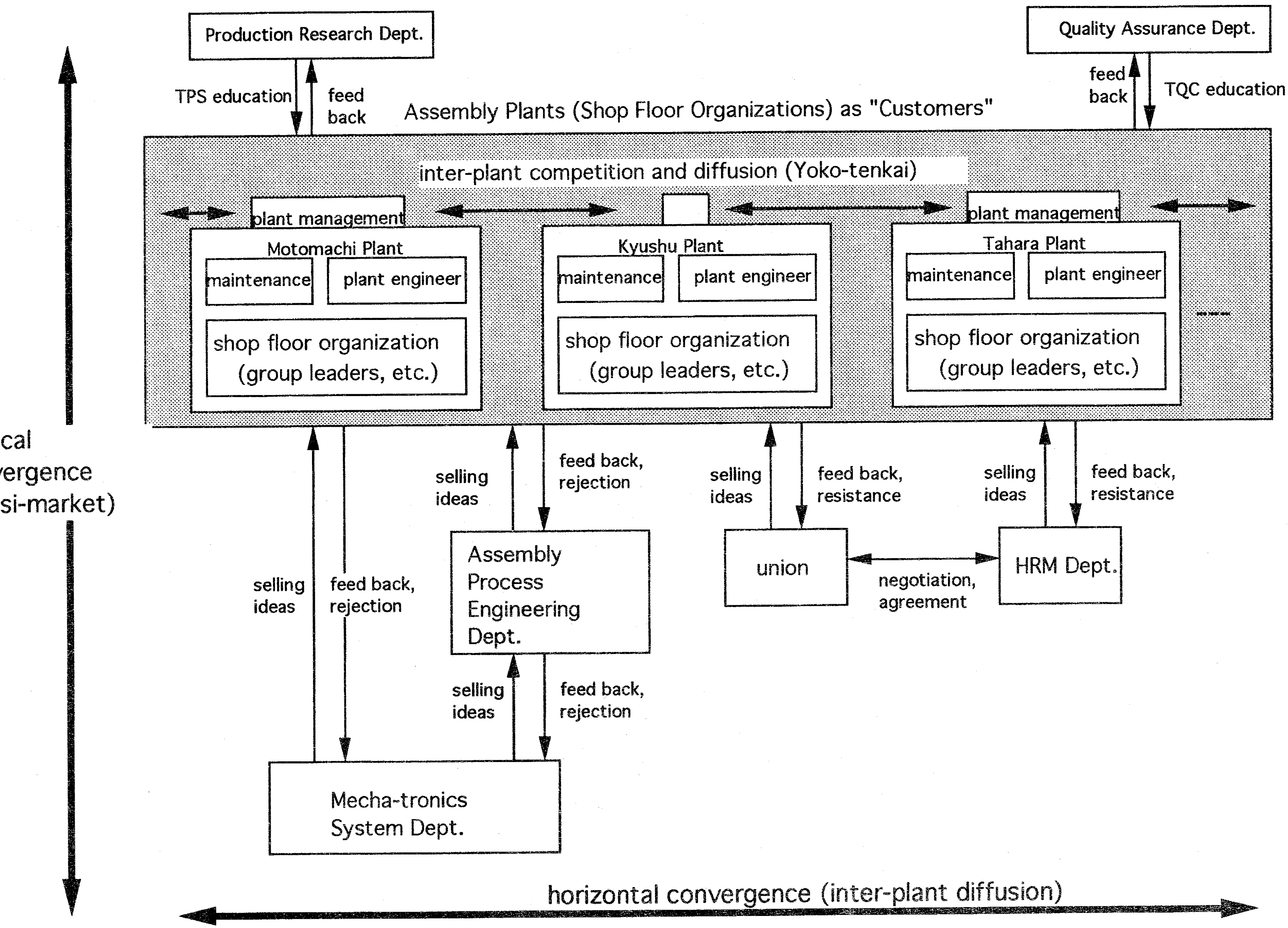
In the case of new production equipment, for example, production engineers have to "sell" the new idea embodied in the equipment to the shop floor organization. Just like customer sovereignty, the shop floor organization (genba) is said to make a final judgment on whether they accept it or reject it. if the equipment does not fit their way of making things, it may be literally discarded or ignored. We have actually heard about some cases in which such scrapping of new equipment happened in the past. This sharply contrasts with many other manufacturers, where plant equipment, once installed is sacred, untouchable, and, of course, un-removable from the shop floor's point of view.

One important aspect of this quasi-market of new production ideas is that the shop floor organizations themselves are customer-oriented partly as a result of continuous penetration of Toyota Production System there. Operations Management Consulting Division, TPS shusa at the plant and other educators and promoters of TPS keep on refreshing this concept. In a sense, it may be possible to say that Toyota's shop floor organization represents both employee's and customer's interests.

