COMPARATIVE ANALYSIS OF PERFORMANCE INDICATORS

AT WORLD AUTO ASSEMBLY PLANTS

by

JOHN F. KRAFCIK

B.S. Mechanical Engineering
Stanford University
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Signature of Author _____
Alfred P. Sloan School of Management
January 15, 1988

Certified by _____
Michael A. Cusumano
Thesis Supervisor

Accepted by _____
Jeffrey A. Barks
Associate Dean, Master's and Bachelor's Programs

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ABSTRACT

The automotive industry is characterized by increasing globalization and competitive rivalry. The ability to compete successfully depends on the strength of a company's product portfolio and its manufacturing capability. Companies which can combine high productivity, high quality, and high product flexibility have a decided competitive advantage. Against this backdrop one finds great variation in the manufacturing practices employed by the main participants in the industry. There is a strong need for the development of tools which will allow the accurate identification of the more capable of these manufacturing practices. With this information, managements and governments can make more knowledgeable decisions on the direction of their manufacturing policies.

This thesis attempts to identify superior manufacturing practice through a comprehensive comparative analysis based on recent visits by the author to 38 assembly plants in 13 countries around the world. A methodology is developed which measures the assembly plant level efficiency indicators of productivity and quality. A model is presented which attempts to explain the wide variation found in efficiency performance through the formulation of a set of input factors, such as production management policy, the level of technology, product mix complexity, and plant scale.

This thesis finds that the type of production management policy in use is a significant predictor of assembly plant performance. Wide performance variations are found in each of the three major areas studied (Europe, Japan, and North America). Evidence is presented which refutes a country explanation for high performance, indicating instead the importance of corporate culture and ownership on plant efficiency.

Thesis Supervisor: Michael Cusumano, Assistant Professor
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Special thanks also go to Yoshimitsu Ogihara, my manager and friend while I worked at NUMMI, for showing me a new perspective on automobiles and the world; Daniel Roos at the Center for Technology, Policy, and Industrial Development (and the IMVP) for his kind support; the Sloan School of Management for maintaining a thesis requirement in the face of less than broad popular appeal; my future wife Sonja for her patience and care throughout the writing of this thesis; and my family for their constant support.

Table of Contents

Page

List of Figures

Page

List of Tables

Introduction: Rationale Behind the Comparison Study

The Global Competitive Outlook in the Auto Industry

Global competition is intensifying in the auto industry. In North America, several trends point out the increasingly competitive environment:

- Many new entrants with low-cost foreign production bases.
- A flood of Japanese transplant facilities.
- Little if any market growth.

These factors are all major contributors to the overcapacity problem faced by the North American auto industry. M.I.T.'s International Motor Vehicle Program estimates automotive assembly overcapacity in North America at 4 million units by the year 1990.[1] This conservative estimate represents roughly 37% of 1990 capacity. Traditional U.S. automakers are under attack from within by Japanese transplants, assembly plants owned or managed by Japanese automakers located in North America. At least 11 transplants will be in operation by 1991, with a total capacity equal to more than half of industry overcapacity.[2]

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[1] O' Donnell and Hussey, p. 16.

[2] Transplant data determined from many public sources, interviews, and personal estimates.

Table 1: North American Transplant Summary Data

Manufacturer	Location	Start	Capacity
Toyota/GM	Fremont, California	1984	250,000
Toyota	Georgetown, Kentucky	1988	250,000
Toyota	Cambridge, Ontario	1988	80,000
Honda	Marysville, Ohio	1982	360,000
Honda	E. Liberty, Ohio	1990	180,000
Honda	Alliston, Ontario	1986	80,000
Mitsubishi/Chrysler	Bloomington, Illinois	1988	250,000
Nissan	Smyrna, Tennessee	1983	250,000
Fuji/Isuzu	Lafayette, Indiana	1988	240,000
Mazda	Flat Rock, Michigan	1987	250,000
Suzuki/GM	Ingersoll, Ontario	1989	200,000

Total North American Transplant Capacity by 1991 = 2,390,000

The influx of this "green-field" manufacturing muscle will prove to be an extreme threat to traditional U.S. automakers, many of whom are saddled with older plants and older work forces.

Competition in the rest of the world looks equally intense. In Asia, producers in Korea, Taiwan, and Malaysia are now producing low-cost, high-quality vehicles which are competing successfully in Western export markets, and could conceivably break into the Japanese domestic market. Newly Industrialized Countries (NICs) such as Brazil and Mexico are both home to world-class auto assembly operations. The European Economic Community (EEC) will lower most of its inter-country trade barriers by 1992, with ramifications that could result in the restructuring of the European auto industry.

Perhaps the greatest threat to the profitability of the European producers is the concerted upscale move by the Japanese automakers in Western markets. Reacting to pressures from a stronger yen and increased competition at the low-end of the market by the Koreans and others, and in a move to increase their profit margins, Japanese producers have expanded their product ranges dramatically. By 1990, Honda, Toyota, and Nissan will have

introduced new upscale brands in North America with distinct marketing channels.[3] Honda's Acura entry in 1986 has been a tremendous success, with sales of over 100,000 units its first full year. While the Acura Legend has soared, European prestige makes like Audi, Saab, and Volvo have shown recent decreases in U.S. sales.[4]

Of course, the Japanese producers' move upscale is not the sole concern of the European producers. Companies like General Motors have already moved out of low-end production because of tough Japanese competition. If the Japanese auto makers prove to be as successful in the middle segments and the high-end, GM may find its path to recovery a difficult one indeed.[5] This scenario is a familiar one. Western manufacturers develop the technology and market, Japanese producers eventually enter at the low-end, gradually move upscale, and with the strategy of low-cost production of a diverse mix of high-quality goods, over time force segment-retreating Western producers into bankruptcy or unrelated diversification. This pattern has emerged in cameras, shipbuilding, motorcycles, and other sophisticated manufacturing-based industries. Whether or not Western automotive producers will overcome this challenge from Japan and, increasingly, the NICs is by no means obvious. The answer lies in their ability to improve their product portfolios and their manufacturing capabilities.

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[3] Toyota will use the Lexus brand for its upscale models while Nissan will use Infiniti. Honda has been using the Acura badge for its upscale line.

[4] Comparing the first 9 months of 1987 and 1986, Volvo sales were down 5%, Saab sales down 4.5%, and Audi sales down 24%. During this same period, Acura Legend sales were up 188%. Data from *Wards Automotive Reports.*

[5] Experience to date shows the Japanese entries into the middle and high-end segments of the North American market have been successful. Honda's Accord and Acura Legend, Toyota's Camry, Mazda's 626, and others have achieved excellent sales levels. Note also that some Acuras, the Camry, and the 626 will be produced in the U.S. by 1991.

Previous Studies and the Importance of Accurate Manufacturing Comparisons

There has been a wide variety of industry literature devoted to manufacturing "competitiveness" and its measurement in the last decade. In the auto industry in particular, comparative studies between U.S. and Japanese producers appeared with great frequency in the late '70s and early '80s. During this period, "landed cost differentials" between U.S. and Japanese producers were estimated at between $1000 and $1600.[6] These works by the likes of Jim Harbour, William Abernathy, and others set the stage for the Voluntary Restraint Agreement with Japan which began in 1981.

The studies that produced these figures used a wide range of methodologies, including whole-economy macroeconomic models, industry-wide approaches using published sources, company comparison efforts correcting for things like vertical integration at the assembler level, and plant-level comparisons using a combination of public sources and internal information.[7]

Since those days of investigative research, there has been relatively little follow-up on the progress made by the U.S. manufacturers, or the current competitive position of the Japanese. Exceptions include work by Michael Cusumano, who has provided a historical perspective of comparative Japanese/U.S. auto industry performance through 1983, and Marvin Lieberman, who has built on Cusumano's work and taken it to 1985. Industry journals such as *Automotive Industries* periodically report on productivity and quality differentials between U.S. and Japanese plants, but this type of work tends only to confuse the issue due to the superficial level of analysis employed.[8] Furthermore, there have been no comprehensive studies that systematically compare the productivity of all the major

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[6] *The Competitive Status of the U.S. Auto Industry*, p. 94.

[7] Ibid., p. 94.

[8] For an example of this type of analysis, see John McElroy, "Sterling Heights: Chrysler's Showcase Assembly Plant", *Automotive Industries*, January 1986, pp. 40-42.

players in the world industry -- Japan, North America, Europe, and the Newly Industrialized Countries (NICs).

With these things in mind, I developed a research plan that was designed to assess the current state of world automotive manufacturing capability. The rationale was simple. Given the increasing internationalization of the industry, the wide spectrum of manufacturing practices employed around the world, and the very different levels of performance (productivity and quality) these varied practices yield, there is a strong need for managements and governments to develop tools which permit accurate assessments of performance and allow the identification of superior manufacturing practices. This study attempts to do this at the assembly plant level across the world.

The study, performed by the author with the financial assistance of MIT's International Motor Vehicle Program, involved visits to 38 final assembly plants in 13 countries, representing 15 major automotive assemblers. Altogether, these plants comprise roughly 25% of world automotive assembly capacity. For each plant, data were collected on the types of activities performed, employee totals, the level of technology, the product mix, and management practices.[9]

The production of motor vehicles involves not only the value added at the final assembly plants but also the activities performed to produce the various parts and components assembled. Indeed, the supply chain contributes a greater portion of the value added to the vehicle than the final assembly point.[10] Therefore, it would be desirable to develop comparative performance measures for parts and components suppliers. This is one of the author's future objectives with the International Motor Vehicle Program.

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[9] The methodology is explained in detail in Chapters 2, 3, and 4.

[10] General estimates of the value-added to an automobile by the assembler hover around 30% -- the supply chain, including the assembler's own captive suppliers, is responsible for the rest.

CHAPTER 1

A Basic Framework and Historical Context

1.1 A Basic Framework for Manufacturing Efficiency Analysis

Productivity and quality are two primary indicators of assembly plant performance. Ignoring wage rate differentials[11], component costs, and marketing strategies, assemblers with high productivity should be lower cost producers and thus enjoy a competitive advantage over assemblers of similar product types. Similarly, those assemblers who produce vehicles with few defects and thus achieve high quality should garner substantial advantage in the marketplace.

Assembly plant productivity and quality are a function of many factors. At the level of the individual assembly line worker, productivity and quality become the direct outputs of skill level, the type and condition of equipment being used, the process used to perform the operation, and the design and quality of the mix of materials being assembled. Together, these factors form a simple analytical framework that one Japanese automaker calls the 4 M's: Man, Machinery, Method, and Material, respectively.[12] Others have developed similar frameworks. Woodward proposes the interaction of production technology, production management systems, and various diverse plant and external environmental factors (product characteristics, union constraints) as the primary predictors of individual worker behavior and plant efficiency.[13]

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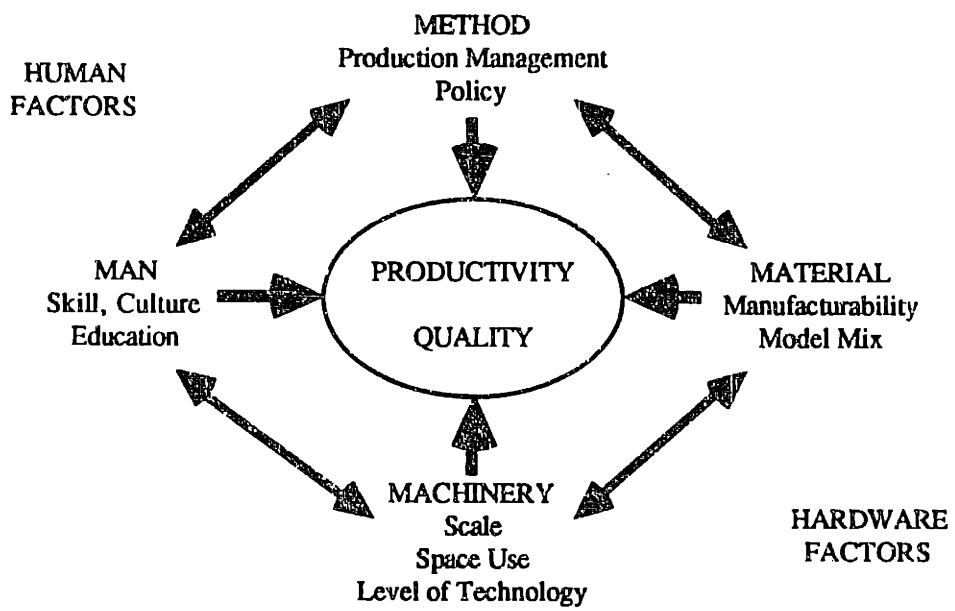
[11] I ignore wage rates and all other "costs" to avoid confusing the analysis. Fluctuating exchange rates make cross-national cost comparisons very short-lived. However, it is an easy task to multiply productivity times wage rate to determine a "spot" assembly plant wage cost.

[12] Toyota uses the 4 M framework as an aid to plant-level problem solving. When workers discover a problem relating to poor quality or reduced productivity, they are trained to determine which of the M's is causing the problem. "QC Circle Activities", Nagoya, Toyota Motor Corporation, 1984, p. 13.

For this analysis, I have taken the basic 4 M framework at the individual worker level and extended it to the assembly plant level. This simple categorization structures the analysis to follow, allowing a systematic look at the effects each of the measured inputs has on plant efficiency. The inputs fall into two basic categories: the Human Factors of Man (work force capability) and Method (production management policy), and the Hardware Factors of Material (product characteristics) and Machinery (physical plant characteristics). Figure 1 shows the 4 M's and their principle components at the assembly plant level.

Figure 1: The 4 M Framework for Assembly Plant Manufacturing Efficiency Determination



The question we will look at is what mix of components and interactions within the 4 M's leads to high productivity and high quality performance (that is, high efficiency). The methodology we will use involves thinking of productivity and quality as the outputs (or dependent variables) of the various inputs or factors (independent variables) in the 4 M framework, such as product mix complexity, level of technology and production

[13] Woodward, pp. 3-10.

management policies.

Our strategy involves finding suitable, quantifiable proxies for the main components of the 4 M's, and then determining the effect they have on plant efficiency. Since many of these components are difficult to quantify, the resulting proxies should be viewed only as approximations of the factors. Nevertheless, this model provides some useful insights into the key characteristics of high performance plants.

We look next at the historical development of production systems in the industry, using the 4 M framework developed here.

1.2 The Evolution of Production Systems in the Automotive Industry

The evolution of automotive production systems parallels the major structural transformations of the industry.[14] The first period began with the introduction of the automobile in the late 1800s. This craftsmen era had as its main characteristics a highly skilled work force and small scale facilities resembling job shops, turning out elegantly designed, nearly hand-made curiosities for the rich. All this was transformed by Henry Ford's successful application of the mass production model. Ford demonstrated the low-cost production capabilities of large scale facilities, and reached a burgeoning middle class with an inexpensive commodity product, the Model T. New production technology was combined with the concept of "scientific management", the routinization of complex assembly operations to their simplest components.[15] By 1913, the highly skilled craftsmen of the previous decade had largely been replaced by low-skilled assembly line workers and labor-saving capital equipment.[16] Scale became the key competitive weapon

[14] Much of this section draws on Altshuler et al., Chapter 2, "A Century of Transformations."

[15] Ibid., p. 15.

[16] Abernathy, p. 106. By this time, most tasks in Ford plants required between ten seconds and one minute to complete.

of the industry, while the skills of the work force became increasingly less important. Many small producers, unable to match Ford's low costs, were forced out of business. By World War II, the U.S. auto industry had been reduced to less than a dozen key players, with the current Big Three of GM, Ford, and Chrysler accounting for an overwhelming majority of the market.

In terms of the 4 M framework, the Fordist mass production model emphasized Method (scientific management), Material (low complexity, standardized parts and models), and Machinery (high scale, high capital equipment requirements), while conspicuously underutilizing Man (low skill, low levels of training, low worker participation in job design).

Alfred Sloan's "product for every pocketbook" philosophy did much to change the competitive structure of the industry, but did little to change the dominance of the Ford mass production model. Although Sloan's General Motors did offer a wide variety of products, plant level model mix complexity remained low. Large scale, dedicated plants were still the order of the day.

The success of the European producers in developing highly differentiated products serving international markets after World War II established the second transformation. Production systems were still largely Fordist, relying on scale economies and scientific management principles to achieve low costs, often at the expense of quality and flexibility. However, specialty producers like Mercedes-Benz and BMW proved that mid-line specialty producers could profit in world markets without the benefit of great scale by emphasizing product quality. Unlike the purveyors of the Ford mass production model, these specialty producers strategically compromised cost efficiency for the sake of improved quality, although they did use the tools of mass production. In this sense, the European specialty

producers can be viewed as remnants of the late 1800s craftsmen era operating on the fringes of the mass production model.

The auto industry is currently in the midst of its third major transformation, a shift that has as its main characteristic the implementation of a new type of production system that seems able to successfully accommodate what previously had been three conflicting objectives: high quality, low cost, and great flexibility. This new paradigm of manufacturing practice was developed in Japan after the Second World War, largely through the work of Toyota engineer Ohno Tai-ichi.[17] Ohno's contribution to the evolution of manufacturing practice, the now-familiar Just-In-Time (JIT) system of production, is now practiced by all of the Japanese auto manufacturers with varying degrees of emphasis and success, and is currently in various stages of adoption by many Western automakers. JIT, the driving force behind Toyota's comprehensive production management system, helped them achieve remarkable production efficiency. For example, Cusumano shows that as early as 1965 Toyota was producing 50% more vehicles per worker per year than U.S. automakers, despite the fact that Toyota's total production volume was only 5% of GM's. By 1983, Toyota's vehicle per worker productivity advantage had increased to over 120%. One could argue that individual plant scale, not company scale, is the key point of comparison. Nevertheless, Toyota's productivity growth has been undeniably impressive. We look more closely at criticisms of this and other productivity measurement techniques later.

The Ford mass production model had been upstaged by a new model of manufacturing practice. The Toyota production system depended less on large scale than on small lots, less on the theory of a simple capital/labor tradeoff than on a strong, synergistic interaction

[17] See Cusumano, pp. 262-307, for a full description of Ohno's work and a more complete explanation of the Just-In-Time system.

between man and machine, less on a low-skilled work force than on a highly participatory, highly flexible team of workers. The result was a system capable of combining high quality, productivity and flexibility at various levels of scale in a way that had not been achieved before.

Table 2 below describes in idealized fashion the predominant characteristics of auto industry manufacturing practice corresponding to the four periods described above, using the 4 M assembly plant level framework.[18]

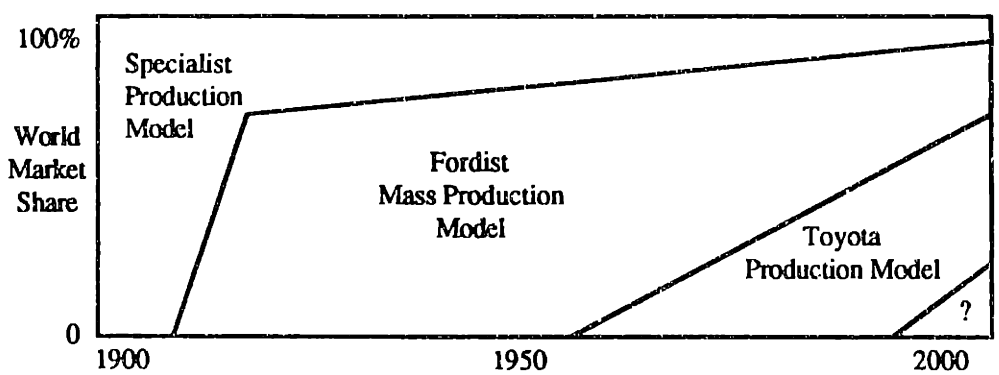
Table 2: A 4 M Categorization of the Four Periods of Manufacturing Practice in the Auto Industry

	MAN	MACHINE	METHOD	MATERIAL
CRAFTSMEN	• High skill	• Low scale	• Job shop • Quality emphasis	• Little standardization • Custom designs
FORDIST	• Low skill	• High scale • Dedicated tools • Space inefficient	• Mass production • Taylorist • Adversarial • Buffer stocks • Productivity emphasis	• Standardized parts • Little product variety
SPECIALIST	• Low/medium skill	• Medium scale • Space inefficient	• Mass production • Quality emphasis	• Standardized parts • Little product variety
TOYOTA	• Medium/ high skill • Multi-task	• Medium-high scale • Space efficient • Flexible tools	• Mass production • Participative • Team structure • JIT • Prod/qual emphasis	• Standardized parts • Product flexibility • More product variety

[18] This table builds on Womack, pp. 6-9. Womack's categorizes the four periods of the industry as low volume specialization, high volume standardization, medium volume differentiation, and high volume specialization, respectively. Note that the author's Specialist producer model applies only to the lower-volume specialty producers such as BMW, Mercedes-Benz, and Jaguar. Therefore, it differs conceptually from Womack's medium volume differentiation transformation, which includes higher volume European producers such as Volkswagen, Renault, and Fiat, along with the specialty producers.

If we consider the specialist production system to be the modern, mass production equivalent of the system practiced in the early craftsmen era, then we can view the evolution of three main production paradigms as shown in Figure 2. Here, the approximate past and expected future trends of these three modes of manufacturing practice in the twentieth century are shown. Note that this figure is a schematic representation of trends, and not a precise indicator of the world market share of each of the models.

Figure 2: The Evolution of Manufacturing Practice



Is there a logical successor to the Toyota production system? Perhaps it will be a model that places a much greater emphasis on flexibility, with one unit lot sizes, total product customization capability, and no productivity/quality/flexibility tradeoffs, courtesy of the successful application of advanced flexible manufacturing systems. Or perhaps it will be a combination of the Ford and Toyota models on a world-wide scale, with many joint-ventures and strategic alliances designed to extract economies of scale while maintaining low-wage production sites using Toyota production techniques at the plant level.[19]

Its is likely that the ascent of a new paradigm of manufacturing "best practice" will not signal the end of any of the other models. The evolutionary advance of best practice to date

[19] These projections on the future of production systems in the industry are drawn from Womack, p. 10.

seems to indicate that previous models live on, albeit in somewhat altered states, alongside more efficient production systems.[20] For example, some combinations of market characteristics are favorable to the continued application of the Fordist mass production model, while Specialist producers will certainly maintain a sizable market niche for a long time to come.

[20] Cusumano has noted the coexistence of various product-process organizations roughly corresponding to the models of manufacturing practice discussed here. Specifically, he notes the following models: Job Shop, Batch, (similar to Specialist model); Automated Factory (Fordist mass production model); Flexible Factory (Toyota model); and Flexible Manufacturing System. See Cusumano, 1987, pp. 8-10.

CHAPTER 2

The Human Factors

Using the 4 M framework, the next two chapters describe the measures developed to quantify the independent variables in the model. Expected effects on assembly plant efficiency are also presented, to be tested in Chapter 4.[21]

2.1 METHOD

2.1.1 Production Management Policy

Shimada and MacDuffie have developed a conceptual framework that is useful in the quantification of production management policy. They characterize the typical Japanese production system as "fragile", and the typical Fordist, Western mass production model as "robust".[22] The Japanese model is depicted as "fragile" because it is so highly dependent on the skills and motivation of the work force. In this depiction of the Japanese paradigm, the line workers are responsible for their own inspection (and thus quality), maintenance of the machines, and improvement of the production process. High employee absentee levels will disrupt production since management has no large stock of "utility" workers. Furthermore, since two of the hallmarks of this type of production are low inventory levels and small repair areas, workers must assure the quality and timeliness of their work or risk stopping the entire production process.

Management, through careful arrangement of its production management policies, is ultimately responsible for the operative success of a "fragile" production system. For

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[21] These expected effects are based on impressions of contemporary manufacturing thought gathered by the author over the past year.

[22] Shimada and MacDuffie, p. 27.

example, it is management who must assure the quality of worker training, develop the logistics of a JIT inventory system, and create a supportive, non-adversarial environment. Without these things, a "fragile" production system will fail.

On the other hand, Shimada and MacDuffie describe the typical Western production system as "robust". Here, workers need not worry so much about quality since there are legions of quality control inspectors to check their work before the product is shipped. Machine maintenance is the responsibility of the maintenance group, not the line worker. High absentee levels can be covered by a large pool of utility workers. Inventory levels are high throughout the process and therefore can absorb work stoppages or poor quality in isolated sections of the production process. Post-process repair areas are large enough so that the importance of building the product right in the first place is reduced.

The role of management in a "robust" system is clearly different from that in a "fragile" system. Here, production management policy revolves around the establishment of various safety nets to keep the system running should something go astray. Buffer stocks, large repair areas, quality inspectors, utility workers and large maintenance staffs are all indications of a production management policy designed to absorb shocks caused by a low skilled, poorly motivated work force.

Depicting all Japanese production systems as "fragile" and all Western systems as "robust" as I have done here is certainly a gross generalization. Some Japanese manufacturers still rely on in-process inspections[23], while others have yet to reach the low inventory levels of Toyota[24], the first and most successful implementor of the Just-In-

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[23] In-process inspection more so than final inspection is characteristic of a "robust" system. All assembly plants use final inspection procedures to confirm the outgoing quality of the product. On the other hand, in-process inspection performed by a separate quality control staff and used as a means to "inspect-in" quality is a procedure that deviates from the self-inspection doctrine of the "fragile" system.

[24] Cusumano, p. 301. Here we see Nissan with roughly half the inventory turnover rate of Toyota in

Time production system. Also, many Western manufacturers are achieving lower inventory levels, decreased absenteeism, and increased employee involvement by overhauling their own production management policies and systems. Nevertheless, it is still useful to think of the range of management philosophies as a continuum from "robust" to "fragile", from "independent" to "interdependent", from the buffer stock systems of Ford in the 1920's to the small-lot production style of Toyota in the 1980's.

Expected Effects on Efficiency: Preconceived notions aside, there is no analytical reason to expect a "fragile" system to produce higher quality products than a "robust" system. One could imagine a "robust" assembly plant with intense effort spent in inspection and rectification activities achieving high quality at the expense of productivity.[25] Similarly, one could imagine a "robust" system sacrificing quality and achieving great productivity through the simple expedient of an assembly line speed increase and/or reduced inspection/rectification efforts. The primary expected virtue of the "fragile" production system lies in its capability of simultaneously achieving high quality and high productivity.[26]

Quantification: The production management policies in place at each plant are reflected in organizational arrangements such as the level of employee participation, the use of the team concept, and various programs such as suggestion systems and quality circles. Other outward manifestations of production management policies are evident in plant facilities design arrangement (for example, the amount of floor space dedicated to repair facilities or inventory holding), pleasantness of the work environment, the inventory control system in

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1983.

[25] In fact, this seems to be the mode of operation for many of the European prestige manufacturers, based on conversations with plant management in Europe. This is consistent with the Specialist model presented in Table 2.

