97-F-16

A Preliminary Note on Comparative Lean Production

——Revisiting the Case of Automobile Body Buffer Management——

Takahiro Fujimoto
University of Tokyo

April 1997

A Preliminary Note on Comparative Lean Production
- Revisiting the Case of Automobile Body Buffer Management -[1]
(first draft)

April 1997

Takahiro Fujimoto
Associate Professor
Faculty of Economics
The University of Tokyo

Table of Content

---

[1] This research was assisted by a grant from the Abe Fellowship Program of the Social Science Research Council and the American Council of Learned Societies with funds provided by the Japan Foundation Center for Global Partnership. The author is also grateful for the logistical support from INSEAD Europe-Asia Center.

Abstract

This paper is a preliminary note on an empirical analysis that compares different interpretations and implementations of so called "lean production system," by different automobile manufacturers in the world. The paper tries to explain why significant inter-firm differences in manufacturing activities exist among the firms that are apparently all moving toward the "lean" manufacturing paradigm. For this purpose, it focused on a specific area in manufacturing management where large quantitative and qualitative differences have been actually observed in recent years: *body buffers* that the auto assembly makers carry at their assembly plant, including welding, painting, and final assembly processes.

For example, several different patterns of activities for body buffer management have been identified among the European assembly plants, including some Japanese transplants in Europe: (i) Random sequence assembly, Random paint sequence, Emphasising keeping planned sequence, Emphasising Levelization (Very low pained body buffer levels); (ii) Lot assembly sequence, Lot paint sequence, Emphasising keeping planned sequence, De-emphasising levelization, Keeping sequence between the upstream and downstream (Relatively low pained body buffer levels); (iii) Random assembly sequence, Small lot paint sequence, Deviation from planned sequence allowed, Emphasising levelization, Emphasising avoidance of assembly line stops, Emphasising product variety (Relatively low pained body buffer levels); (iv) Random assembly sequence, Lot paint sequence, Deviation from planned sequence allowed (Relatively large pained body buffer levels); (v) Random assembly sequence, Random paint sequence, Emphasising keeping planned sequence, De-emphasising levelization, Keeping sequence between the upstream and downstream (Moderate pained body buffer levels). Such a variety indicates that inter-firm learning of effective manufacturing routines is not a simple matter of imitating one best practice -- different strategies, manufacturing traditions, environmental constraints, and capabilities may create different patterns of implementation within the same manufacturing paradigm.

1. Introduction

1.1 Purpose of the Paper

This paper is a preliminary note on an empirical analysis that compares different interpretations and implementations of so called lean production system by different automobile manufacturers in the world (Europe, Japan, and so on). More specifically, the paper outlines an analytical framework and hypotheses by which the author tries to explain why significant inter-firm differences in manufacturing activities exist among the firms that are apparently all moving toward a similar manufacturing paradigm, generally called "lean production" (i.e., a conceptual model based on certain interconnected practices of better Japanese auto makers with regard to productivity, quality, delivery and flexibility in manufacturing. See Womack, et al, 1990.). Being at the initial stage of the research, the present paper limits its scope to building hypotheses and framework, rather than rigorous hypothesis-testing. Preliminary results of some case studies conducted at this point are incorporated into the current analyses, though.

For the above research purpose, the present research focused on a specific area in manufacturing management where a large quantitative and qualitative differences have been actually observed in recent years: *body buffers* that the auto assembly makers carry at their assembly plant, including welding, painting, and final assembly processes. Body buffers are defined here as in-process inventories in the form of car bodies, painted or unpainted, with or without parts attached, in and between various processes at assembly factories, including welding, painting, and final assembly. As discussed later, the current research paid a particular attention to the paint buffer storage (PBS) that exists between the paint shop and the finally assembly shop, for which a large inter-firm differences has been identified in the author's preliminary study. The unit of analysis is a production line, a plant, or a firm depending upon the case.

Conceptually, this research attempts to introduce a framework by which we compare different logic or policies (i.e., a set of logically consistent routines) in manufacturing among the firms that are apparently oriented to the same paradigm, such as lean production (Womack et al., 1990). In other words, a key research question in the current study is as follows: why do firms show persistently different patterns of activities in body buffer management when hey all say they are moving toward lean producers ?

At a higher level of analyses, the current study tries to go beyond the static comparative analysis mentioned above, and tries to explain how different logic and capabilities evolved over time even within the same technological paradigm (Dosi, 1982). As such, the present study is a part of the author's longer term attempts to link the dynamic capability perspective or the evolutionary theory of the firm (Penrose 1959, Chandler, 1990; Teece, et al., etc., 1992) to detailed analysis of technology an operation management (Fujimoto, 1994b, 1995, etc.). In this regard, the evolution of body buffer policies in the automobile makers seems to provide an interesting case that shows inter-firm differences in dynamic organisational learning and capability-building in the field of manufacturing management. Discussing this dynamic issue in detail is beyond the scope of the current paper, but it will touch upon this issue at the concluding part.

1.2 Background: Convergence and Variety in the Lean Production Boom

Before focusing on the buffer issue, let us first discuss the background of the current research, mainly in the international automobile industry. A boarder agenda for the current research is how to explain the diffusion of so called "lean production system" in the Western auto makers, one of the most obvious trend in the world auto industry since the late 1980s. Since virtually all of the large Western car makers have adopted some part of the lean production model by the mid 1990s, the late 1990s seems to be a good timing to start some comparative analyses between various lean producers in the world. In other words, *international comparative studies of lean production systems* is now becoming feasible for the first time. The current study on body buffer and flow policy is a small part of such attempts.

<u>Convergence</u>: Generally speaking, "lean production system" is an ideal type that was modelled from data and observation at high-performance auto makers in

Japan, mainly Toyota (Womack et al., 1990)[2]. Although various parts of Toyota production system and Japanese manufacturing techniques had been documented in English and other languages since the late 1970s (Ohno, 1978; Monden, 1983; Schonberger, 1982; Hall, 1983; Hays and Wheelwright, 1984, etc.), it was through the concept of "lean production system" that many more people in and out of the auto industry understood the total view of Japanese manufacturing-development-procurement system that created competitive advantages in productivity, quality, speed and flexibility.

Although the description of the best-performing Japanese auto makers in the IMVP book was somewhat exaggerated and its prescription (everyone should introduce lean production to survive) may have been too simplistic, the message conveyed in this book and other IMVP activities were so powerful and compelling that adoption of a certain kind of "lean production" became a boom among Western auto and auto parts industry, as well as other industries (Latin America, China, etc.) and regions. Thus, at the level of concepts, paradigms, or slogans, at least, there was a clear convergence of the models in the early 1990s.

Variety: At the same time, it is important also to note that we were observing certain varieties at the implementation levels during the same period. It may not be unusual to see convergence at basic system levels and varieties at subsystem levels simultaneously in any complex systems in general, reflecting the differences in contexts and histories, but there seems to have been additional factors that promoted such verities.

First, the concept of "lean production" was vague and equivocal from the beginning, which allowed various interpretations at the implementation level. Although the concrete practices of better Japanese performers (e.g., Toyota) had become well known to the Western specialists through publications, seminars, consultations, and direct experiences of working with the Japanese firms, much less was known about which practice should be included in the lean production system concept, which should be more emphasized than others, which should be modified

[2] Although Toyota Production System (TPS), as defined at Toyota, itself is narrowly defined as a subset of what Toyota has been doing (or supposed to be doing), this was also different from the lean production concept, which was wider in scope. On the other hand, the lean production concept in the IMVP book (Womack, et. al) is also narrow in a sense that it does not explicitly include TQC (Total Quality Control),

and which should be copied, and how the integrity of the total system maintained. The lean production book (Womack, et al., 1990) was not clear about such concrete prescriptions.

Second, what has been said about lean production system may be somewhat different from what actual firms have been doing. For example, for a given practice (e.g., painted buffer policies), what Toyota describes as a general principle, what outside specialists explains, and what is actually happening may be subtly different (although they are normally the same in principle), which may become a source of diversity in interpretation of the system.

Third, the better Japanese firms (e.g., Toyota) themselves are moving constantly as the environments and priorities change from the 1980s to 1990s[3]. Therefore, depending upon when the observers collected information from such firms, data and impressions may be both different, making the concept of lean production more equivocal.

Consequently, as implementation of the lean production concept made progress in many Western makers, we tended to observe significant varieties, too. Some firms took a practical approach and introduced many of the detailed devices that are found at Toyota's shop floors (e.g., Kanban, Andon, line stop button, U-shape machining lines, Jido-ka, Heijunka, etc.), while others emphasized the conceptual aspects of the system, even purified it, and created some practices that were sometimes more extreme than what the Japanese forms were actually doing. For still others, the word "lean" simply meant "making the company slim" which often implied cost cutting by reduction of work force in the name of lean.

Thus, equivocality of the lean concept created some varieties in interpretations and implementation among the makers which more or less advocate that they have become leaner.

Explaining the Convergence and Variety: Such coexistence of convergence and diversity also stimulated different interpretation of this phenomenon among the academics in social science. One approach was to compare them in terms of the distance from the "one best way" or "pure lean system". The varieties were

---

which is obviously another core manufacturing competence at Toyota.

[3] The author has analyzed such changes as the transition "from the lean-on-growth system to the lean-on-balance system." (Fujimoto, 1994a; Fujimoto and Takeishi, 1994).

regarded as reflecting the inter-firm differences in manufacturing capabilities, which should be eliminated for survival of the firms. Bench marking studies have been continued by IMVP and others researchers, as well as the firms themselves.

However, some other researchers argued that there may be different versions of the lean production system that the firms introduce intentionally or unintentionally, which cannot be explained by a simple "one best way" model. Equally competitive, but significantly different versions of "lean production systems" may coexist in the same environment. There may be different ways of implementing "lean system" for companies facing different external environments or internal constraints. Firms with different histories and different traditions may find different versions of lean systems optimal for them.

The different versions may be so different that we may call them different "industrial models" (Boyer and Freyssenet, 1994). We will not make conceptual arguments, however, on whether they are versions of then lean model or different models that include the lean model, and will concentrate on empirical researches for the time being. Theoretically, however, this is an interesting issue.

To sum up, one of the central theme in the international comparative studies on the lean production system seems to be how to explain the variety that we are observing at the adoption and implementation stage. The current topic of body buffer management will provide an interesting case in this regard.

2. Motivation for the Research: Some Issues on Lean Body Buffer Management

Before getting into analyses, it would be necessary to briefly discuss the main motivation for this research. In the literature of so called Japanese production management, for example, buffer or inventory management has been a central issue since the late 1970s. Then why do we have to choose this topic in the late 1990s? Quite simply, it is because the author has been convinced that the sizeable inter-firm or inter-plant differences observed in this area as of the late 1990s would be an interesting topic for both practitioners and academic researchers. This section will discuss three issues that are related to the lean body buffer management.

2.1 Issues to Practitioners: Why Studying Lean Buffer Management Now?

On the practitioner side, the author has recognised at least three types of reactions to this kind of research (particularly among the Western practitioners) as of the mid 1990s.

(i) "Japan is not a threat any more, so why do we have to be bothered by such an old topic like buffer or JIT? This is an obsolete topics." – This type of reactions are often heard from people who collect information mainly through popular business journals and books. While this type of opinions tend to reflect accurately the short-run atmosphere in the business society, there tend to be some confusion, in the author's view. First, there seems to be a confusion between competitive threat and learning opportunity. Second, there tends to be a confusion between the Japanese firms in general, which as a whole have never been overwhelmingly competitive, and a small part of them with long-term manufacturing capabilities. Third, as a result, there may be a confusion between short-term issues for revealed market performance and long-term issues for capability building.

It is true that Japanese manufacturing firms in general are much less competitive threats to Western firms in the late 1990s than in the early 1980s because of the appreciation of yen, Western catch-up, etc. This, however, does not mean that there is nothing left to learn from the systems of better Japanese manufacturers. Organisational learning and capability building usually need long term commitment, while perceived competitive threats tend to fluctuate in the short run. The business journalism and popular books, because of the very nature of this business, tend to amplify this fluctuation. Consequently those Western firms that continue their learning and those which stops such efforts as perceived threats diminish might behave very differently, which may create profound competitive gaps within the Western firms in the long run, even with less competitive pressures from the Japanese. For this reason, the current research argues that long-term learning from better firms, whether they are Japanese or not, should not be affected too much by the short-term fluctuation of perceived competitive threats.