Facing this type of shop floor organizations, production engineers tend to become "customer-oriented" and try harder to develop production technologies that are more friendly to the shop floor people. The comments of Toyota's engineer at Vehicle and Design for Manufacturing Division that he is process-design-oriented rather than equipment-oriented, and that he emphasizes shop floor efficiency over automation ratios, seem to be consistent with the above description of the "supplier-customer" relations between production engineers and shop floor organizations. Also, some plant managers say that the cases of the plant people throwing away new equipment that production engineers installed has become rare in recent years, indicating that production engineers have become shop-floor-oriented.

Another recent example of the shop floor sovereignty (genba-shugi) is the introduction of the continuous two shift system to Toyota's two shift factories. The continuous two shift was introduced to new Toyota Kyushu Inc. in 1992 and was well received as a worker-friendly arrangement. Both union and management at Toyota Motor Corporation, Toyota Kyushu's mother company, quickly agreed that it should also

Figure 11 Convergence Mechanisms at Toyota's Manufacturing Organizations (Assembly)



introduce this system. Despite this consensus between both union and management, it took them about two years to finally introduce the continuous two shifts in 1995. This was because the shop floor people were not persuaded easily. They tended to be afraid of changes in life style, loss of over-time premiums, and other negative aspects of the new system. The union and Human Resource Division, using their respective channels, approached to the shop floor and tenaciously tried to persuade them. This anecdote seems to more than indicate that new system cannot be introduced without shop floor consensus (particularly that of group leaders, team leaders and veteran workers) at Toyota. This kind of shop floor veto power in the quasi-market inside the company may facilitate the vertical convergence process.

(iii) Horizontal Convergence: Inter-plant Exchange of Information Once a promising production ideas, that may be accepted by the management, union and shop floor, they tend to be quickly disseminated across the plants through various channels, including special projects, management-union meetings, manager meetings at the corporate level (e.g., Assembly Division Head Meeting), special projects, rotation of Plant General Managers (production executives), and so on. At Toyota, horizontal expansion of new ideas, policies and technologies across the plants is often emphasized as "yoko-tenkai" or "yoko-ten."

To sum up, what constitute Toyota's evolutionary capability is difficult to articulate, but certain co-existence of organizational variety and conformity, which is linked by effective convergence mechanisms, both vertical and horizontal, seems to explain at least partially why Toyota historically tended to outperform the other Japanese makers in somehow coming up with coherent, rational and new systems (Fujimoto, 1994b). Further empirical and historical researches would be needed to confirm this, but the current case of the new assembly automation seems to be at least consistent with this description of Toyota's dynamic capabilities.

(4) Standardization and Documentation

Finally, it should be noted that a part of Toyota's dynamic capability may be ascribed to standardization and documentation, which are often regarded as components of bureaucracy and as counter-active. As shown in its Kaizen activities and company rule systems, Toyota is a company that have highly standardized routine problem solving processes (e.g., continuous improvements) and developed documentation systems (a kind of organizational memory storage). Although they may sound contradictory to dynamic capability, we would argue that standardization of regular problem solving and systematic documentation of the results are essential components of dynamic capability.

In this sense, we do not follow a stereotyped dichotomy that simply contrasts bureaucracy and innovation. After all, repetition (i.e., standardization) and retention (i.e., organizational memory in the form of documents and others) are basic elements of the evolutionary process.

4 Implications

The present paper explored Toyota's new assembly automation systems that emerged from the environmental changes since the late 1980s. We have identified components of the system, including the autonomous-complete assembly line, the in-line mechanical automation concept, TVAL, and low cost equipment for better ergonomics, and explained its ex-post rationality in terms of balancing customer satisfaction and employee satisfaction.

Through this analyses of Toyota's recent history in assembly operations, we have derived some implications. First, we argue that Toyota's distinctive capabilities in manufacturing include not only static capability and improvement capability of the existing system (e.g., TPS and TQC), but also dynamic capabilities of making new systems (Fujimoto, 1994b). In other words, Toyota's capability of facilitating system evolution process should be emphasized.

Second, the system change does not always result from deliberate and rational decision making processes. Trial and error, disagreements, unintended success, and ex-post synthesis of ad hoc elements are quite common in the evolutionary process of manufacturing systems, even when the resulting new system appears rational. In this sense, Toyota's distinctive dynamic capabilities include ex-post capabilities.

Third, the stereotypical notion that Toyota is always a monolithic organization seems to be a myth. Although there is a striking uniformity in some core values and philosophies, there are also disagreements in other areas, particularly when major system changes occur. This paradox has to be explained in order to understand the essence of Toyota's dynamic capabilities.

Fourth, both vertical and horizontal convergence mechanisms seems to be functioning, bridging the variety and conformity mentioned above. Vertical convergence means a certain quasi-market mechanism, where shop floor organization has "consumer sovereignty" for new production ideas (i.e., genba-shugi). Horizontal convergence means intense exchange of information across the plants (i.e., yoko-tenkai).

Fifth, we would argue that standardization and documentation are not always enemies of dynamic system changes. They may sometimes be a essential elements of dynamic organizational capabilities.

The above propositions are by no means confirmed. Further empirical researches are needed. The present case of the emergence of a new assembly system at Toyota, however, seems to be a good first step on this direction.

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