[26] Shimada and MacDuffie, p. 3.

use, the way in which worker jobs are designed, the use of visual control systems to broadcast production status, and the level of unscheduled employee absenteeism.

In order to quantify production management policy, data were gathered in several different areas which together seem to offer a reasonable reflection of the production policies in place at each plant. These areas are:

(1) The percentage of assembly area floor space dedicated to post-process repair,

(2) The amount of emphasis placed on "visual control" of the production process,

(3) The degree to which the "team concept" is used in plant operations, and

(4) The average level of unscheduled absenteeism.

A score from one to three was determined for each of these areas in each plant, with a score of one indicating consistency with a "fragile" production/management system and a score of three indicating consistency with a "robust" system.[27] The sum of these four individual scores yielded a production management policies index (Management Index) for each plant.

A correlation matrix consisting of these four components and the Management Index (MI) is shown in Table 3.

[27] Various techniques were used to assign these scores. These are discussed in turn for each component.

Table 3: Management Index and Component Correlation

	Repair %	Visual Control	Team Concept	Absenteeism	MI
Repair %	1				
Visual Control	.459	1			
Team Concept	.452	.520	1		
Absenteeism	.381	.234	.669	1	
MI	.746	.716	.866	.752	1

The intercomponent and component/Index correlations are strong enough to support the composition of this index as a reasonable quantification of production management policies on the "fragile"/"robust" continuum.

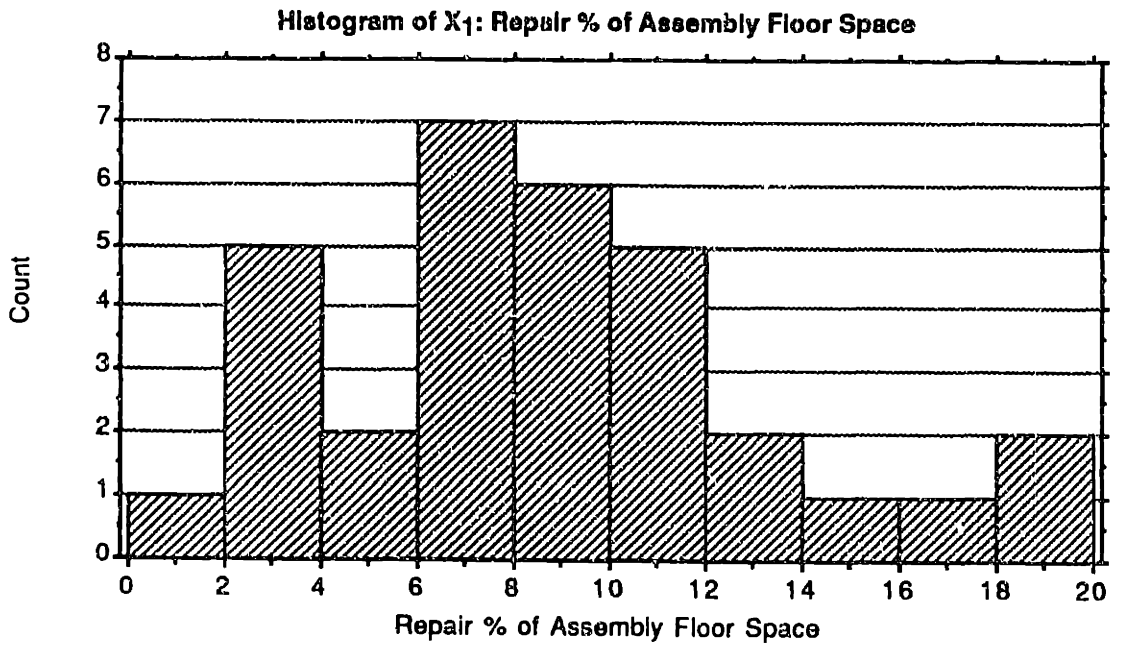
It should emphasized that these components are not the only possible indicators of production management policy. For example, a quantitative assessment of average inventory levels would be an excellent addition to this list. (It is not included because of difficulties in obtaining accurate, consistent inventory data across the plants in the sample.)

• Repair Area Percentage of Floor Space: The basic concept for this indicator of production management policy is that the more space there is dedicated to repair and rectification activities, then the less faith management must have in the capability of its work force to get things done correctly the first time. The data showed a strong relationship between those assemblers using traditional "robust" production techniques and those plants with large areas dedicated to final assembly repair.

The calculation of this indicator is a two step procedure. First, an adjustment is made to assembly area floor space so that compact plants with proportionately large (but

absolutely small) final repair areas are not unduly penalized. Then, the corrected repair area is divided into the corrected assembly area floor space to yield the percentage of assembly floor area dedicated to repair.[28] The range of values for this indicator is large, with a minimum value of 0.5% of total assembly area floor space dedicated to final repair and a maximum value of 18.3%. The average value is 8.6%. The frequency distribution of values for all the plants in the database is as shown in Figure 3.

Figure 3: Frequency Distribution of Repair Area % of Assembly Area



A ranking score from one to three was assigned based on each plant's result. Those plants dedicating from 0 to 6.1% of their assembly floor space to repair received a one (10 plants), 7 to 10% a two (13 plants), and 10.8 to 18.3% a three (9 plants). These lines of

[28] To make this adjustment, first the plant's final assembly repair area is adjusted proportionately to what it would be if the plant ran at 60 units/hour. Then, an average value for assembly shop square footage is determined for all the plants in the survey adjusted to 60 units/hour. Dividing the first term by the second gives the corrected repair area percentage of assembly shop floor space.

demarcation followed the natural clustering of the data points.

• Visual Control of the Production Process: For a "fragile" production system to operate smoothly all members of the production team should be aware of production status. That is, things like quality data, production totals, and employee performance should be broadcast for all to see. Only if these types of data are available can a "fragile" system be scrutinized, kept running properly, and continuously improved. Each plant was subjectively ranked on the degree of visual control in its process by its performance in several key areas:

(1) The continuous broadcasting of production totals and quality performance,
(2) The degree to which the plant uses statistical process control to monitor process quality,
(3) The general level of housekeeping in the plant,
(4) The way in which parts are stocked in the plant, with high bay, line-side storage deemed inconsistent with good visual control practice.

A score was assigned for each of these three categories on a subjective basis. After all the plants had been visited, a content analysis of plant tour notes was performed to ensure these rankings were consistent. Then, a final "visual control" score was computed based on the average of the four component scores.

• Use of the Team Concept: Whereas a traditional Western "robust" production system can function without a high degree of employee interaction, the "fragile" system requires interaction in all facets of operations. Each team member must be trained in more than one job to compensate for the possible absence or transfer of another. Team leaders working on the production floor function much as traditional supervisors, but are capable of responding to problems on the line by actually lending a hand. Furthermore, these teams are the catalyst for the continuous incremental improvement that is one of the hallmarks of the Toyota-style production system.

Here again, plants were scored on the level of team participation in the work force. Scores were decided as follows (number of plants with this score in parentheses):

1 -- Most departments and areas using a team-style organization, for at least one year.[29] Each team has a team leader, who has the capability of performing production work. (9)

2 -- Some departments using a team-style organization. Some teams have team leaders, who may or may not perform production work. (10)

3 -- No departments using a team-style organization. (13)

- Level of Unscheduled Absenteeism[30]: This is the final component of the Management Index. The assumption here is that high levels of absenteeism reflect worker dissatisfaction, a condition which the "fragile" production system overcomes by offering more complete involvement with the production environment.[31] Those plants with high levels of unscheduled absenteeism must maintain large numbers of "utility" workers to take the place of those absent, a "robust" characteristic which leads to reduced productivity and quality.[32] A "fragile" production system does not have the buffer of additional workers

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[29] The one year cutoff is used to differentiate between those plants which have just started using a team-style organization and are therefore still in a transition phase and those plants with more established team organizations.

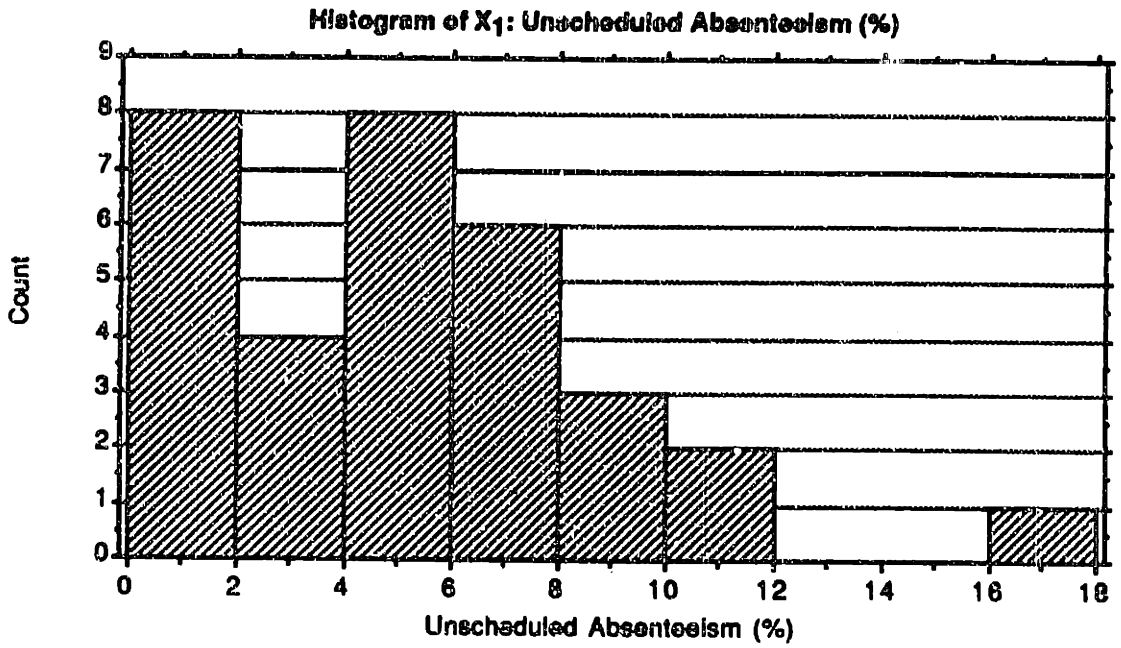
[30] Unscheduled absenteeism is based on absences from work that are not planned beforehand such as unscheduled sick leave. Scheduled vacations and health care leaves are examples of scheduled absenteeism.

[31] High rates of absenteeism may also reflect to some degree the social environment. For example, plants in some European countries have high unscheduled absenteeism rates due at least partially to a state social welfare system that pays the worker full salary for days of work missed. However, anecdotal evidence supports the fact that even in plants located in these countries management has achieved success in reducing unscheduled absenteeism by adopting work organization practices resembling the "fragile" model.

[32] Note that productivity as measured for this study excludes total absenteeism so as not to distort the Standard Activities methodology set forth in Chapter 4. (This methodology requires a consistent set of activities to allow accurate plant-to-plant comparisons. By excluding workers required to cover total absenteeism, we can focus more closely on the amount of effort required to assemble a standard product, without concern for variance in vacation time and other *scheduled* absenteeism across countries and companies. Note that this also has the effect of conservatively understating the productivity differential between "fragile", low total absenteeism Japanese producers and "robust", high total absenteeism European

and therefore would come to halt if high levels of unscheduled absenteeism occurred. The frequency distribution of unscheduled absenteeism around the world is as shown in Figure 4.

Figure 4: Frequency Distribution of Unscheduled Absenteeism



Unscheduled absenteeism values ranged from a minimum of 0.26% to a maximum of 16%, with a mean value of 4.8%. Absentee rates between 0 and 3% were assigned a score of 1 (12 plants), between 4 and 7.9% a score of 2 (14 plants), and between 8 and 16% a score of 3 (6 plants). Here again, the lines of demarcation between the scores followed the natural clustering of the data points.

The Management Index value can now be calculated by adding the scores of each of the

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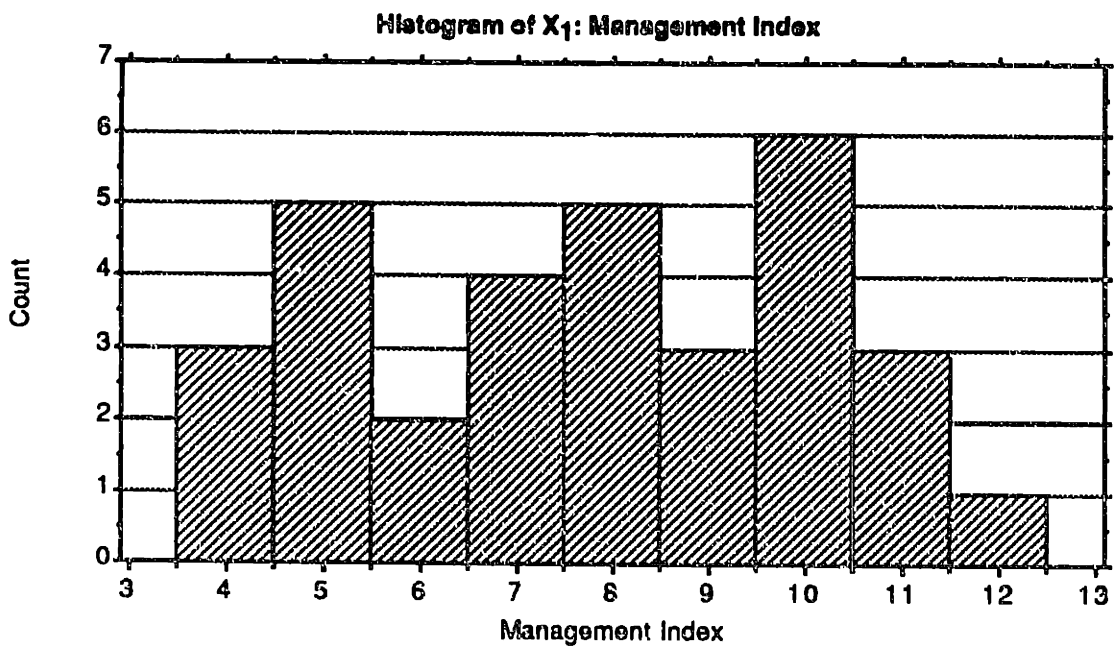
and American producers.) Therefore, the expected mechanism for reduced productivity (as measured in this study) in high unscheduled absenteeism plants is the reduced capability of the utility worker vis-a-vis the absent worker, *not* the physical requirement of the utility worker. Likewise, the expected mechanism for reduced quality is the reduced skill level of the utility worker compared to the absent worker.

four individual components -- repair space percentage, visual control, team concept, and unscheduled absenteeism. This Index score is a reflection of the type of production management policies used by each plant, as determined by the functional layout and appearance of the facility and the social organization and involvement of the work force. A frequency distribution of the Management Index scores is as shown in Figure 5. Note that the range of scores (4 - 12) reflects the fact that some plants achieved a score of one in all four categories, indicating a high degree of correlation with the "fragile" stereotype, while one plant achieved a score of three in each category, indicated a high degree of correlation with the "robust" stereotype.

Figure 5: Frequency Distribution of Management Index Scores



This distribution (with mean of 7.8) shows a relatively flat distribution, a finding which coincides nicely with the idea that production management policy can be depicted as a continuum, with a pure Toyota-style production system at one extreme and a traditional

Fordist system at the other.

2.2 MAN

2.2.1 Work Force Capability

Expected Effect on Efficiency: Based on evidence from other industries and traditional concepts of experience or learning curves, an experienced, well-trained, and well-educated work force can be expected to perform at a higher level of efficiency, other things being equal.

Quantification: At the time of writing, complete data on work force capability was not available. Ideally, this data set would include such categories as average age of the work force, average number of years of experience, level of secondary education, and level of company-provided education, for all the plants in the survey. The effect the omission of this important variable has on the results of the model is discussed in Section 5.1.4. The author plans additional work in this area in the near future.

With the discussion of the human factors and quantification of a proxy for Method complete, we now turn to Chapter 3 and the more physical of the input factors, Machinery (technology, scale, and space use) and Material (product characteristics).

CHAPTER 3

The Hardware Factors

This discussion of the "hardware" factors related to the physical characteristics of the plant and the product mix uses the same format as Chapter 2. The expected effect on plant operating efficiency of each input is followed by an explanation of the methodology for calculating each input.

3.1 MACHINERY

3.1.1 Plant Scale

Expected Effect on Efficiency: The relative scale of the plant could be expected to have an influence on productivity.[33] Based on traditional concepts of economies of scale and scope, a high-output facility should offer opportunities to share resources in various indirect activities such as administration, maintenance, and production control, therefore increasing overall productivity. There is little reason to expect plant scale to affect quality.[34]

Quantification: This independent variable is defined as the net hourly output of the facility, where net hourly output is determined by dividing the total number of vehicles produced in one shift by the number of working hours (excluding meal times but including breaks).

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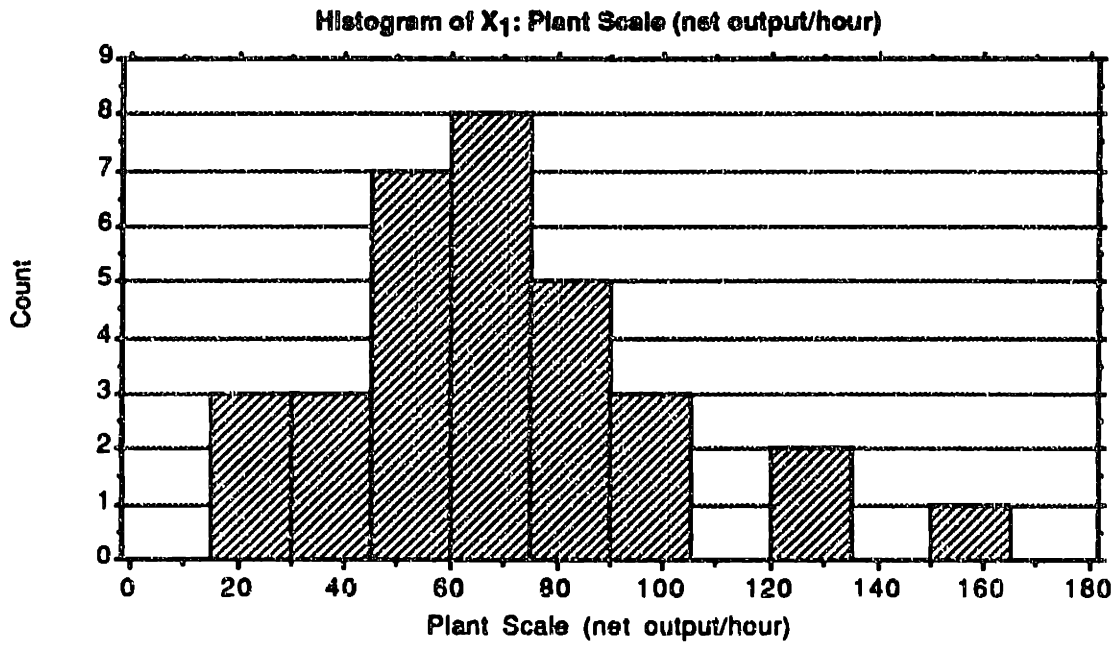
[33] Scale here refers to the level of output of the facility, not the physical size.

[34] Plant scale is not to be confused with lot scale here. One of the main tenets of the Toyota Production System is that small lot sizes lead to higher quality, since large lots and buffer stocks tend to conceal problems while small lots tend to highlight them, thus leading to faster problem solving.

Our average sample Plant Scale was 67.7 units/hour, with a wide range from 18.6 to 150, as shown in Figure 6.

Figure 6: Frequency Distribution of Plant Scale



3.1.2 Space Utilization

Expected Effect on Efficiency: A plant that uses its space efficiently, that is, that seeks to minimize the amount of floor space required to produce at a given level of output, can be expected to operate more efficiently. For example, plants with relatively compact floor areas can be expected to achieve productivity savings through reduced parts delivery effort and improved communication. Quality savings might also be expected through the benefits of improved communication and control.

Quantification: Space utilization is defined as the number of square feet per vehicle per year required for each plant operated at capacity, adjusted for the size of the average vehicle built at each plant. We adjust for average vehicle size as follows:

Defining Unadjusted Space Utilization USU = (Standard Activities Floor

Space)/(Yearly Production at Capacity),

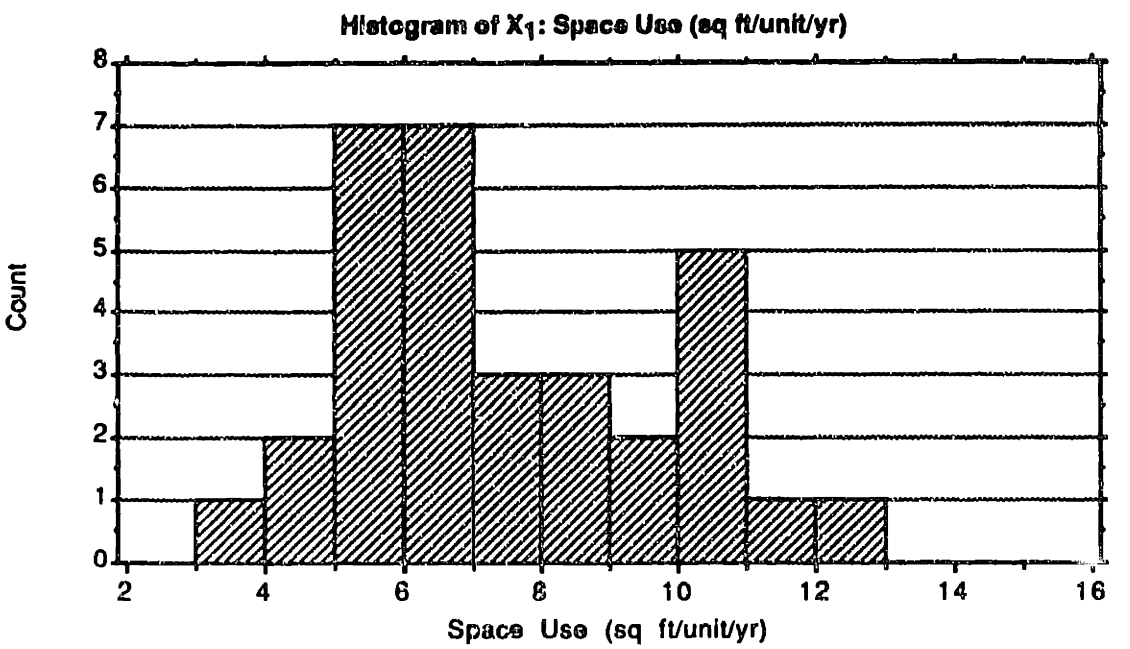
then Adjusted Space Utilization = USU x (Size Correction Factor).

Here the Size Correction Factor = (Standard Vehicle Length x Width)/(Plant Composite Vehicle Length x Width),

where it is assumed that floor space requirements are generally proportional to the product of vehicle length and width.[35]

The average space utilization value for our 32 plant sample was 7.4 sq. ft./unit/year, with a range from 3.9 to 12.2.

Figure 7: Frequency Distribution of Space Utilization



[35] Chapter 4 explains the terms Standard Activities, standard vehicle, and plant composite vehicle in detail. Note that the adjustment made here is more than likely an overcorrection for plants building larger vehicles. This overcorrection will tend to make plants producing large cars more space efficient than they really are.

3.1.3 Level of Technology

Expected Effect on Efficiency: Like other of the inputs, the level of technology is linked to other factors. In this case, the age of the plant, production management philosophy, and geographic location (low wage vs. high wage countries) can all impact the level of technology in the plant. This caveat aside, it seems likely that the higher the level of technology in the plant, the greater the *opportunities* for productivity increases. Further, since the potential for human error is less, one would expect higher quality from increased levels of technology.

Quantification: A Robotic Index, based on the number of installed flexible automation pieces in each plant, was developed as a proxy for the level of technology in the plant. Another possible indicator would be the total level of automation, both flexible and "hard".[36] Unfortunately, it is an extremely difficult task to consistently measure the total amount of automation in assembly plants.[37] On the other hand, determining the number of pieces of flexible automation is a routine exercise. Beyond this simplicity in accounting, measuring the level of flexible automation allows us to determine how effectively plants are using the flexibility these tools allow. Furthermore, the level of flexible automation is a more appropriate proxy for the technological prowess of a plant than the overall level of automation, since flexible automation is likely to be newer and more sophisticated than hard

36 "Hard" automation refers to automation which can not be routinely reconfigured or programmed to accept new part configurations.

37 One method I have used to try to measure "total automation" is by determining the percentage of steps in each major department that are automated. This is relatively simple to do in the case of body welding, where the number of automated welds is a reasonable proxy for the degree of automation there. However, determining the percentage of automated steps becomes more complex in the paint, assembly, and material handling departments. Until appropriate data can be collected and an effective methodology developed that will allow the determination of the percentage of automated steps in these areas, the Robotic Index will have to suffice as an approximation of plant level technology.

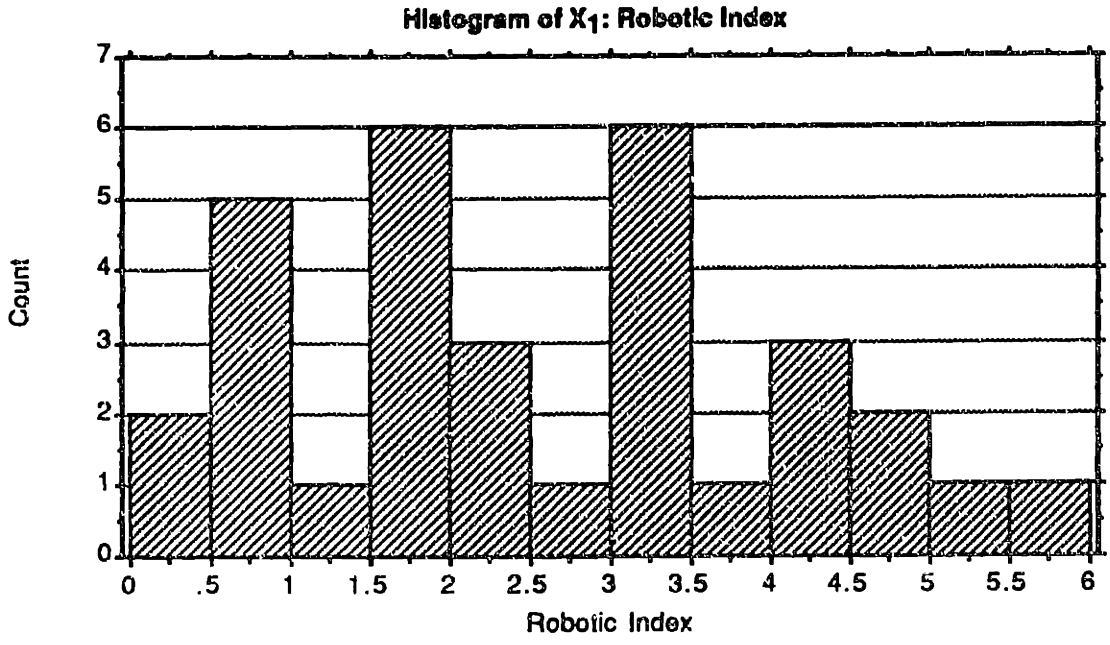
automation.