(ii) "Yes, we know that the catch-up to the Japanese is still going on. It is a long term effort. However, the focus is shifting to things like product development or information technology. Buffer and flow management has been discussed much in the past, and we already know what to do quite well" – This type of reactions are often heard from industry insiders involved in bench-marking studies or those who are monitoring the discussions among the automobile industry specialists. For example, recent studies of International Motor Vehicle Program (IMVP) indicates that, despite significant catch-up by the Western makers, the Japanese on average still continues to keep a significant advantage in such real-term criteria as assembly productivity and quality (MacDuffie and Pil, 1996). For example, the author saw a company goal posted on the shop floor of an European maker as of 1996, targeting an assembly productivity level of 17 person-hours per vehicle, which is nothing but an average Japanese level identified by IMVP.

Thus, people of this group continue their efforts to improve their performance partly by introducing so called Japanese manufacturing practices (Shonberger, 1982, etc.). They tend to keep on doing internal or external bench-marking studies. However, attention to specific action programs may shift over time. Among such programs, inventory and flow control is likely to be the area of declining attention among manufacturing managers, as pointed out by De Meyer and Pycke (1996) in a European case. According to their multi-year surveys, emphasis on "production and inventory control" is declining (although still high) among the European manufacturing executives surveyed. Indeed, inventory control (e.g., Kanban system) was one of the first elements of the Japanese manufacturing systems that were introduced to the Western audience in written forms since the late 1970s (Ohno, 1978, Schonberger, 1982, Hall, 1983, Monden, 1983, etc.), so diminishing return may be inevitable at least intellectually. The author's impression is also that there have been a shift in Western practitioners' attention to product development, product-production interface, information technology, etc., away from traditional production management such as inventory control.

While this trend away from the production control may reflect the actual changes in the international competitive environments, this view may have overlooked at least two things. First, although there have been many text books and other literature on buffers and inventories in general, there have been surprisingly few literature on automobile body buffers and flows, although this is one of the largest items in automobile assembly. Monden (1983), for example, dealt with body sequencing algorithm in a chapter of his book, but did not discuss body buffer management directly. Standard text books of Toyota production systems (Toyota Motor Corporation, 1987, etc.), also, do not discuss body buffer management directly. Toyota's official company histories also have few descriptions on this topic (Toyota Motor Corporation, 1978, etc.). Thus, as far as literature is concerned, there have been much fewer publications than expected on this specific issue.

Second, people in this category sometimes have not paid enough attention to the gaps that often exist between discourses and reality in Japanese manufacturing management. There may be exaggerated expressions in the text books for emphasizing the philosophies behind practices (e.g., "zero inventory" "zero defects" "exactly equal tact times throughout the processes). Intra-company tensions may make the writers choose extreme expressions in their "manifesto" for political reasons. Thus, while the ardent readers of such text books may accurately understand the concepts or philosophies of the proposed systems, there may not be enough information on how to implement it. Body buffer management seems to be a typical case – principles are well known, but practical information for implementation is not.

(iii) "Yes, we know that body buffer and flow policy is still a serious issue." In the author's pilot study conducted in 1996, manufacturing managers and executives in some European auto firms immediately responded like this, which convinced the author that body buffer management is still a hot topic for at least some firms. This , of course, does not mean that the body buffer issue is more important than other manufacturing problems, but it seems to be at least one of the important ones. It is also, important to note that those companies emphasizing body buffer improvements included the ones that are known as better implementers of Toyota Production System in Europe. In any case, there are some serious problem solving activities going on at some European firms in this respect. The goal for the lean manufacturer is obviously to reduce buffers as much as possible without causing negative side effects, but the firms are trying to find their own solutions within this framework.

There may still be differences among the firms in terms of the level of knowledge obtained so far (Jaikumar and Bohn , 1984). In the authors' interviews with the production managers, comments that indicate different levels of knowledge were actually heard from different managers and different firms, such as "We do not know which parameter to see," "We know which parameter to see, but we do not know what others are doing," "We know approximately what others target companies in bench marking are doing, but we do not know what is behind the difference in the numbers." "We know what our main rivals is doing approximately, and we know why they are different."

Also, there were some inter-firm differences as to who in the management hierarchy know this issue deeply. At some firms, not only plant staff but also executives and/or plant heads knew about the nature of the body buffer problem quite deeply; at other firms, some staff in manufacturing were the central figures in problem solving processes. Generally speaking, the author's impression has so far been that more advanced firms in Europe in lean manufacturing management tended to have executives with deep understanding of this issue.

In summary, the pilot studies mentioned above have convinced the author that, as of the late 1990s, the body buffer and flow management is still an important issue for some Western auto makers, including relatively successful ones.

2.2 Issues on Benchmarking: Comparative Production Policies

Now let us turn to the researcher side. In this regard, the current research is closely related to benchmarking (systematic and rigorous comparisons of performance and practices among competing firms), which has made a major progress since the early 1980s in the automobile and other industries (Abernathy et al., 1983; Womack et al., 1990; Miller, De Meyer and Nakane 1992, etc.). As for the comparisons of competitive performance parameters that are closely related to customers' evaluation of the products (e.g., productivity, manufacturing quality, etc.), there has been a general consensus among researchers and practitioners that the higher the performance the better, unless it has negative effects on other performance. As for activities or practices, however, interpretation of the comparative data is not so simple. The current study, focusing on the activities and practices for body buffers, deals with this second aspect.

Suppose, for example, that a significant difference in the level of painted body buffers is observed among the automobile assembly plants of the world. How should we interpret this difference? Three types of interpretations are discussed as follows (**Figure 1**).

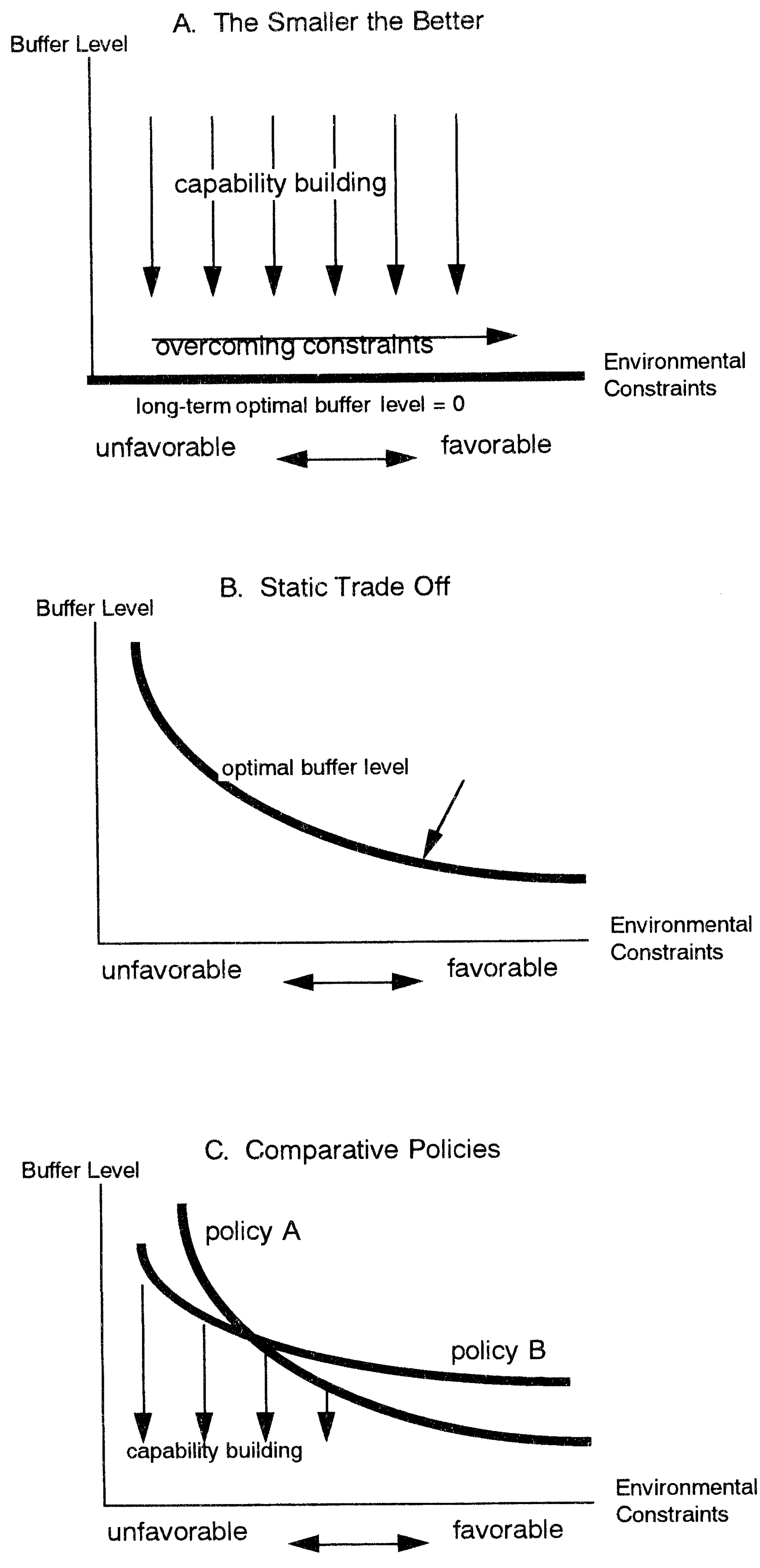
(i) There is one best way, which is "zero buffer. The smaller, the better. No excuse!" – The interpretation here is quite simple: to be a lean manufacturer, the smaller the buffer level, the better. Practically, the plant with the lowest level of painted buffer should be the target for the rest. The difference exists because of slow learning by the firms. Organizational stickiness, past investment, and so on hampers effective catch-up by such companies. This interpretation emphasizes the firms' potential capabilities to improve and overcome constraints, while it tends to ignore all the differences in strategy, history, environmental constraints and other constraints, so this simplistic view often raises oppositions by practitioners facing actual implementation problems.

On the other hand, such a simple message as "no excuse, reduce the buffers" can work as a long-term driver for continuous improvements, which normally has a profound positive effects on the firms' performance. Basically this has been a main messages from Just in Time (JIT) text books.

(ii) You cannot tell who is better practitioner of lean production from the data, as the optimal levels of buffers would be all different from plant to plant, depending upon the difference in constraints. – Theoretically this kind of contingency view would make sense to both researchers and practitioners, at least at the level of a static analysis. After all, buffer reduction is not end but means to achieve improvements in higher-order criteria such as productivity and quality. Each plant faces different levels of constraints, so the optimal level of buffers to achieve the highest possible performance should be different accordingly.

In practice, however, there is a risk in adopting this view, as many proponents of lean production argue, because this kind of static optimization theory might hamper dynamic improvements and capability building. Besides, the problem of determining the optimal level of buffers is so complex that it is virtually impossible to reach optimal solutions ex-ante by analytical methods. Most firms are making trial and errors on pieces of papers, through computer simulations, or

Figure 1 Interpreting the Body Buffer Data



even through physical experiments using their plants to reach tentative conclusions. It is hard to tell that the solutions that they reaches are optimal, even in a static sense. Without precise knowledge on what is optimal, the above contingency (i.e., relativism) view is likely to allow many excuses for the plant practitioners to stay where they are, and thereby decreases pressures to improve, overcome constraints, and build capabilities in the long run. Thus, the second view is theoretically valid, but practically dangerous, given that the people's level of knowledge on what is optimal on the shop floor is limited.

To sum up, neither the view (i) alone nor view (ii) alone seem to provide satisfactory interpretation of the data. The first view emphasizes dynamics and capabilities, while the second view stresses static trade off and constraints. Better practitioners seem to be using both views with a sense of balance.

