Impact of Scale on Performance and Technology in Process-Intensive Industry

by

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Abstract

Two surveys are performed to determine production methods, competitive strategies, and scale disadvantages for a group of small manufacturing plants. Detailed comparisons of economic, operational, and development activities are presented to identify differences between industry production standards and small-scale plants. As a group, the small-scale plants had similar production costs to the standard-scale plants. The small-scale plants experienced lower average unit fixed costs as a result of lower capital investment and indirect labor expenses. The small-scale plants operated closer to their theoretical efficiency levels than the standard-scale plants. The procedure used to collect and analyze data is referred to as the direct comparison method. The direct comparison method involves conducting detailed one-to-one comparisons of production systems at the plant-level. A pattern of operational trends are reported that contribute to the economic performance of small-scale plants. The small-scale plants compensated for scale disadvantages by having greater technology independence, conserving capital, conducting internal development, and promoting process competence.

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1.0 Introduction

1.1 Motivation

Economic theory suggests that plants that operate below an industry minimum efficient scale will not exist in the long-run. Yet, small-scale plants not only exist, but they dominate in their numerical presence in many industrial sectors. Defining a minimum efficient scale in most industries is imprecise and difficult. Surveys of industry structure show diverse distributions in plant size. The objective of this work is to study the role of production assets that appear to operate below accepted industry standards of minimum scale efficiency.

To understand the value of small-scale plants relative to their larger scale competitors, a comparison method must be employed that identifies differences in economic performance and production methods. In this work, a research method is proposed to study scale and production processes at the plant-level. The direct comparison method attempts to couple process methods and performance to understand the role of scale in production industries. Evidence suggests that production establishments in a given industry rarely differ in only their scale of output. A difference in scale often accompanies wholesale differences in production methods. Production technology is not ideally scalable. The intention of this study is not to prove the merits of small-scale productive units. Instead, this work seeks to document the competitive position, economic performance, and operational trends evident in a small group of manufacturing plants operating below the perceived efficient scales of production in their industries. In summary, the primary questions addressed in this study are not why small-scale production assets exist, but how small-scale production assets exist.

The intent of this research is not simply to resolve technical and economic behavior patterns of small-scale plants. Instead, it seeks to apply this behavioral knowledge to the task of promoting the commercialization of new technologies in manufacturing industries. New technologies face a barrier in overcoming the existing standards of entrenched methods of production. Understanding the ability of small-scale plants to operate outside the generally accepted boundaries of efficient production will aid in overcoming the barriers to commercializing new technologies. The ability to develop commercial technologies will be of special interest throughout this study. In the discussion, a framework is proposed based on the operational tendencies of small-scale plants that aid in overcoming the rigid restrictions that limit innovation in established manufacturing industries.

1.2 Focus

The following sections provide details about the limitations and definitions central to the proposed research.

1.2.1 Process-Intensive Manufacturing

The industries examined in this work are described as process-intensive. Such industries are a sub-set of the entire manufacturing sector. Manufacturing industries are defined as establishments engaged in the mechanical or chemical transformation of materials into new products. The process-intensive segment of manufacturing includes industries where materials transformation is significant and process expertise is required. They are industries where commercial success cannot be achieved solely through efficient management or generic manufacturing skills. An untrained user cannot simply purchase the requisite equipment and enter the industry. Process knowledge is a barrier to entry. This process knowledge cannot be directly purchased and acquiring the knowledge independently requires capital and time investments. The condition requiring a "significant" level of materials transformation excludes industries based primarily on assembly. The process expertise requirement demands that complete knowledge for production cannot be isolated to the hardware or software necessary for production. Process-intensive industries are manufacturing industries that require process skill to effectively compete.

1.2.2 Defining Industrial Scale

Many studies have examined scale in process-intensive industries (see Section 2.1). In this research, scale is examined at the plant and process level (Bain, 1954; Silberston). Two different measures of scale are considered. The first is the volume of output. It is the simplest and most universal measure of the operational size and market participation. Consideration is also given to a secondary measure: capital investment. This addresses scale as a barrier to entry which is considered in the discussion.

Throughout this work, references are continually made to relative descriptions of the operational scale of plants. The first description is a standard- or large-scale plant that is defined as a plant that operates at a scale that is selected in the absence of capital constraints. It is the scale of plant that produces a majority of the industry's output. This scale is viewed as the most efficient or technically optimal by industry participants under prevailing technical and market conditions. The second description is a small-scale plant that is defined as a plant that was designed and constructed to operate at a scale below the standard scale of the industry. In this study, the description small-scale plant is used to refer to plants that operate far below the standard scale of production for the industry.

1.2.3 Performance

There are two areas of small-scale plant performance examined in this work. Operational characteristics include operational, economic, and development data of the subject plants (See Chapter 4). Technical characteristics include the utilization of physical, labor, and intellectual resources (see Chapter 5).

1.3 Contribution

The following sections outline the four contributions believed to result from this work. An underlying hypothesis throughout this work is that small-scale plants utilizing different methods of production in compensating for scale disadvantages (Audretsch, 1995).

1.3.1 Economic Impact

Conventional theory assumes that smaller scale production operations will have an inherent cost disadvantage. The data organized in this work will document the existence and magnitude of any economic disadvantage related to production scale in the group of industries examined.

1.3.2 Operational Trends

The range of industries considered in this research may not appear to have many similarities. A goal of this study is to demonstrate their common dependence on the ability to develop and operate process-intensive operations. Additionally, a set of operational trends exists among the small-scale plants that explains their unusual market persistence. Understanding these trends is a primary objective of this study.

1.3.3 Framework

A challenge in manufacturing industries is (responding to change) overcoming the restrictions imposed by existing technologies and market conditions. Based on information regarding the operation of small-scale plants, a framework is proposed to aid in overcoming the structural barriers to change in most established manufacturing industries.

1.3.4 Direct Comparison Method

The majority of research on industrial scale is conducted through multi-industry statistical surveys. These efforts provide a census for the number and size of firms or plants in numerous industries, but they do not resolve the technical differences or objectives among the sample plants. Prior research examining technical factors influencing scale has been industry specific.

The method used in this research is referred to as the Direct Comparison Method (DCM). DCM seeks to understand the operating patterns of small-scale plants by directly comparing the competitive, economic, and technical characteristics of small-scale plants with standard-scale plants of the same industry. It is believed that the direct comparison method is the best method for understanding the dichotomous role of scale in modern manufacturing.

1.4 Outline

This thesis is divided into eight chapters. Chapter 2 establishes the context by reviewing methods and results of past research on industrial scale. Additionally, the basis for understanding scale efficiency is discussed and gaps in this theory are identified. Chapter 3 details the methods and scope of this research. The direct comparison method is proposed and discussed relative to other research methods identified in Chapter 2. The criteria and structure for selection, collection, and analysis are outlined. Chapter 4 presents the results of the classification survey and details the strategic sub-categories exhibited by small-scale plants. Chapter 5 reports the performance data from the comparative survey. Data is presented in three grouping: 1) Operations, 2) Economic, 3) Development. Survey data is presented as nineteen comparative ratios for each of the ten industry pairs. Chapter 6 reports the comparison of trends in operational methods identified between the small-scale and standard-scale plants. Chapter 7 reviews the data presented in Chapters 4-6 and presents a framework for escaping the normal industrial structure imposed in most established manufacturing industries. Chapter 8 summarizes the findings, discusses limitations on the methods and data. Chapter 9 discusses potential areas for further research.

2.0 Background

2.1 Cost and Production

The cost of production for an industry is represented by the long-term average cost curve. Long-term scope assumes industries are technically static and factor costs are fixed. The long-term average cost curve is a construct of short-term average cost functions for all possible production configurations. The long-term average cost curve is the trace of the minimum costs for each level of output. Each point on the curve represents the most efficient technical configuration for a specified level of output (Blair, 1948).

Industrial research shows that the long-term average cost curves are typically u-shaped. They demonstrate decreases in the long-term average cost on the left-hand side of the curve. This phenomenon is known as economies of scale. Economies of scale is the decrease in long-term average unit cost with increases in unit output. The level of output at which average long-term unit cost ceases to decrease is defined as the minimum efficient scale (Scherer, 1974; Shepherd, 1985). That is the smallest scale of efficient production.

Several conditions have been identified as sources of scale economies. Indivisibility occurs at the process, plant and firm levels (Chamberlin, 1948; Stigler, 1966). At the process level, capital equipment may experience increased efficiency due to increased dimension or specialization. At the plant level, massed resources costs and indirect expenses may decrease with higher plant output. At the firm-level, unit cost contributions of distribution, marketing, management, and development may decrease with higher output. Other sources of scale economies include, the ability to exploit superior technical or organization methods, learning effects, or integration benefits.

Conversely, many factors exist that result in rising unit costs with increasing output. First, technical boundaries may be exceeded causing economic benefits to cease. Second, organization may become more difficult due to management limitations or labor relations. Third, increases in transport costs accelerate with larger markets. Finally, the increased susceptibility of capital in uncertain conditions. Changes in technology, market demand, or factors costs could render large capital investments underutilized or underperforming. This final factor acknowledges the limitations of the static assumptions of the long-term cost analysis. The basis for justifying the efficiency of one mode of production can be undermined by dynamic changes in the market.

2.2 Plant Census Data

The underlying economic theory suggests that a minimum scale of production should exist. Surveys of plant data over the past century show diverse distributions of plant sizes (Weiss, 1964 and 1976; Scherer, 1973, Pratten, 1971 & 1991, Chandler, 1990). Plant populations are often skewed in favor of smaller plants, despite the fact that Caves and Barton (1990) show that smaller plants are less efficient than larger plants. Distinct technical regimes exist within industries with diverse plant sizes (Acs & Audretsch, 1987, 1988, 1991). In many industries a significant fraction of the total output is produced by small-scale plants (Weiss, 1976). These plants are often referred to as "suboptimal" (Weiss, 1991).

It has been difficult to identify distinct lower bounds of efficient scale in past industrial research (Caves, et. al., 1975). Past work has focused on several methods of identifying the significant production scale for various industries: trade patterns (Owen, 1976), output concentration levels (Eckard, 1994), engineering estimates, survival criteria (Stigler, 1958) and average plant size accounting for significant fraction of output. Despite a well-defined theory of scale and production efficiency, industry data reports the coexistence of large and small-scale plants in most industries.

2.3 Suboptimal Existence

Why do small-scale plants exist? One possibility is that small-scale plants are more efficient (Viner 1931). This may be true for many reasons. First, small-scale plants may exhibit greater degrees of flexibility (Stigler 1939; Marschak & Nelson, 1962; Carlsson 1989). This concept returns to the idea of Robinson (1958) that large plants cannot compete with small plants in conditions which there is a high degree of uncertainty. Dixit and Pindyck (1994) suggest elements of decisions models in selecting small-scale plants when uncertainty, irreversibility, and investment timing are relevant. Fuller and Gerchak (1989) address the issue of lead time and the tendency to favor smaller investments to avoid the uncertainty of long construction and start-up periods. Flexibility is proposed in several of the classification survey sub-categories (see Chapter 4). Another explanation for the viability of small-scale plants is that they pursue a strategy of compensating factors (Audretsch, 1995). This assumes that small-scale plants secure access to resources at lower costs than larger competitors. It could also include the development of endogeneous technical or organizational advantages.

Throughout this study, small-scale plants are assumed to exist because they have some advantage that provide them relative efficiency. The following research focuses on identifying a pattern of endogeneous advantages exhibited by small-scale plants is several industries.