For this study, flexible automation was defined as any robotic application with at least two axes of motion and programmable capability, the standard industry definition for a robot. Automatic guided vehicles (AGVs) were not included in this definition.

The value of the flexible automation index (Robotic Index), is calculated by dividing the total number of robotic applications used to perform the Standard Activities by the net hourly output of the plant. Dividing by the output is equivalent to making an adjustment for the scale of the plant. Such an adjustment allows us to more accurately compare the technological level of plants of disparate sizes.

The average Robotic Index value for the 32 plant sample was 2.5, with a range from 0.7 to 5.9.

Figure 8: Frequency Distribution of Robotic Index Values

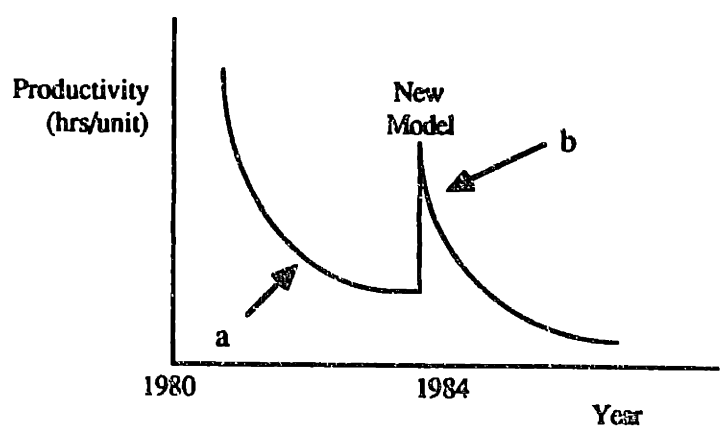


3.2 MATERIAL: Manufacturability and Model Mix Complexity

3.2.1 Manufacturability

Expected Effect on Efficiency: Here we define manufacturability as the ease with which a product can be assembled. Examples of easy manufacturability include doors that are easy to adjust properly, interior trim and body panel pieces that install with little effort and provide a high quality appearance with little need for adjustment, and trim pieces that snap into place instead of requiring fasteners. By this definition we might assume that a plant building a product high on manufacturability would perform at higher levels of quality and productivity than a plant building a product low on the manufacturability scale. However, this ignores the possibility that the benefits from learning curve effects might overcome the disadvantages of building a product low on manufacturability. This concept is illustrated below in Figure 9.

Figure 9: Learning Curve Effect vs. Design Age



Model "a" achieves higher levels of productivity in 1982 than model "b" in 1984, despite the fact that model "b" is inherently easier to build (judging by its superior initial and bottom of learning curve productivity levels). Thus, the expected effects of product

manufacturability on plant efficiency are ambiguous until learning curves are taken into account.

Quantification: Product age is used as a proxy for the manufacturability of the product. The basic concept here is that newer product designs of the same vehicle type will be easier to manufacture, holding the effects of production learning curve differentials constant. Conversations with plant management and workers indicate that this is the case for a time series of vehicles designed by the same manufacturer. However, this may not hold so well across different manufacturers. For example, there is little evidence that a 1981 Ford Escort (basic design introduced in 1980) was easier to build than a 1976 Toyota Corolla (basic design introduced in 1975), despite the fact that the Escort was a newer design. Alternative proxies for product manufacturability present other problems. For example, the number of parts per vehicle has been suggested by some, but this offers confusion in accounting (how to count fasteners?, which trim level to base the count on? how to count optional or alternative parts that increase the plant-level part count but not the individual vehicle part count?) with little clear evidence that this is a more acceptable alternative.

Product age is defined as the weighted average number of years since a major model change introduction for the mix of models currently being built at each plant.[38] For example, if a plant were building 50% each Ford Escort (introduced in the third quarter of 1980) and Ford Taurus (introduced in the fourth quarter of 1985), and we use the mid-point of the fourth quarter of 1987 as our baseline, then the average product age for this plant is as follows:

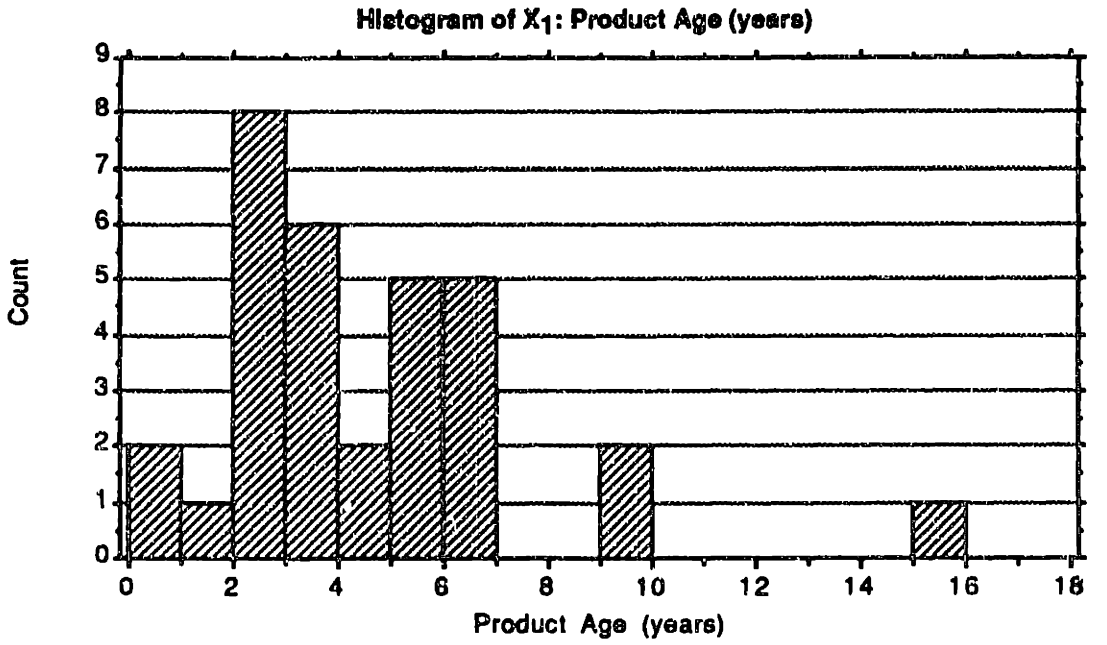
$$0.5 \times (87.87 - 80.63) + 0.5 \times (87.87 - 85.87) = 4.6 \text{ years.}$$

The average product age for the plants in this survey was 4.4 years, with a minimum of 0.25 and a maximum of 15.7 years. The frequency distribution of product age is as shown

[38] From *Revue Automobile: Catalogue de la Revue Automobile, 1987.*

in Figure 10.

Figure 10: Frequency Distribution of Product Age



3.2.2 Model Mix Complexity

Expected Effect on Efficiency: Model mix complexity refers to the various different product platforms, models, body styles, drivetrain configurations, and export variations (such as right and left hand drive) produced in each plant. Conventional wisdom predicts that as the degree of this variation increases, there will be lost economies of scale in material handling (more different part numbers to stock), production equipment (more pieces of equipment to handle increased variety, more maintenance workers to fix them), job performance (more tasks to learn), and scheduling (more variety would tend to mean less efficient use of individual workers from a "line balancing" perspective).[39] Therefore,

[39] "Line balancing" refers to the process of distributing job tasks to individual workers in order to optimize the amount of time each worker spends adding value to the product.

we expect lower productivity to go with increased model mix complexity. The effect on quality is less certain, although traditional Western production philosophy equates more diversity with more potential for mistakes and therefore lower quality.

Quantification: The Model Mix Complexity Index score is a snapshot of the relative complexity of the current production mix, adjusted for the relative scale of the plant. For this Index, scale is defined in terms of the number of body and assembly shops in each assembly plant. For example, a plant with three body shops and two assembly shops would be considered the equivalent of 2.5 "standard" assembly plants.[40] This means that a plant with two body shops and two assembly shops building two different platforms would have the same Model Mix Complexity Index as a plant with one body shop and one assembly shop building one platform.

Weights are assigned to product variation as follows[41]:

- 10 points for each unique platform
- 5 points for each unique model (>50% unique exterior panels)
- 3 points for each body style (3 door, 4 door, etc.)
- 3 points (total) for front and rear wheel drive capability in the plant
- 2 points for left and right hand drive option per model.

A weighted (by model mix proportion) value for each plant is then divided by the appropriate plant scale factor to yield the final Model Mix Complexity Index score.

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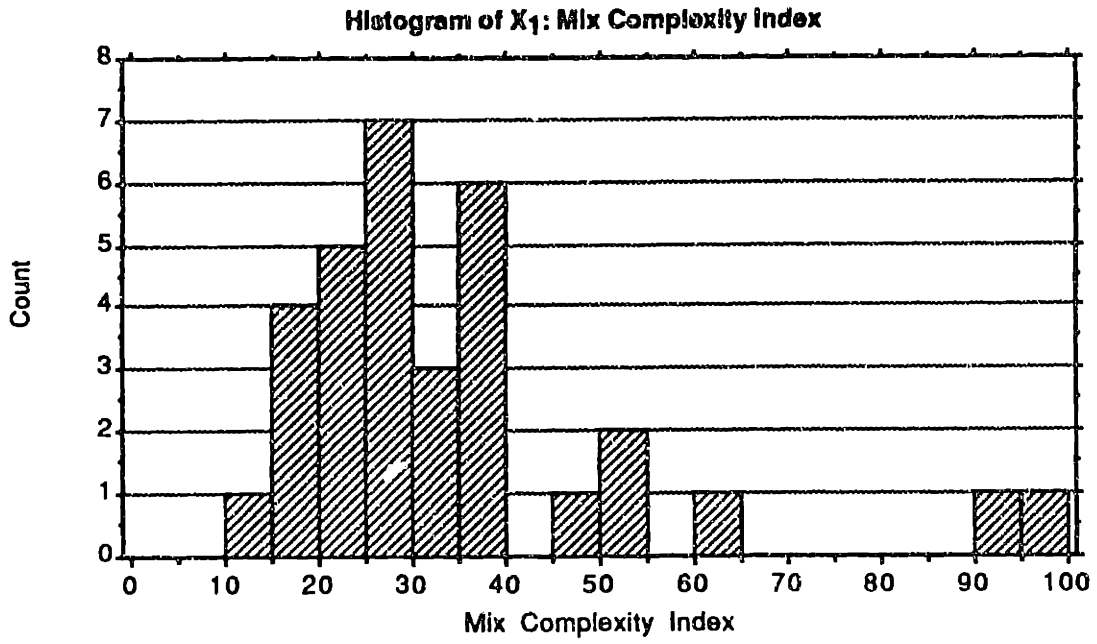
[40] 0.5 x 3 body shops + 0.5 x 2 assembly shops = 2.5 equivalent plants. Note that an assembly shop is defined as an assembly line, while a body shop is defined by the number of physically distinct body welding areas. Note also that this index can not differentiate between plants of similar configuration but different line mix philosophies. For example, plant A produces two platforms, building platform #1 in one equivalent plant and platform #2 in the other. Plant B on the other hand, building the same platforms, produces both platforms in both equivalent plants. Clearly, plant B is more producing more flexibly, yet will achieve the same Model Mix Complexity Index value as plant A. While this is an issue for further study, it was not a factor for the plants in this sample.

[41] This weighting system was developed based on conversations with plant staff personnel and my own judgment. An unweighted index constructed with the same five elements has a correlation coefficient of 0.90 with the weighted MMC Index.

As expected, the range of Model Mix Complexity Index (MMCI) scores around the world is great, reflecting the fact that some plants build an incredible variety of products in one small plant while other larger plants attempt to achieve economies of scale by building just one platform with little meaningful variation. The average MMCI score was 34.3, with a range of values from 11.5 (little complexity) to 98.0 (high complexity). The frequency distribution is as shown in Figure 11.

Figure 11: Frequency Distribution of Model Mix Complexity



Note that minor variations in mix complexity such as option proliferation and trim/color combinations are not included in this Index. Despite a plethora of popular press and consulting company claims (see below) regarding the gains to reducing the number of option combinations, the effect that this has on assembly plant level operations is not yet clear. Let us first examine some of these anti-option combination claims, and then think about the actual scope for potential savings through "option packaging", a solution to

increased quality and productivity requirements that is currently enjoying widespread acceptance in the North American industry.[42]

One possible problem with the current trend toward option packaging is that it may have been based on a misleading accounting of the number of option combinations found in Japanese plants compared to North American plants. For example, an influential 1984 consulting study determined that a Ford Thunderbird offered 69,120 possible option combinations, while a Toyota Corolla offered only 768.[43] While these numbers may have reflected comparative standing in the American market, the story changes considerably when the fact that the Toyota plant produces for more than 100 export markets and a fragmented domestic market is considered. This added complexity through numerous trim levels, variations in safety equipment, and diverse exhaust emission control systems narrows the "option combination gap" as reported in the study considerably.[44]

Others have made untested assertions regarding the high costs of option proliferation. One analyst writes: "Now Detroit is suddenly realizing there's an enormous cost penalty associated with uncontrolled option availability ... Simplified design, purchasing, inventory control, and assembly [through packaging] amounts to an important cost benefit to the Japanese."[45] Here again, it seems the actual complexity of Japanese plants has

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[42] Examples here include Chrysler's America series for the Omni/Horizon and Aries/Reliant models, General Motors' standard equipment upgrades for the 1988 model year, and Ford's continued efforts to package options.

[43] Cited in James Cook, "Where's the Niche?", *Forbes*, September 24, 1984.

[44] At the assembly plant level, it is not the number of option combinations per model that matters so much as the number of option combinations for all the models built in the plant. For example, in 1987 a Toyota plant was producing 5200 different option combinations for the Corolla, but a plant total of 9210 option combinations when the other models built in the plant were considered. This figure may be comparable to the current Thunderbird/Cougar option combination count, considering the work Ford has done to reduce their combinations since the consulting study was performed. Source: The author's plant tour notes and photographs, July 1987.

been underestimated, while the perceived benefits to packaging have been assumed without a full accounting.

When one looks carefully at the concept of option packaging, a case can be made for the view that the direct worker on the assembly line is not so affected by the number of option combinations available as by the number of options. Take an admittedly simple case where plant A builds two vehicles only, one with no options and one with an option package consisting of an upgraded radio (r), leather seats (l), and deluxe wheels (w). Plant B in this example builds the same product, but allows the customer to decide on any possible combination of a base vehicle with or without any of the three options. Thus, the number of vehicle combinations for plant A is two (base vehicle and optioned package vehicle), while the number of combinations for plant B is eight (base vehicle, r, l, w, r+l, r+w, l+w, r+l+w). How is the worker on the production line affected by these differences? The production worker in charge of wheel installation is not impacted by the combination of options -- she simply reads the manifest and installs the appropriate wheel. The same is true for those installing the radios and seats -- one installs either an upgraded radio or a base radio, and the other installs either a standard seat set or a leather seat set. Packaging by itself need not impact direct line productivity.[46]

On the other hand, a reduction in the number of features (not combinations) would tend to increase efficiency. For example, removing air conditioning from the list of available

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[45] Maryann N. Keller, "Freedom of Choice vs. a Good Deal", *Motor Trend*, December 1987, p. 146.

[46] There may be some minor savings from option packaging on the indirect side, specifically related to those who do the parts ordering. Presumably their job will be easier since they will only have to estimate projected volumes for one set of options instead of three individual options. Also, packaging may aid quality by reducing the variety of those parts which are affected by a high number of option combinations, such as wire harnesses. The theory here is that if there are fewer choices of wire harnesses to install, then the operator has a better chance of installing the right one. However, this secondary effect can largely be mitigated by intelligent part design (i.e., flexible harnesses that support many option combinations), clever process design, and well-trained operators.

features would certainly have a positive impact on productivity, since (1) the line would now be easier to balance and (2) installing air conditioning took extra effort. Point (1) of this argument is analogous to the rationale behind the Model Mix Complexity Index. It measures only major product variation, variation which could be expected to decrease efficiency, due primarily to the difficulty in "balancing the line" to cope with additional platforms, body styles, and drive-train configurations. Point (2) is already compensated for by the Equipment Content Adjustment described in Section 4.3.

With the selection and quantification of each of the components of the 4 M's completed, we can now close the discussion of the independent variables in the model. Chapter 4 addresses the measurement of the dependent variables, productivity and quality.

CHAPTER 4

A Methodology for Measuring the Dependent Variables: Productivity and Quality

4.1 The Need for Accuracy and Consistency in Measuring Productivity and Quality

As productivity and quality are the key indicators of assembly plant performance, they must be measured as accurately and in as consistent a manner as possible if we are to believe the results. Thanks to marketing research companies such as J.D. Power and Associates and Maritz Marketing, developing consistent measures of assembly plant quality is no longer the stumbling block it once was.[47] However, the consistent measurement of productivity was, is, and will forever be a difficult task. The method developed for this study is by no means perfect, but is meant to improve upon some of the previous efforts attempted by auto industry researchers.

4.2 A Sample of Previous Productivity Comparison Efforts

- Harbour and Associates, 1980: Harbour and Associates' "Comparison and Analysis of Manufacturing Productivity in the North American and Japanese Automotive Industry" and "Comparison of Japanese Car Assembly Plant Located in Japan and U.S. Car

[47] There is some contention in the industry as to whether or not these studies are (1) consistent with each other, (2) consistent with internal company data, (3) accurately reflective of consumer opinion, and (4) comparable across a full range of products (due to problems of differing consumer expectations for high end vs. low end products). These contentions aside, there are still no viable alternatives to these marketing studies for the research community. Their importance can be measured by the fact that the surveys' largest consumers are the assemblers themselves. An additional problem is the fact that there is no world-wide cross-company quality survey available, a problem we contend with in Section 4.4.

Assembly Plant Located in the U.S." were the first major efforts to assess productivity differentials between the U.S. and Japan. These reports came out in late 1980. Both are comprehensive studies dealing not only with assembly plant productivity but also construction costs and production launch curves. Their productivity findings as presented in "Comparison of Japanese Car Assembly Plant Located in Japan and U.S. Car Assembly Plant Located in the U.S." can be summarized as follows[48]:

Table 4: Harbour Comparison of U.S. and Japanese Hours per Car
(Sub-compact -- Car Assembly Only)

	Hours per Car	%
Total U.S. Hours per Car	31.1	100.0
Total Japanese Hours per Car	14.1	45.3
Difference	17.0	54.7
Explanation of Difference		
• Management Systems and Techniques		
Plant Complexes/Size/Location	1.1	6.5
Quality Systems	3.3	19.4
Just-In-Time Production	1.8	10.6
Productivity	9.1	53.5
Material Handling Engineering	0.5	2.9
• Sourcing	-1.6	-9.4
• Union/Management Relief/union	1.6	9.4
• Japanese Staff or Purchased Services	1.2	7.1
		100.0
Total Difference	17.0	
Less Japanese Staff/Purchased Services	1.2	
Net Japanese Productivity Advantage	15.8	

The data base used to develop these startling numbers (startling because if accurate they show the Japanese auto makers requiring less than half the manpower of the U.S. automakers) are a montage of three plants in the U.S. (Wayne, Michigan -- Ford Escort;

[48] Harbour and Associates, 1980, p. 69.

Wilmington, Delaware -- Chevrolet Chevette; Belvidere, Illinois -- Dodge Omni) and industry-wide data for the Japanese automakers (from "Labor Productivity Statistics Survey for 1979" by the Japanese Ministry of Labor, adjusted by Harbour for "estimated 1980 productivity improvements", with additional information coming from "Toyota Production and Kanban System").[49] These two distinct methods of gathering data -- on a plant-by-plant level for the U.S. automakers and through secondary sources for the Japanese-based producers -- undoubtedly biased the productivity estimates. Further, Harbour provides little evidence of correcting for different levels of option content or other product variation. Thus, it is not entirely clear that a satisfactory "apples-to-apples" comparison was accomplished.

• Joint Ford/UAW Study, 1981-1982: Ford and the United Auto Workers' Union commissioned a study to compare productivity between a Ford plant located in the U.S. (Wayne, Michigan -- Ford Escort) and a Mazda plant located in Japan (Hiroshima -- Mazda 323). The results of this study are summarized below in Table 5.

[49] Ibid., pp. 91-92.

Table 5: Ford/UAW Comparison of Hours per Car[50]
(Subcompact -- Car Assembly Only)

	Hours per Car	%
Total U.S. Hours per Car	19	100.0
Total Japanese Hours per Car	13	68.4
Difference	6	31.6
Explanation of Difference		
Design	0.99	15.5
Line Balance	0.94	14.8
Automation	1.20	18.8
Break Time	1.13	17.7
Just-In-Time Production	0.16	2.5
Maintenance Procedures	0.32	5.0
Quality Control Improvements	0.33	5.2
Other	1.30	20.4
	6.37	100.0

Unlike the Harbour study, the Ford/UAW study involved an in-depth, plant-level comparison of facilities in both countries. Aggregated industry-level data were not used. One initially puzzling aspect of a comparison between the Ford/UAW study and the Harbour work is that the Japanese hours per car figures are roughly equivalent (14.1, Harbour; 13, Ford/UAW) despite using different techniques, while the U.S. producers' figures show great disparity (31.1, Harbour; 19, Ford/UAW) despite using similar techniques. One possible explanation might be found in the fact that Harbour used aggregated Ford, GM, and Chrysler data while Ford/UAW used only Ford data -- perhaps the GM and Chrysler plants were significantly less efficient than the Michigan Escort plant.[51] Whatever the reason for the discrepancy, the Ford/UAW study would seem to be

[50] From "Cost of Building a Comparable Small Car in the U.S. and in Japan -- Summary of a Consultant's Report to the UAW", pp. 3-4. This is a summary report of a more detailed study that remains confidential.

[51] This explanation seems plausible in light of the large differentials in intra-national productivity

more accurate if only because of its consistent, plant-level focus. Of course, its major shortcoming is the small sample size of plants.

• Fuss and Waverman, 1986: In a paper entitled "The Extent and Sources of Cost and Efficiency Differences Between U.S. and Japanese Automobile Producers", authors Melvyn Fuss and Leonard Waverman perform an econometric analysis of the Japanese and U.S. auto industries. Like many industry-wide econometric analyses, this work's downfall is its lack of plant-level focus (and consequent dependence on unreliable aggregated government Standard Industrial Classification code data) and its emphasis on transient cost measures. Fuss and Waverman criticize cost studies by Abernathy, Harbour and Henn (1981) and Abernathy, Clark and Kantrow (1983) for including "double-counting of U.S. cost data, ad hoc adjustments for vertical integration and product mix, and the inability to separate out factor price effects from efficiency effects and short-run phenomena from long-run underlying trends"[52,53]. They attempt to avoid these pitfalls by looking at industry aggregated totals for all vehicle assembly and parts production, and by factoring out short-term disequilibrium conditions such as underutilization of capacity. Although Fuss and Waverman concern themselves primarily with cost differentials and not productivity differentials, their findings as presented in Table 6 are if nothing else provocative.[54]

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performance, which we will examine in detail in Chapter 4.

[52] Fuss and Waverman, p. 1.

[53] The two Abernathy et al. cost studies used here are based on Harbour's studies. See Abernathy, Clark, and Kantrow, p. 139.

[54] This table is as presented in Fuss and Waverman, p. T12.

Table 6: A Comparison of U.S.-Japan Unit Production Cost Calculations (% Japanese Cost Advantage)

Study	1979	1980
Abernathy, Harbour, and Henn (1981)	50.0	
Abernathy, Clark, and Kantrow (1983)	Range of 36.6 to 43.5	
Federal Trade Commission (1983) -- strict weights	-0.3	15.0
Federal Trade Commission (1983) -- liberal weights[55]	16.3	34.7
Fuss and Waverman (1986)		
Unadjusted	6.7	34.4
Adjusted for Equilibrium (Mix, Capacity, Scale)	2.9	11.9
Adjusted for Equilibrium and Exchange Rates	-0.9	5.2

If we look at the Abernathy, Harbour, Henn and Abernathy, Clark, Kantrow results, the results of the FTC liberal weights version, and the Fuss and Waverman unadjusted results, we see a relatively consistent range of 34-50% as the total Japanese cost advantage (including material, capital, and labor costs). However, after Fuss and Waverman adjust for things such as disequilibrium in exchange rates and underutilization of capacity in the U.S., the fundamental cost differential is found to be only 5.2%, a strikingly small difference. This is an interesting finding with a surprising implication -- although things were indeed bad for the U.S. producers in 1980, inexorable long-term adjustment toward equilibrium in exchange rates and capacity utilization meant the future should not have looked so bad after all. In fact, if we assume that by 1987 such long-term adjustments have been made, then a Fuss and Waverman-style econometric analysis of current cost differentials may very well show a large U.S. cost advantage. I reason as follows. The 1980 "equilibrium" exchange used by Fuss and Waverman is 212 ¥/$. The current 1987

[55] The two FTC studies were broad-based economic analyses. The strict and liberal weights mentioned here refer to the size classification scheme used in the FTC study. According to Fuss and Waverman, "the difference between the strict and liberal weights versions depends on the interpretation of the way in which Japanese automobiles compete with U.S. autos, and the value to consumers of the additional weight of U.S. produced autos." Fuss and Waverman, p. 29.

exchange rate has averaged about 145 ¥/$. Making the conservative assumption that productivity growth in the Japan and U.S. auto industries has been roughly equivalent since 1980[56], this 46% depreciation of the dollar should more than compensate for the initial 5.2% U.S. fundamental cost disadvantage[57], effectively giving U.S. producers a cost advantage.

Actually, the idea of a U.S. cost advantage in auto production is not as far-fetched as it seems. Honda has stated that its Marysville, Ohio facility can assemble Accords and Civics at costs comparable to Japanese Honda plants. However, too much emphasis on cost and exchange rates blurs the fundamental questions this thesis is trying to answer -- what are the components of a highly efficient manufacturing system, and where are these systems found?

• Cusumano, 1985 / Lieberman, 1987: Marvin Lieberman's study builds on the work of Michael Cusumano in comparing the time-series productivity trends of three Japanese automakers (Toyota, Nissan, and Mazda) and three U.S. producers (GM, Ford, and Chrysler). According to Lieberman, in 1985, all the U.S. producers average between 8 and 9 vehicles per employee per year, while the Japanese producers are in a range from 19 to 24. By this analysis, Japanese producers are more than 2.5 times as productive at motor vehicle manufacturing as U.S. producers. This degree of productivity differential is consistent with Cusumano's analysis for 1983.