(iii) The activity data has to be evaluated by taking into account not only constraints and dynamic aspects but also differences in manufacturing policies or logic. – This is a revision of (i), or compromise of (i) and (ii), and this is the view that the current study emphasizes. According to this view, the interpretation of the data should be made at two levels: First, the data should be evaluated in relations to *policies* (i.e., a set of internally consistent routines) adopted by each plant. Second, the policies themselves have to be compared and evaluated in terms of both static and dynamic contributions to competitive performance.

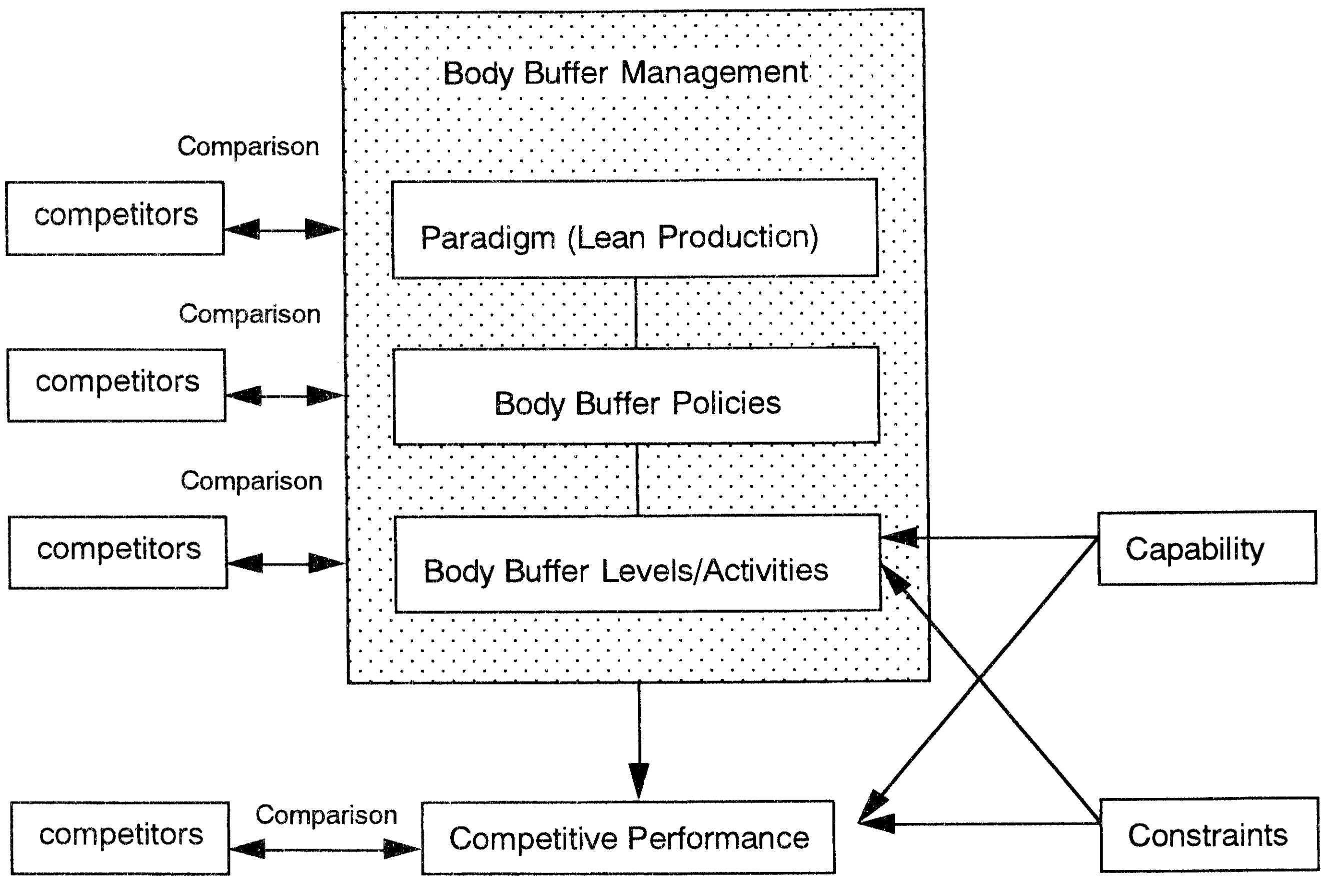
The logic behind this view is simply that we need multi-level comparisons as the manufacturing systems are also multi-layered. For complex decisions such as that for buffer levels, firms choose what to do in a hierarchical manner, selecting basic manufacturing paradigms, then selecting a set of inter-related routines (i.e., policies or programs) and then set specific activity levels for each relevant parameter **(Figure 2)**. Thus, the inter-plant comparison should be made at least for three levels[4]. In this sense, simple comparisons of the numbers (levels of activities) themselves may not mean much.

When we observe sizeable difference in individual activity levels (e.g., number of painted buffers) among the firms all advocating the same paradigm (e.g.,

---

[4] The three layer model is used for some empirical researchers in manufacturing management: Spina et al.

Figure 2 Comparison of Buffer Management Practices



lean production), interpreting this phenomenon by the two layer model (activities and paradigms) may create confusion. By adding another intermediary layer, policies, we may be able to do more realistic interpretation on the comparative data observed.

Let us take the example of the body buffers again. Suppose that all the firms surveyed are apparently converging toward lean production system at least at the paradigm level. However, there may be more than one policies that aims at achieving lean manufacturing, just like different paths to the peak. Buffer Policy A and Buffer Policy B, for example, may be both oriented to lean production paradigm in internally consistent manners, but they may give different priorities to a given set of activity parameters. Policy A may strictly monitor and control variable 1, while Policy B may emphasize variable 2. In this situation, it is not so meaningful to compare these variables between firms adopting Policy A and those adopting Policy B and make quick conclusions on who is the better lean manufacturers. What we need, instead, would be the following steps: first, to make sure that those firms are all following the lean production paradigm; second, to identify different policies that a sub-set of those firms may be adopting; third, to compare and evaluate levels of activities that are measured with the above policy differences taken into account; fourth, to compare and evaluate the policies themselves in terms of their static and dynamic contribution to the higher-order performance of lean-ness. The fourth question is difficult to answer, as we have to evaluate not only current performance but also flexibility to environmental changes and potentials for dynamic capability building. When we cannot make conclusions on which policy is superior to others, we have to postpone this judgement and evaluate the activity variables with the policy differences explicitly taken into account.

In the present research of body buffer management, the author will try to take the third approach, identify different policies among the producers aiming at lean production, and compare not only the numbers (activity variables) per se but also different policies behind the numbers. The current research will also investigate whether there is a dominant policy that outperform the other policies in

---

(1996), Mishina (1995), and so on.

the long run.

2.3 Issue on Dynamic Capability

We have discussed, in the previous section, a framework of static benchmarking when we observe a sizeable differences in activity levels within the same manufacturing paradigm. Let us now turn to a dynamic aspect of the phenomenon. Generally speaking, when we observe a variety in a certain complex and stable system (i.e., structure), there are at least two approaches for researchers to explain why we observe the variety. One is the functional analysis, which tries to show that each of the variations has a certain set of functions that help it survive, whether they were intended or unintended in advance (Merton, 1968). The other is to the evolutionary analysis, in which different versions of the system are explained by different paths or trajectories that they followed historically. Each path is a cumulative series of responses to changing environments, which are more or less sticky (i.e., difficult to change in the short run) and specific to each version. The explanation by the functional analysis and that by the evolutionary analysis may match, but they do not always match. Thus, the two approaches are often complementary with each other, so that both are needed for more complete understanding of a given phenomenon (Fujimoto, 1994b, 1995).

The current research starts with a functional approach to the body buffer management. Accordingly, the present paper proposes an analytical framework that outlines various functions of body buffers, as well as a set of hypotheses that may explain the observed variety in the body buffer management. In a broader context, however, the research will go on and try to explain the variety by the evolutionary approach. That is, the dynamic aspects of body buffer management will be explored. Patterns of organisational learning, problem solving, adaptations to changing environments, capability building, and so on, will be compared and analyzed between different plants and firms to see how and why they reached different solutions.

There is an academic background for this direction of research. The dynamic approaches to social science and managerial issues has attracted increasing attention particularly since the 1980s. At the level of the overall economic or corporate systems, there have been various works in evolutionary economics and dynamic approaches to strategic management ([illegible] **1982; Dosi, 1982; Chandler, 1990; Teece, et al., 1992**). Many of them were motivated by criticism against static or ex-ante rational (i.e. planning) perspectives of standard economic analyses and strategic management.

On the other hand, dynamic approaches to manufacturing management was advocated by some leading researchers in production and operations management (Jaikumar and Bohn, 1984; Hayes et al., 1988, etc.), which were motivated partly by the advent of so-called Japanese manufacturing management, and partly by criticism against traditional static approaches to typical American mass production management up to the 1970s, including the conventional Taylorism.

The two streams of the researches were not integrated tightly, though, partly because they were motivated somewhat differently, and partly because their units or levels of analysis were different. The author has made some attempts to strengthen the links between the evolutionary approach to economics or strategic management on the one hand, and detailed aspects of technology and operations management and their dynamics on the other hand (Fujimoto, 1994b, 1995). The historical part of the present study on the body buffer management can be regarded as another attempt along this line of business academic researches.

Having addressed some issues around the automobile body buffer management, both practical and academic, let us now start building some frameworks and hypotheses to respond to some of the above issues.

3. Definitions and Framework for Body Buffer Management: A Functional Approach

3.1 Introduction to Body Buffers

Body Buffer-Flow Policy Defined Body buffer policy is defined as a plant's policy, or an inter-related set of routines, that determines or influences the level of buffers in different locations, patterns of body flows, as well as sequence and lot sizes of the bodies, more or less simultaneously. The decisions on body buffers-flows are also closely related to the decisions on aggregated production rate, operating time (shift patterns), plant layout, and so on. Thus, the body buffer-flow policy is related to most aspects of traditional production planning and control at the assembly lines.

Body Buffer as "Microcosm" The current study chose body buffers of the automobile assembly plants as a "microcosm" to be studied. By microcosm the author means a small part of the total system that gives researchers a lot of insights on the behaviours of the total system.

(i) Core Element: Body buffer is a central element of Toyota Production System or lean production system. Its reduction is obviously one of the main paths to become lean. There is a general consensus among the lean producers to reduce the level of body buffers wherever possible, other things being equal.

(ii) No Textbook for Prescription: And yet there are not much written on how body buffers and body flows are handled in the lean production context. There are some discussions on body sequencing in relation with the concept of product mix levelization (heijunka), such as Monden (1983), but how to carry body buffers has not been discussed in Toyota Production textbooks.

(iii) Self Learning: Therefore, companies adopting the lean production system have to find some solutions based on their own experiences, philosophies or historical constraints, often through trials and errors. Since text books do not work here, the decisions in this filed tend to reflect the companies'basic way of thinking in manufacturing. This creates a certain inter-plant variety in practices of body buffer management.

(iv) Interdependence: Body buffer decisions are interrelated with various aspects of production management: organisational capabilities, business strategies, environmental constraints, etc. For example, basic process capabilities, levels of mechanisation, capabilities of rework and equipment maintenance, suppliers capabilities and locations, plant layout and locations, strategies on product customisation and product variety, strategies on product architecture (e.g. moidularization), plant location and layout, and so on, all affect the decisions.

As a result of the above characteristics, studying the body flow and body buffer policy of the company may reveal some important differences between the competing firms in organisational learning and problem solving at the level of total manufacturing systems.

3.2 Functions of Body Buffers

Having described the nature of the body buffers, this section proposes a framework from which specific hypotheses may be derived. For this purpose, let us start with a general framework of classifying inventories.

Generally speaking, inventory is the state in which materials, work in process, or finished goods are not absorbing value-added to the customers (**Fujimoto, 1994b**). As such, text books on Toyota Production Systems regards the inventories as "muda," or non-value-adding activities, which should be reduced or eliminated as much as possible. This is the principle.