3.0 Research

3.1 Research Design

3.1.1 Objectives

Based on consideration of past work on industrial scale, and some of the evidence collected during field work, the objective of this research is development of a theory explaining how small-scale production assets exist. This thesis has been limited to the following tasks:

1. Examination of the range of competitive strategies exhibited by small-scale plants.
2. Comparison of relevant economic data of small-scale plants to standard-scale plants.
3. Define differences in process design and resource deployment between small-scale and standard-scale plants.

3.1.2 Direct Comparison Method

This study examines the issue of scale at the plant level. Detailed comparisons of economic, operational, and development activities are made to identify differences between industry standards of production and small-scale plants. This technique is referred to as the direct comparison method (DCM). Its purpose is to understand if scale disadvantages exist and how small-scale plants compensate for those disadvanatages. Historically, studies of the role of scale economies in shaping industrial structure are conducted via multi-industry statistical surveys (see Section 2.x). While these studies document the current structure for a broad group of industries, they do not address small-scale plant survival. The direct comparison approach seeks to focus on the small-scale plants.

Application of the direct comparison method requires examination of specific industrial establishments at the plant level to document their operational characteristics. Two plants are selected from a industry. One representative of the standard scale of production in its industry. Standard-scale was determined through informal surveying of leading firms in an industry and with public records. The second plant operates at a scale below (less than half) the scale of the standard-scale plant. The operational characteristics of the two plants from a variety of target industries are documented primarily through field research. The direct comparison method seeks to document these operational differences in production that are not typically captured in most industrial data.

3.1.3 Outline

There were three phases to this study. The first was the selection processes during which a target industry and representative plants were identified. Scale is the primary difference exhibited by the plants selected in each industry pair. The second was the data collection process. This phase included two industrial surveys. The first survey documented the range of competitive strategies commonly employed by small-scale plants. The second survey examined the relative operational characteristics of pairs of plants using DCM. The third phase is analysis and presentation of the data. The following sections provide additional details for each phase of research.

3.2 Selection Phase

The selection process involves the identification and evaluation of potential industries and plants. Criteria were established for selecting industry and plants. Appropriate candidates received further investigation. The following sections detail the industry and plant criteria.

3.2.1 Industry Criteria

Three criteria were used in selecting industries. The first criteria was that the industry be process-intensive. The second criteria was that the industry have a competitive structure. The third criteria was that the industry demonstrate some diversity in the scale of establishments. The following sections detail the criteria.

3.2.1.1 Process-Intensity Industry

This study examines a sub-set of manufacturing industries. Process-intensive describes manufacturing industries that involve significant material transformation and require significant process expertise. This definition excludes simple assembly , conversion processes, or distribution industries. Factors that catergorized industries as process-intensive include highly skilled labor force, process technology development, or specialized equipment requirements.

3.2.1.2 Competitive Industry Structure

The second criteria is a competitive structure. This criteria requires that the industry have a structure in which there are several competitors, no competitor has a dominating share of the market, the product is well-defined, and entry is open but limited. While these conditions do not demand perfect competition, they do seek to avoid monopolistic or oligopolistic industries.

3.2.1.3 Diverse Production Scales

The final industry criteria is some diversity in the scale of establishments. At a minimum, one establishment exists as an outlier that operates at a scale significantly below the industry standard scale of operation.

3.2.2 Plant Criteria

Four criteria were used in selecting plants within target industries for inclusion in this study. The first criteria was design of the plant as a small-scale asset. The second criteria was that the plant have an adequate continuity of operation. The third criteria a was a willingness to cooperate and share the necessary information to be part of the study. The following sections detail the criteria for qualification of an plant.

3.2.2.1 Small-Scale Design

Within an industry, only some of the small-scale plants were intentionally designed to operate below the industry standards. Some plants are legacies of earlier periods when the market or technical conditions dictated lower standard levels of output. For a plant to be included in this study, the design scale must be significantly below the standard design scale of the period when the plant was built.

3.2.2.2 Sustained Operation

A criteria was imposed that the subject plant must be in operation for five years prior to the period in which the plant data was collected. This condition excludes inefficient plants that have not displayed a minimum level of market success.

3.2.2.3 Available Information

The final criteria is that the ownership/management of the plant be willing to share the information necessary to meet the survey requirements. In addition to a willingness to share information, the plant must have the relevant data available.

Several of the candidate plants conducted inadequate or insufficient reporting of the relevant data to be included in the surveys.

3.3 Collection Phase

Collection of data for this study involved two surveys. The first survey documents competitive strategies pursued by process-intensive small-scale plants. The second survey examined ten pairs of plants from separate industries. Information from each pair of plants was collected regarding the relative economic and operational characteristics of the small-scale plant to the standard-scale plant. The following sections provide additional focus and procedural detail about the surveys.

3.3.1 Classification Survey

To develop a basis for understanding the competitive strategies employed by small-scale plants, a survey was conducted to document the competitive position of thirty-three plants that meet both the industry and plant criteria.

The information regarding the competitive nature of small-scale plants was collected by means of interviews with persons linked to each subject plant. Information for twenty-five of the plants was acquired through an on-site interview, while the remaining eight plants were included through interviews that were not conducted in person. Most of the plants involved interviewing more than one person from the respective plant or multiple interviews of the same person.

3.3.2 Comparative Survey

A survey was conducted to document the economic and technical differences of pairs of plants from ten industries. The ten small-scale plants used in this survey were selected from the classification survey based upon the availability of data. Ten corresponding standard-scale plants were selected as control subjects for comparison to the selected small-scale plants. The standard-scale plant had to have a similar product output as the small-scale plant.

The information regarding the operational differences between small-scale plants and standard-scale plants was collected by means of interviews and on-site visits. Preliminary information was gathered through informal interviews. This was followed by an on-site visit and additional interviews. In some cases, supplemental documents were provided.

3.4 Analysis Phase

In the analysis phase of the research, parameters were defined by which the data collected in the two surveys could be organized and evaluated. The objective in the classification survey is organizing small-scale plants into descriptive categories of similar behavior. The objective in the comparative survey is defining relevant characteristics for evaluating the relative differences between the small-scale and standard-scale plants.

3.4.1 Classification Survey

The information regarding the nature of competition experienced by the thirty-three small-scale plants examined in the classification survey was analyzed along two dimensions (see Table 3-1). First, what is the primary factor of competition. Subject plants fall in two categories: 1) Price Competitors, 2) Non-Price Competitors. The second dimension is the source of advantage held by the plant. Subject plants fall in two categories: 1) endogeneous, 2) exogenous. Endogeneous advantage is defined as any source of advantage that resides within the control of the plant (Mills, 1984). Exogenous advantage is defined as any source of advantage that resides outside the control of the plant. Within this two dimensional structure, subcategories are defined to group small-scale plants by similar behavior patterns.

3.4.1.1 Factors of Competition

The first dimension of analysis is the primary factor of market competition. Common factors of market competition include price, functional characteristics, quality characteristics, and time characteristics of the products produced by the subject plants. Simplest differentiation along this dimension is specifying whether the primary factor of competition is price or a factor other than price. Small-scale plants that compete primarily on price are categorized as price competitors. Small-scale plants that compete on other market factors are categorized as Non-Price Competitors.

TABLE 3-1 Small-Scale Plant Classification Survey Categories

	Endogeneous Advantage	Exogenous Advantage
Price Competitors	Process Expertise Output Flexibility	Input Advantage
Non-Price Competitors	Market Development Product Differentiation	Regulation Motivated

3.4.1.2 Source of Advantage

The second dimension of analysis applied in the classification of small-scale plants is whether the source of advantage is endogeneous or exogenous. Small-scale plants that compete on endogeneous advantages are perceived to rely upon conditions or abilities that are under their control or influence. Typically, endogeneous advantages are the result of internal plant assets or activities. Plants that compete on exogenous advantages are perceived to rely upon conditions or abilities that are beyond the control or influence of the plant organization. Typically, exogenous advantages are the result of external market condition or regulatory environments.

3.4.1.3 Sub-Categories

Sub-categories are defined to group small-scale plants of similar behavior within the price and advanatge categories (see Table 3-1). These sub-categories assist in understanding the competitive positions commonly taken by small-scale plants.

3.4.2 Comparative Survey

There are two parts to the evaluation of the ten industrial pairs examined in the comparative survey. The first part is the organization and presentation of the quantitative performance characteristics of the industry pairs. The second is the organization and presentation of the mixed quantitative and qualitative information detailing the technical characteristics of the industry pairs.

3.4.2.1 Performance Data

Performance data is organized into three major categories. The first category is operational data that includes relative measures of unit output, design capacity, and production time. The second category in economic data that includes relative measures of capital investment, manufacturing cost, and labor costs. The third category is development data that includes relative measures of development expenses and development cycle times.

3.4.2.2 Technical Data

Technical data is divided into four groups. The first area is process design. Process design examines the objectives in designing small-scale plants and the factors that determine scale. The second area is physical assets. The physical assets section-documents trends in processing and non-processing equipment. Sources for equipment are discussed. The third area is materials inputs. Finally, labor trends are considered.

4.0 Results of Classification Survey

The objective of the classification survey is to take a census of the distribution of competitive strategies pursued by sub-plants. Subject plants in the survey were analyzed along two primary dimensions: 1) principle market factor (price or non-price), 2) origin of competitive advantage (endogeneous or exogenous). Within each of the four categories, sub-categories were defined descriptive of the competitive behavior and conditions exhibited by subject plants. Thirty-three plants were included in the classification survey. The plants represented twenty-two different industries. Appendix A summarizes the classification survey information.

4.1 Price Competitors

Examination of the thirty-three small-scale plants selected for the classification survey revealed that eight competed in markets primarily on the basis of price (see Figure 4-1). Small-scale plants that competed on price were in commodity industries. The price competitors were divided into two categories based on their source of production advantage: 1) endogeneous advantage, 2) exogenous advantage.

FIGURE 4-1 Price Competitors Classification Results

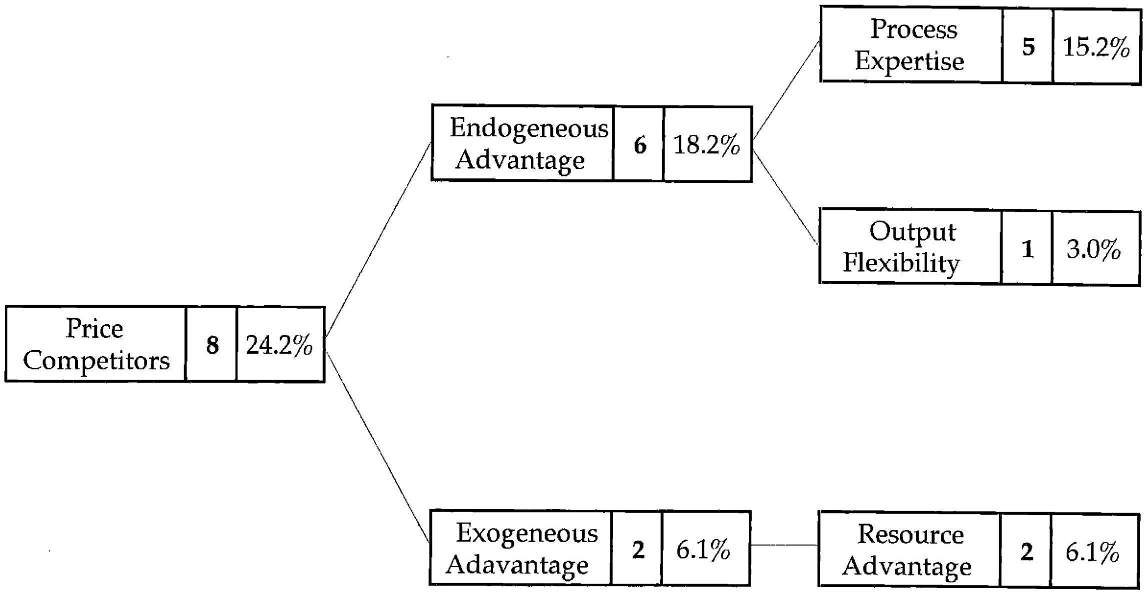

Figure 4-1 shows the distribution of small-scale plants in the price competitor category. The boxes contain the name, number of plants, and percentage of the thirty-three plant sample for each group.