Both Cusumano and Lieberman argue the importance of management systems in determining efficiency, stating that "much of the 2-fold productivity differential stemmed

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[56] Lieberman, p. 9: "...Japanese producers maintained faster productivity growth than the American firms until about 1980; since that time, the evidence suggests that productivity growth rates have been relatively greater in the U.S.."

[57] We can even assume a "pass-through rate" of exchange rate change much less than 50% here and still come up with a substantial U.S. cost advantage.

from the techniques Nissan and Toyota developed, prior to 1970, to manage their technological, capital and labor resources to raise worker output ..."[58], and that Japanese productivity performance was not simply the result of substituting capital for labor but rather the result of a "tighter coupling between production stages (enabling) an increase in the span of control of individual workers."[59]

While these explanations seem appropriate and in keeping with the expected benefits of a "fragile" production system, the methods used to determine the productivity differentials are somewhat suspect. Both Cusumano and Lieberman attempt to measure productivity based on an analysis of company reports. Several shortcomings of this method are apparent, some of them mentioned by Lieberman. First, the data used to perform the productivity calculations include all the consolidated operations of each firm, not just automotive activities. Second, in Lieberman's case the data pertain to domestic operations only for four of the firms, but to international operations for the other two. Third, Cusumano ignores differences in product mixes, while Lieberman makes only a rather crude value-based adjustment for the varying complexity of vehicles made by these manufacturers. This correction factor looks only at the mix of Japanese product coming into the U.S., effectively ignoring the mix of models in the domestic and other export markets. Furthermore, in Lieberman's study after 1976 the U.S. input to the value adjustment is the average unit value of U.S. auto exports, a decidedly non-representative proxy for total U.S. auto production judging by recent export performance. Finally, in Lieberman's work no adjustments are made for differing levels of capacity utilization or actual hours worked.

With all of these shortcomings, the results are understandably provocative. The fact

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[58] Cusumano, p. 217.

[59] Lieberman, p. 8.

that the range of productivity performance within each of the two countries is so narrow, and the differential between the performance of the two countries so great, would seem to indicate that this method picks up a component related as much to the peculiarities of annual report accounting conventions and corporate structure in each country as to actual productivity performance. Plant level data gathered for this study indicates a much wider range of North American productivity performance than indicated in the work of Lieberman and Cusumano, and substantial overlap in the productivity performance of Japanese and American plants.

Clearly there is a great deal of variability in the results of these four appraisals of the U.S./Japan productivity differential. Further compounding this confusion for managements and governments is the inconsistency of the methods applied, the lack of explanation of the methods employed in some cases, and various degrees of ambiguity and disagreement as to the causal factors of the differential. Regarding this last point, Harbour lumps 53.5% of the differential under the catchall heading of "productivity", while the Ford/UAW study attributes about one-third of a much smaller differential to "productivity"-related areas such as extra quality control and maintenance workers in the U.S. plant.[60] Fuss and Waverman place the blame on differing levels of capacity utilization, proposing there was no fundamental U.S. cost disadvantage. Cusumano adjusts for capacity utilization and still finds a substantial productivity differential.

The comparative methodology developed here, combined with the 32 plant data base, seek to put to rest some of the uncertainty caused by the degree of variability in previous studies. The methodology is straightforward and wholly documented, while the data base

[60] "Cost of Building a Comparable Small Car in the U.S. and in Japan ", p. 4.

is of adequate size. Together these characteristics allow for a reasonably accurate assessment of the current state of comparative international automotive assembly efficiency and the identification of those components that are associated with high performance.

4.3 The Standard Activities Methodology of Assembly Plant Productivity Comparison[61]

With this brief look at previous attempts at measuring auto industry productivity completed, I will explain the methodology used to compute the productivity results for the 32 plants represented in this paper[62]. We will first examine the core of Standard Activities to be measured, then look in turn at the various correction factors for weld number, relief time, product size, and equipment content.

4.3.1 The List of Standard Activities

In the quest to achieve a true "apples-to-apples" comparison it is necessary to define the activities which will be compared. To assume that any two automotive assembly plants are performing the same manufacturing steps could lead to large distortions of actual productivity differentials. For example, many U.S. and European assembly plants still produce their own seats, while in Japan this activity is almost always done by a supplier. A list of the Standard Activities as defined here are as shown in Table 7. This list represents the most common set of assembly plant activities, based on the sample of plants visited for this study.

Table 7: Auto Assembly Plant Standard Activities

1. Welding: all body panels (adjusted later for total weld number);

[61] Readers less interested in the formal presentation of the productivity and quality determination methodologies are advised to skip ahead to Chapter 5.

[62] Although 38 plants were visited for this study, data were used from only 32 plants due to difficulties in obtaining all necessary information.

2. Painting-related Activities: body cleaning, electrolytic dip, one primer coat, top coat, and all sealing activities;

3. Final Assembly Activities: bumper paint and sub-assembly, full engine dress (installation of hoses, accessories, etc.), instrument panel build, front and rear strut assemblies, clutch and brake pedal sub-assembly, tire/wheel assembly and balancing, glass installation, seat installation, interior and exterior trim application and other part installation activities;

4. Indirect Activities: product repair and inspection, production control and delivery, and maintenance;

5. General Administrative Tasks: including direct supervision, all plant management, and manufacturing and facilities engineers.

A partial list of non-Standard Activities is shown in Table 8. These activities were deemed non-standard because the majority of the plants in the study did not perform them. If a plant was performing any of these activities, the total number of direct, indirect, and salaried people associated with the activity were removed from the plant employee total used in the productivity calculations.

Table 8: Auto Assembly Plant Non-Standard Activities

1. Welding: any welded sub-assemblies shipped to other plants as kits;

2. Painting: a second coat of primer, often used in Europe by up-market manufacturers;

3. Final Assembly: steering column painting and sub-assembly, exhaust pipe bending, fuel and brake tube bending and sub-assembly, door trim panel sub-assembly, wire harness building or modification, fan-to-fan shroud sub-assembly, seat sub-assembly, rear wheel drive rear axle sub-assembly, front wheel drive rear solid axle sub-assembly, cigarette lighter sub-assembly, engine mount sub-assembly, window regulator sub-assembly, drive shaft sub-assembly, steering gear sub-assembly, lift rail

to window sub-assembly, AC compressor sub-assembly, fuel pump sub-assembly, engine mount sub-assembly;

4. Indirect Activities: indirect labor to support any of the above direct non-standard activities, customs workers, fire brigade, security personnel, lease car maintenance, water purification, vehicle delivery to transporter;

5. General Administrative Tasks: corporate functions such as engineering design, component purchasing, and supervision for non-standard direct and indirect activities.

With these lists of standard and non-Standard Activities in hand, data were then collected from the assemblers on the breakdown of employment into these various categories. Where exact data were not available, estimates were made based on first-hand observation of plant operations.

Another key aspect in the quest for an accurate comparison of manufacturing efficiency is to remove those employees required due to absenteeism. Although clearly the level of absenteeism is an important component of labor costs, our goal is to measure the efficiency of the plant after factoring out as many extraneous variables as possible. The level of *total* absenteeism[63] is often more a function of the country a plant is located in and its social services than a reflection of plant efficiency. Therefore, all employment figures used are based on the number of employees required to operate, not the total on-roll.

With the number of "Standard Activities" employees now determined, one could calculate an "uncorrected" productivity figure simply by multiplying the number of Standard Activities employees by the hours worked each shift, then dividing by the number of vehicles produced in a full day. Assigning variables as follows:

[63] Total absenteeism includes both scheduled and unscheduled absenteeism. Recall that we use the level of *unscheduled* absenteeism as an indicator of production management policy.

USAP = uncorrected Standard Activities productivity (hours/vehicle),
SAE = number of Standard Activities employees,
h = number of hours worked by each employee,
s = number of shifts per day the plant operates and
v = number of vehicles produced per shift,

we then find the following equation defines uncorrected productivity:

$$USAP = (SAE*h)/(s*v).$$

We now begin the process of making corrections to adjust for various systemic and product differences that exist across plants, companies, and nations.

4.3.2 The Relief Time Factor

One of the key goals of this methodology is to adjust for things that may not be under the influence of the management and/or workers due to social or environmental factors. One such difference is the amount of relief or break time taken in each assembly plant. Relief time ranges from less than 10 minutes to more than 50 minutes per shift for the plants in our data base. Since our goal is to measure the efficiency of the time spent working, not just the time for which a worker is paid, it is necessary to factor out these differentials in relief times. We established a baseline of 20 minutes per eight hour shift (or 95.83% productive work time) as the standard to which all the other plants would be adjusted. Defining an additional variable as follows:

rt = relief time per shift,

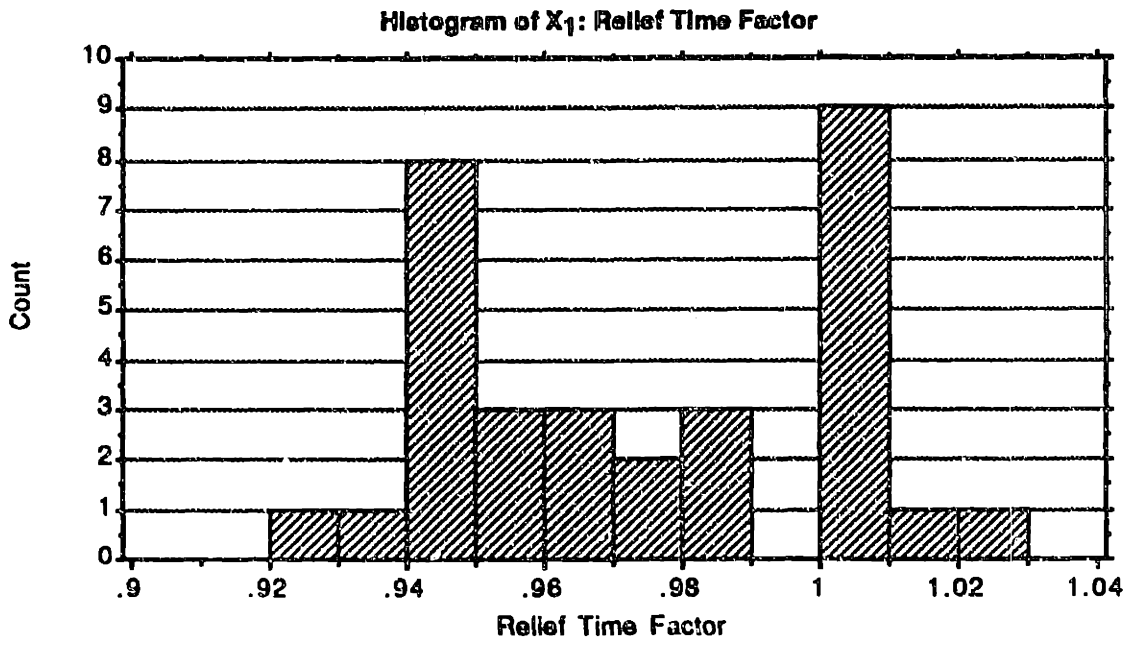
we find the Relief Time Factor (RTF):

$$RTF = ((h-rt)/h)/0.9583.$$

Note that this factor is applied to direct and indirect hourly workers, and not to salaried personnel.

The range of values for 32 plants for the Relief Time Factor is from 0.92 to 1.02, with an average of 0.97. The frequency distribution is as shown in Figure 12.

Figure 12: Frequency Distribution of Relief Time Factor Values



4.3.3 The Product-Specific Factors -- Weld Number, Size, and Equipment Content

In much the same way a set of Standard Activities was selected, a standard vehicle was also selected and an attempt was made to adjust each plant's work load to correspond to the effort required to build this product. To facilitate these adjustments, a typical subcompact car was selected with a given number of body welds, a given set of physical dimensions, and a given equipment loading.

- Weld Factor: This correction is designed to equalize the varying weld requirements

of the plants in the study. Due to modularization of some welded sub-assemblies and the different sizes and designs of the vehicles built in the plants, the total number of welds applied varies from 1500 to 4000. The weld factor corrects for this disparity by calculating the equivalent welding shop work force required to apply 3850 welds, the number of welds in our standard vehicle. The key assumption in the weld factor calculation is that the number of welds applied in the plant is a reasonable proxy for the amount of effort expended there. Defining variables as follows:

CWW = current welding work force,
ATWW = adjustment to welding work force,
w = number of welds per vehicle applied in the plant and
SAHE = Standard Activities hourly employees,

we define ATWW as follows:

$$ATWW = 0.5*(3850*(CWW/w) - CWW),$$

where 3850 is the baseline number of welds against which this weld correction is made, and where it is assumed each weld above or below the baseline of 3850 will take only half as much weld work force effort as the number of welds the plant is already completing.[64] This assumption takes into account the economies of scale of increasing numbers of welds, and has been tested empirically through data provided by one manufacturer.[65] With the

[64] For example, a plant applying 3000 welds per vehicle would require 850 welds to bring it to our SA level of welds. The assumption made here is that these extra welds could be completed with only half the effort per weld as the previous 3000 welds. Similarly, a plant applying 4000 welds must shed 150 welds to achieve SA parity. Here we assume the deletion of these 150 welds will result in a weld work force reduction given by half the welds/worker ratio required for the initial 4000 weld level.

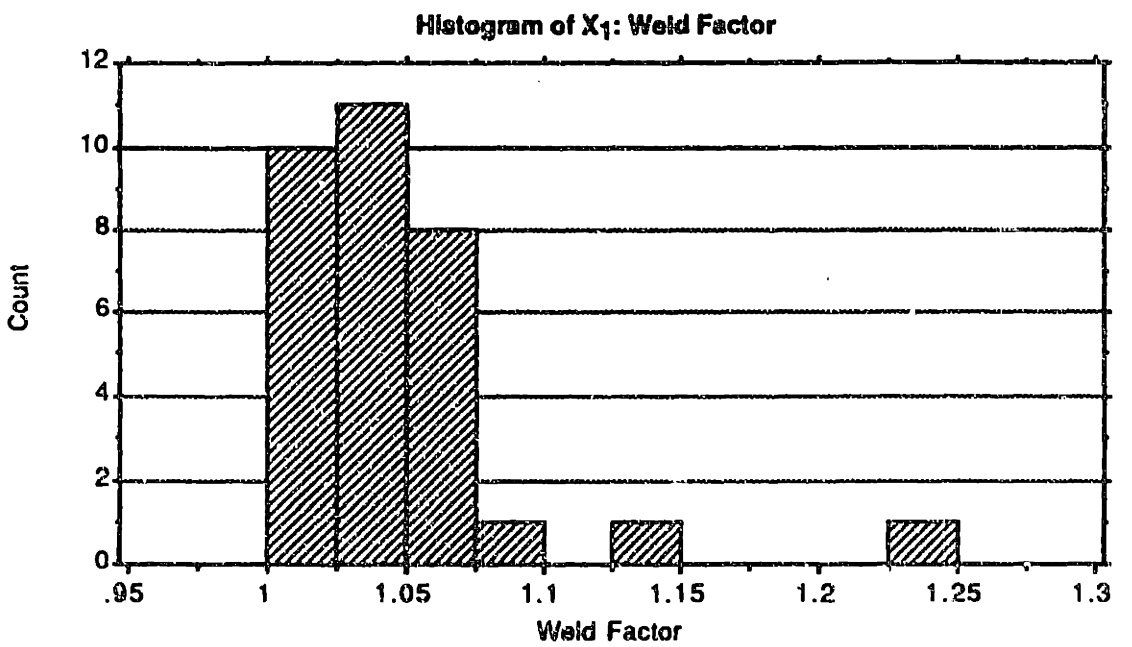
[65] This manufacturer provided data for weld employment based on final "respot" line direct and indirect staffing levels and whole body shop direct and indirect levels. The number of welds for the first case was 720, and 3555 for the second. Applying the appropriate weld factors to each case resulted in Standard Activities productivity results within 0.94% of each other. Source: Author's notes, September 1987.

ATWW determined, we calculate the Weld Factor (WF) as follows:

$$WF = (SAHE + ATWW)/SAHE.$$

As the average number of welds in the plants in this survey was substantially below 3850, the average Weld Factor was greater than unity, equal to 1.044. The range of values was from 1.0 to 1.23. The distribution of Weld Factor values for all 32 plants is as shown in Figure 13.

Figure 13: Frequency Distribution of Weld Factor Values



To give an example of the effect of the Weld Factor on Standard Activities hourly productivity, a plant producing a vehicle mix with a weighted average of 2228 welds per vehicle using a weld work force of 500 and a Standard Activities work force of 3482 would end up with a Weld Factor of 1.05. This means that to accomplish the baseline

number of welds (3850), this plant would require a Standard Activities work force 5% larger than that currently being used. In this case that would mean an increase of 174 workers, all in the welding shop, to accomplish the extra 1622 welds of the standard vehicle.

Note that no adjustment has been made for varying levels of automation in the welding area. This means that plants with low levels of automation in the body shop might be expected to show reduced productivity compared to more highly automated plants. However, plants with high Robotic Index values, indicating a high proportion of automated welds in the body shop, do not show meaningful productivity gains. This is explored in detail in Chapter 5.

- Product Size Factor: The Product Size Factor (PSF) is an important component of accurate productivity measurement. This factor attempts to correct for the great variety in physical size of the products included in this study. The rationale behind the correction is simple -- a larger vehicle will in general have greater surface area and part attachment points, and therefore require more effort to assemble than a smaller vehicle. However, the actual value of the PSF is impossible to measure exactly without making a detailed inventory of every assembly step, an impossibly complex task for a survey of 32 plants. Therefore, we make the following assumptions in an attempt to capture the general magnitude of the "real" PSF:

  - The physical dimensions of length, width, and height are reasonable proxies for size. The square root of the product of these dimensions was selected as the mathematical relationship to quantify product size, thus invoking a marginal returns to increasing vehicle size argument. This relationship is much more conservative than a linear relationship would be, and results in relatively small product size factor adjustments, as shown in Figure 14. Weight was considered as an additional variable, then dropped, as it has been found to be more closely correlated with age of the model and material selection than with physical size.[66]

- Standard Activities workers in the weld shop and paint shop and all indirect workers in the plant are relatively unaffected by vehicle product size. This is because in the weld shop work content is largely corrected for by the Weld Factor. In the paint shop most activities are independent of size (except sealing and inspection/repair) because most plants have largely automated paint application. In the final assembly area[67], it is the direct workers who are affected most by product size differences. It is this group who must deal with the added difficulties of larger parts, more attachment points, and overall greater task complexity. Indirect workers can be assumed to be only slightly impacted by increased vehicle size. Most plant maintenance workers are assigned to the body and paint areas and are therefore unaffected by product size. Only material handlers and quality control inspectors could be expected to be impacted in any way by vehicle size, and in both cases effects appear to be small relative to their direct assembly counterparts.

With these assumptions in mind, the PSF is derived as follows:

1. Determine the average size (length (l), width (w), and height (h)) of the typical vehicle built in each plant. This composite vehicle (COMP) size is a weighted average based on the model mix at each plant.

2. Determine the initial PSF (IPSF) from the following formula which provides a ratio between the square root of the products of length, width, and height between the composite plant product and our baseline standard vehicle (STD):

$$IPSF = (l*w*h)_{COMP}^{0.5}/(l*w*h)_{STD}^{0.5} .$$

3. Factor out the welding and painting direct workers and all indirect workers from the

[66] Abernathy and Wayne have used weight as a proxy for manufacturing cost in a time-series study of Ford products. (Abernathy and Wayne, p. 113.) While this may have been suitable for a cost investigation of one manufacturer over a long time period, it seems less so for a cross-sectional productivity analysis of many producers. One problem is that their definition of cost includes components, not just assembly plant labor. Further, with the current trend toward lightweight designs, weight becomes less an indicator of manufacturing effort than an indication of such things as the amount of aluminum in the engine and transmission and the amount of plastic in the body structure.

[67] Final assembly area is here defined as all activities after body welding and paint shops. The assembly area is often divided into three sub-areas: trim, chassis, and final.

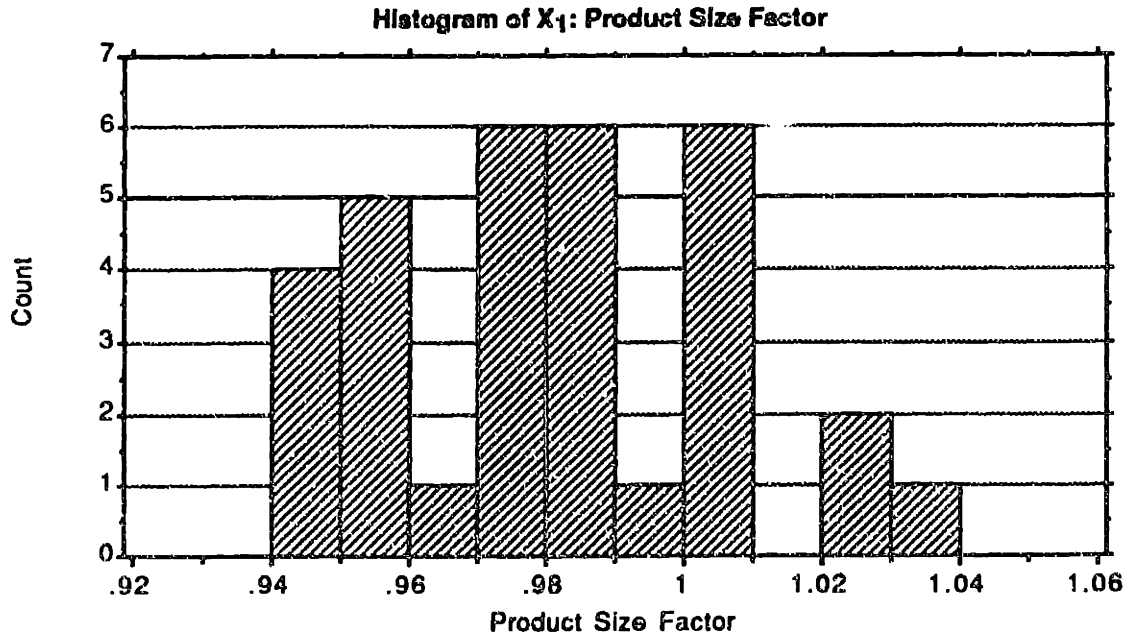
plant total of Standard Activities workers, leaving only final assembly area direct workers as the group whose size will be adjusted by the PSF. That equation is:

$$PSF = (SAHE - SADA)/SAHE + IPSF*(SADA/SAHE),$$

where SAHE = standard activity hourly employees and
SADA = standard activity direct assembly employees.

As the average composite vehicle in the sample was larger than the baseline vehicle, the average Product Size Factor was less than unity, equal to 0.976. The range of PSF values was from 0.94 to 1.03. The frequency distribution of PSF values is as shown in Figure 14.

Figure 14: Frequency Distribution of Product Size Factor Values



A test of the accuracy of the Product Size Factor is difficult to perform due to differences in product age, manufacturability, and levels of technology across plants, even

if one tests different size products from the same manufacturer. Therefore, due to these inherent difficulties in checking the robustness of this correction, the formulation was kept relatively conservative. In fact, the range of Product Size Factors indicates only a 10% productivity differential attributable to product size across the plants in this sample.[68] Discussions with industry experts in productivity and cost analysis indicate these corrections for product size are reasonable.

- Equipment Content Adjustment: The final technical correction factor made in this analysis is the Equipment Content Adjustment (ECA). This adjustment attempts to correct for varying levels of technological sophistication by examining differences in standard and optional equipment. These data are readily available for vehicles sold in the U.S. market from industry sources such as *Ward's Automotive Reports*. For vehicles not sold in the U.S. market, plant-level estimates of optional and standard equipment levels were used.

Because of the difficulties in obtaining accurate estimates of labor required for the installation of individual major features, a technique was developed to estimate incremental assembly plant labor cost of equipment installation based on the typical vehicle from each facility. Sales-weighted equipment levels and retail prices for the typical vehicle are shown in Table 9.[69]

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[68] Most of the vehicles in this sample would be classified as compacts or sub-compacts based on exterior dimensions. The smallest composite product (with PSF = 1.03) is a very small car in the Sprint/Festiva/Starlet size class, while the largest composite product (with PSF = 0.94) is a mid-size car in the Taurus/Celebrity size class.

[69] Price data from *Automotive News 1987 Market Data Book*.

Table 9: Major Equipment and Typical U.S. Retail Cost

	$ Cost
Air Conditioning	743
Power Steering	230
Power Windows	264
Power Seats	240
Power Door Locks	211
Cruise Control	175
Remote LH Mirror	33
Remote RH Mirror	71
Sun Roof/T-roof	400
Four-Wheel Drive	500
Anti-Lock Braking System	750

Note that these features were chosen because each increases the amount of effort expended in the assembly plant compared to the case where the equipment is not installed. Therefore, options like upgraded seats, high-performance tires and wheels, and upgraded exterior trim were not included because installation of these features generally involves a substitution of one set of components for another and thus does not increase the amount of effort expended.[70]

The major assumption behind the Equipment Content Adjustment is that, on average, the retail price of the group of features is roughly proportional to the additional assembly plant labor required to control, deliver, install, and functionally check this equipment.[71] From here, an estimate of the total percentage of vehicle retail price devoted to Standard Activities labor costs is calculated. This labor cost percentage is determined from the Standard Activities work force at each plant, the production rate, an assumed constant labor rate ($25/hour) for each plant, and the average 1987 retail price for the typical vehicle from

[70] This is similar in concept to the argument in Section 3.2.2 concerning option combinations.

[71] While this will clearly not be the case for each individual option, it is likely to be a reasonable assumption for the group of specific options shown in Table 9.

each plant.[72] Labor cost percentage is then multiplied by the typical equipment loading (expressed in terms of retail price) for each plant based on the options and prices shown in Table 9 and then divided by the labor rate to determine an hours per vehicle effect for equipment loading. The final Equipment Content Adjustment for a plant is then determined as the differential between the number of hours required to install the sales-weighted composite vehicle equipment content for each plant and the baseline number of hours calculated for our standard plant and product/equipment mix. This explanation of the intuition behind the ECA is followed by a mathematical derivation below.

We define the Plant Composite Equipment Content Retail Price (PCECR) as:

$$PCECRP = \sum \Omega_i \sum \beta_j * p_j / 100,$$

where Ω_i = each of the models produced in the plant,

β_j = percentage of vehicles from the plant equipped with each of the options in Table 9 and

p_j = retail price of each of the options as shown in Table 9.

After defining the Plant Composite Base Price (PCBP) as:

$$PCBP = \sum \Omega_i * BP_i,$$

where BP_i = 1987 initial model year retail base price for each model produced in the plant,

we then determine the Plant Composite Retail Price (PCRP) as:

[72] Note that this world-wide constant $25 wage rate is used not as an indicator of actual world wage rates but more as a scaling factor to determine the ECA. Since all the vehicle and option prices in this study ar based on market conditions prevailing in the U.S., a U.S.-level wage rate offers a reasonably accurate scale factor to arrive at the estimated productivity effect of varying equipment levels.

$$PCRP = PCBP + PCECRP.$$

To determine Standard Activities Labor as a Proportion of PCRP (SALP) , we find:

$$SALP = (\$25*SAE*h)/(PCRP*v*s),$$

where SAE = the number of Standard Activities employees,
h = the number of hours worked by each employee,
v = the number of vehicles produced per shift,
s = the number of shifts per day the plant operates.