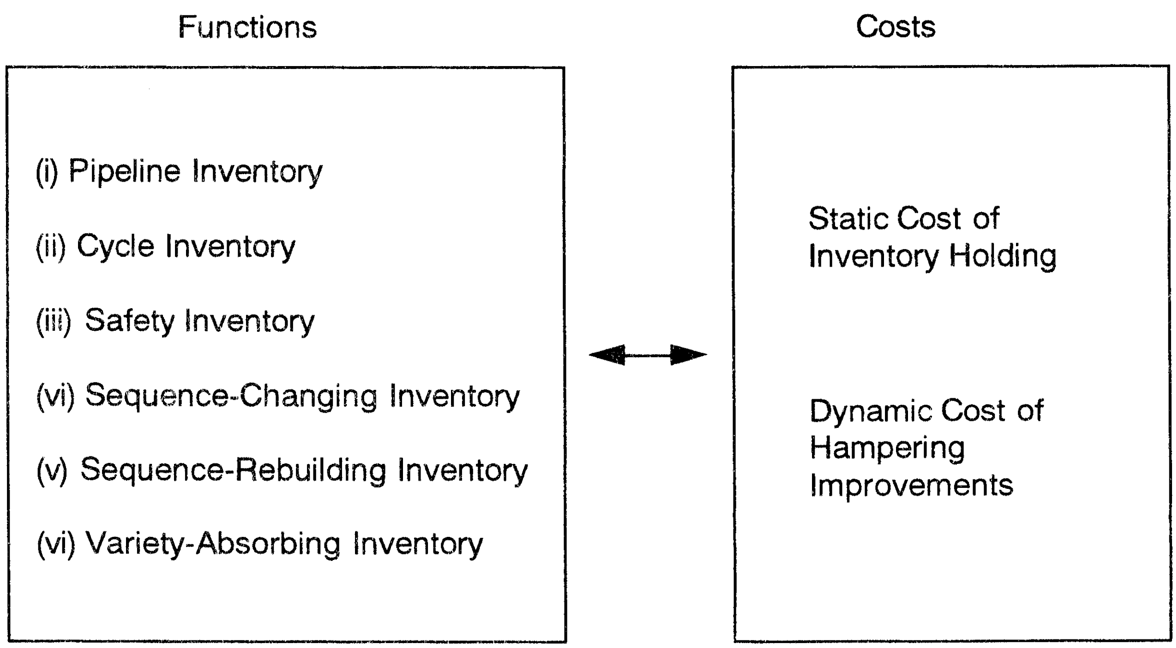
In practice, however, there are certain functions, or at least reasons, for inventories to exist, which even the most aggressive proponents of Just-in-Time would admit. In a word, functions of the buffer inventories is to absorb certain differences in parameters that is related to two work stations in a process flow – lead times in particular. They can be classified into several types based on such functions. In this regard, the very basic concepts and classification schemes of inventories in the standard text books of operations management can be applied almost directly to the case of the body buffer inventories (Chase and Aquilano, 1985, for example)

Along this line, the body buffer inventories (or inventories in manufacturing plants in general) can be classified as follows (let us assume that there are inventories between work stations A and B) : (Figure 3)

(i) Pipeline Inventory: This is the simplest form of inventories that are created by differences in locations, or *distance*, between stations A and B. In other words, pipeline inventories create lead time in order to absorb the distance. The size of the buffer depends on the distance and transportation speed between A and B. Suppose that the paint shop and the assembly shop are 500m apart for whatever the reason. Painted bodies from the former have to be transported to the latter through "tubes," through which painted bodies with hangers are continually moved by chain conveyers, or by other transportation carriers (trucks, etc.). If the speed of transportation in the tube is synchronized to the assembly line at, say, 5 meters per minute (1 body per minute), then there are 100 bodies in the tube.

Even if there is no other function for these inventories, the plant still have to keep them just because of the distance. However, there may be other functions for

Figure 3 Functions and Costs of Buffer Inventories



the pipeline inventories, such as "buying lead times." If, for example, an assembler needs to order, at station A, certain parts to a supplier, which delivers the parts to station B, the assembler needs to keep the time between stations A and B long enough for the supplier to deliver parts in time. If the time between A and B is too short, then the assembler may keep intentional pipeline buffers to compensate for the difference between the assembler's lead time and the supplier's lead time. This type may be called an *intentional pipeline inventory,* as there are other reasons than distance for the existence of the pipeline buffer.

(ii) Cycle Inventory: The second type of inventory is built up to absorb differences in *production pace* and consequent differences in operation time. When transportation of materials is involved, the cycle inventory will be created by the transportation batches, but the principle is the same. Suppose, for example, that paint shop has a capacity of 75 bodies per hour, while the assembly shop's capacity is 50 per hour (ignoring down times). In order to balance the two stations, an obvious solution is to limit the operating time for paint to two-thirds of that of the assembly (e.g., 2 shifts, 16 hours per day for painting, and 3 shifts, 24 hours for assembly, each making 1200 bodies per day). In this case, painted bodies will be accumulated at a pace of 25 units (75- 50) per hour for 2 shifts, peaking at the level of 400 units, which will be cleared at the pace of 50 vehicles during the last shift when the paint shop stops. In this way, inventory levels fluctuate within a day. Such cycle inventories are necessary to the extent that technological constraints on the equipment create them, but they may be also created by poor capacity planning in the past that created unbalanced capacity patterns.

(iii) Safety Inventory: This type of inventory is created in order to absorb equipment shut downs or other kinds of line stops in a certain station. Essentially the function of the safety buffer is to absorb differences in *lead times* from station A to B between different bodies on the process. Suppose that paint shops was shut down due to an equipment break down for 1 hour. Without buffers, downstream process (assembly) and upstream processes (welding) will be shut down immediately. If there are painted body buffers of 1 hour at the end of the paint shop and 1 hour capacity of white body storage at the beginning of the paint shop, however, the other two shops will continue to operate without line stops. Assuming that the lead time between paint start and assembly start is 5 hours without buffers. The bodies which are in the paint process when it stopped would need 5 + 1 = 6 hours, but the painted body buffers of 1 hour would absorb this difference, so that all the bodies have equal lead times of 6 hours despite the plant shut down. The same principle applies to the other end of the process.

Analytically, the level of the safety inventory between stations A and B is determined by two things: (i) distribution patterns of lead times between A and B, which, in turn, is determined by frequency of equipment break downs at station A and the distribution of process recovery time once the break down happens; (ii) optimal levels of line stops at the downstream (station B), after considering inventory carrying cost, opportunity cost of B's line stop, and the dynamic effect of Kaizen pressures by having fewer buffers.

Safety buffers may be also used for intentional (or controlled) line stops, as opposed uncontrollable system break downs, though. For example, a supervisor in an assembly line may decide to make a small experiment for new assembly method, which requires 5 minutes of line stops. If their line has 5 minute equivalent of buffers and empty storage on both ends of the line, the experiment can be done without stopping the other lines. In a broad sense, safety buffers may include such de-coupling buffers for intentional line stops.

(iv) Sequence-Rebuilding Inventory: This type of inventories have a similar function to the safety buffers mentioned above, in that the buffers absorb the difference in lead times between different bodies in the process. What is different is that the cause of the lead time difference is not the equipment break downs or process stops mentioned above, but rework of a specific body caused by defects on that particular body. So the lead time deviation occurs for a particular body, creating changes in the body sequence in the process, rather than all the bodies in the system that broke down. In other words, the function of the sequence-rebuilding inventory is to restore the originally planned body sequence that has been disturbed by rework and other noises. Suppose, for example, that paint rework happens pretty frequently, and that it takes a maximum 2 hours for rework. If the plant also has 2 hour equivalent of painted body buffers at the end, the bodies without rework can wait for the reworked bodies to catch up with them, and rebuild the originally planned sequence, so that the final assembly can be started according to the planned sequence.

Thus, to the extent that the plant needs to keep its original sequence for the purpose of optimal line balancing, synchronised parts delivery , and so on, the function of sequence-rebuilding may be emphasized by the plant.

(v) Sequence-Changing Inventory: This type of body inventory is different from the previous ones in that it creates lead time differences between different bodies, as opposed to absorbing them. In other words, this inventory is used for changing the body sequences between process A and process B. For example, suppose that optimal sequence at the paint shop and that at the assembly shop are different, so that the body sequence plan is made differently for the two processes. The paint shop may want to make a certain batch of an identical collar to minimize wasted time, materials and thinners used for each color change, while the assembly shop may stick to product mix levelization (heijunka) for the purpose of line balancing or even pace of material/parts usage. In this case, painted body buffers may be used to create lead time differences between the bodies and thereby change the body sequences between the paint and assembly shops.

(vi) Variety-Absorbing Inventory: This type of inventory is not so visible, but it is often used, in the assembly line setting, for equalising lead times between stations A and B when there is a significant difference in product content between the bodies. Compare, for example, a high content car with full options and a standard model without them. The former needs more time to absorb value added from the assembly process, which means that the former's lead time tends to be longer than the latter. One way of absorbing such a difference in product content is to let two or more assembly jobs overlapped at the same station for high content ones (the idea of levelization), while another way is for low content vehicles go thorough buffer (empty) processes. For example, if there is a sun roof installation station on an assembly line, high content versions will receive sun roof at this station, but low-content ones will simply pass this station, which is nothing but being an inventory at this station.

Such kinds of variety-absorbing inventories normally exists in the middle of the process, however, so this function is not directly related to inter-process inventories such as painted body buffers.

Cost of Inventories: The following part of the paper discussed different types of buffer inventories by functions. For each case, of course, the benefits from the functions have to be carefully compared with the costs of holding inventories. In traditional analyses, the benefits from the above functions were compared with static inventory carrying cost (e.g. the economic order quantity formula). In the texts of Just in Time or Toyota Production System, however, dynamic costs of inventories have been emphasized. That is, the inventories hide the problems that would be otherwise revealed, and thereby reduce the pressures for continuous improvements. In some text books this dynamic aspect is so emphasized that the readers would have an impression that this dynamic cost of inventory is prohibitively high. That is, the inventory level should be infinitely close to zero no matter what the reason for the inventory is.

In principle, this may be a correct expression. In practice, however, this does not mean that companies like Toyota ignores the functions of the inventories. For example, Toyota would oppose to the idea of piling up safety inventories, in principle, because they will hamper thrusts for improvements, but this does not mean the company actually bring the safety buffer down to zero. At the level of implementation, the firm seems to be carefully seeking for the optimal levels of safety buffers with the upstream automation levels, process capabilities, maintenance capabilities and other factors taken into account. Then, however, the firm tries to keep on reducing this safety buffer levels by improving its capabilities. Again, the principle is strictly followed, but implementation is somewhat more flexible and relaxed.

3.3 Locations of Body Buffers : Where Do You Want to Make Lean?

Managing Buffer Systems: We have so far discussed the potential functions and cost of body buffers, assuming a single inventory area between station A and Station B (e.g., painted body buffers between the last painting station and the first assembly station). In the actual situation, however, it is needless to say that assembly is a multiple stage process, and that body buffers of various manufacturing stages are deployed at various places of an assembly plants. Thus, body buffer management means not only management of a single point inventories but also management of the interrelated network of body buffer inventories. Also, the body in-process inventories are also interrelated with other inventories such as finished goods inventories after the assembly line (both makers and dealers), as well as material and work-in process inventories at the upstream press shop, parts inventory for assembly lines, and so on (**Figure 4**). Let us now classify these inventories by locations.