4.1.1 Endogeneous Advantage with Price Competition

Six survey plants were in the endogeneous advantage with price competition category (see Figure 4-1). Endogeneous advantages include internal assets or expertise that results in an advantage over competitors. In the case of small-scale plants that are categorized as price competitors, the endogeneous advantage translates into production cost advantage. The six small-scale plants identified as price competitors with endogeneous advantages can be divided into two groups: 1) Process Expertise, 2) Output Flexibility.

4.1.1.1 Process Expertise

Five survey plants were classified as a member of the process expertise sub-category. The members of the process expertise sub-category were considered to exhibit superior production productivity over comparable plants in their industry regardless of scale. The sources of the apparent productivity advantage varied among the five plants survey. Two plants conducted extremely limited scopes of production and therefore developed an acute specialization in their segments of their markets. Another two plants attributed their advantage to the process expertise of their labor forces. The process expertise that they describe was mainly the result of the heuristic process knowledge and lengthy employment relationships of key member of their direct and indirect labor force. The final plant in the Process Expertise sub-category attributed their production skill to a novel process that was not used by other producers in the industry. The nature of the process had limits on its maximum feasible scale of operation. It had been rejected by other producers in the industry. In general, the small-scale plants examined in the Process Expertise sub-category exhibited acute or specialized production skills that provided them with a basis for competition in their industries.

4.1.1.2 Output Flexibility

One survey plant was categorized as an output flexibility producer. This plant utilized production processes that allowed it to accommodate volatility in the volume or mix of their output (Fiegenbaum, 1991). While they did not enjoy an absolute advantage in production efficiency, their processes made their average performance comparable to larger more efficient plants in the industry (Stigler, 1939; Carlsson, 1989). The subject plant utilized batch processes that demanded much lower levels of capital investment and correspondingly imparted a much smaller "under absorbed burden" during periods of under utilization (Mills & Schumann, 1985; Sheshinski & Dreze, 1976).

4.1.2 Exogenous Advantage with Price Competition

Two survey plants were in the Exogenous Advantage with Price Competition category. Exogenous advantages include market condition or a regulatory environment that provides an advantage to the subject plant over direct competitors in the same industry. The two small-scale plants identified as price competitors with endogeneous advantages were both classified in the Resource Advantage sub-category.

4.1.2.1 Resource Advantage

The two subject plants in the Resource Advantage sub-category both held advantages in their ability to acquire their production resources at a lower cost than their industry competitors. In both cases, the reduced scale of the production facilities allowed for their placement in areas where the necessary resources could be acquired under more favorable conditions. One of the subject plants in this category was able to purchase input materials below the average industry price. The other had lower labor costs than its competitors in its industry.

4.2 Non-Price Competitors

Examination of the thirty-three small-scale plants selected for the classification survey revealed that twenty-five competed in markets on a non-price basis (see Figure 4-2). This finding is consistent with the finding of the Bolton Committee (1971) where 83% of small-scale plants examined considered non-price factors to be their main competitive advantage. Small-scale plants that competed on non-price factors typically were in industries with lower levels of competition. The lower level of competition resulted from fewer participants, more differentiation among products, competitive restrictions external to the market, or the larger role of innovation in industry products or processes. The non-price competitors were examined in two categories based upon the origin of their production advantage: 1) endogeneous advantage, 2) exogenous advantage.

FIGURE 4-2 Non-Price Competitor Classification Results

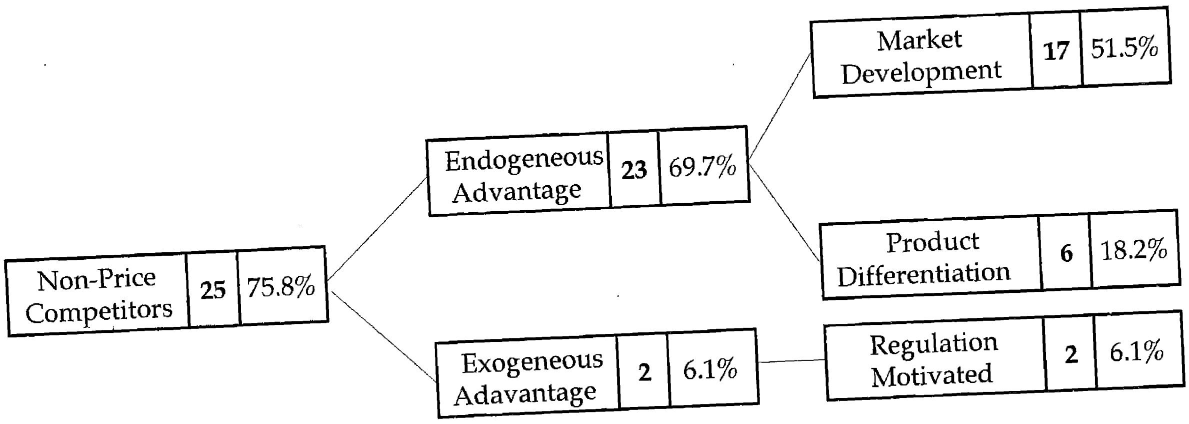

Figure 4-2 shows the distribution of small-scale plants in the non-price competitor category. The boxes contain the name, number of plants, and percentage of the thirty-three plant sample for each group.

4.2.1 Endogeneous Advantage with Non-Price Competition

Twenty-three survey plants were in the endogeneous advantage with non-price competition category (see Figure 4-2). Endogeneous advantages include superior product functionality, quality standards, or time factors that resulted in a market advantage. The twenty-three small-scale plants identified as non-price competitors with endogeneous advantages can be divided into two groups: 1) Market Development, 2) Product Differentiation.

4.2.1.1 Market Development

Seventeen subject plants were classified in the Market Development sub-category (see Figure 4-3). In this group, the subject plants sought to expand the their markets through innovations in products, processes, or geographic location. Their efforts to further develop their markets required that they pursue different production methods from the larger scale producers in their industry.

FIGURE 4-3 Market Development Sub-Category Results

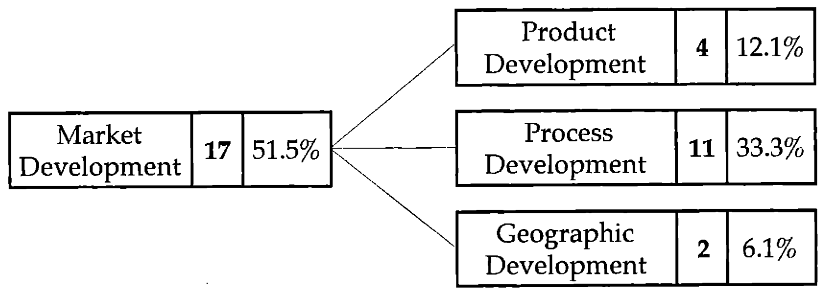

Figure 4-3 shows the distribution of small-scale plants in the market development sub-category.

4.2.1.1.1 Product Development

Four survey plants were classified as pursuing a strategy of product development. The small-scale plants in this subcategory were making investments in product innovations that gave them an Advantage over the standard-scale plants in the industry. Typically, the product innovations were rejected, incompatible, or beyond the technical abilities of the standard-scale plants in the industry.

4.2.1.1.2 Process Development

Eleven survey plants were classified as pursuing a strategy of process development (see Figure 4-3). Process development involved the advancement of production capabilities through a strategy of commercialization of process innovations. The small-scale plants in this subcategory were making investments in processing equipment and techniques that gave them an advantage over the standard-scale plants in the industry. Typically, the process innovations were viewed as incompatibility with the current technologies or unproven enough to prevent adoption by standard-scale plants in the same industries.

4.2.1.1.3 Geographic Development

Two survey plants were classified as pursuing a strategy of geographic development (see Figure 4-3). Geographic development involved the establishment of production capabilities in new geographic areas. The small-scale plant sought to provide new service or more effective service to a defined geographic region.

4.2.1.2 Product Differentiation

Six survey plants were classified in the product differentiation sub-category. The product differentiation sub-category includes subject plants that serve a niche market. These products may be overlooked or have insufficient demand to warrant production by standard-scale plants (Dosi, 1988). The subject plants in the product differentiation sub-category produce products that are well established unlike the products from the product development sub-category.

4.2.2 Exogenous Advantage with Non-Price Competition

Two survey plants were in the Exogenous Advantage with Non-Price Competition category. Exogenous advantages include market condition or a regulatory environment that provides an advantage to the subject plant over direct competitors in the same industry. The two small-scale plants identified as price competitors with endogeneous advantages were both classified in the Regulation Motivated sub-category

4.2.2.1 Regulation Motivated

Two survey plants were characterized as deriving their basis for competition from regulatory conditions that permitted or favored their small-scale structure. Regulation in involvement in this sub-category of plants includes statutory monopolies, environmental policy, trade restrictions, industrial subsidies, or general political manipulation. The subject plants demonstrated an ability to conform to the regulatory conditions overshadowing market forces in the industry.

4.3 Summary

The classification survey organized small-scale plants into categories of similar competitive behavior. Ten plants were selected for the comparative survey. The comparative survey documents economic and operational differences between these ten small-scale plants and ten standard-scale plants from the same industries. All plants selected for the comparative survey were from the endogeneous advantage categories. A major interest in this study is the methods that allow small-scale plants to exist. The endogeneous plants rely on internal capabilities. The classification survey is summarized in Appendix A.

5.0 Comparative Survey: Performance Data

The comparative survey examines the performance characteristics of pairs of plants from ten industries. One plant represented the standard scale of production within the industry. The other plant represented a plant that operated below the standard level of production. It is reffered to as the small-scale plant. Chapter five reports quantitative comparison of nineteen performance characteristics for each pair of plants. Table 5-1 identifies the industries and the category of classification of the small-scale plant from the classification survey.

TABLE 5-1 Categorization of Industry Pairs in Classification Survey

#	Industry	SIC	Classification Category	Class
1	Investment Casting	3369	Process Expertise	PEX
2	Seamless Rings	3462	Process Expertise	PEX
3	Engineered Timber	2436	Product Development	PDD
4	Structural Bearings	3562	Product Development	PDD
5	Dye Pigment	2816	Process Development	PCD
6	Plastic Extrusions	3084	Process Development	PCD
7	Printed Circuits	3625	Process Development	PCD
8	Stamped Panels	3469	Process Development	PCD
9	Structural Shapes	3312	Process Development	PCD
10	Packaging Materials	2631	Geographic Development	GED

Table 5-1 lists the industry in which pairs of plants were evaluated. The standard industrial code (SIC), classification category from Chapter 4, and a classification category abreviation (Class) are also provided for the small-scale plants .

5.1 Format of the Comparative Performance Data

The data presented in this chapter was acquired through interviews and documents as outlined in Section 3.3.2. Data for this chapter was based on quarterly aggregate figures for each plant. All data reported in this chapter is presented as the ratio of the small-scale plant's performance to the standard scale plant's performance. Ratios compare data for corresponding quarterly periods. For example, if the cited ratio is one half , then the reported value for the small-scale plant was half the value for the standard-scale plant.

The industries included in the comparative survey were selected from the classification survey (see Table 5-1). Two industries included in the comparative survey had small-scale plants that were classified in the process expertise sub-category. The symbol PEX is used in all tables to identify this classification. Two industries had small-scale plants that were classified in the product development sub-category. The symbol PDD is used in all tables to identify this classification. Five industries had small-scale plants that were classified in the process development sub-category. The symbol PCD is used in all tables to identify this classification. One industry had its small-scale plant classified in the geographic development sub-category. The symbol GED is used in all tables to identify this classification.