Multiplying the Standard Activities Labor Proportion by Plant Composite Retail Price yields the proportion of plant composite equipment retail price attributable to assembly plant labor, or the Imputed Plant Equipment Installation Cost (IPEIC):

$$IPEIC = SALP*PCRP.$$

Dividing this cost by our assumed constant $25 labor rate yields the Gross Equipment Content Adjustment (GECA):

$$GECA = IPEIC/\$25.$$

Subtracting our baseline plant/product mix equipment adjustment of 1.12 hours per vehicle from GECA leaves the final Equipment Content Adjustment:

$$ECA = GECA - 1.12.$$ [73]

This exercise complete, we now turn to the distribution of ECA results across our 32 plant sample. We can look at these results in two ways -- first the actual value in hours per vehicle of the ECA, then in terms of its effect on Standard Activities productivity (which is

[73] Note that this last step is not strictly necessary since we are primarily concerned with relative productivity performance, not absolute accuracy. Nevertheless, this adjustment serves two useful purposes: retaining consistency with all of our previous corrections from a baseline plant/product, and keeping the resulting productivity figures closer to what they would be in absolute terms.

consistent with the presentation of distributions on the effect of Relief Time, Weld Number, and Product Size). Turning to the first case, we find a range of ECA values from -1.07 to 3.83 hours/vehicle, with a mean of 1.395. The frequency distribution is as shown in Figure 15.

Figure 15: Frequency Distribution of Equipment Content Adjustment Values

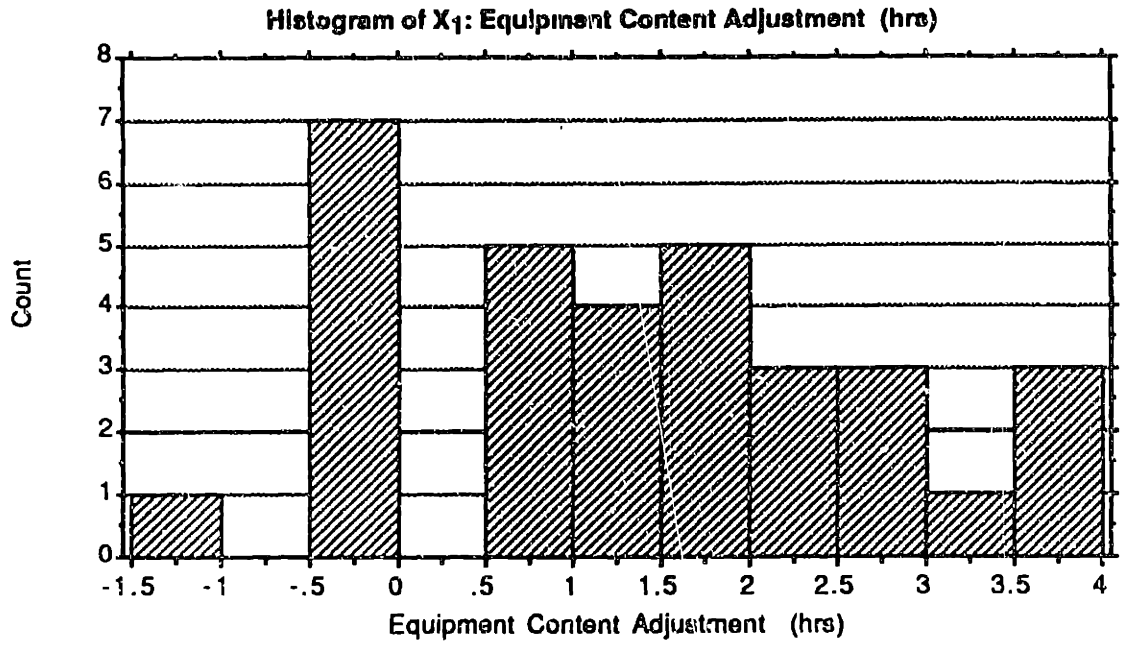
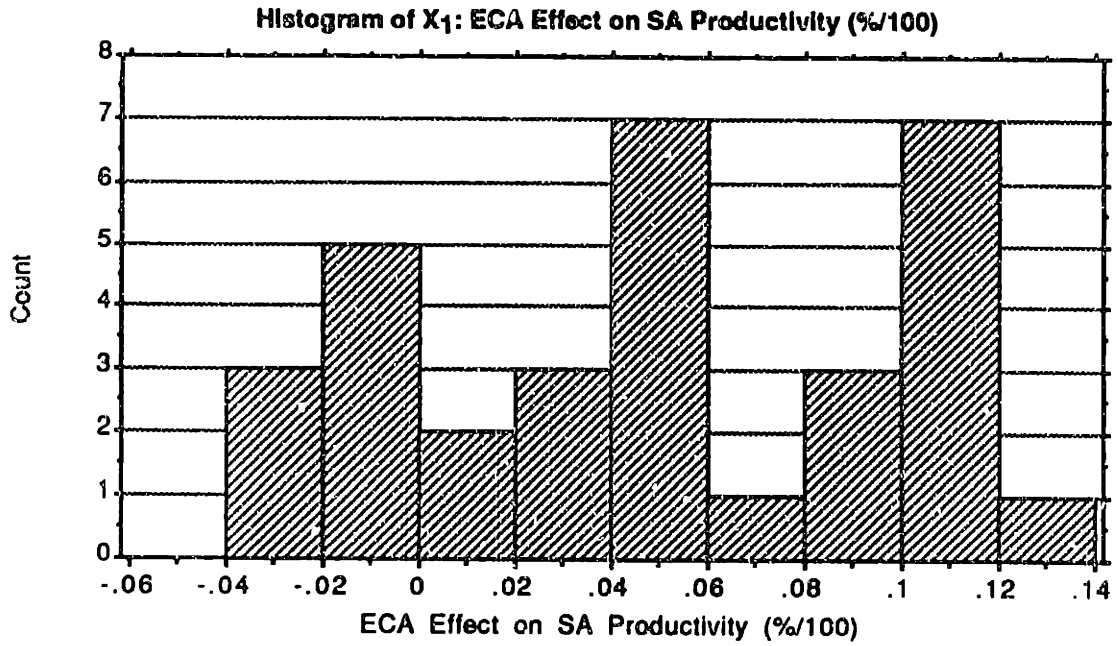


Figure 15 indicates that the range of values of the ECA is large, and that the absolute size of the adjustment can be great. However, the ECA methodology weights equipment content installation efficiency consistent with the overall efficiency of the plant. Thus, plants on the far right of Figure 15 generally are high content *and* high effort producers, with the result that the percentage effect on Standard Activities productivity is not as great as Figure 15 seems to portend. This effect is captured in Figure 16 below, which depicts the distribution of the amount of impact the ECA has on final productivity results.

Figure 16: Frequency Distribution of ECA Effect on SA Productivity



The range of Equipment Content Adjustment effect on productivity is -0.037 to 0.126, with a mean of 0.051. This translates to an average correction to apparent productivity performance of 5.1% compared to the baseline plant/product mix, with the largest effect being a 12.6% correction for a plant with especially high equipment content.

4.3.4 The Distribution of World-wide Productivity

With all of the various correction factors and adjustments in hand, all that remains is the exercise of applying the adjustments to the Standard Activities productivity as defined in Section 4.3.1 to determine the Corrected Standard Activities Productivity (CSAP). We define CSAP as follows:

$$\begin{aligned} CSAP = {} & USAP*WF*PSF*RTF*(SAHE/SAE) \\ & + USAP*WF*PSF*(SASE/SAE) - ECA, \end{aligned}$$

where USAP = Uncorrected Standard Activities Productivity,

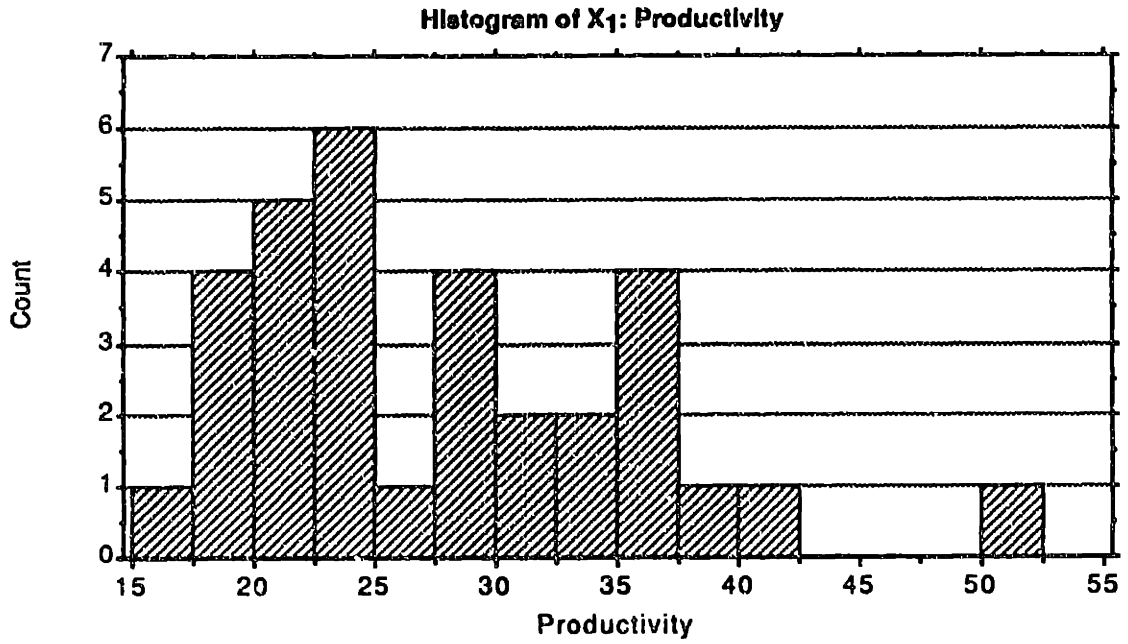
SASE = Standard Activities Salaried Employees,
WF = Weld Factor,
PSF = Product Size Factor,
RTF = Relief Time Factor,
SAHE = Standard Activities Hourly Employees,
ECA = Equipment Content Adjustment, and
SAE = Standard Activities Employees.

Note that the Relief Time Factor operates only on the hourly or plant floor workers, while all the other corrections work on all the plant employees.

Despite the great many adjustments made to Uncorrected Standard Activities Productivity, the simple correlation between it and Corrected Standard Activities Productivity is very significant (R = 0.924). This indicates that the corrections made shape the data relatively moderately and consistently. It also highlights the importance of establishing a consistent set of Standard Activities on which to apply the correction factors.

Figure 17 shows the distribution of Corrected Standard Activities Productivity for the 32 plants in our sample. It is important to remember that these productivity figures are not exact *absolute* figures of the number of hours required to assemble the vehicles produced in each plant. Rather, they are relative figures that can be compared with one other to discern the extent of differences between plants theoretically performing the same tasks. And as the figure below shows, the differences are great and certainly worth investigating.

Figure 17: Frequency Distribution of World-wide Productivity Performance



The range of productivity performance is large indeed, with a minimum of 16.0 and a maximum of 50.0 hours/vehicle. The mean productivity performance across the sample was 27.7 hours/vehicle.

We turn now for the rest of this chapter to a brief discussion of the determination of the other key dependent variable, quality.

4.4 Applying a Standard Methodology to the Calculation of Quality

Each year J.D. Power and Associates conducts a mail survey to determine owner perceptions of quality within the first three months of ownership.[74] Every model sold in the United States is sampled, and approximately 200 questionnaires are returned for each

[74] This survey is called the J.D. Power New Car Quality Survey. Results are confidential. The material included herein is used with the gracious permission of J.D. Power and Associates, Westlake Village, California.

model. Responses are tabulated to questions related to problems experienced in all of the following areas:

1.	Body	(9)
2.	Exterior Paint and Moldings	(6)
3.	Interior	(11)
4.	Electrical and Accessories	(16)
5.	Temperature Control	(6)
6.	Brakes	(5)
7.	Transmission	(7)
8.	Engine	(12)
9.	Steering and Handling	(5)
10.	Squeaks and Rattles	(7)
11.	Water Leaks	(3)
12.	Wind Noise	(2)

The number in parenthesis indicates the total number of sub-categories within each main area.

Many of these problem areas are not specifically related to assembly plant quality. For example, customer-perceived defects in the engine, transmission, or steering and handling areas could likely be design problems or reliability problems which the assembly plant has little direct control over. Therefore, in keeping with the basic philosophy of maintaining plant-to-plant comparability and factoring out obvious product-related differentials, areas and sub-categories that were deemed to be either reliability, design-related, or defective component-related were removed from the J.D. Power composite quality rating. A sampling of the list of quality categories used to compile the Assembly Plant Quality Index (APQI) for this study, and some of those excluded, are as shown in Table 10.[75]

[75] Not all categories are shown to protect the identity of the plants in the survey.

Table 10: Assembly Plant Quality Index Category Determination

Area	Included Categories	Excluded Categories
1. Body	Sheet Metal Dents/Dings Hood Fits Poorly Side Door Fits Poorly Trunk/Hatch Fit Poorly Side Door Hard to Open Trunk/Hatch Hard to Open	Sunroof Does Not Work Exterior Door Locks
2. Exterior Paint and Moldings	Paint Chip/Scratch Sags/Runs in Paint Paint Thin/Color Mismatch Exterior Molding/Ornament Body Rust or Corrosion	None
3. Interior	Carpet Wrinkled/Loose Interior Door Locks Window Trouble Poor Glove Box Door	Interior Soiled Poor Seat Material Seat Hard to Adjust Poor Door Material
4. Electrical and Accessories	Interior Lights Exterior Lights Gauges/Warning Lights	Ignition Switch Windshield Wipers Poor Sound on Radio
5. Squeaks and Rattles	All	None
6. Transmission	None	All
7. Engine	None	All
8. Steering and Handling	None	All

Two key points behind the calculation of the APQI are as follows: First, in many cases

it was difficult to decide whether or not a category should be included or excluded from the APQI. In these cases, I used input from plant management and my own experience as an assembly plant engineer to help guide categorization decisions. Second, in those cases where a plant built more than one model, a weighted average APQI was developed based on the individual model quality index scores and the model mix ratio. With these points in mind, the resulting index values can be viewed as reasonable estimates of the level of actual assembly plant quality.

One problem with the Power quality survey is the fact that only models marketed in the U.S. are included. However, many of the plants represented in this survey build vehicles that are not sold in the U.S. This difficulty was dealt with in two ways. First, for those plants whose primary market is the U.S., the APQI based on U.S. market models was used as a proxy for overall plant quality performance. This should introduce only a minor distortion to the APQI's. Second, derived plant APQI's were determined for some multinational assemblers who had comprehensive corporate-wide quality monitoring systems. In these cases, U.S. market models' APQI scores were regressed against the multinational's internal quality scores. This relationship was used to predict the APQI the non-U.S. market vehicles would have achieved. The breakdown of method of APQI determination for the plants in this survey is as shown in Table 11.

Table 11: Summary of APQI Determination Methods

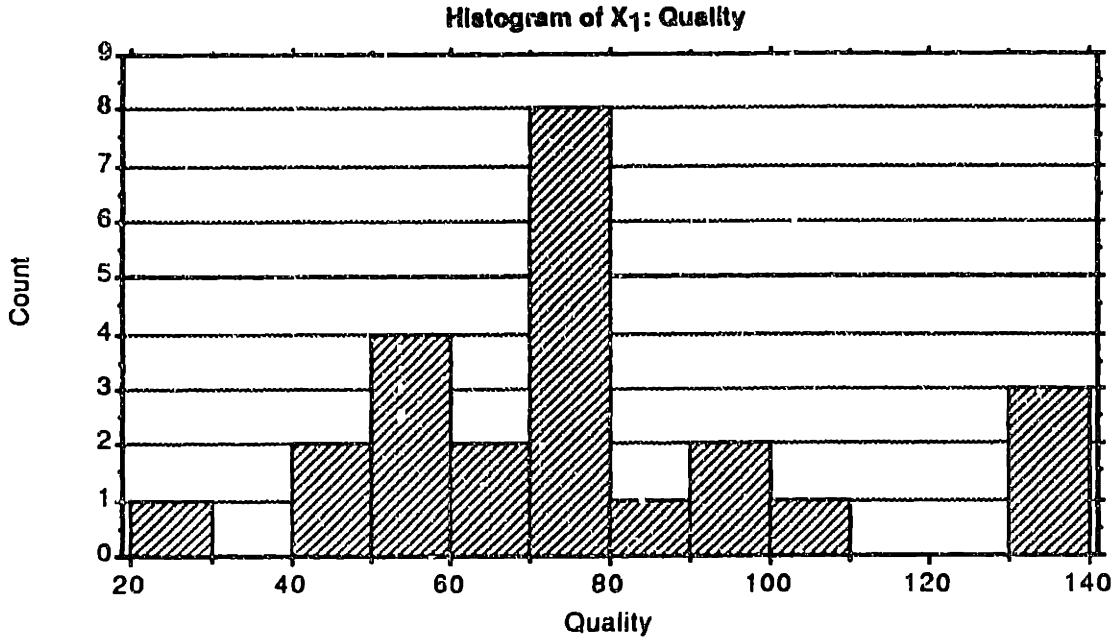
Market for Plant's Products	Method	Number of Plants
North America	J.D. Power data to derive actual APQI	11
Mixed, with North America represented	J.D. Power data to derive proxy APQI	9
Mixed, without North America	Power and company data regression to derive proxy APQI	4
	Total Number of Plants with APQI Scores:	24

Note that there are 8 plants without APQI scores. There are two causes for these omissions: 1) A lack of consistent internal company quality data (4 cases),

2) Some plants were producing 1988 models only and therefore no Powers data were available (4 cases).

An examination of the range of assembly plant quality performance reveals a wide spread, similar in appearance to what was found for productivity, as shown in Figure 18 below.

Figure 18: Frequency Distribution of World-wide Quality Performance



This 24 plant sample shows a minimum (best performance) Assembly Plant Quality Index of 21.4 defects per 100 units, a maximum APQI of 138.5, and a mean of 77.6. Note that this mean is a simple average of the 24 plant scores, and is not weighted by the number of vehicles produced at each plant.

CHAPTER 5

Analysis of the Results

With the methodology and key variables in hand, we begin the process of analyzing the results. This analysis is approached in several ways:

(1) By multiple regression analysis.

(2) By looking at summary data grouped by various combinations of assembly plant and parent locations, and

(3) By examining relationships between pairs of variables using 2X2 matrices.

5.1 A Multiple Regression Approach to the Analysis

Three groups of variables are used for the multiple regressions performed in this section. The first set involves the six basic components of the 4 M's. A second grouping tests the interaction between the level of technology and production management policy. Finally, a dummy variable is added to the original six variables to test the effect having a Japanese parent has on plant productivity and quality.

5.1.1 The Basic 4 M Components

Multiple regression analysis allows us to determine which of the components of the 4 M's have significant effects on plant efficiency. The components as developed in Chapters 2 and 3 are as follows:

METHOD:	Production Management Policy (Managem[illegible] Index)
MAN:	Capability of Work Force (no suitable proxy)
MACHINERY:	Scale, Space Utilization, Level of Technology (Robotic Index)

MATERIAL: Manufacturability (Product Age), Model Mix Complexity

Table 12 shows the intercorrelations of these independent variables. The intercorrelations are generally low, indicating little multicollinearity within the data.

Table 12: Independent Variable Correlation Matrix

	MI	Scale	Space	RI	PA	MMCI
Management Index (MI)	1					
Scale	-.264	1				
Space Utilization	.39	-.132	1			
Robotic Index (RI)	-.441	.214	.209	1		
Product Age (PA)	.391	-.093	-.019	-.278	1	
Mix Complexity (MMCI)	-.327	-.054	-.394	.036	.063	1

The first regressions were performed using these six independent variables and the two dependent variables, productivity and quality. A stepwise procedure was used in order to maximize the explanatory power of the model.[76] The results are shown in Table 13 for productivity and Table 14 for quality.

[76] Stepwise regressions allow the selective insertion of independent variables, depending on their contribution to the explanatory power of the model (as measured by the adjusted R^2). If an independent variable does not increase the adjusted R^2, the variable is dropped from the model. Note that the stepwise procedure used here does not compromise the model because in all cases the variables excluded have extremely low significance levels.

Table 13: Multiple Regression Results
Productivity vs. 4 Independent Variables

DF	R:	R-squared	Adj. R-squared	Std. Error
31	0.732	0.535	0.466	5.881

Beta Coefficient Table

Parameter	Beta	Std. Value	t-Value	Partial F	Probability
Intercept	(5.607)				
Management Index	1.831	0.538	3.565	12.707	0.0014
Space Utilization	1.017	0.295	1.963	3.854	0.06
Model Mix Complexity	0.115	0.281	1.895	3.59	0.0689
Scale	-0.054	-0.202	1.462	2.138	0.1552

Variables Not in the Equation

Parameter	Partial F
Product Age	0.19
Robotic Index	0.053

The explanatory capability of this set of independent variables is quite good. Close to one-half of the variation in productivity performance is predicted by the combination of Management Index, Space Utilization, Model Mix Complexity, and Plant Scale. Management Index is significant at the 99% level, Space Utilization and Model Mix Complexity at the the 93% level, and Plant Scale at 84%.[77] The variables that showed little predictive capability were Product Age and Robotic Index. We summarize the effects of all of these variables, and compare the results with the expectations set forth in Chapters 2 and 3, in Table 15.

[77] These significance levels indicate the highest confidence interval not containing zero for each beta value.

Table 14: Multiple Regression Results

Quality vs. 3 Independent Variables

DF	R:	R-squared	Adj. R-squared	Std. Error
23	0.663	0.44	0.356	23.407

Beta Coefficient Table

Parameter	Beta	Std. Value	t-Value	Partial F	Probability
Intercept	(55.169)				
Management Index	6.67	0.591	2.752	7.574	0.0123
Scale	-0.253	-0.266	1.428	2.04	0.1686
Product Age	-2.078	-0.217	1.096	1.202	0.2859

Variables Not in the Equation

Parameter	Partial F
Space Utilization	0.107
Model Mix Complexity	0.1
Robotic Index	0.031

The adjusted R-squared value indicates that this group of independent variables predicts about one-third of the variation in quality performance. This figure, like that determined for productivity, is respectable considering the cross-sectional nature of the data and the estimates employed in determining the independent variables. As was the case for productivity, the Management Index is the most significant predictor of quality performance (at the 98% level), while Plant Scale (83%) and Product Age (71%) are important contributors but at lower confidence levels.[78] Variables found to offer little predictive ability for quality were Space Utilization, Model Mix Complexity and Robotic Index.

[78] The link between Plant Scale and quality is somewhat perplexing. This link does not seem to be a function of the fact that the Japanese-managed plants are generally higher quality and higher output facilities, as the simple correlation coefficient between a Japan parent dummy variable and scale is only 0.375.

Table 15: Expected Effect on Efficiency vs. Regression Results

	Expected Effect		Regression Result	
	Productivity	Quality	Productivity	Quality
METHOD				
Production Management Policy (Robust --> Fragile)	up	–	up	up[79]
MAN				
More Work Force Capability	up	up	not tested	not tested
MACHINERY				
Greater Plant Scale	up	–	up	up
Improved Space Utilization	up	up	up	–
Higher Robotic Index	up	up	–	–
MATERIAL				
Reduced Product Age	–	–	–	down
Increased Model Mix Complexity	down	down	down	--

This summary of expected effects vs. actual regression results validates most of the assumptions made earlier. Significant exceptions include the strong correlation between Production Management Policy and quality and the lack of explanatory power of the Robotic Index.

The strong relationships between productivity and quality and Production Management Policy indicate the degree to which these two dependent variables are intertwined. The "fragile" production system is capable of achieving high quality and productivity without compromise while, apparently, "robust" systems seem more likely to run in a low productivity/low quality mode. We look at this more closely later in the chapter.

[79] We will see in Section 5.1.3 that Production Management Policy loses significance when a Japan parent dummy variable is included in the quality regression model.

The lack of explanatory power of the Robotic Index seems more a symptom of manufacturers' prerogative than an indication of an ill-designed variable. Robotic applications have been installed to achieve various goals, such as increased flexibility, quality, productivity, and improved ergonomics and working conditions. While clearly some of these have been achieved, many have not. The issue of unfulfilled flexible automation promise is discussed in detail later.

A noteworthy confirmation of conventional manufacturing thought is the adverse effect of increased mix complexity on productivity. The Model Mix Complexity Index beta value of 0.115 indicates that if the MMCI for a plant were increased by 19 points (equivalent to adding a new platform with three different body styles), then productivity would decrease by 2.2 hours/vehicle. That is, the addition of a new platform with three body styles would increase the number of hours required to assemble a vehicle in the average assembly plant by 7.9%.[80] Clearly there is a penalty to additional complexity -- the issue is how well various plants cope with it. We explore this area in detail later by examining the capability of "fragile" plants to achieve high levels of productivity, quality, and complexity simultaneously.

The effect of Product Age on quality also confirmed one of the initial hypotheses -- that the beneficial effect of a newer design might be tempered by learning curve considerations. Here we find that as the age of the product increases, the quality of the product does tend to improve, although this is true at a low significance level (71%). The data, none the less, suggest that learning curve effects might blur the advantages of new designs.

5.1.2 The Basic 4 M Components and Management/Technology Interaction

Although the independent variables of Management Index and Robotic Index exhibited

[80] 0.115 x 19 = 2.2 hrs/vehicle per platform with three body styles, 2.2/27.7 = 7.9%, where 27.7 hours/vehicle = sample mean.

quite different degrees of explanatory power of plant performance, one could imagine the interaction of these two variables having some predictive capability for productivity and quality.[81] The theory is straightforward. Plants which practice a "fragile" management system are more likely to gain additional benefits from automation, since this type of management system has as one of its hallmarks a strong emphasis on training and multi-functional workers. A well-trained worker, perhaps in charge of maintaining his own machine, is more likely to extract additional performance from it. In contrast, plants practicing a "robust" management style tend to place less emphasis on training and a multi-functional work force. Therefore, gains from increased technology levels in a "robust" facility would tend to be less than in a "fragile" plant.

The quantification of the Management/Technology Interaction Index (MTII) was accomplished simply by multiplying the Robotic Index (our proxy for the level of plant technology) by a "reversed" Management Index.[82]

The strategy for testing the effect of the Management/Technology Interaction Index on plant performance involved the stepwise regression technique used early. Two data groupings were tried:

(1) The six original variables plus MTII, and

(2) The original variables plus MTII, excluding Management Index and Robotic Index.