Classification by Locations Many of today's car assembly plants, in a broad sense, consist of the following four shops: a press shop, a welding shop, a paint shop, a final assembly shop (press shops are often separated out, particularly in America, though). Each of the four shops, in turn, consists of several distinctive processes, which can be further broken down into many line segments and work stations (see Appendix for further descriptions). Body buffers of various types may exist between these shops, processes, segments, and stations, which are listed up as follows (a case of the standard process architecture of high volume assembly plants):

(1) Inter-Shop Inventories (body buffers are underlined)

Before Press Shop: Steel Coils Inventory

Between Press and Welding Shops: Panel Inventory

Between Welding and Paint Shops: White Body Storage / Inventory

Between Paint and Final Assembly Shops: Painted Body Storage / Inventory

After Final Assembly Shop: Finished Goods Inventory, Dealer Inventory

(2) Intra-Shop, Inter-Process Inventories (body buffers are underlined)

Press Shop ----------- Between Blanking and Press: Sheet Steel Inventory

Welding Shop ------- Between Underbody and Mainbody Marriage

Between Mainbody Marriage and Respot

Between Mainbody Respot and Body Fitting

Between Body Fitting and Finish

Paint Shop ----------- Between Pre-treatment and Cataphoresis (Electro-Dip)

Between Cataphoresis and Primer (Under Body Coating)

Between Primer and Filler

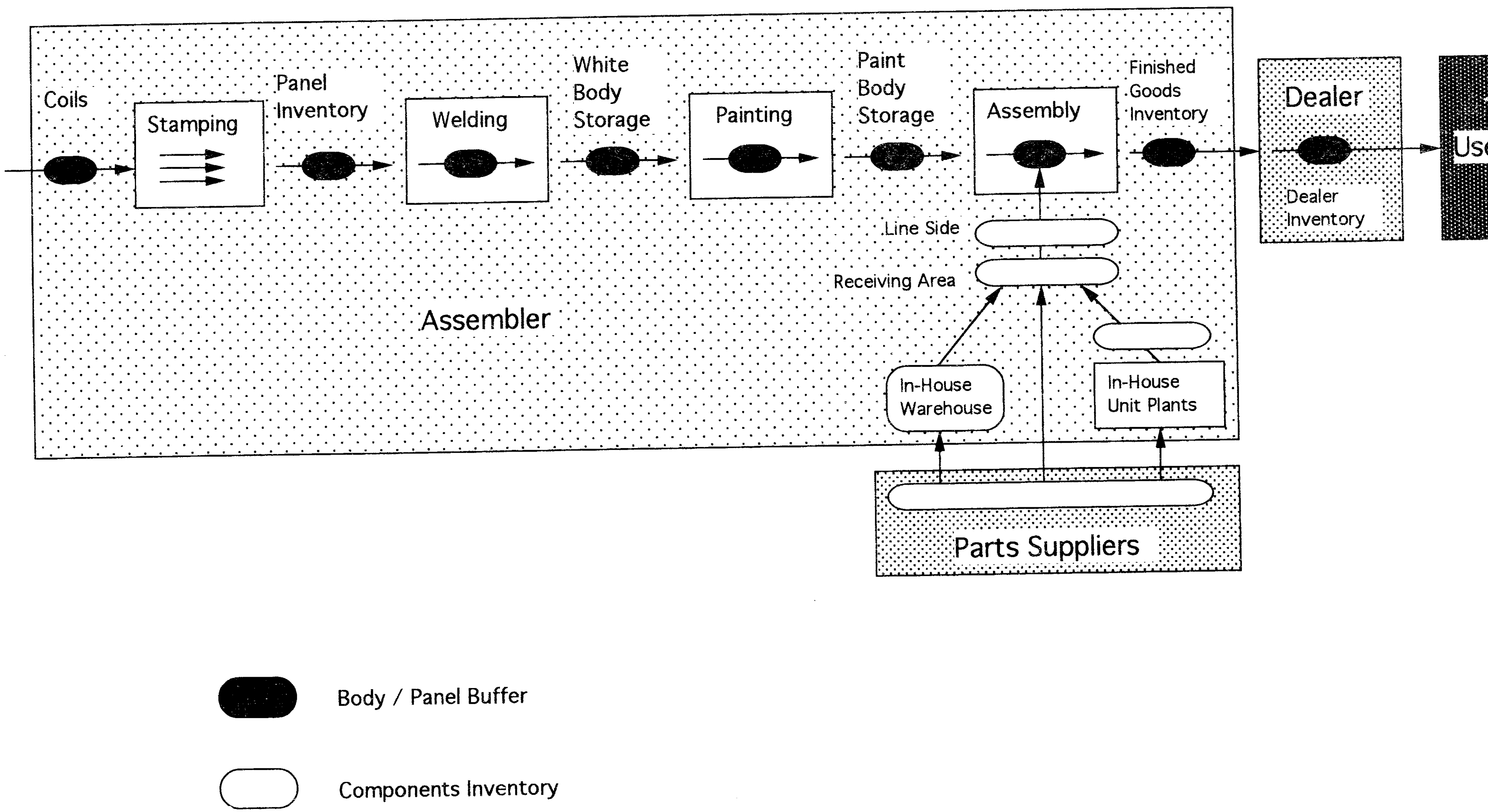
Between Filler and Top Coat

Between Top Coat and Paint Finish

Final Assembly ------ Between Trim and Chassis (Mechanical) Lines

Between Chassis and Final Lines

Figure4 Where Do You Want to Make Lean?



Between Final and Final Inspection Lines

(3) Intra-Process Body Buffers ---- Within each of the above processes

(4) Component Inventories Assembly Line Side

Receiving Area in the Paint Shop

In-House Warehouse

External Warehouse

Between Sub-Assembly Lines and Main Assembly Lines

Interrelations between Buffers: The buffers in different locations are interrelated within the framework of inventory system management. It is true that, in the long run, a plant can reduce the overall level of buffers by enhancing its manufacturing capabilities and by overcoming external or internal constraints. This long-term aspect is often emphasized in the Just-in Time, Toyota Production System literature. At a certain point in time, however, we may not be able escape from certain trade-off relations between the buffers of different locations.

For example, a plant that is producing cars based on final customer orders (as opposed to dealers' orders or manufacturers' forecast) would carry very few finished goods inventories at the end of the assembly lines, but it may have to carry many parts inventories in order to absorb uncertainty of final customer orders themselves (e.g., last minute change in option content). Another plant that aims at a very low level of component inventories by going for synchronised-sequential delivery by its suppliers may need to add body buffers in the assembly shop or between paint and assembly shops in order to allow the suppliers sufficiently long delivery lead time. Still another company may go for a Kanban system (i.e., a pull system) for parts delivery and try to make the parts order frequency even by levelizing product mixes (i.e., heijunka), but this may mean carrying a certain level of painted body buffers for re-sequencing, depending upon paint shops flexibility.

Thus, in the short run, even those firms aiming at lean producers should consider such trade-off relations between buffers, given their current capabilities, constraints and policy choices, and answer the following question -- *where do you want to make lean?* Different firms or even different plants in one firm may have different answers on the distribution of body buffers for achieving overall leanness.

Inter-Relation with Other Manufacturing Policies: The foregoing section argued that body buffers in different locations are interrelated so that they have to be managed simultaneously. Besides, the body buffer management itself affects, and is affected by, almost all of the other elements of manufacturing management and even technology management, as already mentioned.

In production control, for example, both long-term and short term production plans are related to the buffer decisions. Overall plant location/layout plans will affect the level of pipeline inventories of bodies. Long-term capacity plans may influence the level of cycle inventories. On the other hand, mid-to-short-term plans for lot sizing (e.g., in stamping) and body sequence formation (in welding, painting and assembly) will directly affect the levels and patterns of sequence-changing inventories of bodies. Customer order policies, such as choices among production to final customer orders, to dealer stocks, or to maker stocks, will also have a direct impact on the levels of finished goods inventories, as well as component inventories.

In quality management, the process capabilities of "making right things the first time," standards of quality inspection, as well as capabilities of rework on defects at each process may influence the levels of sequence-rebuilding inventories, etc. Policies on how to handle defects (e.g., ejecting to rework areas, stopping lines and rework, letting it flow to the end of the line for rework, etc.) will also affect the levels of safety buffers and sequence-rebuilding buffers.

In equipment management, the level of automation at each process would affect the levels of safety inventories, down time ratios and recovery times from breakdowns, which in turn is influenced by process capabilities, capabilities of maintenance specialists, capabilities of Total Productive maintenance (TPM), etc.

In purchasing management, Types of parts delivery system, such as choices between scheduled batch delivery, synchronised sequential delivery and Kanban-pull delivery, will influence sequence-rebuilding, sequence-changing, or pipeline inventory levels and patterns. The choice of delivery systems, in turn, may be affected by the company's choice of product architecture and product designs, such as degrees of modularization, common parts, product varieties, option package, and so on.

In human resource management, the plant's choice on the level of empowerment and delegation to basic work groups at the shop floor may be linked to its decisions on the level of safety buffers, which absorbs the impacts of both uncontrollable and controlled line stops caused by each group (see Fujimoto, 1996, for the case of Toyota).

To sum up, body buffer management is intertwined with many other elements of manufacturing management. As mentioned before, body buffer management is a microcosm in that focusing on this particular issue inevitably results in exploring almost entire areas of assembly plant management in the automobile industry.

4 Determinants of Buffer Levels: Hypotheses in the Case of Painted Bodies

4.1 Some Basic Facts about Painted Body Buffers

Having described basic nature of the body buffer problems, let us now make a series of hypotheses on factors affecting the buffer body decisions. Since the overall decisions on the entire buffer system is very complicated, this section focuses again on painted body buffers between the paint and the assembly shops. The discussion here could be applied almost directly to other areas of buffers, though.

Let us start from an almost stylized fact in the 1990s: virtually all of the high-volume car manufacturers in Europe, U.S. an Japan are aiming at becoming lean manufacturers, at least subjectively. This fact is easily confirmed by looking at statements of executives and managers, internal documents, journal and news paper articles, actual action programs of the firms, as well as their performance improvements. Given this fact, a key research question is, *why are painted body buffer levels so different between these manufacturers sharing the same manufacturing paradigm?*

Existing researches have already indicated that there are significant inter-regional differences in the level of painted body buffers. According to the IMVP data collected and analyzed by MacDuffie and Pil (1996), the average level of painted buffer storage (measured in % of production per shift) was: 17% in Japan, 28% in the U.S., and 61% in Europe.

The inter-firm difference of the painted body buffers is much wider. Although systematic data analyses are beyond the scope of this preliminary paper, some of the author's pilot field studies have already revealed a sizeable difference of painted body buffers. In the case of about ten assembly plants in Europe (including Japanese transplants in Europe), the levels ranged from almost zero to several hundreds (equivalent of about one day's production in two shifts).

Interestingly enough, the plant with the lowest level of painted buffers was neither a Japanese plant nor a Japanese transplant overseas. Also, different assembly plants at the same company sometimes had very different policies and levels of painted buffers. Thus the preliminary data have already indicated a sizeable inter-firm, or even inter-plant, difference in painted body buffer management.

4.2 General Framework for the Hypotheses

How can we explain such a significant inter-plant differences at the levels of painted body buffers? Generally speaking, the levels of body buffers are determined by manufacturing capabilities of the plant in question, constraints in both outside and inside of the plant, and choices of policies/strategies related to the body buffers. The policies, in this case, include decisions on overall body buffer levels, distribution of buffers at various locations (i.e., where do you want to make lean?), functions assigned to each buffer area, as well as other detailed routines on managing the buffers. As mentioned before, other manufacturing policies also affect the painted buffer levels.

More specifically, we can apply the general framework discussed in section 3.2. That is, the factors affecting the sizes and patterns of painted body buffers and storage may be classified functionally into the following categories[5]:

(1) Factors affecting painted bodies as the pipeline inventories:

- (1a) Distance between the paint and the final assembly shops
- (1b) Delivery lead times of synchronised-sequential delivery suppliers

(2) Factors affecting painted bodies as the cycle inventories:

---

[5] The variety-absorbing buffer was omitted as it is not relevant in the case of painted body storage.

(2a) Difference of production capacity between the paint and the assembly shops

(2b) Difference in shift patterns and operating time between the two shops

(3) Factors affecting painted bodies as the <u>safety</u> inventory

(3a) Frequency of line breakdowns at the paint shop

(3b) Distribution of the time for recovery from the paint shop breakdowns

(3c) Cost of assembly line stops due to paint shop breakdowns, and other factors affecting the optimal rate of assembly line stops

(3d) Estimated benefits from higher process autonomy created by the buffers

(4) Factors affecting painted bodies as the <u>sequence-rebuilding</u> inventory

(4a) Frequency of paint rework at the paint shop

(4b) Distribution of the time for paint rework

(4c) Cost of the actual body sequence at the assembly shop deviating from the planned assembly sequence

(5) Factors affecting painted bodies as the <u>sequence-changing</u> inventory

(5a) Cost of large lot body sequence at the assembly shop

(5b) Cost of random (lot size =1) body sequence at the paint shop order entry (following the downstream sequence?)