The performance data is divided into three groups: 1) Operations, 2) Economic, 3) Development. The following sections explain and report the data collected in the comparative survey.

5.2 Operations Performance Ratios

The operational group includes data concerning the macroscopic performance of the plants. Four performance statistics were reported in this group: 1) Relative Production Scale, 2) Relative Capacity, 3) Relative Production Time, 4) Relative Operating Efficiency.

5.2.1 Relative Production Scale

Relative production scale is defined as the ratio of total quarterly unit output of the small-scale plant to the total quarterly unit output of the standard-scale plant. An appropriate basic unit of output was selected in each industry. Relative production scale statistics were compiled for all ten industry pairs. The relative production scales reported in Table 5-2 vary from 0.17 to 0.35 with an average value of 0.23.

These ratios indicate that the small-scale plants surveyed on average produced only one quarter of the output of their standard-scale competitors.

TABLE 5-2 Relative Production Scale of Industry Pairs

	Industry	Class	Production Scale
1	Investment Casting	PEX	0.35
2	Seamless Rings	PEX	0.17
3	Engineered Timber	PDD	0.24
4	Structural Bearings	PDD	0.15
5	Dye Pigment	PCD	0.18
6	Plastic Extrusions	PCD	0.30
7	Printed Circuits	PCD	0.30
8	Stamped Panels	PCD	0.23
9	Structural Shapes	PCD	0.20
10	Packaging Materials	GED	0.22
		Average	**0.23**

Table 5-2 lists the relative production scale of the small-scale plant to the standard-scale plant for each industry pair for the same quarterly period. The classification categories (Class) for the small-scale plants are provided.

5.2.2 Relative Design Capacity

The second operations statistic reported is relative design capacity (see Table 5-3). Relative design capacity is defined as the design capacity of the small-scale plant to the design capacity of the standard-scale plant. The unit of output for the design capacity values was the same as that used for relative scale. Relative design capacity statistics were reported for all ten industry pairs. Reported values ranged from 0.16 to 0.33 with an average value of 0.22. Relative design capacity is a measure of the ratio of theoretical capacity for the two plants based on their design specifications.

TABLE 5-3 Comparison of Operating Performance to Design Specifications

	Industry	Class	Design Capacity	Production Time	Operating Efficiency
1	Investment Casting	PEX	0.33	N/A	N/A
2	Seamless Rings	PEX	0.16	1.11	0.96
3	Engineered Timber	PDD	0.22	1.01	1.10
4	Structural Bearings	PDD	0.16	N/A	N/A
5	Dye Pigment	PCD	0.17	1.04	1.00
6	Plastic Extrusions	PCD	0.25	1.02	1.19
7	Printed Circuits	PCD	0.31	1.02	0.96
8	Stamped Panels	PCD	0.21	N/A	N/A
9	Structural Shapes	PCD	0.20	1.03	1.00
10	Packaging Materials	GED	0.20	1.06	1.05
		Average	**0.22**	**1.04**	**1.04**

Table 5-3 lists the relative design capacity, production time, and operating efficiency of the small-scale plant to the standard-scale plant for each industry pair for the same quarterly period.

5.2.3 Relative Production Time

The third operations statistic is relative production time (see Table 5-3). Relative production is defined as the cumulative hours of production for the small-scale plant relative to the cumulative hours of production for the standard-scale plants. Relative production time statistics were reported for seven industries (see Table 5-3).

Reported values ranged from 0.99 to 1.11 with an average value of 1.04. All small-scale plants operated for more hours than their standard-scale competitors.

5.2.4 Relative Operating Efficiency

The fourth ratio in the operations statistic category is relative operating efficiency. This is a calculated ratio of how much output was actually produced relative to the expected output based upon the design capacity. The relative operating efficiency is the ratio of the small-scale plants' calculated operating efficiency to the standard scale plants operating efficiency. Ratios were reported for seven industries (see Table 5-3). These ratios varied from 0.96 to 1.19 with an average of 1.04.

5.3 Economic Performance Ratios

The economic performance group includes ratios concerning the plants manufacturing costs. Eight performance statistics were reported in this group: 1) Relative Capital Investment, 2) Relative Investment per Unit Capacity, 3) Relative Production Cost, 4) Relative Variable Cost, 5) Relative Fixed Cost, 6) Relative Production Cost (80% Utilization), 7) Relative Direct Labor Cost, 8) Relative Indirect Labor Cost.

5.3.1 Relative Capital Investment

The first ratio in the economic statistic category is relative investment. The relative investment is the ratio of the total capital investment for the small-scale plant to the total capital investment for the standard scale plants. Ratios were reported for nine industries (see Table 5-4). These ratios varied from 0.11 to 0.24 with an average of 0.18.

TABLE 5-4 Total and Unit Capital Investment

	Industry	Class	Investment	Unit Capital
1	Investment Casting	PEX	0.22	0.67
2	Seamless Rings	PEX	0.13	0.81
3	Engineered Timber	PDD	0.19	0.85
4	Structural Bearings	PDD	0.21	1.32
5	Dye Pigment	PCD	N/A	N/A
6	Plastic Extrusions	PCD	0.19	0.77
7	Printed Circuits	PCD	0.24	0.78
8	Stamped Panels	PCD	0.18	0.84
9	Structural Shapes	PCD	0.16	0.80
10	Packaging Materials	GED	0.11	0.58
		Average	**0.18**	**0.82**

Table 5-4 lists the relative design capacity, production time, and operating efficiency of the small-scale plant to the standard-scale plant for each industry pair for the same quarterly period.

5.3.2 Relative Investment per Unit Capacity

The second ratio in the economic statistic category is relative investment per unit capacity. The relative investment per unit capacity is the ratio of the total capital investment for the small-scale plant per unit of design capacity to the total capital investment for the standard scale plant per unit of design capacity. Ratios were reported for nine industries (see Table 5-4). These ratios varied from 0.58 to 1.32 with an average of 0.82.

5.3.3 Relative Production Cost

The third ratio in the economic statistic category is relative production cost. The relative production cost is the ratio of the unit production cost for the small-scale plant to the unit production cost for the standard scale plant of a comparable product. Production cost includes cost linked to the production process and excludes design, development, distribution, sales, and non production administrative and overhead. Ratios were reported for ten industries (see Table 5-5). These ratios varied from 0.92 to 1.19 with an average of 1.02.

TABLE 5-5 Production Cost

	Industry	Class	Production Cost / Unit
1	Investment Casting	PEX	0.97
2	Seamless Rings	PEX	0.98
3	Engineered Timber	PDD	1.06
4	Structural Bearings	PDD	1.19
5	Dye Pigment	PCD	1.04
6	Plastic Extrusions	PCD	1.07
7	Printed Circuits	PCD	0.92
8	Stamped Panels	PCD	1.05
9	Structural Shapes	PCD	0.94
10	Packaging Materials	GED	0.98
		Average	**1.02**

Table 5-5 lists the ratio of production costs for the small-scale plants to the standard scale plants. Production cost excludes non-plant administrative, non-plant development, marketing, distribution, and sales expenses.small-scale

5.3.4 Relative Variable Cost

The fourth ratio in the economic statistic category is relative variable cost. The relative variable cost is the ratio of the variable component of production cost for the small-scale plant to the variable component of production cost for the standard scale plant. The variable component of production cost includes direct material costs, direct labor costs, and working capital interest expenses. Ratios were reported for seven industries (see Table 5-6). These ratios varied from 0.97 to 1.31 with an average of 1.14.

TABLE 5-6 Variable and Fixed Costs for Industry Pairs

	Industry	Class	Var	Fix
1	Investment Casting	PEX	1.11	0.76
2	Seamless Rings	PEX	1.14	0.77
3	Engineered Timber	PDD	1.15	0.87
4	Structural Bearings	PDD	N/A	N/A
5	Dye Pigment	PCD	1.08	0.95
6	Plastic Extrusions	PCD	1.31	0.70
7	Printed Circuits	PCD	N/A	N/A
8	Stamped Panels	PCD	N/A	N/A
9	Structural Shapes	PCD	0.97	0.84
10	Packaging Materials	GED	1.21	0.67
		Average	**1.14**	**0.79**

Table 5-6 lists the relative design capacity, production time, and operating efficiency of the small-scale plant to the standard-scale plant for each industry pair for the same quarterly period.

5.3.5 Relative Fixed Cost

The fifth ratio in the economic statistic category is relative fixed cost. The relative fixed cost is the ratio of the fixed component of production cost for the small-scale plant to the fixed component of production cost for the standard scale plant. The fixed component of production cost includes indirect labor costs and physical capital costs. Ratios were reported for seven industries (see Table 5-6). These ratios varied from 0.67 to 0.95 with an average of 0.79.

5.3.6 Relative Production Cost (80% Utilization)

The sixth ratio in the economic statistic category is relative production cost at 80% utilization. The relative investment is the ratio of the unit production cost at 80% utilization for the small-scale plant to the unit production cost for the standard scale plant. This ratio measures the change in relative production costs when the subject plants are operating at 80% of their design capacity. Ratios were reported for six industries (see Table 5-7). These ratios varied from 0.95 to 1.05 with an average of 1.00.

TABLE 5-7 Production Cost (80% Utilization)

	Industry	Class	80% Mfg. Cost
1	Investment Casting	PEX	0.95
2	Seamless Rings	PEX	0.96
3	Engineered Timber	PDD	1.05
4	Structural Bearings	PDD	N/A
5	Dye Pigment	PCD	N/A
6	Plastic Extrusions	PCD	1.04
7	Printed Circuits	PCD	N/A
8	Stamped Panels	PCD	N/A
9	Structural Shapes	PCD	1.02
10	Packaging Materials	GED	0.95
		Average	**1.00**

Table 5-7 lists the relative design capacity, production time, and operating efficiency of the small-scale plant to the standard-scale plant for each industry pair for the same quarterly period.

5.3.7 Relative Direct Labor Cost

The seventh ratio in the economic statistic category is relative direct labor cost. The relative direct labor cost is the ratio of the direct labor expense for the small-scale plant to the direct labor expense for the standard scale plant. Ratios were reported for six industries (see Table 5-8). These ratios varied from 0.99 to 1.09 with an average of 1.02.

TABLE 5-8 Labor Expense for Industry Pairs

	Industry	Class	Direct	Indirect
1	Investment Casting	PEX	N/A	N/A
2	Seamless Rings	PEX	1.04	0.49
3	Engineered Timber	PDD	0.99	0.66
4	Structural Bearings	PDD	N/A	N/A
5	Dye Pigment	PCD	1.06	0.71
6	Plastic Extrusions	PCD	1.09	0.59
7	Printed Circuits	PCD	N/A	N/A
8	Stamped Panels	PCD	N/A	N/A
9	Structural Shapes	PCD	0.97	0.58
10	Packaging Materials	GED	0.99	0.73
		Average	**1.02**	**0.63**

Table 5-8 lists the relative design capacity, production time, and operating efficiency of the small-scale plant to the standard-scale plant for each industry pair for the same quarterly period.

5.3.8 Relative Indirect Labor Cost

The eighth ratio in the economic statistic category is relative indirect labor cost. The relative indirect labor cost is the ratio of the indirect labor expense for the small-scale plant to the indirect labor expense for the standard scale plant. Ratios were reported for six industries (see Table 5-8). These ratios varied from 0.49 to 0.73 with an average of 0.63.

5.4 Development Performance Ratios

The development performance group includes ratios concerning the plant development activities. Seven performance statistics were reported in this group: 1) Relative Development Expenditures, 2) Relative Development Expenses, 3) Relative External Development Expense, 4) Relative Internal Development Expense, 5) Relative Manufacturing and Development Cost per Unit, 6) Relative Mean Time Between Innovations, 7) Expected Production Process Design Life.