The first grouping of independent variables showed no increase in the predictive capability of the model for productivity or quality. MTII exhibited a low partial correlation coefficient of -0.142 and a partial F of 0.535 for the productivity regression, and an even

[81] Harry Katz, Tom Kochan, John Paul MacDuffie and Haruo Shimada have all explored the interactions between management and technology in their work. This discussion owes much to their ideas.

[82] Instead of the actual Management Index value, (12 - Management Index value) was used for each plant. This was necessary to ensure high MTII facilities were unambiguously high robotic/fragile plants, and low MTII facilities were unambiguously low robotic/robust plants.

lower partial correlation coefficient of -0.023 and a partial F of only 0.102 in the quality regression.

The second grouping of independent variables showed a decrease in predictive ability based on adjusted R-squared values (0.403 for productivity, 0.317 for quality), with the non-MTII components largely unchanged in effect.

Thus it seems the synergistic effects of the management/technology interface are not captured by the MTII as calculated here. One possible reason for this could be the high degree of simple correlation among MTII, the Management Index, and the Robotic Index.[83] This indicates that perhaps some of this expected synergy has been captured in the Management Index, and is therefore already built into the original model.

5.1.3 The Basic 4 M Components and a Japan Parent Variable

In this section we examine the effect on productivity and quality of Japanese management. There are five plants in our sample operating in Japan, and three transplants operating in North America with Japanese parents. A dummy variable was created to capture the effect on assembly plant performance of having a Japanese parent.

Using stepwise multiple regression as before, the Japanese Parent dummy variable offered no additional explanatory power to the model, consistent with its low partial correlation coefficient of 0.231 and low partial F value of -0.094.

However, the Japanese Parent variable did provide a marginal increase in the explanatory power of the quality model. The adjusted R-squared increased from 0.356 to 0.389, with only two variables, Japanese Parent (99%) and Plant Scale (86%) significantly different from zero. Surprisingly, Management Index dropped out of the stepwise regression, with a partial F of only 0.368. No doubt part of the reason for this is the high

[83] These simple correlation coefficients are: MTII:MI = 0.689, MTII:RI = 0.924, MI:RI = 0.441.

degree of intercorrelation between Management Index and Japanese Parent (R = 0.752).[84]

There are two other possible explanations for the relative power of Japanese Parent over Management Index. The first is related to the sample size. All eight of the Japanese parented plants appear in both the productivity and quality samples. Since the quality sample size (24 plants) is smaller than the productivity sample size (32 plants), the Japanese Parent variable can be expected to have a larger explanatory effect on quality than on productivity. Another possibility is related to the fact that all of the Japanese parented plants are building Japanese products, which may have an edge in product design quality that is not captured in our model.

As mentioned previously, the relative significance of Plant Scale in explaining quality performance is puzzling. One possible explanation may be that the shorter cycle times of high-output plants tend to result in shorter duration, simplified job tasks, characteristics that may have the potential to increase quality.

5.1.4 Explaining the Unexplained Variation in the Model

The model of assembly plant efficiency developed here can explain roughly one-half the variation in productivity performance, and slightly more than one-third of the variation in quality performance. A question that must be answered is what explains the remainder of the wide variation in performance around the world. Three primary explanations can be offered: the lack of a measure for Man (work force capability), the approximate nature of the independent variables, and inevitable inaccuracy in the measurement of the dependent variables.

The capability of the work force is clearly an important determinant of plant level performance. The qualifications of the work force, (skill level, education, and cultural

[84] Other simple correlations between the Japan parent dummy and the independent variables are as follows: Robotic Index (0.589), Scale (0.375), Space Utilization (-0.279), Product Age (-0.194), MMCI (0.155), and MTII (0.787).

values), can all be expected to directly affect the quality and productivity of a manufacturing operation. Unfortunately, the quantification of this capability is not an easy task. Nevertheless, a cleverly designed proxy might be expected to greatly improve the predictive capability of the model.

Turning to the independent variables already in the model, the proxy for Production Management Policy can only offer approximations of the actual management systems in place. And while the Robotic Index may do a reasonable job of indicating the technological sophistication of the plant, it can not effectively substitute for a more thorough measure of the capital stock in the plant. Finally, our proxy for product manufacturability, Product Age, is clearly only a gross substitute for something more directly related to the ease with which a product can be assembled.

The dependent variables, although more accurate reflections of reality than many of the independent variables, also suffer from various types of measurement and methodological problems. Although every attempt was made to ensure consistency in the reporting of data by manufacturers, it is inevitable that some errors were made. Further, the methodology itself is based on several assumptions, and while meant to measure assembly plant productivity and quality more accurately and consistently than previous efforts, is certainly not without its own flaws and consequent inaccuracies.

These caveats aside, the data presented thus far do confirm several long-standing hypotheses, among them the productivity advantages of a "fragile" production system, the gains to increased scale, and the penalty to increased model mix complexity. However, having a Japanese parent was not significantly linked to high productivity performance, indicating that the type of production management policy being used, not the nationality of the corporate parent, is a key performance driver. The Japanese Parent variable was linked

to high quality performance, but perhaps more through the quality of the design being built than the "Japanese-ness" of the plant.

We turn next to selected data groupings to more closely analyze regional trends and international relationships among combinations of dependent and independent variables. The wide range of intra-regional performance will confirm the observation that "country effect" alone is not a singular determinant of plant characteristics or performance.

5.2 Productivity and Quality Results by Plant and Parent Location

This section includes data and commentary based on regional groupings of productivity and quality performance results. Data are grouped by plant location and by a combination of parent and plant location. Later we examine relationships between productivity and quality using these and various other data groupings.

Regional data groupings are a traditional means of comparing gross national trends in an industry and illustrating regional tendencies. Unfortunately, such groupings tend to cloud the differences among the various producers in a region. The Japan-U.S. comparison studies of Harbour and others in the early 1980s have been mentioned as examples of this type of comparison, and some of their deficiencies have been pointed out. In the remainder of this chapter, we will look at regional data groupings, but the emphasis here is not on average regional performance but rather on regional tendencies and the variation in performance within each region. The findings are significant in that the hypothesis of monolithic intra-regional performance is largely discounted.

One consideration to keep in mind when reviewing the data presented here is the sample size of each data grouping. Some groups, such as European-based assembly plants with European parents, have small sample sizes (in this case five) and may not be representative of the entire population. The sample size for each group is shown separately in each

figure.

Figure 19: Productivity Performance by Plant Location

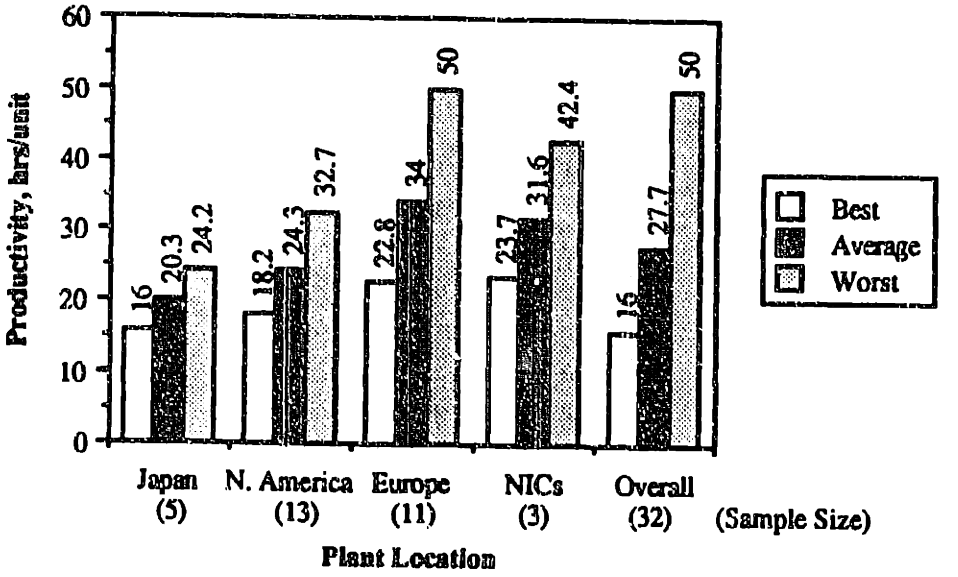


Figure 19 clearly shows the comparative advantage the Japan-based manufacturers have managed to attain, based on average regional performance.[85] More important is the degree of overlap between the North American and Japan-based producers. One caveat is the fact that of the 13 North American plants in the survey, three are Japanese transplants with productivity performance substantially better than the North American average. However, there are two U.S.-parented, North American plants with productivity performance better than the Japanese average of 20.3 hours/unit. When contrasted with the findings of many of the early 1980s researchers, this is surprising news indeed.[86] The

[85] Due to the relatively small sample size and wide variation characteristic of each of these regional groupings, the differences in means among these groupings were not statistically significant at a high confidence level. This is true for most of the regional comparisons made with the dependent variables in the discussion to follow. This poses no significant problem for this analysis, since our objective is the illustration of intra-regional differences as well as inter-regional tendencies.

[86] It is not clear how much of this high productivity performance was achieved since the earlier studies

fact that some U.S. producers have developed the capability to assemble cars at productivity levels superior to the Japanese average is at least partial refutation of the idea of monolithic country performance.

The range of productivity performance in Europe was somewhat surprising.[87] The five traditional European manufacturers examined all exceeded the Europe-based average of 34.0 hours/unit. This five plant sample included plants building cars in the subcompact class (1), compact class (2), and intermediate/near-luxury class (3). North American multinational plants fared better in general, with productivity performance approaching that of their North American sister plants.

The three plant Newly Industrialized Country (NIC) sample was a mixed lot, with some plants doing remarkably well, especially considering their lack of experience. Note that low levels of productivity in these countries can be balanced by relatively low wage rates. The NIC sample included plants in Mexico, Korea, and Taiwan.

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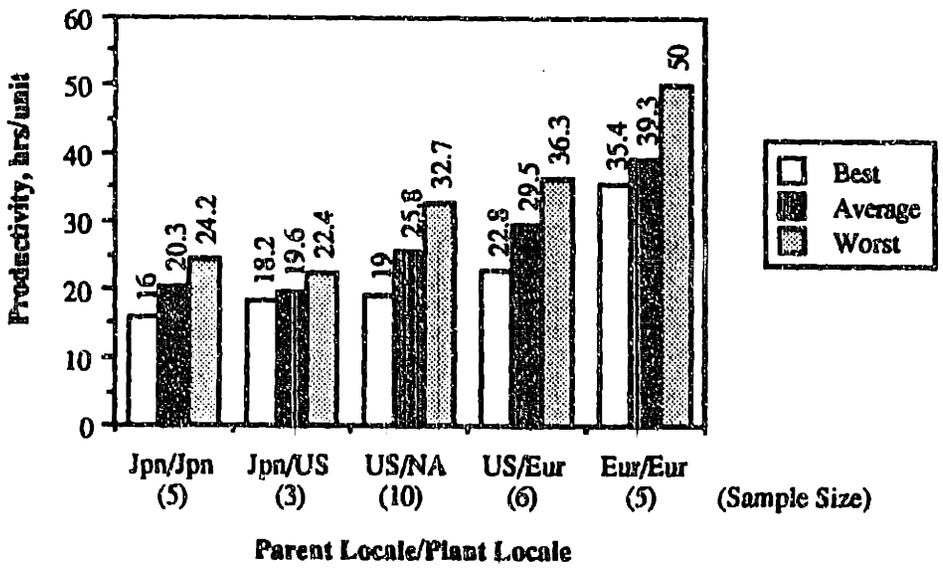
[86] It is not clear how much of this high productivity performance was achieved since the earlier studies were completed. However, a comparison of the Harbour and Ford/UAW study results in Chapter 4 show that there did seem to be a wide range of productivity performance for U.S. producers at that time with some producers achieving respectable productivity levels.

[87] It is important to keep in mind that the methodology used to calculate productivity corrects for differences in the product such as size and option content, as well as plant differences such as absenteeism and vertical integration.

Figure 20: Plant Productivity Performance by Parent/Plant Location



The Figure 20 data grouping allows us to clearly see the competitive performance of the U.S.-based transplants, with productivity performance essentially equivalent to our five plant Japan-based sample. At least by this measure, the transplants can be considered a success.

Average U.S. multinational plants based in Europe show productivity within 14% of North American-based, U.S.-parented performance, while the small traditional European sample size average of 39.5 hours/vehicle lags U.S. European-based multinational performance by over 33%. Although it is important to note the small size of some of these plant data groupings, it is nevertheless interesting to note the magnitude of the differences, and to ponder the significance. Will the traditional European assemblers be able to withstand the increasingly competitive environment fostered by the proposed opening of the EEC in 1992, or will political considerations prevail, keeping more efficient Japanese and American-parented corporations from achieving large market share gains? British

economist Garel Rhys considers the specter of U.S. auto exports to Europe "a problem that the European motor industry is reluctant even to consider, as it presents a nightmare with no apparent solution."[88]

Figure 21: Assembly Plant Quality Performance by Plant Location

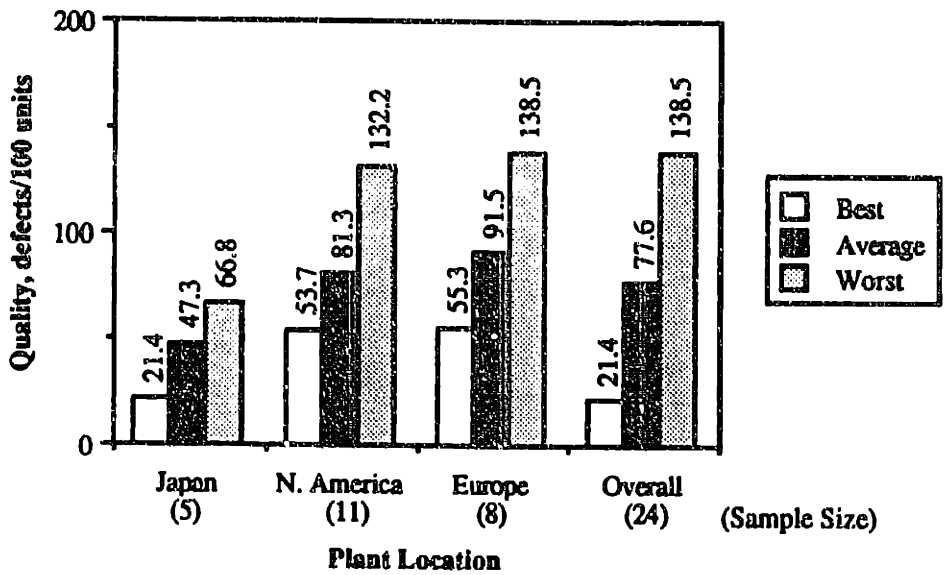


Figure 21 shows assembly plant quality performance by geographical region, using the Assembly Plant Quality Index developed in Section 4.4. The pattern of results is similar to productivity by region, with the Japan-based plants scoring substantially better on average than other plants in the world. North American quality performance has been improving more than the other regions, with several plants in this survey scoring 40-50% gains over 1985 quality levels.[89] European-based plants showed the worst average level of quality

[88] Jake Lucas, "U.S. Export Plans Called Problem for European Makers", *Automotive News*, November 16, 1987, p. 28.

[89] Plant quality data based on a comparison of 1985 and 1987 Assembly Plant Quality Index figures. For all U.S. nameplates, total vehicle defects per unit (not just APQI defects) decreased by 34.3% over this period. Comparable figures for Japanese and European nameplates are 23.7% and 28.6% respectively. All figures are based on data from J.D. Power and Associates "New Car Initial Quality Survey", 1985 and 1987.

of the three areas. Ironically, the best and the worst quality plants were based in the same country and produced similar upmarket vehicles.

Figure 22: Quality Performance by Parent/Plant Location

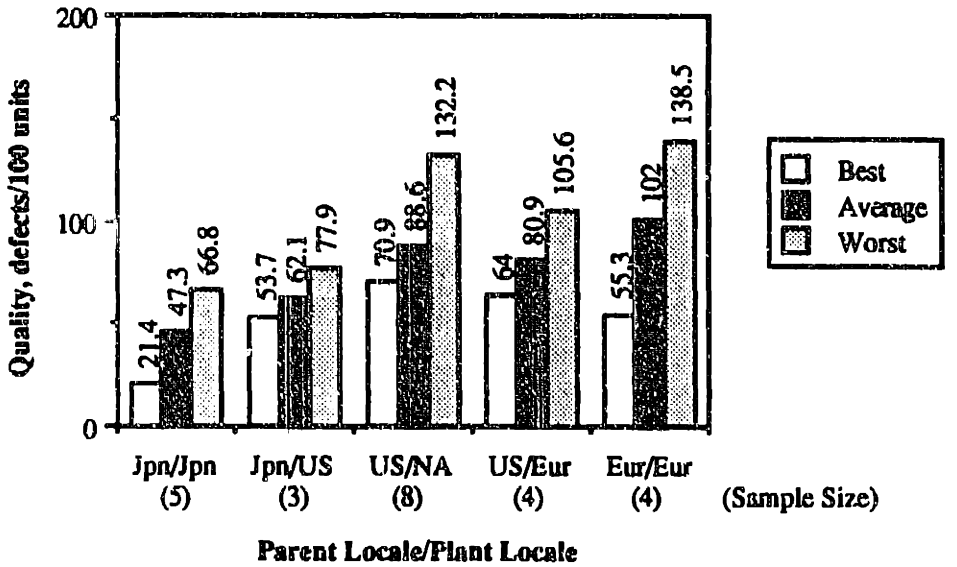


Figure 22 shows that the average quality performance of the U.S.-based transplants lags that of the Japan-based plants. Actually, one transplant is producing vehicles with essentially the same quality level as its mother plant in Japan, while the other two produce more than twice as many defects for equivalent product mixes compared to their mother plants. One partial explanation for this performance differential could be found in the experience level of the work force -- the best performing transplant vis-a-vis its mother plant also has the most experienced work force.

Another explanation might be found in the differing quality control philosophies these companies used for the transplants. Company B uses an extremely efficient production system in Japan, with no separate in-process quality control function.[90] However, this

[90] In-process quality control refers to those activities performed while the vehicle is being assembled. For this plant, quality control is performed in-process, but it is the responsibility of the production worker, not a separate in-process quality control group. Recall that in-process inspection by a separate quality control group was described as being characteristic of a "robust" production system.

company decided to use a more traditional in-process quality control group for the transplant, at least until high quality levels could be established. This conservative, "robust" amendment to an otherwise "fragile" philosophy seems to have been effective, as Company B's U.S. transplant is within 18% of the Assembly Quality Index rating of the mother plant.[91] Company C on the other hand uses a separate in-process quality control group in Japan, but decided to abandon this approach for its new plant in the U.S.[92] A "fragile" production system, without separate in-process quality control, could be expected to take longer than a "fragile" system with a separate in-process quality control function to produce high quality products. Perhaps the combination of aggressive implementation of a "fully fragile" production philosophy and a less experienced work force is the reason for this company's relatively poor transplant quality performance.

Traditional North American plant quality covers a wide range of performance, although even the best plant has yet to achieve the quality level of the worst Japan-based plant. There has been improvement, but there is still much work to be done. American multinational plants based in Europe show slightly better quality performance than their North American based brethren.[93]

For the traditional European assemblers we see the widest range of quality performance. As mentioned previously the extreme values are for similar vehicles

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[91] It seems this quality performance was achieved at the expense of productivity, as this transplant's productivity performance lags it mother plant's by more than 10%, while Company C's transplant/mother plant pair operate at roughly equivalent productivity levels. These figures are consistent with the additional staffing requirements of in-process quality control groups.

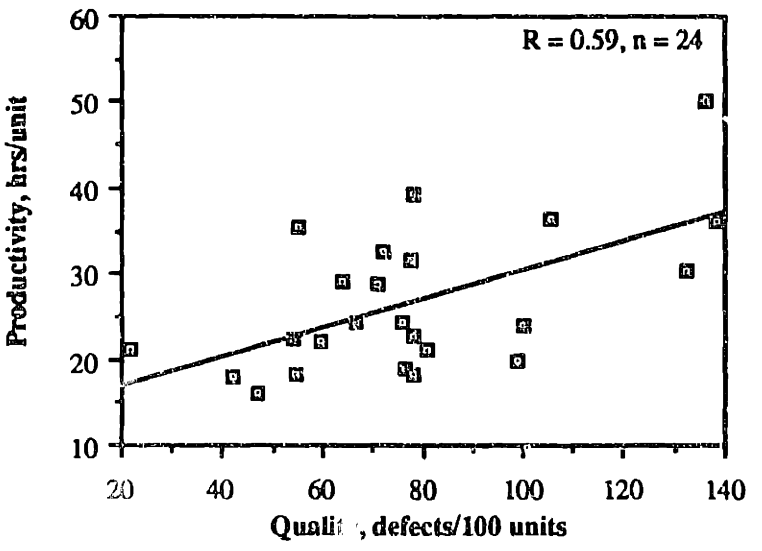
[92] One of Company C's goals is to make each new plant it builds an improvement over previous facilities, regardless of the new plant's location.

[93] Recall from Section 4.4 however that these U.S.-parented, Europe-based Assembly Plant Quality Index values were derived through a correlation of internal company quality indices and J.D. Power North American plant quality data and, consequently, are less robust than other values.

produced in the same country. This sample size is too small relative to the total number of European assembly plants to make any conclusive remarks. However, J.D. Power quality data does indicate that on average, European automakers are producing at lower quality levels than their Japanese and American competitors. European produced autos average 190 defects per one hundred units in 1987, while Japanese and U.S. nameplates average 129 and 176 defects per one hundred vehicles sold, respectively.[94]

With this summary of geographical productivity and quality results completed, we now turn to the interaction between these two output variables. Does there appear to be a tradeoff between high quality and high productivity, or do they go hand-in-hand? The answer is a break from traditional Western management philosophy, at least when looked at on a world-wide scale. Figure 23 below shows the result that to a healthy degree of correlation, those plants producing high quality products are doing so with *substantially less effort* than low quality plants.

Figure 23: High Quality Tends to Go with High Productivity



The main implication of Figure 25 is that when looked at from a world-wide

[94] J.D. Power, 1987. Note these are total vehicle defects and not just assembly plant-related defects.

perspective, there does not appear to be a tradeoff between quality and productivity. The quality gurus of industry -- Juran, Deming, Crosby and others -- have all espoused the "Quality is Free" doctrine, the view that productivity tends to increase with improved quality due to reduced rework efforts, more attention to process controls, less inspection requirements, and the like. Here is some evidence that they may be right.

Unfortunately, when we look at the relationship between quality and productivity on a regional basis, the "cost of quality" in some parts of the world appears to go up. Figure 24 below depicts this tendency.

Figure 24: Productivity/Quality Matrix by Plant Location

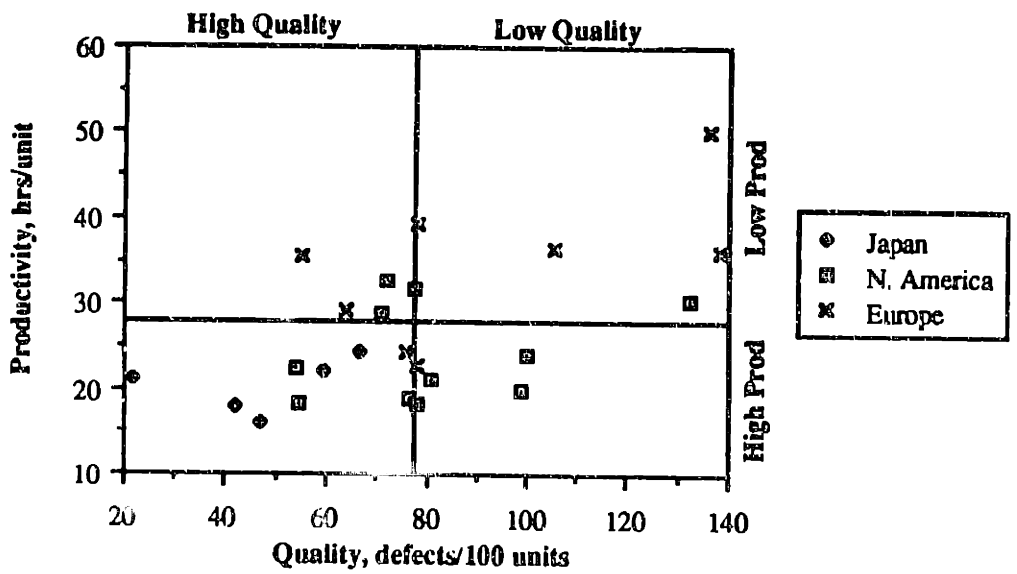


Figure 26 shows that what appeared to work on a world-wide basis falters a bit in North America and Europe, although high quality still seems to coexist with high productivity in Japan. Notice that all of the Japan-based plants are in the high quality/high productivity quadrant.[95] Two of the three North American-based plants in this high

[95] The lines in Figure 24 (and all 2X2 matrices like this one to follow) are drawn at the world average values of (in this case) productivity and quality.

performance quadrant are Japanese transplants. The traditional North American and European plants, when taken by themselves, show little positive correlation between productivity and quality. This indicates that on average, Western firms have been less effective in combining high quality and high productivity.

Figure 25: Productivity/Quality Matrix by Parent Location

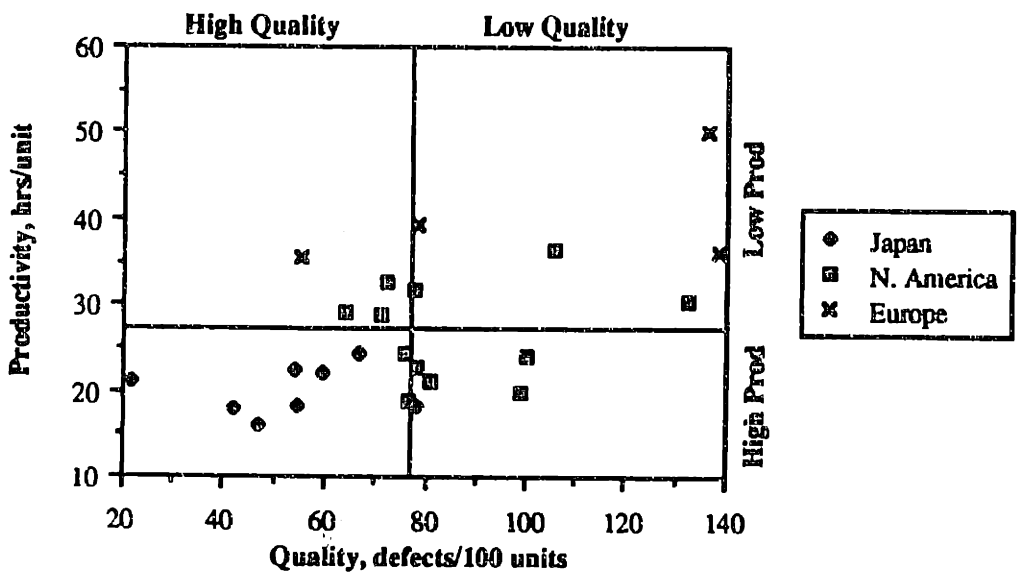


Figure 25 depicts the tendencies of assembly plants by parent location. Here we see all the Japan-parented plants essentially in the high performance region of the matrix, the North American-parented plants covering a large middle ground, and our small European sample tending toward the low productivity/low quality corner. Figure 26 below allows us to extend this type of analysis one step further by including an additional grouping, that of North American-based multinational company A.