(6) Cost of inventories that the firm estimate

(6a) Static inventory holding cost

(6b) Dynamic cost of inventory die to lower pressures for improvements

By tracking the cause-effect relations further down, we can reach a set of hypotheses that might explain the levels and behaviors of the painted buffer inventories, which will be discussed later on(in section 4.4). Again, a similar logic would apply to other areas of body buffers.

In any case, it is important to note again that simplistic comparisons of the body counts without investigating the policies and logic behind each number may not make much sense, or may be even misleading. The numbers should be always interpreted in the context of the policy choices made by each assembly plant.

4.3 Body Sequencing Policies

Before generating specific hypotheses, we have to clearly distinguish two different policies on body sequencing. As mentioned before, body sequencing is the most closely connected area to body buffer management, and thus needs a particular attention. Let us again concentrate on the paint and assembly shops (A similar argument can be made for other processes such as welding.).

(1) Fixed Sequence Policy: This is a policy that makes the paint body sequence (i.e., the upstream) and assembly body sequence (i.e., the downstream) identical at least at the planning stage. The fixed sequence policy is pursued by the firms mainly in the following three situations. First, if a firm decides to calculate a globally optimal sequence by taking into account constraints and objectives of both the paint shop and the assembly shop, a common sequence, as a compromise solution, will be shared by the two shops. In this case, though, the solution is sub-optimal to both shops. Second, if the assembly shop needs a certain sequence pattern (e.g., randomization), while the paint shop is totally flexible without significant constraints to be considered, then the paint shop will simply follow the assembly sequence, which results in the common sequence between them. Third vice versa.

The fixed sequence policy has some advantages. First, production and inventory control can be simplified this way. For example, it would be easier to conform the actual sequence to the planned one. Second, when the assembler emphasizes synchronized and sequential delivery of parts from many suppliers, keeping the same sequence throughout the both process may mean that the assembler can release the final sequence information early on, so that the supplier can do its sequential parts production with enough lead times.

At the same time, it may be more important for the plants following the fixed sequence routine to match the actual and planned sequence, particularly when sequential delivery is widely pursued. As a result, the sequence-rebuilding body buffers, explained earlier, are emphasized in this policy.

(2) Variable Sequence Policy: This is a policy in which locally optimal sequences are pursued at the paint shops and the assembly shops respectively. To the extent that both processes have different constraints and objectives, the variable sequence policy may be preferred by the firms. For example, if the assembly shop emphasizes randomization of bodies (i.e., lot size = 1), while the paint shop wants to reduce the number of color changes that adds set up costs or

environmental problems and thereby increase the painted body lot size, each process will pursue different body sequences. As a result, the sequence-changing body buffers are emphasized in this case[6].

Figure 5 summarizes different body sequence policies. There are some plants that are oriented to relatively large lot size in assembly, while others are committed to random sequence (lot size = 1) assembly. For each cells in the diagram, the plants may choose between relatively small or relatively large size of painted body buffers. According to the author's pilot study in Europe, the policies of actual firms have been dispersing in different cells of this diagram. That is, the initial survey indicated a large variety at the level of body flow and buffer policies across the assembly plants.

4.4 Listing up Specific Hypotheses

Combining the foregoing arguments in sections 4.3 and 4.4, and by using a cause-effect tree like **Figure 6,** we can now derive some hypotheses on the possible determinants of painted body buffers. In a general form, the hypotheses specify that the buffer level is a function of policy choices, capabilities, and constraints. The hypotheses are listed up according to the general framework shown in section 4.2.

H1. <u>Hypotheses on Pipeline Inventories (distance, or needs to add lead times)</u>

H1.1 Historically <u>process-focused</u> plants **(Skinner, 1985)** tend to have larger pipeline inventories, other things being equal.

Whether a plant has been historically process-focused or product-focused can be judged usually by simply looking at its plant building layout, body flow patterns, and its patterns of expansion.

---

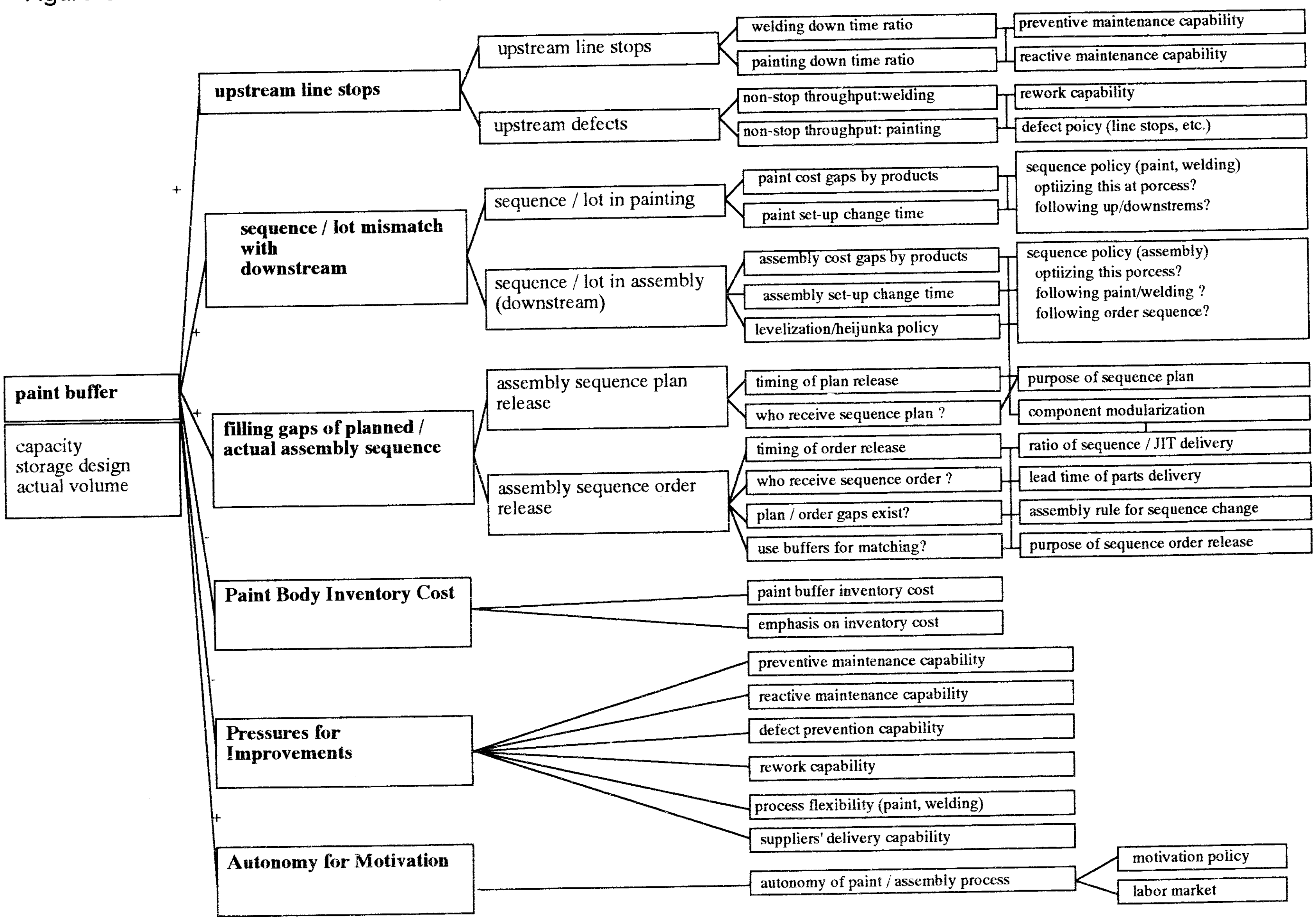
[6] Note that both the fixed and the variable sequence policies described here assumes so called a push system, in that pre-determined sequence plans are delivered to both of the processes. Mertins, et al. (1995), however, propose a new system, which is an application of a pull system (e.g., Kanban system) to the case of body flows. In this case, bodies are pulled from the painted body storage by the assembly shop, while the paint shop makes identical painted bodies to replenish the pulled bodies.

Figure 5 Types of Body Sequence Policies

	random sequence assembly	lot assembly
fixed sequence policy	small PBS large PBS	small PBS large PBS
variable sequence policy	small PBS large PBS	small PBS large PBS

PBS = painted body storage

Figure 6 Determinants of Paint Body Buffers



T. Fujimoto, Tokyo Univ. 96/5

There are at least two cases in regard to this hypothesis. First, process-focused assembly factories tend to separate their paint buildings and assembly buildings, which are more likely to be located with a certain distance than the case of product-focused assembly factories.

Second, a process-focused factories may still build paint, assembly, and other shops next to each other at the beginning, but they tend to try to expand each of the shops and find no rooms to do so (Product-focused firms would build the second plant with all the processes). Consequently, for further expansion, it tends to separate a certain process (e.g., a part of the paint shop) and locate the building for that process separate from the other buildings, creating distances. In any case, historically process-focused factories tend to result in complex inter-shop material flows, which means longer pipeline inventories, including painted bodies.

H1.2 A plant that emphasizes synchronized-sequential delivery, tend to have a pipeline paint body inventories, particularly when certain sequential suppliers needs relatively long delivery lead times.

For a plant that emphasizes synchronized-sequential delivery, one of the key is when to release reliable assembly sequence information to suppliers inside and outside the firm. If early release is possible, this would give sequential suppliers enough lead time to conduct synchronized-sequential parts production more effectively. However, there are normally many paint reworks that disturb the sequence, so reliable assembly sequence information is available only after the painting process in many cases. So, many companies release this information only when actual final assembly starts. This, however, may create lead time problems for suppliers providing parts to relatively early work stations (e.g., wire harness, head lining), since the body will reach the station pretty soon. In this case, the assembler may intentionally add pipeline buffers prior to the assembly line to buy time for these suppliers.

For example, suppose that the earliest sequential delivery point on the assembly line is wire harness at station #30, and the line speed is 1 minute per station. Without pipelines, this gives the wire harness suppliers only 30 minutes from order to delivery, which would be impossible. Thus, if it needs 90 minutes to do sequential delivery in a cost-effective way, then the assembler may intentionally add 60 pipeline bodies, or 1 hour buffers, to absorb the difference (90 - 30).

Thus, the size of such an intentional pipeline may be a function of the plant's emphasis on sequential delivery, the location of the first station where it applies this system, and suppliers' capability for quick sequential delivery.

H2. Hypotheses on Cycle Inventories (capacity unevenness, shift patter unevenness)

H2.1 Historically process-focused factories tends to have more cycle inventories, other things being equal.

The logic behind this hypothesis is similar to that of H1.1. First, process-focused factories tends to focus on utilization of individual equipment at each process, which tends to create equipment capacity imbalance compared with the case of product-focused factories. This also means that, when the plant grows, this unevenness in production capacity across the processes tends to persist. Second, since the process-focused factories tend to have separate and powerful organizational units specializing by processes, each process units (e.g., assembly, paint, welding, etc.) may find it easier to set up different shift patterns and operating times process by process. As a result, more cycle inventories may be observed in historically process-focused factories than the product-focused factories.

H2.2 Where a certain process is inflexible against volume changes for technological, economical, managerial, or institutional reasons, more cycle inventories tend to be observed around this process, other things being equal.

This hypotheses is almost self-explanatory. It may not apply directly to the case of painted body buffers, but this can often explain the size of other buffers. For example, for technological and economic reasons, it is difficult to slow down press machines and synchronize them to body welding cycle time. So cycle inventory always exists at the end of the press process. A paint shop may want to run some of its ovens 24 hours for energy conservation, when other processes are two shift operations. A strict rules with labour unions may prohibit some companies from changing assembly line speed following the volume changes. All these constraints can be sources of cycle inventories.