5.4.1 Relative Development Cost

The first ratio in the development statistic category is relative development cost. The relative development cost is the ratio of the total costs related to development activities for the small-scale plant to the total costs related to development activities for the standard scale plant. Ratios were reported for eight industries (see Table 5-9). These ratios varied from 0.22 to 1.12 with an average of 0.74.

TABLE 5-9 Total In-Plant Development Cost

	Industry	Class	Development Expenditures
1	Investment Casting	PEX	1.01
2	Seamless Rings	PEX	0.22
3	Engineered Timber	PDD	1.12
4	Structural Bearings	PDD	N/A
5	Dye Pigment	PCD	N/A
6	Plastic Extrusions	PCD	0.68
7	Printed Circuits	PCD	N/A
8	Stamped Panels	PCD	0.67
9	Structural Shapes	PCD	0.88
10	Packaging Materials	GED	0.61
		Average	**0.74**

Table 5-9 lists the relative design capacity, production time, and operating efficiency of the small-scale plant to the standard-scale plant for each industry pair for the same quarterly period.

5.4.2 Relative Internal Development Expenses

The second ratio in the development statistic category is relative internal development expenses. The relative internal development expenses is the ratio of the internal development costs expensed during the period for the small-scale plant to the internal development costs expensed during the period for the standard scale plant. Ratios were reported for six industries (see Table 5-10). These ratios varied from 1.33 to 4.14 with an average of 2.38.

TABLE 5-10 Development Cost Composition

	Industry	Class	Internal Expense	External Expense
1	Investment Casting	PEX	N/A	N/A
2	Seamless Rings	PEX	2.43	0.00
3	Engineered Timber	PDD	1.84	0.20
4	Structural Bearings	PDD	N/A	N/A
5	Dye Pigment	PCD	N/A	N/A
6	Plastic Extrusions	PCD	1.33	0.24
7	Printed Circuits	PCD	N/A	N/A
8	Stamped Panels	PCD	1.93	0.00
9	Structural Shapes	PCD	2.63	0.34
10	Packaging Materials	GED	4.14	0.18
		Average	**2.38**	**0.16**

Table 5-10 lists the relative design capacity, production time, and operating efficiency of the small-scale plant to the standard-scale plant for each industry pair for the same quarterly period.

5.4.3 Relative External Development Expense

The third ratio in the development statistic category is relative externel development. The relative external development expense is the ratio of the external development costs expensed during the period for the small-scale plant to the external development costs expensed during the period for the standard scale plant. Ratios were reported for six industries (see Table 5-10). These ratios varied from 0.00 to 0.34 with an average of 0.16.

5.4.4 Relative Development Cost per Unit

The fourth ratio in the development statistic category is relative development cost per unit. The relative development cost per unit is the ratio of the development cost expensed per unit of output for the small-scale plant to the development cost per unit of output for the standard scale plant. Ratios were reported for eight industries (see Table 5-11). These ratios varied from 1.15 to 5.27 with an average of 3.02.

TABLE 5-11 Unit Development Cost

	Industry	Class	Development Cost / Unit
1	Investment Casting	PEX	1.15
2	Seamless Rings	PEX	1.31
3	Engineered Timber	PDD	4.67
4	Structural Bearings	PDD	5.27
5	Dye Pigment	PCD	N/A
6	Plastic Extrusions	PCD	2.27
7	Printed Circuits	PCD	N/A
8	Stamped Panels	PCD	2.91
9	Structural Shapes	PCD	4.40
10	Packaging Materials	GED	2.21
		Average	**3.02**

Table 5-11 lists the relative design capacity, production time, and operating efficiency of the small-scale plant to the standard-scale plant for each industry pair for the same quarterly period.

5.4.5 Relative Manufacturing and Development Cost per Unit

The fifth ratio in the development statistic category is relative manufacturing and development cost per unit of output. The relative manufacturing and development cost per unit expenses is the ratio of the combined manufacturing and development costs per unit for the small-scale plant to the combined manufacturing and development costs per unit for the standard scale plant. Ratios were reported for eight industries (see Table 5-12). These ratios varied from 0.99 to 1.24 with an average of 1.07.

TABLE 5-12 Manufacturing Unit Cost with Development Expenses

	Industry	Class	Production w/ Develop. Cost / Unit
1	Investment Casting	PEX	0.99
2	Seamless Rings	PEX	1.01
3	Engineered Timber	PDD	1.09
4	Structural Bearings	PDD	1.24
5	Dye Pigment	PCD	N/A
6	Plastic Extrusions	PCD	1.10
7	Printed Circuits	PCD	N/A
8	Stamped Panels	PCD	1.03
9	Structural Shapes	PCD	1.03
10	Packaging Materials	GED	1.05
		Average	**1.07**

Table 5-12 lists the relative design capacity, production time, and operating efficiency of the small-scale plant to the standard-scale plant for each industry pair for the same quarterly period.

5.4.6 Relative Mean Time Between Innovations

The sixth ratio in the development statistic category is relative mean time between innovations. The relative mean time between innovations is the ratio of the average time between minor improvements to the production process for the small-scale plant to the average time between minor improvements to the production process for the standard scale plant. These values were typically reported in weeks.

Ratios were reported for all ten industries (see Table 5-13). These ratios varied from 0.33 to 1.00 with an average of 0.57.

TABLE 5-13 Rate of Process Innovation

	Industry	Class	MTBI
1	Investment Casting	PEX	0.75
2	Seamless Rings	PEX	0.60
3	Engineered Timber	PDD	0.50
4	Structural Bearings	PDD	0.33
5	Dye Pigment	PCD	0.50
6	Plastic Extrusions	PCD	0.50
7	Printed Circuits	PCD	0.40
8	Stamped Panels	PCD	1.00
9	Structural Shapes	PCD	0.33
10	Packaging Materials	GED	0.80
		Average	**0.57**

Table 5-13 lists the relative mean time between process innovations in the small-scale plant to the standard-scale plant for each industry pair for the same quarterly period. Innovations include all changes to the plant that do not alter the underlying unit processes of production.

5.4.7 Relative Mean Time Between Process Replacement

The seventh ratio in the development statistic category is relative mean time between replacement of the processing system. Replacement of the processing system involves extensive changes to the process design and processing equipment. The relative mean time between replacement is the ratio of the expected time between a replacement of the small-scale plant to the expected time between a placement of the standard scale plant. These values were typically reported in years. Ratios were reported for six industries (see Table 5-14). These ratios varied from 1.00 to 1.75 with an average of 1.26.

TABLE 5-14 Expected Production Process Design Life

	Industry	Class	MTBR
1	Investment Casting	PEX	1.00
2	Seamless Rings	PEX	N/A
3	Engineered Timber	PDD	1.25
4	Structural Bearings	PDD	1.33
5	Dye Pigment	PCD	1.25
6	Plastic Extrusions	PCD	N/A
7	Printed Circuits	PCD	1.00
8	Stamped Panels	PCD	N/A
9	Structural Shapes	PCD	1.75
10	Packaging Materials	GED	N/A
		Average	**1.26**

Table 5-14 lists the relative mean time between replacement of the small-scale plant to the standard-scale plant for each industry pair for the same quarterly period.

6.0 Comparative Survey: Technical Data

Data regarding technical trends among the small-scale plants is presented in this section The trends reported in this section do not reflect day-to-day operational differences or specific technologies. Instead, this comparison focuses on differences in process design and resource deployment. The technical comparison is divided into four areas: 1) Process Design, 2) Physical Assets, 3) Material Inputs, 4) Labor.

Using the DCM, comparisons are made of the small-scale producers against the standard-scale sample plants in each industry. The tables presented in this chapter detail responses and observations about a variety of process design and resource deployment differences between the industry pairs. Table 6-1 examines the sources of advantage of small-scale plant over their standard-scale counterparts. Table 6-2 follows with information about sources of disadvantage experienced by small-scale plants. The objective of this information is to provide a basis for understanding process design and resource deployment decisions.

TABLE 6-1 Small-Scale Producer Advantage

Primary advantage of small-scale producers over standard-scale competitors?	
Technical Advantage (Technology)	2
Market Selectivity (Market)	3
Cycle Times (Time)	1
Labor Advantage (Labor)	1
More Independence/Less Restriction (Flexibility)	3

Table 6-1 summarizes observations and responses to questions about what small-scale plant officials view as their primary advantage over standard-scale plants in their industry. The right column indicates the number of plants in each category from the left column.

TABLE 6-2 Small-Scale Producer Disadvantage

Primary disadvantage of small-scale producers over standard-scale competitors?	
Equipment Sourcing (Equipment)	5
Equipment Utilization (Utilization)	1
Material Sourcing (Materials)	2
Labor Disadvantages (Labor)	1
Market Acceptance (Market)	1

Table 6-2 summarizes observations and responses to questions about what small-scale plant officials view as their primary disadvantage relative to standard-scale plants in their industry.

6.1 Process Design

Scale and production technology are both determined at the process design stage of investment. This section presents data on the ideal scalablity of production processes, objectives in designing the small-scale plants, and factors that determine the design scale of production.

TABLE 6-3 Core Process Technology Difference

Are the core process technologies of small-scale plants different from standard-scale plants?	
Yes	8
No	2

Table 6-3 summarizes observations and responses to questions about if the core process technologies of the small-scale plants were different from those used by the standard-scale plants in the industry.

Table 6-3 considers the ideal scalability of production processes. If production processes were ideally scalable, then the small-scale plants should use similar production processes as the standard-scale producers in the same industry. In Table 6-3, eight of the ten small-scale plants used significantly different production processes than those of their standard-scale competitors. The efficient set of production processes in an industry often varies with scale. To operate at a smaller-scale requires the adoption or development of different processes than the standard-scale plants in an industry.

TABLE 6-4 Unique Process Technologies

Are unique process technologies used relative to all industry competitors?	
Yes	6
No	4

Table 6-4 summarizes observations and responses to questions about if the small-scale plant was using process technologies that no other industry competitor used.

When undertaking a small-scale investment, changes are often required in one or more core production technologies. Table 6-4 indicated that unique processes had been introduced in six of the small-scale plant's process design. This deviation from more standard production methods often leads to attempting other product or process innovations.

TABLE 6-5 Small-Scale Plant Design Objectives

What are the design objectives of the small-scale plants?	
Develop Alternate Process Technology	3
Develop Alternate Product Technology	1
Maximize Economic Efficiency at Specific Scale	5
Efficient Utilization of Capital Resources	1

Table 6-5 summarizes response to questions about what small-scale plant officials view as their primary advantage over standard-scale plants in their industry.

Table 6-5 examines the objectives of changes in standard production methods to determine if changes are motivated by a desire to develop new technologies or to accommodate a specific operational scale. Three of the ten small-scale plants indicated that the objective of their process design was to develop alternate process technologies. Half of the ten small-scale plants indicated that the use of new or different process technologies was intended to maximize efficiency at a specific operational scale. These plants set the scale of operation and made processes design decisions to be most efficient at that scale. This leads to the question of how the operating scale of the small-scale plants was determined.

TABLE 6-6 Scale Determinant

Primary factor determining the scale of production for small-scale producers?	
Reliable Supply of Material Inputs (Material Inputs)	1
Limited Market Demand (Market)	6
Availability of Capital Resources (Capital)	3

Table 6-6 summarizes response to questions about what small-scale plant officials view as their primary advantage over standard-scale plants in their industry.

The scale of operation established by the process design for the standard-scale plants typically was dictated by existing capabilities. A new plant was designed in a manner that utilized production technologies that were well understood and compatible with existing skills and equipment. Substantial investments had been made in these capabilities, and the large investment associated with the new plants could not be justified in the presence of uncertain technologies.