Figure 26: Productivity/Quality Matrix by Parent Location, w/ Company A

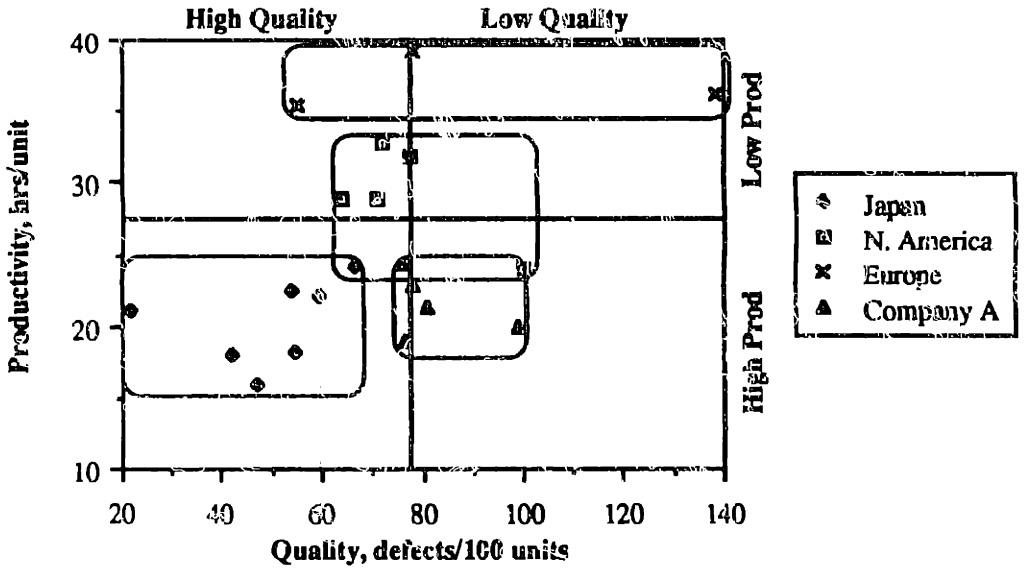


Figure 26 follows the same format as the previous figures, with the addition of a separate grouping for U.S.-parented Company A. Note that one outlying data point was removed from each of the four data groups to reduce clutter and emphasize the grouping tendencies. What emerges is an interesting set of "performance zones" that reflect general regional tendencies of the corporate parents. In particular, the compactness of the Company A performance zone is noteworthy. The five plants in the Company A grouping span four countries and a wide range of product types, plant equipment and design ages. Yet despite this disparity of culture and hardware, all five plants produce at roughly equivalent efficiency levels.

Is this phenomenon of consistent multinational world-wide performance seen elsewhere? Yes. Although the company sample size is smaller, each of the Japanese producers has been quite successful in rapidly achieving relatively consistent world-wide performance levels.[96] The other large North American multinational producer also

[96] Company C's U.S. transplant/Japan-based plant quality differential is a notable exception here.

achieves remarkably compact world-wide performance zones. One implication of these compact multinational performance zones is further refutation of the "country as a monolith" mentality. There are broad performance ranges for all of the regions. For example, in terms of productivity performance the best plants in Europe are better than the U.S. average. Even within Japan we see a relatively large spread of performance, with several Western plants exceeding Japanese plants' productivity and quality performance. Although we can still see regional trends, neither Japan, North America, nor Europe can be considered a monolithic entity. Corporate culture ranks with national culture as a factor correlated with differences in assembly plant performance levels.

Clear differences in performance do indeed exist across the world when one compares regional averages. This phenomena was demonstrated in Figures 19 through 22. But data groupings like those in Figure 26, and the results of the multiple regression analysis performed earlier, hint at the importance of variables within the capability of managements and governments to affect -- variables like Production Management Policy.

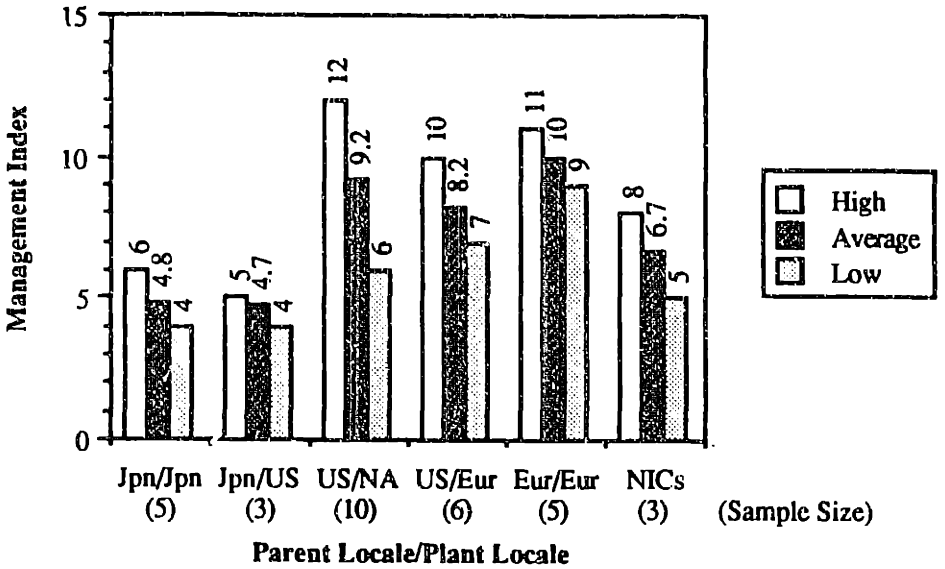
5.3 A Closer Look at Key Independent Variables

5.3.1 Production Management Policy

As we saw in the multiple regression analysis, Production Management Policy has the greatest explanatory power of assembly plant performance. In Section 2.1 we defined the Management Index as a means to quantify Production Management Policy. The components that make up the Management Index are repair area percentage of assembly shop floor space, visual control of the production process, use of the team concept, and the level of unscheduled absenteeism. We had earlier described the range of management philosophy as lying on a continuum between the traditional Western "robust" style and the "fragile" style as exemplified by the Toyota production system. Plants with "fragile"

tendencies would score at the low end (four) of the Management Index, while plants with "robust" characteristics would tend toward the high end (twelve). The distribution of Management Index scores by parent/plant location is shown in Figure 27.

Figure 27: Management Index Values by Parent/Plant Location

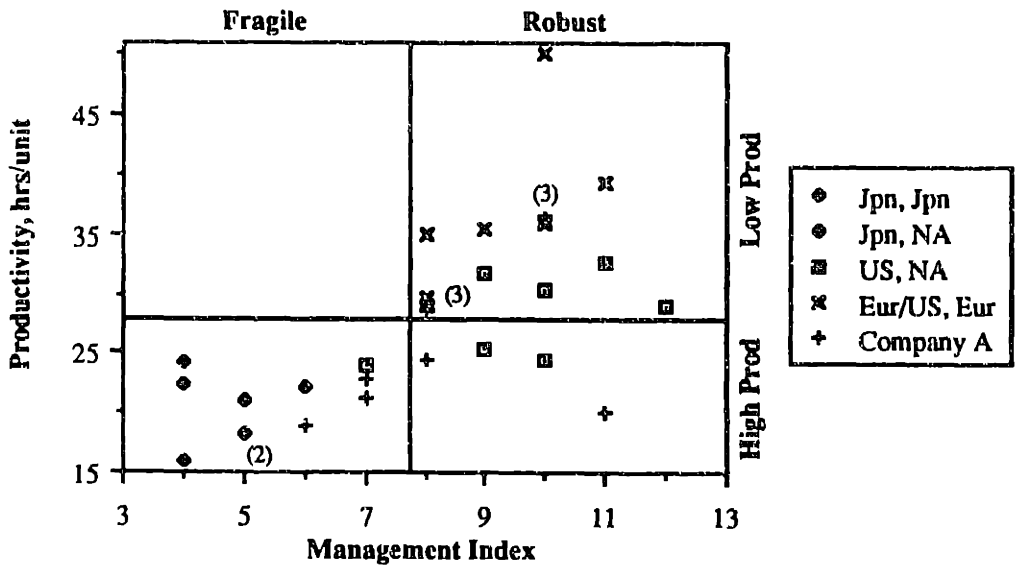


The cleavage between Japanese-parented and Western-parented facilities is vividly apparent here. In fact, only in the group of traditional North American plants is there any evidence that parent geographical region does not absolutely predict the Management Index value. The range of values found in North American plants, covering over 75% of the possible range of values of the Management Index, is enough evidence to maintain that regional characteristics need not overshadow corporate culture as an indication of Production Management Policy. Further, this wide range seems to indicate that the U.S.-based producers more than the Europeans are transforming their management policies from the "robust" model toward the "fragile" model. We see in Figure 28 that some U.S.-based producers are having greater success in this drive than others.

Using the same type of graphical presentation used in Figure 26, in Figure 28 we see

the relationship between Management Index and productivity for five groups of plants: Japan-based, U.S. transplants, traditional North American, European-based, and U.S.-based Company A's world-wide plants. Note that this sample size equals 30, reflecting the fact that two outlying, non-representative NIC plants are not included in this matrix for the sake of clarity.

Figure 28: Management Index/Productivity Matrix



The explanatory power of the Management Index in predicting productivity performance can be seen in this figure. For example, note that no plants operate in the fragile/low productivity quadrant, and only a handful operate in the robust/high productivity sector.

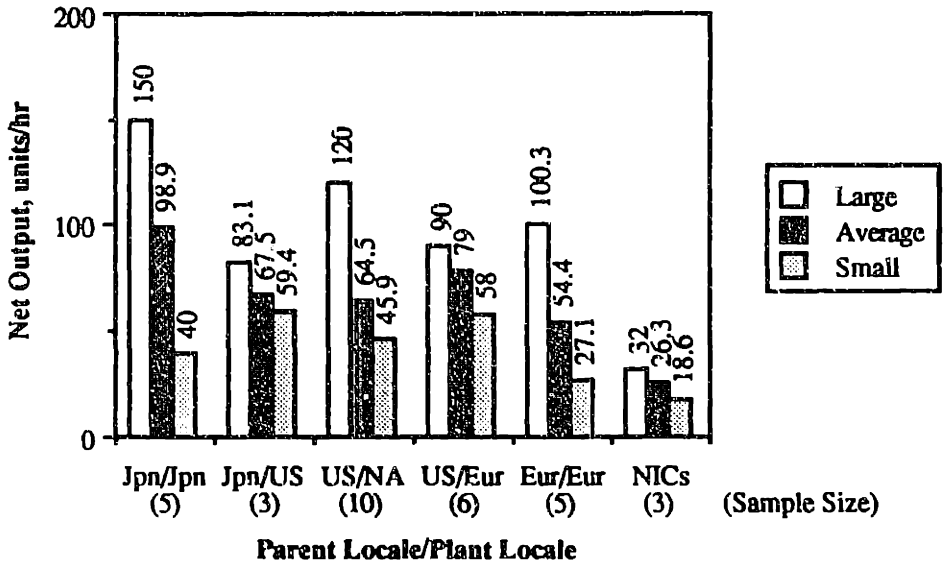
As expected, the Japanese-parented plants all perform in the fragile/high productivity region. More surprising is the strong positive correlation between productivity and Management Index for Western plants. Also evident in Figure 28 is the relatively tight clustering of Company A plants. Five of Company A's seven plants operate with similar "fragile" production management policies and relatively high productivity. This is in

keeping with our thesis of the strong effects of corporate culture on plant performance.

5.3.2 Plant Scale

Plant scale by parent and plant location is as shown in Figure 29.

Figure 29: Plant Scale by Parent/Plant Location



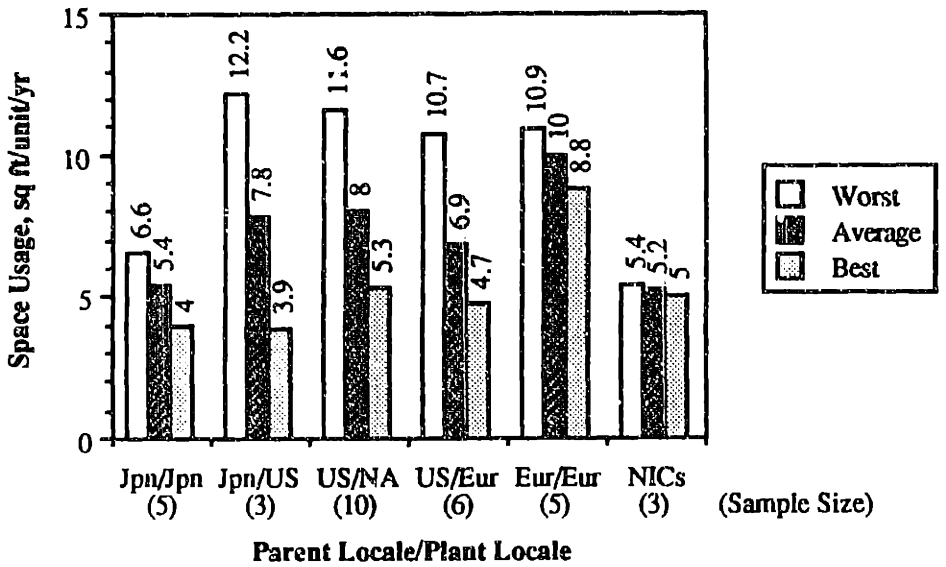
The Japanese plants in the sample had the largest scale in terms of net hourly output, followed by U.S. multinational plants in Europe and U.S.-based transplants. The large Japanese plants were often the equivalent of 2-2.5 traditional plant modules, where a module is defined as a net 60 vehicle per hour plant. We would expect some economies of scale from high output plants due to reduced indirect support required per unit. The multiple regression analysis performed earlier confirms this beneficial effect.

5.3.3 Space Utilization

It is interesting to note that the high-output plants in the sample are not necessarily the largest in terms of physical size. Indeed, one hallmark of the "fragile" production system is its relatively low floor space requirement due to the twin effects of low in-process

inventory and reduced post-process rectification requirements.

Figure 30: Space Utilization by Parent/Plant Location



The average results by parent/plant location are generally as expected, with the Japan-based plants making the most efficient use of their floor space. Beyond the space-saving virtues of the "fragile" production system, Japan space usage figures benefit from the steadily increasing production volumes of the '60s and '70s , after all the plants had been constructed. Capacity was incrementally increased, in most cases without facility extensions.

North American and European plants show less impressive space utilization figures, indicative of the old school of manufacturing thought in place when the plants were constructed. Ironically, the best and worst space utilization plants in North America are both recently constructed transplants. Honda's plant in Marysville, Ohio is "...the smallest major automobile manufacturing plant in the United States, yet (it) produces more cars per day than any other automobile plant in the United States."[97] This plant was built to suit

[97] Ohkubo speech, p. 7. Note that GM's Lansing, Michigan facility produces more than Marysville per day, but that this facility is sometimes referred to as two separate assembly plants.

the manufacturing philosophy of the parent company, and is therefore compact and efficient. Material flows are short, inventories are low, climate control bills are reduced, and communication and teamwork are enhanced. Adds Shin Ohkubo, executive vice-president of Honda of America:

> "A key part of achieving low cost is having a good plant layout. Because land is much cheaper in the U.S. than in Japan, building a large plant here is less difficult. But if a plant has a lot of space, it consumes a larger amount of energy. In a large plant, it takes more time to transport material within the plant, and the larger space is an invitation to create large inventories and stock a large quantity of parts."[98]

The least space efficient plant, Nissan's facility in Smyrna, Tennessee, was built in a more traditional Western fashion. Body, paint, and assembly shops are physically separated from each other. Marvin Runyon, former president and CEO of Nissan Motor Manufacturing Corporation U.S.A. has remarked: "We had to explain to (the Japanese Nissan managers) that American employees prefer to work in smaller areas and groups, which is the reason we ended up with the [modularized, physically separated] layout we have now."[99] Compared to the compact Honda layout, Smyrna's layout leads to less efficient material flows and communication, higher initial investment, and increased maintenance and utility charges. Figure 31 below shows the tremendous difference in space utilization between the two transplants, especially considering the fact that Marysville has about 50% more capacity than Smyrna.[100] Note that these layouts are approximations, based on available published information and personal plant visits.

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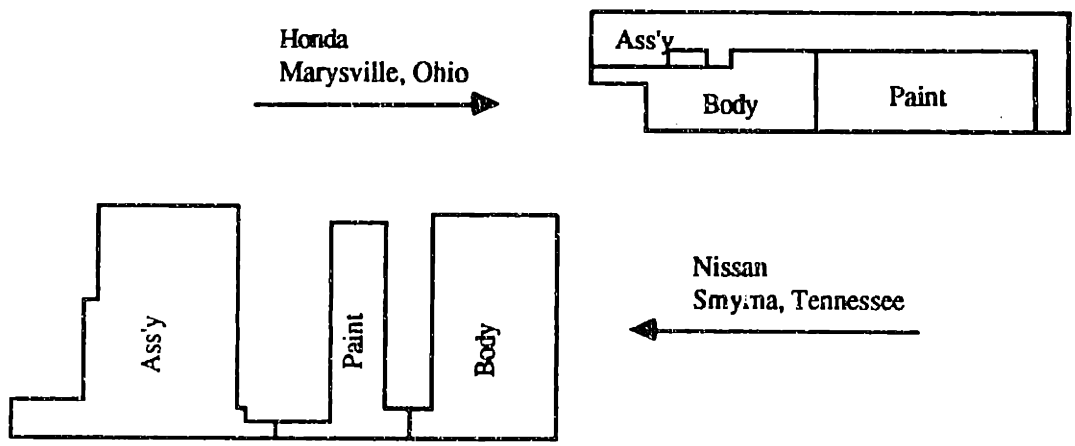
[98] Ibid., p. 6-7.

[99] Rose Thomas, "Tokyo Meets Tennessee with Moral Admiration", *Building Design and Construction*, August 1985, p. 69.

[100] Smyrna's large layout may allow for easier capacity increases, which could explain some of this plant's inefficient use of space.

Figure 31: Honda and Nissan U.S. Transplants: Space Usage Comparison



5.3.4 Level of Flexible Automation

The level of flexible automation in each plant is measured by the Robotic Index, which we defined earlier as the number of robots performing Standard Activities divided by the net hourly output. A study of this measure allows an understanding of the degree of success automakers have had in implementing high technology hardware. The multiple regression analysis indicated little correlation between a high Robotic Index value and high quality or productivity. We investigate this finding more closely here in an attempt to provide a qualitative explanation for the unfulfilled promise of flexible automation.

Figure 32 shows the distribution of Robotic Index values by parent/plant location. Japan-parented plants lead the U.S. and European-parented plants by about two-to-one on average. The NIC plants lag behind, reflecting the low wage rates in these countries. The North American based plants show a tremendous range in the Robotic Index ranking. Each of the transplants place substantially above the world average of 2.5, while most of the traditional North American plants in our survey were below the world average. The

exceptions were three newly refurbished facilities with high robotic applications in body welding, sealing, and painting.

Figure 32: Robotic Index by Parent/Plant Location

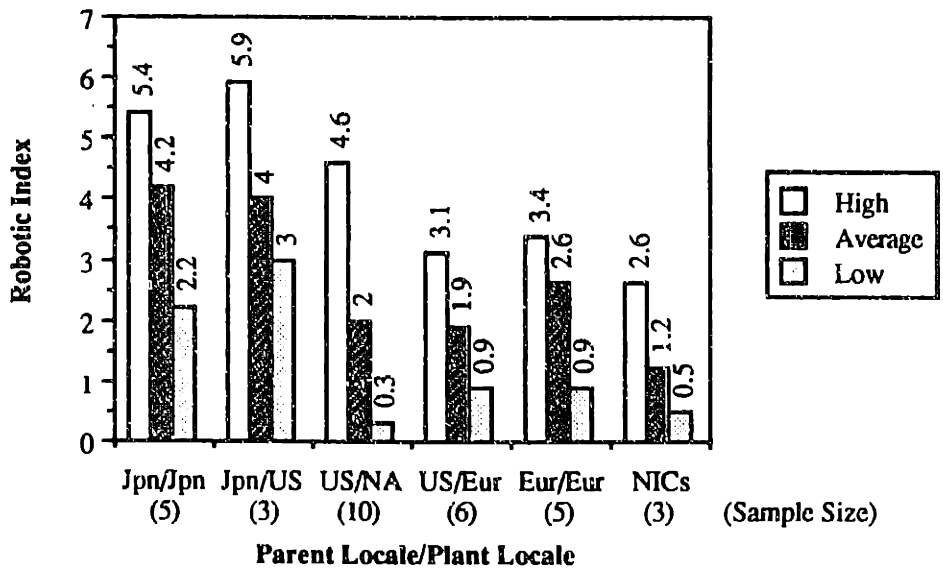
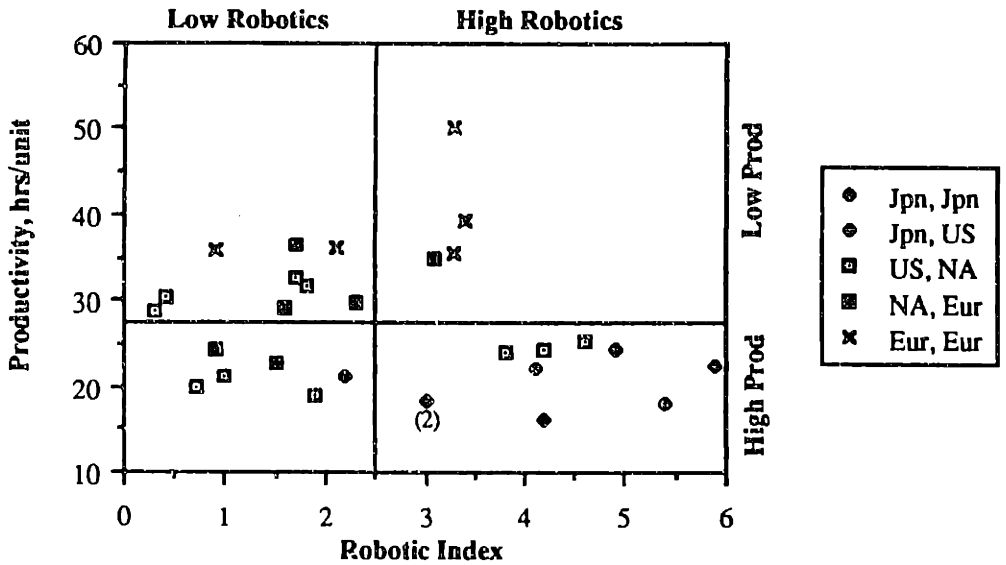


Figure 33 shows the relationship between productivity and Robotic Index for most of the plants in our survey. (The low Robotic Index NICs are excluded for the sake of clarity.)

Figure 33: Productivity/Robotic Index Matrix



As this figure shows, only three non-Japanese parented plants perform in the high productivity/high robotics zone. Note that all the U.S. transplants and all but one of the Japan-based plants perform in this quadrant. There are three explanations for the generally low level of robotics, and the inconsistent relationship between productivity and Robotic Index, in Western-parented plants. First, several of these facilities had heavy investments in "hard" automation, and were not yet ready to invest in new technology. Second, it seems several of these producers have made conscious decisions not to invest in flexible automation until the gains of their implementation have been better quantified. Indicative of this cautious approach to productivity enhancement through flexible automation is the fact that the three highest productivity traditional North American facilities all had Robotic Index values less than 2.0.

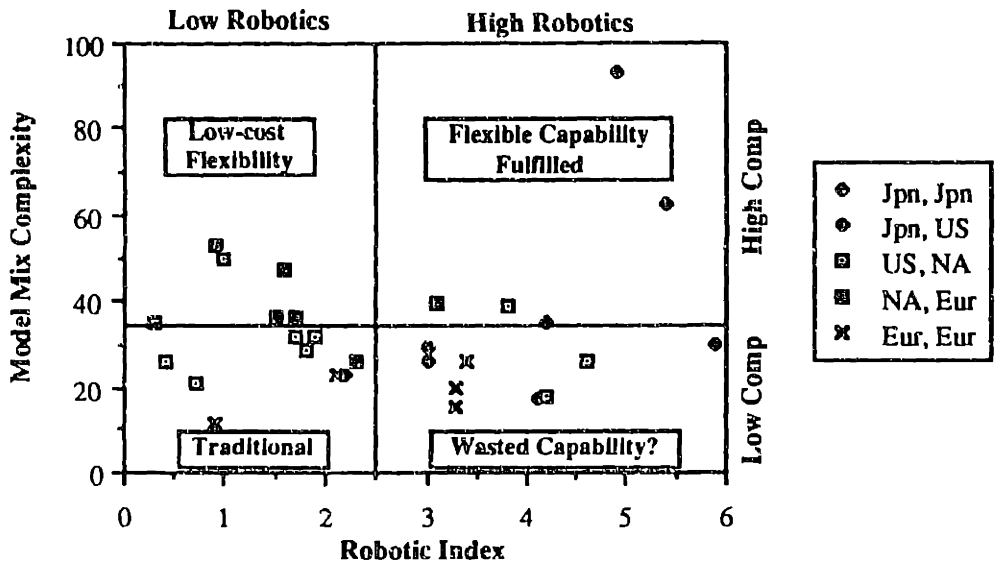
As long as the market provides these producers the volumes by model to sustain relatively inflexible plants, this low-cost strategy will succeed. However, as the market continues to fragment this inflexibility will become extremely costly. At the same time,

competitors who have mastered the technology of flexible automation (and use it to achieve increased mix complexity without sacrificing productivity) will have further increased the gulf between those who delay and those who improve their processes through technological innovation.

A final explanation for the poor relationship between productivity and Robotic Index is the fact that many of the flexible systems were installed not to improve productivity but to improve quality (over manual systems) and flexibility (over hard automation systems). Based on the data, there is only slight empirical evidence to back the quality claim, and less to back the increased flexibility argument. Based on the 32 plants in the sample, there was reasonable simple correlation between Robotic Index and quality (R = -0.378)[101], but little evidence of a significant explanatory effect from the multiple regression analysis. There was no correlation between our proxy for flexibility (MMCI) and the Robotic Index (R = 0.036). The data by parent/plant location for this pair of independent variables is as shown in Figure 34.