H3. Hypotheses on the Safety Inventory (upstream breakdowns, autonomy, etc.)

H3.1 The higher the equipment down time ratio at the paint (i.e., the upstream) process, and the longer the maximum recovery time from the break downs, the higher the paint buffer level tends to be, other things being equal.

This is almost a definition of the function of the safety buffer itself. More precisely, the level of safety buffers is determined by the distribution patterns of lead times for the bodies to travel from the paint shop to the assembly shop, which is affected by the down time frequency and the distribution of recovery times. As the complete data for the lead time distribution is hard to get, the down time ratios and recent maximum recovery time from the break downs were chosen as proxies.

The down time ratios and recovery times are, in turn, affected by overall automation ratio (+), novelty of the process technology (+), age of the upstream equipment (-), maintenance capabilities (-), and TPM (Total Productive Maintenance) capabilities (-), and so on, at the upstream, other things being equal.

Also, to the extent that the paint process is physically linked tightly with its upstream operations, welding and even stamping, the down time ratio and recovery time would also affect the level of painted buffer storage. At today's large volume assembly plants, for example, the down time ratio of a highly automated welding shop is usually much higher than that of a paint shop or an assembly shop, so the former's equipment break downs have to be taken into account when the body shop and the paint shop are tightly connected with few buffers.

H3.2 When the plant's desired levels of assembly (the downstream) line stops due to the upstream break down is lower, .the level of painted body buffers tends to be higher, other things being equal.

This is also another side of the definition of the function of the safety buffers. The assembly shop is one of the most labor intensive process in the automobile manufacturing, so opportunity cost of assembly line stops is regarded to be relatively high (lost sales opportunity, lower labor productivity, etc.). On the other hand, the plant staff may estimate the cost of painted body inventories, evaluate the dynamic negative effects of the buffers that reduce pressures to the paint shop improvements (a classic JIT argument), evaluate the overall marginal costs & benefits of adding one safety buffer, and decides the desirable level of the downstream line stops caused by the upstream break downs.

Thus, given the upstream's patterns of process break down, an ardent JIT advocate may evaluate the dynamic cost of body buffers as extremely high in the long run, and try to eliminate the paint body buffers even if it means frequent assembly line stops. However, the Japanese auto firms, including Toyota, does not seem to go that far. Even though they do emphasize reduction of buffers for dynamic Kaizen (improvements) effects, the managers seem to be still seeking for a balance in the short run,

H 3.3 When a firm has an employee empowerment program through a group work structure, certain buffers may be added to promote autonomy of each work group.

In the early 1990s, employee empowerment program has attracted increasing attention of some manufacturing managers in Europe (De Meyer and Pycke, 1996) and Japan (Fujimoto, 1996), particularly in the auto industry. Most of such attempts in the 1990s emphasized autonomous group work or team work in the assembly and other shops (e.g., Fiat, Renault, etc.), while maintaining the assembly line process concept itself, as opposed to some attempts to abandon the assembly lines in the 1970s and 80s. Some companies such as Toyota even modified the physical layout of the newer assembly lines, cut the line into many short segments, and added small buffer areas between the segments, so that each work group for each segment would enjoy more autonomy (Fujimoto, 1996).

In this context, some buffers have been added to the assembly process. They are essentially safety buffers or decoupling buffers, which reduce the impact of line stops in one work group, whether they are uncontrollable break downs or controlled experiments, on the other groups. Higher assembly automation also tends to create more down times, which may be another reason to have such inter-segment buffers at the assembly process.

Thus, this empowerment factor may not directly affect the level of painted body buffers, but it has certainly some impacts on other areas of buffers.

H4. Hypotheses on the Sequence-Rebuilding Inventory (rework time, conformance, etc.).

H4.1 When the rework ratio at the paint shop is low and maximum paint rework lead time is long, the level of painted body buffers tends to be high, other things being equal. This is particularly the case for a plant that is adopting the fixed sequence policy.

This hypothesis can be derived directly from the definition of the sequence-rebuilding inventories discussed earlier. The distribution patterns of rework time, as well as rework ratio (or 1 - direct run ratio), determines the distribution of lead times for each body to travel from the paint shop to the assembly shop. Again, the rework ratio (or conversely direct run ratio) and the recent maximum rework time are proxies of the lead time distribution patterns. If the plant is following the fixed sequence policy for body flows, it would want to equalize the paint-assembly lead times of individual bodies as much as possible. Paint body buffers may be used for this purpose.

In this regard, the car body painting process is a notorious place for a high rework ratio. Compared with the welding process (body shops), for example, the direct run ratio (i.e., the ratio of the bodies going through without ejected from the line for rework) at paint shops is normally much lower than that at body shops, while the body shop down time is normally higher than the paint shop down time[7].

In any case, the paint rework patterns are affected, in turn, by various things such as process capabilities of painting correctly the first time, strictness of paint inspections, capabilities of quick and accurate paint rework. The optimal levels of

---

[7] Note, however, that the definition of direct run ratio may be different for different companies.

painted buffer storage for sequence-rebuilding would change accordingly.

H4.2 When a plant tries to achieve a higher ratio of conformance between actual and planned assembly sequence, it needs larger painted body buffers for the sequence-rebuilding purpose, other things being equal. This is particularly the case for a plant that is adopting the fixed sequence policy.

This hypothesis is also derived directly from the functional definition of sequence-rebuilding buffers discussed earlier. Given the capabilities and patterns of paint rework, a plant that is more committed to near 100% conformance ratio between planned and actual body sequence at the assembly shop may be willing to add more buffers to achieve this goal. The plant also has to balance this desire with the perceived cost of buffers, both static (normal inventory carrying costs) and dynamic (costs of hampering Kaizen).

Thus, other things being equal, the firms that are more committed to synchronized-sequential delivery of parts and to the fixed sequence policy at the same time may have more incentives for higher conformance ratios, because it allows the plant to release accurate assembly sequence information earlier than the assembly actually starts, giving the suppliers enough lead times to do sequential parts production and delivery in an efficient way. This is particularly important when not all of the sequential suppliers are located near the plant.

An interesting corollary is that a plant that is going for so called modular supply system may have more incentives for higher conformance ratios and thus larger sequence-rebuilding buffers. Modular delivery, in this context, means asking suppliers to deliver bigger sub-assembled parts directly to the assembly shop, rather than piece parts. In this way, the assemblers can drastically reduce the number of suppliers and establish closer partnership relations with a relatively small number of capable system suppliers. This approach was advocated by some Western (particularly European) auto makers. A part (but not all) of the Japanese auto makers are also interested in this concept.

Given the product architecture of today's cars, however, delivering subassembled modules means that each module becomes not only bulky but also more specific to each individual versions of the cars. As we see in the case of seat complete modules or cockpit modules, these bulky and version-specific components needs to be supplies in the synchronized-sequential way. Thus, we can predict that the plants that are committed to the module delivery concept will tend also to be committed to sequential delivery, and thus emphasize sequence-rebuilding buffers, other things being equal (unless all the module suppliers are located right next to the assembler).

There may be other reasons for the plants with the fixed sequence policy to keep a high conformance ratio between the plan and the actual. Generally speaking, lower conformance ratio means deviation from the optimal sequence, assuming that the planned sequence was in fact an optimal solution. Thus, the commitment to high conformance would depend upon the cost penalty of deviation that each plant estimates. Some plants seem to be using computer simulation programs for such calculations. Since this area has not been explored, future researches would be needed here.

H5. Hypotheses on the Sequence-Changing Inventory (color batches, assembly levelization)

H5.1 When a plant estimates heavily the costs and the other negative effects incurred by paint color changes, it tends to prefer larger color batches, and thus larger sequence-changing buffers, other things being equal. This is particularly the case when the plant is following the random sequence policy for assembly.

In today's highly automated painting processes for mass production, top coat (final painting) is done automatically by robots or reciprocal spray machines. Every time the color changes, the equipment has to rinse the nozzles and prepare the next paint. The change is done quickly within a cycle time, but still the cumulative effect of the set -up change times may be regarded as significant for some manufacturers. Other companies may not care about the lost time, but they may still be concerned about material costs of the wasted paint for each color change. Still others may be concerned about environmental impacts of the wasted thinners for rinsing, particularly where environmental regulations are tight (Those which are using newer water-based or power paints may be less concerned about the last problem). Still others may prefer larger color batches because of higher stability of paint quality that way. Thus, the reasons may be different, but there is a recent tendency for some plants to reduce the number of paint changes and thereby enlarge the size of color batches. The challenge is that the plants have to do it with the paint variety high and even increasing (20 colors or more in many cases).

Consequently, as long as the plants seeking for larger color batches are also following the random sequence policy (i.e., body lot size = 1) at the assembly shop, sequence changes is inevitable between the paint and the assembly shops, and it is more so when the pressure for larger color batches is higher.

For those which are following a lot assembly policy, this may not be a problem, though. A lot assembler may simply adapt the assembly sequence to the paint sequence. In this case, sequence change would not be needed in the first place.

H5.2 The plant that are committed to the product mix levelization (heijunka) policy, or the random sequence policy with the lot size of 1, at the assembly shop, will tend to need more painted body buffers for sequence changes, other things being equal. This will be the case particularly for those which are committed to larger paint color batches.

This hypothesis deals with the other side of the problem of the paint-assembly gap in body sequences. The plants that are more committed to product mix levelization, which is one of the central principles of Toyota Production System, will face the requirements to change the body sequence between the paint and assembly, particularly when they seek for a larger paint color batches on the other hand. The role of sequence-changing buffers will be more important for them than others.

Following the standard Just-in-Time principle, we can derive two corollaries, as product mix levelization is justified for two main reasons: assembly line balancing between heavily equipped cars and simple models; making the parts order frequency even so that Kanban-type suppliers can be run smoothly.

First, when the difference in assembly work content is very different between the most complex version (e.g., a large 4 door model with full options, sun roof and air conditioners) and the simplest one (e.g., a small 2 door model without any options) on the same line, the assembly line planner has to carefully randomize the "heavy" and "light" models. If there are a number of heavily equipped models flowing back to back, assembly workers in charge of the option parts will be overwhelmed by the wave of high work load, and will be literally drifted to the next work station, when they would have to stop the line. There are some other options to absorb such a difference in assembly work content across the bodies (expanding sub-assembly lines, letting modules absorb the gap, setting up special work stations for option installation, etc.), but for the plants following the levelization rule, randomization of bodies is emphasized, particularly when a wide difference exists between the heavy cars and the light cars.

Second, JIT text books point out that levelization or randomization of the product mix is important also because the assembler can evenly distribute timing of order to any supplier that makes a certain version-specific component. This levelization of order frequency is particularly important for a Kanban-type delivery or a pull system. Thus, we can hypothesize that, even when the inter-version difference in assembly work content is not a big factor, levelization may be still emphasized when a Kanban-type delivery policy is chosen. This, together with a tendency toward a larger paint patches, will create pressures to use painted buffers for sequence-changing, other things being equal.

H6. Hypotheses on the Perceived Cost of Inventories

H6.1 To the extent that the perceived cost of inventory holding is high for a plant, its buffer level tends to be low accordingly.

This is a quite standard statement in traditional approaches of production and operations management, such as the economic order quantity formula. All the positive functions that are described in hypotheses H1 - H5 are compared against this cost of holding inventories.

H6.2 To the extent that the perceived dynamic cost of the inventories hiding problems and hampering continuous improvements is high for a plant, its buffer level tends to be low accordingly.

This is now a standard statement in every text of Just in Time or Toyota Production System and does not need further explanation. It is obvious that ardent followers of JIT emphasize this dynamic cost and justify zero inventory as an ultimate goal.

We have proposed thirteen tentative hypotheses so far based on the conceptual framework on the functions of buffers. They are by no means an exhaustive list of all possible hypotheses. They are not necessarily fully operationalized, either. The list has to be further refined and articulated as the empirical studies make progress. The foregoing list might be a good basis for further analyses and empirical studies, though.

Also, while the current hypotheses building focused on painted body buffers as a dependent variable, it would be reasonable to predict that hypotheses building for other buffer areas would be possible in a similar manner with some modification from the above discussions.