Two major factors were cited for the design scale of the small-scale plants (see Table 6-6). First, the market demand for the proposed output was viewed as being limited. This limitation was most often due to the newest of the product, process, or local market. Investment in a small-scale plant was view as an attempted entry into unproven or unestablished markets. Second, the capital available for investment limited the scale of the production facility. Typically, capital was limited due to uncertainty about the production technology or market potential. Both of the major factors cited in Table 6-6 were related to uncertainty about the production process or market response. In each case uncertainty over technical and demand issues in the industries resulted in the pursuit of small-scale alternative methods of production.

6.2 Physical Assets

The physical asset category includes processing and non-processing equipment. Processing equipment includes all durable machinery and tooling used in materials transformation processes. Process control hardware and software are included in the processing equipment category. Non-processing equipment includes storage, materials handling, and integration equipment. Hardware and software used to track, manage, and optimize production is considered non-processing equipment.

6.2.1 Processing Equipment

The small-scale plants examined typically used unique or different processing methods that the standard-scale plants. This suggests that small-scale plants will require special processing equipment. In this section, the source of small-scale plant's processing equipment is examined.

TABLE 6-7 Processing Equipment Sourcing

Source of primary processing equipment?	
Custom Design built by External Source (Custom)	1
Standard Design built by External Source (Stock)	2
Standard Design modified by Internal Source (Modified)	6
Custom Design built by Internal Source (Proprietary)	1

Table 6-7 summarizes response to questions about the source of the primary processing equipment. Primary processing equipment is defined as the equipment that performs key material transformations.

Table 6-7 summarizes the sources of primary processing equipment. For this analysis, primary processing equipment is defined as the new, unique, or critical equipment central to the small-scale process. The standard-scale plants typically relied on external equipment suppliers that specialized in their industry or had expertise to build specialized equipment for their industry. In some cases, the process design as well as the custom equipment were supplied to the standard-scale plants by external suppliers. In contrast, the small-scale plant were more involved in both the processes design as well as the fabrication of their processing equipment. Seven of the ten small-scale plants had some involvement in producing their own processing equipment. Most often, the small-scale plants purchase general processing equipment and modified it to achieve their production needs. In one case, a small-scale plant designed and fabricated a majority of their processing equipment at the plant with plant labor. Why did the small-scale plants not purchased processing equipment from the established industry suppliers?

TABLE 6-8 Industry Equipment Suppliers

Primary difficulty small-scale producers have with equipment suppliers of their industry?	
Differences in Equipment Technology (Technology)	4
Prohibitive Cost (Cost)	3
Differences in Equipment Scale (Scale)	2
None (None)	2

Table 6-8 summarizes response to questions about what small-scale plant officials view as their primary advantage over standard-scale plants in their industry.

Small-scale plants offered a variety of reasons they were not able to use the established processing equipment suppliers. The most common reason was differences in the technology that the small-scale plant wanted to use in their processing equipment. The established suppliers either did not have the capability or were not willing to sell the specific technologies that the small-scale plants wanted. The second reason cited for not using the established processing equipment suppliers of their industry was excessive cost. The cost of the equipment requested by the small-scale plants was prohibitively expensive due to the custom nature of the equipment or because of the construction methods of the suppliers. The third reason was the scale of the equipment offered by the equipment supplier. The scale of the standard equipment of the supplier was not easily reduced. Finally, two of the ten small-scale plants indicated that they did not have any difficulty obtaining their processing equipment from standard industry suppliers. If the small-scale plants were often involved in the fabrication of their own processing equipment, who did the development work for the custom or heavily modified equipment they produced?

TABLE 6-9 Processing Equipment Development

Source of development work for current processing equipment?	
Internal: Plant Level (Plant)	5
Internal: Firm Level (Firm)	2
External: Affiliated Source (Supplier)	1
External: Unaffiliated Source (Other)	2

Table 6-9 summarizes response to questions about what small-scale plant officials view as their primary advantage over standard-scale plants in their industry.

In Table 6-9, the sources of development of the processing equipment are summarized. In half of the ten small-scale plants, a significant contribution was made to processing equipment by plant development. Two other small-scale plants indicated that the development work had occurred internally but at the firm-level. One plant cited an external supplier as the developer of their process technologies. Finally, two plants did not know the source of their process technology. These results for the small-scale plants differ significantly from the standard-scale plants examined. The standard-scale plants cited development of the process technology at the firm-level or by an external supplier. Of the small-scale plants that conducted internal process technology development activities, who was responsible for performing the development work?

TABLE 6-10 Development Activity

Who conducted internal development of processing equipment?	
Direct Labor: Plant Level	3
Indirect Labor: Plant Level	2
Indirect Labor: Firm Level	2
Not Applicable	3

Table 6-10 summarizes response to questions about what small-scale plant officials view as their primary advantage over standard-scale plants in their industry.

Of the seven small-scale plants in Table 6-9 that reported internal development work, three indicated that the development responsibility within the plant was held by the direct labor force. In this analysis, direct labor includes all individuals directly involved in production. Two plants credited indirect labor within the plant as responsible for process development efforts. Indirect labor includes all individuals performing support duties in the plant (engineering, maintenance, administrative, etc.). Two other plants cited development work off-site at the firm level.

6.2.2 Non-Processing Equipment

While the non-processing equipment does not effect the nature of the production process output, it is important to production flow and the capital cost of the plant.

TABLE 6-11 Non-Processing Equipment Selection

Primary factor in selection of non-processing equipment?	
Utilize Existing Equipment (Utilization)	3
Compatibility with Processing Equipment (Compatibility)	2
Conserve Capital Resources (Capital)	4
Maximize Process Flow (Flow)	1

Table 6-11 summarizes response to questions about what small-scale plant officials view as their primary advantage over standard-scale plants in their industry.

Small scale plants selected non-processing equipment differently than their standard scale competitors. The typical standard scale plant in this survey selected equipment to maximize process flow. This increased both the total cost and complexity of production equipment. In contrast, Table 6-11 cites factors in the selection of non-processing equipment for small-scale plants. Only one plant cited maximization of process flow as their primary factor in selecting non-processing equipment. The other three reasons cited centered around two concepts. First, conservation of limited capital. This was achieved by using existing equipment or purchasing inexpensive stock equipment. This explains the lower fixed costs reported in Table 5-6. The second main category for selection of non-processing equipment is compatibility. The compatibility condition applies both to compatibility with the core processing equipment as well as compatibility with the direct labor force. Compatibility was achieved through using existing equipment or acquiring equipment with familiar technology.

TABLE 6-12 Non-Processing Equipment Sourcing

Source of non-processing equipment?	
Custom Design built by External Source (Custom)	1
Standard Design built by External Source (Stock)	1
Standard Design acquired from External Source (Used)	5
Standard Design modified by Internal Source (Modified)	3
Custom Design built by Internal Source (Proprietary)	0

Table 6-12 summarizes response to questions about what small-scale plant officials view as their primary advantage over standard-scale plants in their industry.

Small-scale plants used different sources for their non-processing equipment than for their process equipment. Non-processing was sourced to conserve capital and maintain compatibility with other areas of the production process. This led small-scale plants to purchase stock equipment. The stock equipment may or may not have been used prior to purchase. Three plants reported heavy modification of the stock equipment while other acknowledge only limited modification. The standard-scale plants were more likely to require custom built equipment to support other aspects of their production process.

6.3 Material Inputs

Small-scale plants had a more difficult time obtaining the necessary material inputs for their processes than their standard-scale competitors. The material inputs used by the small-scale plants typically differed from the standard-scale plants in type, quality, and quantity. The small-scale plants demanded inputs that were not readily available from the existing material suppliers in their industry.

TABLE 6-13 Difficulties with Industry Material Suppliers

Difficulties with established industry sources of material inputs?	
Low/Inconsistent Quality	4
Minimum Purchase Quantities	1
Not Commercially Available	2
None	3

Table 6-13 summarizes response to questions about what small-scale plant officials view as their primary advantage over standard-scale plants in their industry.

Small scale plants cited three complaints about the established sources of raw materials in their industries. First, the material available was of low or inconsistent quality. The quality of the material was not ideal or compatible with the particular processing methods they were using. Second, supplier sold material in large quantities that were beyond the capacity of the small scale plants. Third, special inputs were required by the small-scale producers that were foreign to their industry. Table 6-13 reviews the difficulties experienced by small-scale plants in obtaining materials inputs. If established suppliers were not offering the necessary materials inputs, how did small-scale plants obtain their material inputs?

TABLE 6-14 Alternate Material Sources

How do small-scale plants obtain material inputs?	
Pre-Processing of Standard Inputs	5
Develop Independent Sources	1
Purchase through Intermediaries	1
Standard Suppliers	3

Table 6-14 summarizes response to questions about what small-scale plant officials view as their primary advantage over standard-scale plants in their industry.

The small scale plants pursued different strategies in avoiding material input difficulties. The most common response was to design some pre-processing step into the production process to modify or create the necessary inputs. The second method was developing a independent source to supply material that was not commercially available before. Third, intermediaries were sought to reduce the minimum purchase quantity. Three plants indicated that established industry suppliers provided adequate materials for their processes.

6.4 Labor

The final area of comparison is the use of labor in the production process. Two categories are compared: 1) Indirect Labor, 2) Direct Labor. Direct labor is defined as the input of individuals who have an immediate role in the production process. This includes all individuals who work in the production process or monitor it. Indirect labor is the input of all other individuals in the plant. This includes engineering, maintenance, and administrative duties. The following sections cite the main differences between the role of labor in the small-scale plants and their standard scale counterparts.

6.4.1 Indirect Labor

The small-scale plants had significantly less indirect labor than their standard-scale competitors. The was true in all aspects of indirect labor. There were less supporting engineering, maintenance, and quality control personnel. The administrative staff were drastically smaller. Even after adjusting for the differences in scale, the small-scale plants had less indirect labor supporting their production processes. Many of the small plants surveyed indicated that they used external service providers to provide non-essential support services. Several standard-scale plants also reported using external service providers for non-essential support service, but the reduction in indirect staff was not as noticeable.

6.4.2 Direct Labor

Comparison of the direct labor forces of the industry pairs demonstrated major differences in their responsibilities. The primary difference was the broad range of support duties that direct labor personnel at small-scale plants conducted in addition to production activities. In the small-scale plants, the direct labor force was likely to be responsible for process tracking, maintenance, sanitation, and development duties. Direct labor personnel handled the majority of production support activities in many of the small-scale plants.

How is the direct labor force able to handle these added responsibilities? Several possible explanations were observed. First, the production systems of the small-scale plants were much simpler on average than the standard-scale plants. The small-scale plants saved cost and avoided complexity by purchasing used and stock processing and non-processing equipment. Second, the involvement of the direct labor force in the development and modification of the processing equipment provides a higher degree of process expertise among the direct labor force of the small-scale plants. Third, the additional duties are designed and scheduled into the production process. Finally, small-scale plants typically hire direct labor personnel with no previous industry work experience and are more likely to set drastically different work policies than the industry norms. Table 6-15 reports the previous industry experience of the direct labor force of the small-scale plants.

TABLE 6-15 Employment History of Direct Labor Force

Percentage of current direct labor forces previously employed in same industry?	
46% - 60%	0
31% - 45%	1
16% - 30%	4
1% - 15%	5
0%	0

Table 6-15 summarizes observations and responses to questions about the employment experience of the current small-scale plant direct labor force in their respective industries. The results are reported in percentage of current force who had work in the same industry prior to their current employment.