[101] This correlation is deemed reasonable since most of the quality gains of increased robotics come in the categories of body fits and squeaks/rattles, categories which make up less than half of the defects in the APQI.

Figure 34: Complexity/Robotic Index Matrix



In this matrix, we see only a handful of plants fulfilling the flexible promise of their technology, most of these Japanese.[102] Other plants seem to be wasting their capability, although three of the plants in the lower right-hand corner are U.S. transplants just beginning to exercise their flexibility.[103] The remaining plants are split between the traditional zone of low robotics and low complexity and a low-cost flexibility zone. This last group has managed to establish a reasonably diverse product mix with relatively low levels of flexible automation. At the same time, these six plants average 27.1 hours to assemble a vehicle, just below the entire sample average of 27.7 hours/unit, a remarkable achievement. In keeping with the concept of tightly clustered corporate "performance zones" and the importance of corporate culture in explaining performance indicators, it is worth noting that four of these six plants are Company A facilities.

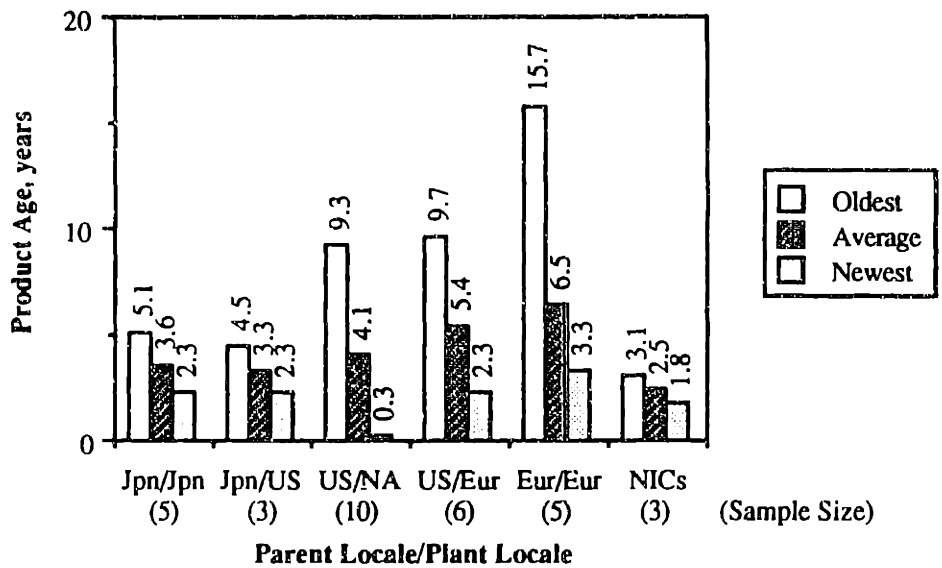
[102] Jaikumar shows evidence of U.S. underutilization of flexible capability in his comparative study of flexible manufacturing systems in the U.S. and Japan. The data presented here show a similar trend, although the wide range of regional performance is perhaps a more important point.

[103] The trend toward increasing North American transplant mix complexity it discussed in more detail in Section 5.3.6.

5.3.5 Product Age

Recall that product age was decided on as a proxy for something that is extremely difficult to measure -- in this case product manufacturability. The distribution of product age by parent/plant locale as shown in Figure 35 holds few surprises.

Figure 35: Product Age by Parent/Plant Location



As expected, the eight plant Japanese-parented sample (and the NIC plants, which are all building Japanese designs) achieve the lowest average product age. Their average product age is lowest (other than the NIC's, who are all building Japanese designs), reflecting the traditionally shorter Japanese model cycles. The Western plants in the study assemble products averaging five years old, although the range is quite large (0.3 - 15 years).

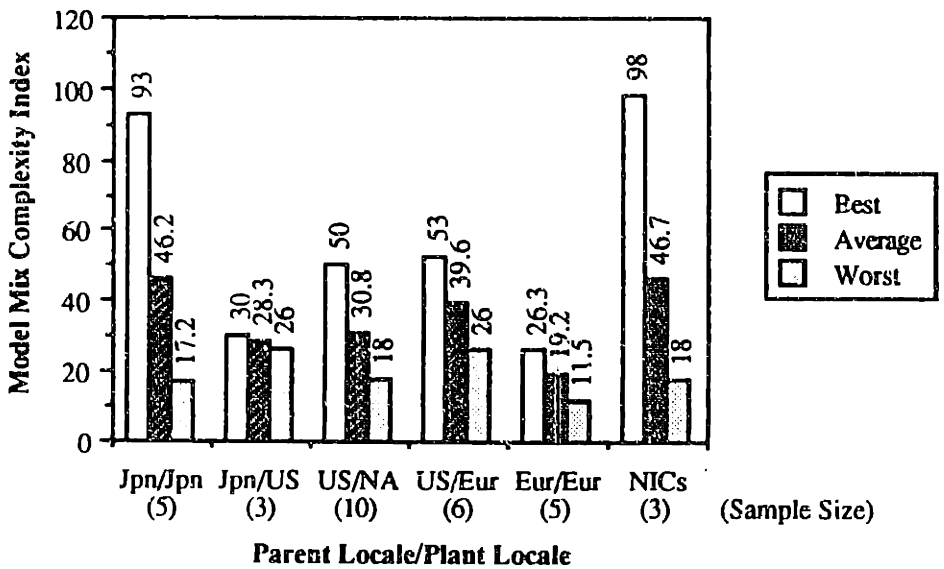
There was little simple correlation between product age and productivity (R = 0.190) or product age and quality (R = 0.158). This corroborates what was seen earlier in the multiple regression analysis, indicating that the learning curve effects of building the same product over a long period of time tend to overcome the presumably lower

manufacturability of an older design.

5.3.6 Model Mix Complexity

Figure 36 below dispels the potential argument that Japan-based assemblers deal with less complexity in their assembly plants. Note that for the Model Mix Complexity Index, a larger number means more plant level mix complexity.

Figure 36: Model Mix Complexity by Parent/Plant Location



The Japan-based plants are on average accommodating a more complex mix of platforms and body styles than their North American or European-based competitors, a fact which runs counter to many common perceptions of "standardized" Japanese products. The myth of the simple Japanese product line, promoted largely through U.S. analysts' exposure to the Voluntary Restraint Agreement-inspired, high-content, optioned-packaged, U.S.-bound Japanese product line, must be put to rest. Japanese home market competition is fierce, and as in most mature markets competitive advantage is found in differentiation. So, in addition to producing for as many as 130 export markets[104], each major

manufacturer is forced to cope with the myriad platforms, trim levels, and stand-alone options necessary to please an increasingly fragmented home market.

Examples of extremely flexible Japanese plants abound. Mazda's main plant in Hiroshima builds the RX-7 (a rear wheel drive sports car in standard and convertible versions), the 929 (a rear wheel drive luxury car), the 121 (a front wheel drive mini car), and the 323 (a front wheel drive compact), all on one assembly line. All are distinct platforms, with various trim levels, body styles, and right or left-hand drive options. Mitsubishi's Okazaki plant produces the Starion/Chrysler Conquest (a sports car), the Cordia/Tredia (a compact 2 door sport coupe/4 door sedan pair), the Galant (a mid-size), and the Vista wagons, also all on the same line. Honda's Sayama plant builds the Acura Legend/Rover 800 (near-luxury cars), the Accord, the Prelude, and the Civic Shuttle wagon. (Sayama uses two assembly lines, but this is still a relatively complex mix.) As we will see, some Japanese producers seem to have been able to accommodate this additional complexity without incurring great losses in productivity or quality. And certainly, in an increasingly competitive world market, offering the consumer additional variety at low cost and with high quality is a strategy that provides a firm with a potent advantage.[105]

Meanwhile, a major push among the North American producers is to reduce plant level complexities by consolidating platforms, packaging options, and reducing trim variation. Indeed, industry literature abounds with examples of the gains to reduced complexity. Abbeglen and Stalk boldly state the advantages of the so-called "focused factory": "The more variety of product fabricated or assembled on a line, the less focused, the more difficult to manage, and the greater the required overhead support will be. By inference,

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[104] For example, the Nissan Micra, built in Nissan's Murayama plant, is exported to 130 countries. Source: Interview with Toshihiro Nishiguchi, based on his interview with plant personnel at the Murayama plant.

[105] See Michael Porter's *Competitive Strategy* for background on competitive analysis theory.

the more products a factory manufactures, the less focused, the greater the overhead requirements and costs, and the higher its total production costs will be."[106] Others have found evidence that Western producers have tended to follow this logic. Abernathy has shown that the number of different cars produced in a typical Ford assembly plant fell from 2 to 1.5 between 1950 and 1975.[107] Perhaps the most ironic example of this trend can be found in General Motor's plant sourcing strategy for the new GM-10 intermediates, a multi-model project based on one platform. Four highly automated, extremely flexible plants were earmarked for this colossal project -- yet each will initially produce only one model and body style.[108] This expensive flexible capability, in the form of thousands of AGVs (automatic guided vehicles) and robots, will scarcely be taken advantage of, except during model changes.[109]

It is not clear that a "focused factory" approach is the best defense against the accomplished, flexible niche producers some Japanese automakers have proven themselves to be. In a time of increasing competition, product line expansion would appear to be a sounder competitive strategy than product line contraction, as long as an increase in complexity can be managed in a way to avoid excessive cost increases or a decline in quality. As mentioned in the multiple regression analysis section earlier, the key to achieving this mix of high complexity with high productivity and quality appears to be the Production Management Policy in place at each plant. This relationship is shown in Figure 37 below, which indicates the "fragile" Japanese producers are most successful at

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[106] Abegglen and Stalk, p. 83.

[107] Abernathy, The Productivity Dilemma, p. 131.

[108] Oshawa-2 will produce the Buick Regal, Oshawa-1 the Chevrolet GM-10 product, Fairfax the Pontiac Grand Prix, and Doraville the Oldsmobile Cutlass Supreme. Source: *Ward's Automotive Reports.*

[109] GM undertakes a major model change once every 5-10 years. The GM-10 intermediates will remain essentially unchanged for at least 6 years, judging by past experience. Four door versions of the intermediates will be added to some plants.

simultaneously achieving high productivity and high model mix complexity.

Figure 37: Productivity/Complexity Matrix by Parent Location

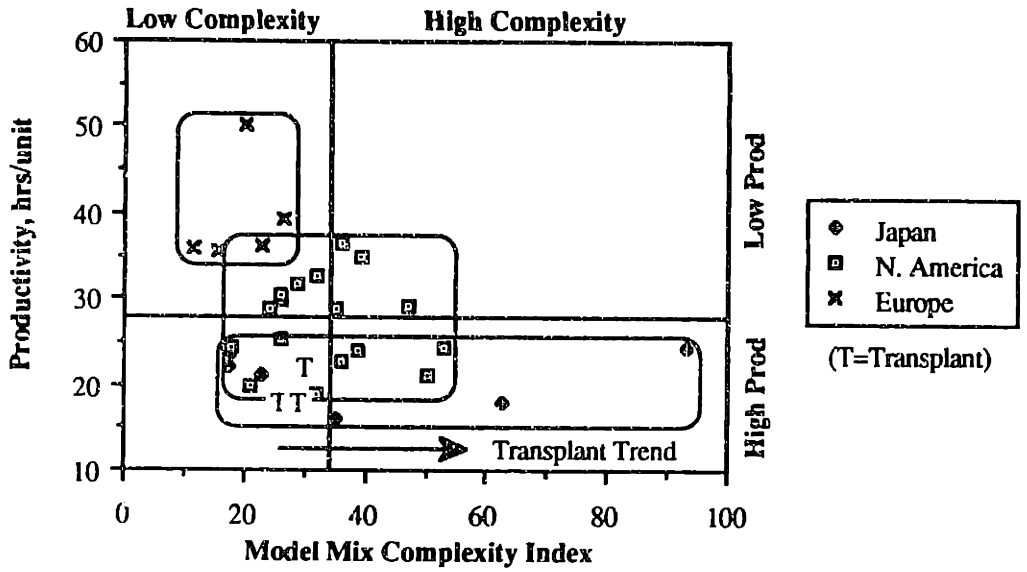

Figure 37 shows productivity/complexity performance tendencies by parent location. Here again, we find the traditional European producers in the low-performance quadrant. The Japan-parented plants perform along a wide range of model mix complexity values, with transplants at the "simple" end and more established plants at the "complex" end. As indicated by the arrow in the figure, one can imagine a time-series progression rightward for the transplants -- as they mature they will tend to increase complexity without sacrificing productivity.[110] As in the productivity/quality matrix, we see a tendency for the North American-parented plants as a group to stay in the mid-performance area, although four plants do land in the high-performance quadrant, three of these from Company A.

[110] This trend is already in evidence at NUMMI, with the addition of a 5 door Nova and a 2 door Corolla since plant start up, and at Honda Marysville, where two platforms (Civic and Accord) and four body styles are now produced, compared to just one body style at plant start up. Nissan Smyrna started with one platform, but now builds several truck body styles and two Sentra body styles. It may add a passenger van in the future. Source: Author's trip notes, 1987, and *Ward's Automotive Reports*.

Summary, Conclusions, and Outlook

The data examined in this thesis lead to a number of conclusions and implications for the auto industry. Some of the more important findings are summarized below:

1) Production management policy was found to have a great effect on plant operating performance. Several North American plants, many managed with a "fragile" production policy, achieved performance levels equal to or better than some Japanese plants. Production management policy offered a greater explanatory effect on productivity than Japanese parentage.
2) "Fragile" plants had an increased capability of simultaneously achieving high levels of productivity, quality, and mix complexity.
3) Intra-regional variation in operating performance was found to be significant in North America, Europe, and Japan. Substantial overlap among these regions and relatively consistent international intra-corporation performance supports the notion that corporate parentage is at least as important as location in determining the performance of an assembly plant.
4) Level of technology as measured by the Robotic Index seemed to have little effect on operating performance. Robotic applications are not being used to accommodate mix complexity in most of the plants in this survey.

With these conclusions in hand, several implications for the industry can be offered. One of the most important is that an effective production management policy can be shaped in any location. The success of the transplants and some U.S.-parented plants suggests that a "fragile" management policy is most conducive to high productivity and quality

performance. This could very well contribute to the competitive tempo of the industry, as some older "robust" plants evolve into more "fragile" facilities instead of succumbing to the threat of increased foreign-based capacity. Of course, in the North American market the new transplant capacity additions will bear on the outcome of this scenario. Older plants will be under pressure to increase the rate of their evolution from the "robust" to the "fragile" model and hence risk compromising the transformation of their management policies.

The relatively poor performance of the European producers sampled in this survey indicates that the 1992 plan involving intra-EEC trade barrier removal and common trade policy implementation, if undertaken, may lead to dramatic changes in market structure. Imports from more efficient Japanese plants located in the U.S. or Japan, and even traditional U.S. producers, may threaten traditional European manufacturers with the fruits of successful "fragile" production systems -- low-cost, high-quality, differentiated products. Few of the European plants visited for this survey exhibited "fragile" characteristics. It seems likely that the diffusion of this production management policy through traditional European operations will take some time.

The performance of the NIC plants in the survey indicate their viability as low-cost producers, although available quality performance to date has been unimpressive.[111]. The success of Korean-built and marketed cars in the U.S. market is already evident, and U.S.-nameplate, Korean-origin cars such as the Pontiac LeMans and Ford Festiva seem to be achieving a similarly warm welcome. Their success increases the competitive pressure on established capacity in each of the triad regions.

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[111] For example, the Hyundai Excel quality rating of 315 defects per one hundred units is twice as bad as the average car marketed in the U.S. (industry average equals 167 defects per one hundred units). Source: J.D. Power, 1987.

With these findings and implications in mind, we can return to the evolution of manufacturing practice, and the likely direction it will take through the end of the century.

Figure 38: The Future Direction of Manufacturing Practice

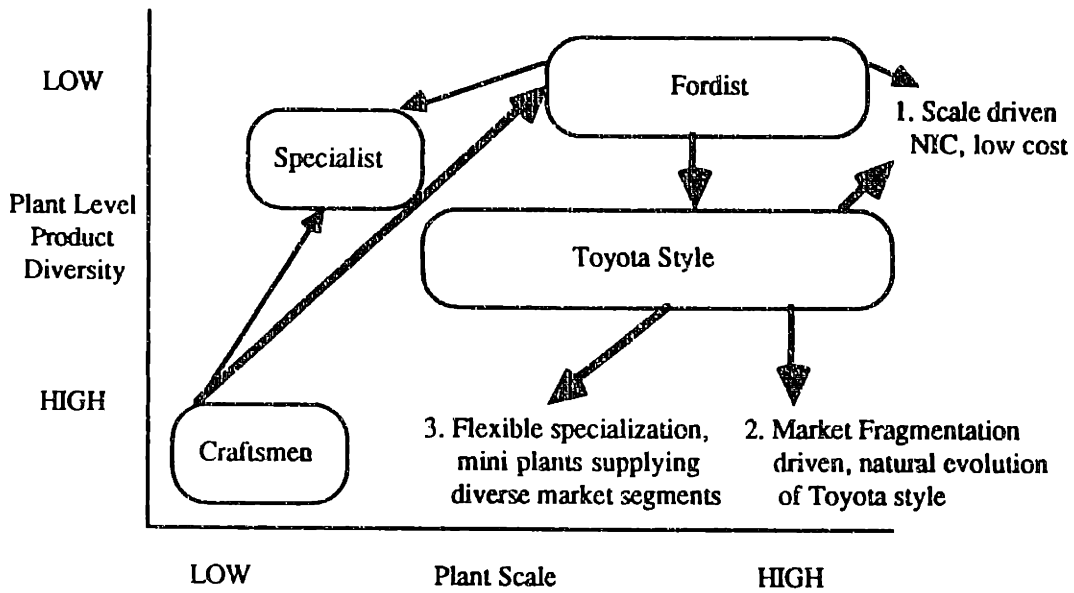

Figure 38 depicts the general trends of manufacturing practice as discussed in Chapter 1. The evolution of "dominant practice" follows the model developed in Table 2, with the Craftsmen paradigm superceded in turn by the Ford mass production model and Toyota small-lot production techniques. Three distinct possibilities are presented here as next steps in the progression of plant level manufacturing practice.

The first possibility is the volume-driven, low-cost, standardized product model. One could imagine this model being developed in NICs by multinationals incorporating elements of both the Ford and Toyota paradigms. Requisite to the success of such a model are large world markets for relatively standardized products. Restrictive trade policies and a trend toward market fragmentation thus render the ascent of this hybrid quite uncertain.

A second possibility is the evolution of the Toyota model toward even more diverse

plant level product mixes. This progression seems a likely evolution given the increasing segmentation of the automobile market and resulting reduction in volumes per platform. Plants capable of accommodating diverse mixes while maintaining high productivity and quality levels should attain a strong competitive advantage. Many Japanese-based plants have already achieved a high level of mix diversity at high efficiency levels, while U.S.-based transplants seem poised to follow a similar trend.

A final possibility is the flexible specialization model put forth by Piore and Sabel. Here, plants capable of profitable low-scale operations turn out a wide array of products to please diverse market tastes. The appeal of this alternative is great, and, although the analysis presented here indicates plant scale is an important contributor to efficiency, anecdotal evidence supports the notion that "fragile" low-scale assembly plants will eventually combine high levels of productivity, quality, and product diversity. New Honda and Toyota mini-plants in Canada have both targeted productivity levels comparable to their Japanese parent plants. Product diversity is initially low in both of these plants, but will likely increase. Ford's venture with Lio Ho in Taiwan is another example of a relatively new mini-plant. Established in the early '70s and similar in scale to the Honda and Toyota mini-plants, it flexibly produces four distinct platforms for domestic and export markets.

Future Research

The research reported here is just an initial step in the understanding of manufacturing performance in the auto industry. Further work must be done in refining the methodologies and selecting appropriate performance indicators. The measurement of work force capability in particular would greatly increase the merit of future comparative studies. A greater range of product types, beyond the largely compact class vehicles of this

study, should be examined. The impact of product manufacturability and option complexity on plant quality and productivity should be explored in greater detail. Finally, an extension of this kind of comparative study to the automotive supplier chain seems a logical progression. Together, these extensions on the work done here and elsewhere could permit a more accurate assessment of manufacturing performance, providing managements and governments with more appropriate tools with which to identify superior manufacturing practices.

BIBLIOGRAPHY

Abeggien, James C., and George Stalk, Jr. *Kaisha: The Japanese Corporation.* New York, Basic Books, 1985.

Abernathy, William J., *The Productivity Dilemma: Roadblock to Innovation in the Automobile Industry.* Baltimore, John Hopkins University Press, 1978.

----------, Kim B. Clark, and Alan M. Kantrow. *Industrial Renaissance: Producing a Competitive Future for America.* New York, Basic Books, 1983.

----------, and Kenneth Wayne. "Limits of the Learning Curve." *Harvard Business Review.* September-October 1974.

Altshuler, Alan, Martin Anderson, Daniel Jones, Daniel Roos, and James Womack. *The Future of the Automobile.* Cambridge, MIT Press, 1984.

Anderson, Martin L. "The Real World of International Cost Data: A Recommended Method of Analysis." Cambridge, Future of the Automobile Program, MIT, 1982.

Automobile. Monthly.

Automobile Panel, Committee on Technology and International Economic and Trade Issues. *The Competitive Status of the U.S. Auto Industry.* Washington, D.C., National Academy Press, 1982.

Automotive Industries. Monthly.

Automotive News. Weekly.

Car and Driver. Monthly.

Chrysler Corporation. *Annual Reports.*

Cook, James. "Where's the Niche?" *Forbes,* September 24, 1984.

"Cost of Building a Comparable Small Car in the U.S. and in Japan -- Summary of

Consultant's Report to the UAW." April 30, 1985.

Cusumano, Michael A. *The Japanese Automobile Industry: Technology and Management at Nissan and Toyota*. Cambridge, Harvard University Press, 1985.

----------. "The 'Factory' Approach to Large-Scale Software Development: Implications for Strategy, Technology, and Structure." Cambridge, Sloan School of Management, MIT, November 1987.

Ford Motor Company. *Annual Reports*.

Fuss, Melvyn, and Leonard Waverman. "The Extent and Sources of Cost and Efficiency Differences Between U.S. and Japanese Automobile Producers." Cambridge, National Bureau of Economic Research, 1986.

General Motors Corporation. *Annual Reports*.

Harbour and Associates, Inc. "Comparison of Japanese Car Assembly Plant Located in Japan and U.S. Car Assembly Plant Located in the U.S." Berkeley, Michigan, 1980.

Hayes, Robert H., and Steven C. Wheelwright. *Restoring Our Competitive Edge: Competing Through Manufacturing*. New York, John Wiley and Sons, 1984.

Jaikumar, Ramchandran. "Postindustrial Manufacturing." *Harvard Business Review*, November-December 1986.

J.D. Power and Associates. "New Car Initial Quality Survey, 1987 Models." Westlake Village, California, 1987.

----------. "New Car Initial Quality Survey, 1985 Models." Westlake Village, California, 1985.

Katz, Harry C., Thomas A. Kochan, and Kenneth R. Gobeille. "Industrial Performance, Economic Performance, and QWL Programs: An Interplant Analysis." *Industrial and Labor Relations Review*, October 1983.

Katz, Harry C., Thomas A. Kochan, and Jeffrey Keefe. "The Impact of Industrial Relations on Productivity: Evidence from the Automobile Industry." Cambridge, International Motor Vehicle Program, November 1987.

Keller, Maryann N. "Freedom of Choice vs. a Good Deal." *Motor Trend*, December 1987.

Kennedy, Peter. *A Guide to Econometrics*. Cambridge, MIT Press, 1985.

Krafcik, John F. "Learning from NUMMI." Cambridge, International Motor Vehicle Program, MIT, September 1986.

----------. "Trends in International Automotive Assembly Practice." Cambridge, International Motor Vehicle Program, MIT, September 1987.

---------- and James P. Womack. "Comparative Manufacturing Practice: Imbalances and Implications." Cambridge, International Motor Vehicle Program, MIT, May 1987.

Lieberman, Marvin B. "Learning-By-Doing and International Competition: Autos and Semiconductors in the US and Japan." NBER Conference on Empirical Studies of Strategic Trade Policy, 1987.

Lucas, Jake. "U.S. Export Plans Called Problem for European Makers." *Automotive News*, November 16, 1987.

McElroy, John. "Sterling Heights: Chrysler's Showcase Assembly Plant." *Automotive Industries*, January 1986.

Monden, Yasuhiro. *Toyota Production System*. Norcross, Georgia, Industrial Engineering and Management Press, 1983.

Motor Trend. Monthly.

Nissan Motor Company. *Annual Reports*.

O' Donnell, John, and Laurie Hussey. "Brownfields, Transplants and New Entrants: The Overcapacity Problem." Cambridge, International Motor Vehicle Program, MIT, 1987.

Ohkubo, Shin. "The Honda Approach to Productivity." Text of speech to Baldwin-Wallace College, Berea, Ohio, March 2, 1987. Honda of America Mfg., Inc.

"Outline of Toyota, 1987." Nagoya, Toyota Motor Corporation, 1987.

Piore, Michael J., and Charles F. Sabel. *The Second Industrial Divide: Possibilities for Prosperity*. New York, Basic Books, 1984.

Porter, Michael E., ed. *Competition in Global Industries*. Boston, Harvard Business School Press, 1986.

----------. *Competitive Strategy: Techniques for Analyzing Industries and Competitors*. New York, The Free Press, 1980.

Revue Automobile: Catalogue de la Revue Automobile, 1987. Berne, Switzerland, Hallwag S.A., 1987.

Road and Track. Monthly.

"QC Circle Activities." Nagoya, Toyota Motor Corporation, 1984.

Schonberger, Richard J. *Japanese Manufacturing Techniques*. New York, The Free Press, 1982.

Sheriff, Antony. "The Work Force: The Forgotten Technology in Automobile Production." Cambridge, Sloan School of Management, MIT 1984.

Shimada, Haruo, and John Paul MacDuffie. "Industrial Relations and 'Humanware': Japanese Investments in Automobile Manufacturing in the United States." Cambridge, International Motor Vehicle Program, MIT, 1986.

Tabachnick, Barbara G., and Linda S. Fidell. *Using Multivariate Statistics*. New York, Harper and Row, 1983.

Thomas, Rose. "Tokyo Meets Tennessee with Moral Admiration." *Building Design and Construction*, August 1985.

Toyota Motor Corporation. *Annual Reports*.

Ward's Automotive Reports. Weekly.

Womack, James P. "A Century of Transformations, or The Progression of Best Practice."

Cambridge, International Motor Vehicle Program, 1987.

Woodward, Joan. *Industrial Organization: Behaviour and Control*. London, Oxford University Press, 1970.

Zysman, John, and Laura Tyson, eds. *American Industry in International Competition: Government Policies and Corporate Strategies*. Ithaca, Cornell University Press, 1983.