5. Future Prospects

5.1 Prospects on Data Collections

The present paper have explored a possibility of comparing and analyzing different policies and activity patterns within the same manufacturing paradigm. The issue of body buffers in the automobile assembly plants that are all aiming at becoming lean were chosen as a focus. A framework of analyzing functions of body buffers was proposed, and some hypotheses on the determinants of painted body buffers were derived from this framework. Preliminary ideas and observations from the initial stage of the empirical study was presented as supplementary data wherever possible. Based on the foregoing discussions, the author would argue that, nearly twenty years after the buffer management practices of the Japanese lean producer were introduced to the Western audience, this apparently old topic in manufacturing management still provides us with a lot of insights, particularly with regard to its actual implementation on the shop floor.

As this is still an early stage of the research, let us discuss future prospects of the study. On the side of empirical studies, data collection through a questionnaire is an obvious next step. Also, some of the hypotheses proposed here should be more articulated and operationalized, so that they can be tested in the future. In this way, data collection through the questionnaire, in-depth clinical surveys through plant visits, and refinement of the working hypotheses would have to be made interactively. Both qualitative and quantitative, as well as static and dynamic, aspects of the phenomenon will have to be explored.

Through such data collection, the author aims at analyzing at least the following points:

(i) levels of buffers at each stock points
(ii) distribution of buffers in different locations (potential trade-off between them)
(iii) functions for each area of buffers
(iv) determinants of the buffers
(v) identification of distinctive buffer policies
(vi) comparison and evaluation of the buffers observed, given the policy
(vii) comparison and evaluation of the buffer policies identified

5.2 Identifying Distinctive Buffer Policies

Among the agenda listed above, one of relatively challenging tasks is to identify and compare distinctive buffer policies, which involves more or less qualitative judgement.

Generally speaking, a policy in manufacturing is defined here as a set of internally consistent routines and practices. Based on the data collected from the assembly plants, we may identify more than one distinctive policies for body buffer management. Among them, there may be only one dominant policy that clearly outperform the other policies in the short urn as well as in the long run, but there may be more than one effective policies that may coexist for a long time.

In practice, however, it is not a simple task to identify and evaluate different body buffer policies. We need at least two steps:

(i) Checking internal consistency of buffer-related activities and practices – Can we call them a distinctive policy?
(ii) Evaluating competitive effectiveness – Is the policy in question outperforming, or outperformed by, the other policies?

In the author's preliminary field studies, several different patterns of activities for body buffer management have been already identified among the European assembly plants, including some Japanese transplants in Europe (Comparison between European plants and Japanese transplants in Europe may be more relevant than that between European and Japanese plants, as the external conditions and constraints, such as the situation of the supplier base, are more similar to each other in the first case).

A: Random sequence assembly, Random paint sequence, Emphasising keeping planned sequence, Emphasising Levelization, – Very low pained body buffer levels

B: Lot assembly sequence, Lot paint sequence, Emphasising keeping planned sequence, De-emphasising levelization, Keeping sequence between the upstream and downstream, – Relatively low pained body buffer levels

C: Random assembly sequence, Small lot paint sequence, Deviation from planned sequence allowed, Emphasising levelization, Emphasising avoidance of assembly line stops, Emphasising product variety, --Relatively low pained body buffer levels

D: Random assembly sequence, Lot paint sequence, Deviation from planned sequence allowed – Relatively large pained body buffer levels

E: Random assembly sequence, Random paint sequence, Emphasising keeping planned sequence, De-emphasising levelization, Keeping sequence between the upstream and downstream, – Moderate pained body buffer levels

Again, this is a tentative analysis, and is by no means an exhaustive list of feasible policies. According to the author's first impression, though, policies B and C seem to be stable and reasonably competitive. Policy A has potential, but its sustainability does not seem to be confirmed yet. D and E may not be as competitive as B and C. The present research will continue and refine this type of comparative policy analyses.

5.3 Historical Analysis: Evolution of Body Buffer Policies

Another line of research to be conducted is an evolutionary analyses that focus on organizational learning and dynamic capabilities of the assembly plants. This branch of the studies will need not only qualitative field surveys but also certain historical studies.

In-Depth Historical Analysis: For example, the author has studied a forty years history of body buffer policies at one of the relatively high-performing auto makers in Japan, which may be summarized as follows:

1950s: Apparently a large lot assembly and few paint body buffers. Functions of body buffers were not regarded as important.
1960s: Some painted body buffers were created as safety inventories. This was the time when mechanization of the upstream processes (press, welding, painting) made a major progress, increasing the upstream down times. The company had to respond to it by adding buffers.
1970s: Painted body buffers were added to cope with increased product varieties and the inter-version differences in assembly work content. That is, levelization of assembly product mix became emphasized. This was caused mainly by rapid expansion of exports during this period. As a result, sequence-changing body buffers were added between the paint and the assembly shops. The upstream down time became a less problem as the firm's process capabilities and maintenance capabilities improved.
1980s -: The policy was basically kept unchanged, but efforts were made to reduce the painted buffer levels by improving manufacturing capabilities.

Here, we see an example of organizational learning for revising buffer policies, cumulative adaptation to environmental changes, and new capability building in manufacturing. Other than the above descriptions, the company in the above case have done some major experiments on different body buffer policies by changing the buffer levels and seeing the results on the shop floor. Thus, there seem to have been significant trials and errors for this company to reach a certain stable solution. Note also that this kind of data may not be found in companies' official histories. A combination of literature surveys and interview researches may be needed here.

Comparisons of Organizational Learning Patterns: Another type of dynamic analysis is to compare the patterns of organizational learning for body buffer management across the plants and firms. In the preliminary field surveys, for example, at least two patterns of company-wide learning have been identified as to how multi-plant firms learn from their manufacturing experiences:

(i) Quick Learning and Quick Diffusion: Some companies have made quick experiments for different buffer policies, made quick conclusions for better solutions, and then rapidly diffused what they perceived to be the best solution of that time. Thus, at a certain point in time, this type of the firms tend to follow a similar body buffer policy across the plants, but they are in fact doing many experiments over time.

(ii) Parallel Learning from the Diversity: Some other companies keep different types of body buffer policies at different plants for an extended time, learn from the different experiences at the same time, and try to reach better solutions for the next opportunity to change. Thus there tends to be a significant inter-plant difference in body buffer policies even within the same company at the same time.

Comparing the effectiveness of the above two learning strategies is beyond the scope of the current paper, but future researches may be conducted along this line.

5.4 Tentative Conclusion

The present paper has made some efforts to propose certain analytical frameworks and hypotheses on the body buffer management at lean-production-oriented manufacturers in the international automobile industries (European in particular). Although, at this stage of the research, conclusions are all tentative, the initial analyses have convinced he author that the buffer management of lean manufacturers, an old topic in this field in theory and concept, is not at all an old topic as for its implementation even in the late 1990s.

Detailed analyses of actual body buffer management, both at the activity and policy levels, seem to provide both practitioners and researchers rich insights as to interpretation and implementation of the lean production concept, as well as organizational learning through these processes. The study may reveal that what we know in concept and what we know in actual implementation can be very different, and that what is stated (discourse) and what has been done (patterns of activities) can be also different. Depending upon how plants and firms understand such differences, their competitive performance could become very different in the long run.

Reference

Abernathy, W.J, Clark, K.B. and Kantrow, A.M. (1983). "The New Industrial Competition." Harvard Business Review September - October: 68-81.

Boyer, R. and Freyssenet, M. (1994). "The Emergence of New Industrial Models," working paper for GERPISA, December, Paris.

Chandler, A.D., Jr. (1990). Scale and Scope: The Dynamics of Industrial Competition. Harvard University Press, Cambridge U.S.

Chase and Aquilano (1985). Production and Operation Management (4th edition), Irwin.

De Meyer, A., and Pycke, B. (1996) "Separating the Fads from the Facts: Trends in Manufacturing Action Programs and Competitive Priorities from 1986 Till 1994." INSEAD Working Paper Series 96/21/TM.

Dosi, G. (1982) "Technological Paradigms and Technological Trajectories." Research Policy 11, 147-162.

Fujimoto, T. (1994a) "The Limits of Lean Production." Politik und Gesellschaft, Friedrich-Ebert-Stiftung, Germany, January, pp. 40-46.

Fujimoto, T. (1994b) "Reinterpreting the Resource-Capability View of the Firm: A Case of the Development-Production Systems of the Japanese Auto Makers." Paper Presented to Prince Bertil Symposium, Stockholm, June.

Fujimoto, T. (1995) "Note on the Origin of the 'Black Box Parts' Practice in the Japanese Auto Inudstry." in Shiomi, H., and Wada, K., ed., Fordism Transformed: The Development of Production Methods in the Automobile Industry. Oxford University Press.

Fujimoto, T. (1996) "An Evolutionary Process of Toyota's Final Assembly Operations -The Role of Ex-post Dynamic Capabilitys -." Tokyo University Faculty of Economics Discussion Paper Series 96-F-2

Fijimoto, T., and Takeishi, A. (1994) Jidosha Sangyo 21 Seiki he no Shinario [The Automobile Industry: a Scenario toward the 21st Century] Seisansei Shuppan, Tokyo (in Japanese)

Hall, R.W. (1983) Zero Inventories. Dow Jones-Irwin, Homewood, Illinois.

Hayes, R.H., Wheelwright, S.C. (1985) Restoring Our Competitive Edge. Wiley, New York.

Hayes, R.H., Wheelwright, S.C., and Clark, K.B. (1988) Dynamic Manufacturing. The Free Press, New York.

Jaikumar, R., and Bohn, R. (1984) "Production Management: A Dynamic Approach. " Harvard Business School Working Paper 9-784-066.

MacDuffie, J.P., and Pill, F. (1996) "Presentation on IMVP Assembly Plant Study" International Motor Vehicle Program, Annual Sponsor meeting, Sao Paulo, Brazil, June 10, 1996.

Mertins, K, Rabe, M., Albrecht, R., Beck, S., Bahns, O., La Pierre, B., Rieger, P., Sauer, O. (1995) "Gaining Certainty While Planning Factories and Appropriate Order Control Systems - A Case Study." Proceedings at Seminar CAD/CAM 795, Bandung, Indonesia, 8B1 - 8B20.

Merton, R. (1968) Social Theory and Social Structure. Free Press, New York.

Miller, J.G., De Meyer, A., and Nakane, J. (1992) Benchmarking Global Manufacturing. Irwin, New York.

Mishina, K. (1995) "What is the Essence of Toyota's Manufacturing Capability?: Self-Manifestation by the Transplant in Kentucky, 1986-1994" Presented at GERPISA, Paris, June 15-17, 1995.

Monden, Y. (1983, 1993). Toyota Production System. Industrial Engineering and Management Press, Norcross, GA.

Nelson, R.R., and Winter, S.G. (1982) An Evolutionary Theory of Economic Change. Belknap, Harvard University Press, Cambridge, U.S.

Ohno, T. Toyota seisan hoshiki [Toyota Production System] Diamond, (Tokyo) (in Japanese).

Penrose, E.T. (1959) The Theory of the Growth of the Firm. Basil Blackwell, Oxford.

Schonberger, R.J. (1982). Japanese Manufacturing Techniques. Free Press, New York.

Skinner, W. (1985) Manufacturing: The Formidable Competitive Weapon. Wiley New York.

Spina, G., Bartezzaghi, E., Bert, A., Cagliano, R., Draaijer, D., and Boer, H. (1996) "The Multi-Focused Manufacturing Paradigm: Adoption and Performance Improvements within the Assembly Industry." Working paper, Politecnico di Milano, Italy.

Teece, D.J., Pisano, G., and Shuen, A. (1992) "Dynamic Capabilities and Strategic Management." University of California at Berkeley working paper. (forthcoming in Strategic Management Journal)

Toyota Motor Corporation (1978), Toyota no ayumi [History of Toyota] (in Japanese).

Toyota Motor Corporation (1987). An Introduction to the Toyota Production System.

Womack, D., D. Jones, and D. Roos. (1990) The Machine that Changed the World, Rawson / MacMillan , New York.