The direct labor for the small-scale plants were often involved in development or modification of the processing equipment. In the standard-scale plants, direct labor rarely played a role in the development process. Involvement in the development usually translated into greater ability to maintain and control processes. Typically, the small-scale plants tracked fewer control variables yet had more consistent process results. Additionally, the small-scale plants experienced more frequent process stoppages, but the average time of a single stoppage was shorter. Finally, direct labor in the small-scale plants exhibited better understanding of the interface between mechanical systems (machinery and tooling) and the control systems (software and electronics).

7.0 Discussion

The discussion section covers three main areas. First, the research is examined to identify some conditional aspects of the information presented. Second, data presented in Chapters 4-6 is reviewed to highlight trends and weaknesses. Finally, a framework on escaping the structural and operating barriers found in many manufacturing industries is outlined.

7.1 Research Review

The results presented in Chapters 4-6 rely on the integrity of the plant selection process and the quality of the data collection process. The following sections review some of the major issues.

7.1.1 Plant Selection

Comments and patterns presented about the operational behavior of small-scale plants are based on a set of plants that were not selected at random. The small-scale plants presented in this work are in many ways exceptional in their abilities and achievements. This suggests that the methods used and the results achieved by them are not representative of all small-scale plants in process intensive industries.

7.1.2 Data Quality

The information presented was obtained from conversations and internal documents. Its accuracy is largely dependent upon the quality of collection and reporting by the independent plants. The accuracy of the view of the internal performance and objectives of the plants is dependent upon the completeness of shared data. Attempts were made to compare the data in a consistent manner. Due to different methods of classification and recognition, there is some inherent error in the presented data.

7.2 Summary of Small-Scale Plant Behavior

The objective of the data collected throughout this study was to identify a pattern of behavior exhibited by a group of successful small-scale plants from process-intensive industries. In each case, the industry pair demonstrated distinct operational differences. From the information in Chapters 4-6, a pattern of behaviors emerged that suggest an explanation as to how small-scale plants can be designed and operated differently than larger scale competitors.

7.2.1 Process design

In process intensive industries, production scale is not ideally scalable. Changes in the scale of production require changes in the processing methods to remain efficient. More simply, scale is a function of process technology.

Most of the standard-scale plants had a rigid set of process technologies in which they had made large investments (Farrell & Saloner, 1985; Freeman & Soete, 1997 p. 244). These plants did not intend to limit technology, but their efforts to minimize process volatility had that indirect affect. Changes in process technology were viewed as risky and uncertain. Limiting possible process technologies predetermined the scale of production. Generational production scale changes were small when technology became entrenched. Once the scale of production was determined, markets were forged to accommodate its output. This is a reoccurring theme among standard-scale plants. The large plants had to find a market segment to absorb their output.

The small-scale plants were more likely to enter the process design phase with a scale of production defined by a specific market objective. This is illustrated in Chapter 4 were 51.5% of the small-scale plants examined in the classification survey exhibited market developing competitive behavior. Based on market conditions, they designed a production process that was appropriate for that scale. In cases where small-scale plants were attempting to develop specific process technologies, they were careful in selecting an appropriate production scale and supporting technologies.

FIGURE 7-1 Methods of Defining Scale

Comparison of Methods Defining Production Scale				
		Standard-Scale Plants		
Process	---->	Scale	---->	Market
		Small-Scale Plants		
Market	---->	Scale	---->	Process

Figure 7-1 illustrates an apparent difference in the how standard-scale and small-scale plants define scale in the process design stage.

Because small-scale plants often needed to adopt non-mainstream process technologies to accommodate their chosen production scale, they were more likely to introduce an unproven process technology than the standard-scale plants. A surprising result of the surveys was the extent to which small-scale plants were actively engaged in some type of development activity (see Section 6.2.1). Other aspects of the small-scale plant behavior supports this ability to introduce new process technologies.

The most likely segment of a production process to be circumvented by small-scale plants are ones that are highly specialized or indivisible. These areas are typically high capital cost and highly specialized functional areas of standard-scale plants. Small-scale plants often focus their development interests on process designs that eliminate or replace these process obstacles. Standard-scale plants are often concerned about these process obstacles, but are unwillingly to replace them due to the technical uncertainty or because viable alternative processes would requires a decrease in production scale that would be incompatible with their modes of operation. Developing an alternative process to one of these process obstacles is usually a first step in assuring long-term existence and growth for small-scale plants.

A final trend relating to process design and process development differentiating the small-scale plants from their standard-scale competitors is the timing of process changes. The small-scale plants conduct continuous process development activities and integrate the results on a regular basis into the production process. They practiced a staged system of process development and integration. Over a period of time, many small innovations to the production process result in accumulative gains in efficiency. Because the small-scale plants make frequent improvements, they are projected to have longer process lives than the standard-scale plants.

Small-scale plants demonstrated a process innovation philosophy based on "learning-by-trial" principles. This philosophy assumed that process innovations are highly uncertain, and that over time, a series of small innovations is the most efficient method for advancing process technology and conserving capital. These policies are consistent with the internalization of development efforts and the promotion of process competence.

Tables 5-13 and 5-14 compare the relative frequency of minor process innovations and major process redesigns. In the standard-scale plants, process innovations were introduced less frequently, but the process design was expected to have a shorter life.

7.2.2 Physical Assets

There were two patterns of investment in plant equipment. First, the overarching theme concerning investing in non-processing equipment was conserving capital. All equipment categorized as non-essential (this was primarily non-processing equipment) was acquired on a lowest cost basis. This resulted in the purchase of used or stock equipment. Incompatibilities were managed by modifying the equipment at the plant to suit production needs. Second, processing equipment was given a much higher capital priority. Although much of the processing equipment was stock equipment, there was typically extensive modifications within the plant. Small-scale plants would focus on specific unit processes and invest heavily in improving processing equipment associated with that process.

The capital investment in plant and equipment was consistently lower for the small-scale plants (see Table 5-4). This number is somewhat misleading due to the extensive developments and modifications that occurred within the plants. Small-scale plants had a higher per unit development expense (see Table 5-11). On average, process development activity within small-scale plants often involves extensive processing equipment development as well as process output research.

Another area where the small-scale plants exhibited superior performance was managing the integration of machinery and tooling with process control hardware and software. Many of the small-scale facilities had plant personnel that had great expertise in designing and maintaining the process control systems. While the small-scale plants on average had much simpler process control systems, the small-scale plants had more machine/controls expertise at the plant level. This resulted in more consistent process control using fewer process variables. The benefits of better process control and the need to track fewer process variables cannot be overestimated.

The small-scale plants consistently used non-"mainstream" suppliers relative to their industry. Some of the reasons cited for looking outside the mainstream supplier networks are listed in Table 6-13. This trend occurs in other areas of operations. The value of the ability to develop or control process equipment technology is easily underestimated (Carlsson, 1984).

7.2.3 Material Inputs

Small-scale plants exhibited the ability to use low quality and unconventional materials inputs. This was accomplished in the process design phase. Wide material specifications were established in the process design phase to utilize low cost alternative materials. The cost associated with this ability was the design of more robust processing equipment or the inclusion of pre-processing of raw material prior to the main production stages. Again, the small-scale plants show a reoccurring ability to accommodate alternative process technologies and develop new technologies to exploit production cost savings.

Sources of material inputs for the small-scale plants were often outside the mainstream suppliers for their industries.

7.2.4 Labor

Small-scale plants overwhelming exhibited much more generalized labor duties than the standard-scale plants. This generalization is motivated by two phenomena. First, the minimization of indirect labor. Second, the internalization of development activities. These trends require that the small-scale plants abandon strict specialization of labor. In addition to generalized responsibilities, there was an emphasis on greater process competence at all levels of plant labor. This appears to be the best explanation for how the direct labor force was able to manage much of the indirect support duties without a significant rise in indirect labor cost (see Table 5-8).

7.3 Pattern of Efficient Small-Scale Production

Overall, the behavior of the small-scale plants does not present a formula for greater production efficiency. What they do offer is a process design that can accommodate the uncertainties of process technology development. Process development is integrated with production to reduce the development cycle time and consolidate personnel with both production and development expertise. The success of key development efforts is critical to continued existence. The higher development and production costs per unit are minimized by adopting drastic cost-saving measures in non-essential areas.

The challenge facing small-scale plants in process-intensive industries is to develop alternate modes of production that compensated for size disadvantages. Despite the enormous nature of this task, ten small-scale plants were identified that exhibited some degree of success in doing this. Studying these plants reveals a pattern of how they commercialized new technologies. The following sections review the four elements of the development pattern.

7.3.1 Technology Selection

The small-scale plants examined in the comparison survey were effective at identifying important new technologies and applying them at a scale where they would be efficient. Two areas of focus were highly specialized processes and indivisible processes utilized by standard-scale competitors in their industries. The small-scale plants focused their development efforts at finding alternate technologies to replace these process barriers or developing new process technology that minimized their restrictiveness (Carlsson, et. al., 1994). The small-scale plants would corresponding adjust other production processes to be consistent with the designed operational scale.

7.3.2 Capital Conservation

Due to their limited capital base, continued survival demanded conservation of capital. Despite their limited availability of capital, successful small-scale plants made decisive investments to advance their competitive position. Plants invested heavily in critical processing equipment through purchases and development expenditures, but accepted stock and used equipment for non-essential applications. Small-scale plants made many similar investment decisions where capital was reserved for only the most critical elements of the process design. This is particularly true with respect to development investments. Development efforts were focused on a limited number of critical technologies that provided the small-scale plants with an operational advantage or a potential advantage.

The production data in Chapter 5 reported cost differences between small-scale and standard-scale plants that were much smaller than expected. A likely explanation based on site visits to all the plants, is that small-scale plants operate closer to their theoretical efficiency than the standard-scale plants. Liebenstein (1966) and Lieberman (1987)

7.3.3 Internal Development

The small-scale plants were effective at conducting many low risk process development trials. These trials were meant to introduce minor, low cost improvements to the production process in a controlled manner (Garud, et. al., 1997). Success of these trials led to frequent process improvements that accumulated into a substantial advantage over time. The fact that development work was conducted at the plant-level resulted in an shortened development cycle. The small-scale of the plant made it susceptible to failure at the plant level if process innovations caused an extended shutdown of the plant. The real key to conducting the successful trial and error development program was the process expertise of the plant labor force. They were able to fix problems before they became serious and to provide informed feedback about the future development trials.

7.3.4 Process competence

Small-scale plants emphasized process competence throughout the plant level. This competence allowed production and development problems to be addressed immediately. Innovations happened more regularly, and the plants experienced less downtime (Mansfield & Wagner, 1975). Also, the high level of process expertise permitted the labor force to handle a variety of production tasks increasing production efficiency.

7.4 Commercializing Technologies: General Case

The same pattern by which small-scale plants successfully commercialized new technologies provides guidance for all manufacturers in process-intensive industries attempting to commercialize new processes.

7.4.1 Appropriate Technology

Mainstream producers in established industries become captive of the supplier infrastructure in their industry. They rely on suppliers for all equipment requiring process expertise in design and construction. Once the ability to design, produce, and modify processing equipment is lost, it is difficult for the producer to alter their production technology from that of the industry suppliers. It is extremely difficult to compete in process-intensive industries with generic production technology.

Manufacturers need to retain process expertise and development skills to maintain a competitive process design and to understand the appropriate role of different technologies in their production process.

7.4.2 Conserve Capital

Conservation of capital is essential to remaining efficient as well as pursuing second generation process designs. Small-scale plants were forced to conserve capital due to its scarcity. Large producers need to conserve capital when commercializing new technologies to fund the second generation process changes that are routinely required. Commercializing new technologies is a multi-step process, expending too much capital in the first round will prevent later round corrections to the process when the benefits begin to materialize. Additionally, new technologies are very uncertain by nature and capital expenditures should be minimized in the absence of reliable data of there outcome.

7.4.3 Trial & Error

Information from the survey of small-scale plants suggests that "trial & error" is an effective method of developing process technologies. Standard-scale producers are more likely to attempt a single-stage, well-planned development effort. The problem with this approach to process development is that many of the critical problems will not be known until the process innovation is implemented. At that point, if there is not capital and a plan to respond to these critical problems, the development effort will be viewed as a failure. Small-scale plants demonstrate the effective use of "trial & error" methods in their process development activities.

7.4.4 Process Competence

The single most important aspect of commercializing new technologies is having individuals with process competence involved in not only the development, but also the day-to-day operation of the production system. Many large producers fail in their process development efforts because they separate responsibility for development and production. To effectively develop new commercial processes, the development individual must understand the operational details of the system it will be part of which it will be part. Equivalently, to efficiently operate the production system, the operator must have information intrinsic to the development process. Process competence requires the combination of development and operational knowledge.

8.0 Conclusion

8.1 Survey Results

TABLE 8-1 Summary of Scale and Performance Data

	Industry	Class	Scale (Volume)	Unit Cost
1	Investment Casting	PEX	0.35	0.97
2	Seamless Rings	PEX	0.17	0.98
3	Engineered Timber	PDD	0.24	1.06
4	Structural Bearings	PDD	0.15	1.19
5	Dye Pigment	PCD	0.18	1.04
6	Plastic Extrusions	PCD	0.30	1.07
7	Printed Circuits	PCD	0.30	0.92
8	Stamped Panels	PCD	0.23	1.05
9	Structural Shapes	PCD	0.20	0.94
10	Packaging Materials	GED	0.22	0.98
		Average	**0.22**	**1.02**

Table 8-1 summarizes scale and performance data.

Thirty-three plants were identified that operated at a scale significantly below the standard operating scale of their industries. These plants demonstrated a diverse set of operating strategies (see Table 3-1). Ten small-scale plants were selected that exhibited endogeneous competitive advantages (see Table 5-1). Economic and performance comparisons were made of each of the small-scale plants to a standard-scale plant from the same industry.

The small-scale plants had on average 23% of the total unit output of the standard-scale plants. Contrary to economic theory, the small-scale plants exhibited similar production unit costs to the standard-scale plants (see Table 8-1). Two explanations were cited for the similarity of production costs.

First, the small-scale plants had lower fixed costs than their standard-scale competitors (see Table 5-6). This is in direct opposition to the result predicted by economic theory. Fixed costs were reduced in both of the major fixed cost categories. First, capital investment in the small-scale plants was much lower than in the standard-scale plants (see Table 5-4). This was achieved by utilizing different production methods that required lower investment in both processing and non-processing equipment. The only area of capital investment where small-scale plants exceeded their standard-scale competitors was in equipment expenditures for the primary processing step. The small-scale plants focused investment on critical processing steps that often involved new process technologies. The second area that reduced fixed cost was indirect labor. The indirect labor costs for the small-scale plants were lower than the standard-scale plants' indirect labor cost (see Table 5-8). This was evident by the reduced presence of indirect plant personnel.

The second explanation for the similar production costs was greater operating efficiency by the small-scale plants (see Table 5-2). Although the standard-scale plants may have had a greater absolute efficiency due to their larger scale of operation, the small-scale plants are believed to operate closer to their maximum potential efficiency. This may be a benefit of managing and operating smaller and simpler plants.

8.2 Behavioral Pattern

The small-scale plants exhibited a pattern of behavior that differed from the standard-scale plants. Four trends were identified that contributed to the ability of the small-scale plants to exists and maintain comparable production costs.

First, the small-scale plants selected technologies and operational scales that were the most appropriate for their intended markets. Technology and scale decisions in standard-scale plants were heavily influenced by previous operational experience. Small-scale plants were more likely to identify and change traditional processes that were viewed as an obstacle to their market objectives. Small-scale plants were less likely to be restricted by industry standards set by suppliers.

Second, small-scale plants placed a greater emphasis on conserving capital resources. They had less capital invested per unit output than the standard-scale plants. Exhausting capital resources resulted in plant failure. The small-scale plants undertook staged investment to stretch capital resources through several generations of plant design before arriving at a stable commercial production process.

Third, the small-scale plants were more likely to conduct internal development activities. While the small-scale plants consistently had lower overall development expenditures (see Table 5-9), they had greater in-plant development expenditures (see Table 5-10). Development expenditures for the standard-scale plants resulted from work largely conducted outside the plant. The small-scale plants also exhibited a different type of development activity. The nature of this development work was small, frequent changes to the process technology of the plant (see Table 5-13). Development was an iterative process seeking to improve or establish a stable commercial production process. A significant faction of development work within small-scale plants was conducted by the direct labor force. The direct labor force was able to be involved because of a consistently higher level of process competence within the small-scale plants.

Fourth, the small-scale plants exhibited greater process competence among the direct labor force. This was evident by their ability to accomplish many of the task traditionally handled by indirect labor. Performing development and maintenance duties requires an understanding of the core processing technologies. Proficiency in performing these tasks is evident in longer operating times achieved by the small-scale plants (see Table 5-3).

8.3 Direct Comparison Method

In this study, ten industries are examined to identify differences in the operational behavior of small-scale plants. A method is proposed to examine scale at the plant-level. This method selects two contrasting plants from an industry. One plant represents the standard production scale for the industry. The other plant operates at a scale significantly below the standard scale of operation. The aggregate operational characteristics of the plants are analyzed to identify economic disadvantages associated with the differing scales of production. In addition to economic data, strategic and technical information is compared for the two plants. This method is referred to as the direct comparison method (DCM).

Although this method is time consuming and difficult to perform across several industries, DCM allows the documentation of quantitative and qualitative differences that result from differences in scale. It allows technology to be included as a dependent variable in determining efficient scales of production.

Appendix A

Summary of Classification Survey

Appendix A provides a summary of the data gathered in the classification survey. Table A-1 lists all thirty-three plants included in the classification survey detailed in Chapter 4. Information is provided for the major dimensions of classification: 1) competition and 2) advantage. The two categories of competition are price-competitors (Price) and non-price competitors (Non-Price). The two categories of advantage are endogeneous (Endo) advantage and exogenous (Exo) advantage. There are eight sub-categories: 1) PEX - Process Expertise (see Section 4.1.1.1), 2) RES - Resource Advantage (see Section 4.1.2.1), 3) OUT - Output Flexibility (see Section 4.1.1.2), 4) Regulation Motivated (see Section 4.2.2.1), 5) Product Differentiation (see Section 4.2.1.2), 6) PCD - Process Development (see Section 4.2.1.1.2), 7) PDD - Product Development (see Section 4.2.1.1.1), 8) GED - Geographic Development (see Section 4.2.1.1.3). Figure A-1 displays the organization of the various categories. Each box contains the group name, the number of plants in the group, and the plant percentage in the group.

TABLE A-1 Summary of Classification Survey Data

#	Name	Industry	Process	Competition	Advantage	Sub-Category
1	Plant A	Airfoil Investments	Casting	Price	Endo	PEX
2	Plant B1	Consumer Products	Fabrication	Non-Price	Endo	PRO
3	Plant B2	Consumer Products	Casting	Non-Price	Endo	PCD
4	Plant B3	Consumer Products	Casting	Price	Exo	RES
5	Plant C1	Dye Pigment	Chemical	Non-Price	Endo	PCD
6	Plant C2	Dye Pigment	Chemical	Non-Price	Endo	PRO
7	Plant D1	Engineered Timber	Chemical	Non-Price	Endo	PDD
8	Plant D2	Engineered Timber	Chemical	Non-Price	Endo	PDD
9	Plant E	Industrial Controllers	Fabrication	Non-Price	Endo	PCD
10	Plant F	Industrial Hydraulics	Fabrication	Non-Price	Endo	PCD
11	Plant G1	Medical Implants	Casting	Non-Price	Endo	PDD
12	Plant G2	Medical Implants	Casting	Non-Price	Endo	PCD
13	Plant H	Medical Instruments	Fabrication	Non-Price	Endo	PRO
14	Plant I1	Packaging Material	Chemical	Non-Price	Endo	GED
15	Plant I2	Packaging Material	Chemical	Non-Price	Endo	GED
16	Plant J	Photographic Processing	Chemical	Non-Price	Endo	PRO
17	Plant K1	Plastic Extrusion	Casting	Non-Price	Endo	PCD
18	Plant K2	Plastic Extrusion	Casting	Price	Endo	OUT
19	Plant L	Power Equipment	Fabrication	Non-Price	Endo	PCD
20	Plant M1	Power Generation	Mechanical	Non-Price	Exo	REG
21	Plant M2	Power Generation	Mechanical	Non-Price	Exo	REG
22	Plant N	Optic Film	Deposition	Non-Price	Endo	PCD
23	Plant O	Printed Circuit	Chemical	Non-Price	Endo	PCD
24	Plant P	Seamless Rings	Deformation	Price	Endo	PEX
25	Plant Q1	Stamped Panels	Deformation	Non-Price	Endo	PRO
26	Plant Q2	Stamped Panels	Deformation	Non-Price	Endo	PCD
27	Plant R	Structural Beam	Casting	Price	Endo	PEX
28	Plant S	Structural Bearings	Machining	Non-Price	Endo	PDD
29	Plant T1	Structural Shape	Casting	Non-Price	Endo	PRO
30	Plant T2	Structural Shape	Casting	Price	Endo	PEX
31	Plant T3	Structural Shape	Deformation	Price	Exo	RES
32	Plant U	Synthetic Fiber	Chemical	Non-Price	Endo	PCD
33	Plant V	Wire Product	Deformation	Price	Endo	PEX

Appendix B

Sample of Quantative Data from Comparative Survey

Appendix B summarizes the data gathered for one pair of industry plants (packaging material) in the comparative survey. Three groups of data were collected.

TABLE B-1 Operational Data for Packaging Material Plants

	Units	Stand.	Small	Ratio	Reference
Total Investment	($)	$600M	$132M	0.22	see Table 5-4
Unit Capital	($/ton/d)	$345,000	$200,000	0.58	see Table 5-4
Design Capacity	(ton/hr)	110	22	0.20	see Table 5-3
Operating Time	(hrs)	1691	1785	1.06	see Table 5-3
Rated Output	(tons)	186,010	39,270	0.21	
Actual Output	(tons)	172,000	38,000	0.22	see Table 5-2
Output Efficiency		92.5%	96.8%	1.05	see Table 5-3

TABLE B-2 Development Data for Packaging Material Plants

	Units	Stand.	Small	Ratio	Reference
External	($)	$98,561	$17,740	0.18	see Table 5-10
Internal	($)	$16,679	$69,051	4.14	see Table 5-10
Total Development	($)	$115,240	$70,296	0.61	see Table 5-9
Development/Unit	($/unit)	$0.67	$1.48	2.21	see Table 5-11
MTBI	(weeks)	13	10	0.80	see Table 5-13
MTBR	(years)	12	N/A	N/A	see Table 5-14

TABLE B-3 Economic Data for Packaging Material Plants

	Stand.	Small	Ratio	Reference
Direct Material	47.59	59.84		
Input Materials		38.63		
Conversion Materials		8.17		
Utilities		13.19		
Working Capital	1.51	1.26		
Direct Labor	7.70	7.62	0.99	see Table 5-8
Variable Cost	**56.80**	**68.72**	**1.21**	**see Table 5-6**
Indirect Labor	2.54	1.85	0.73	see Table 5-8
Physical Capital	40.66	27.09		
PPE		12.25		
Interest		14.76		
Fixed Cost	**43.2**	**28.94**	**0.67**	**see Table 5-6**
Production Cost	100.00	98.00	0.98	see Table 5-5
80% Production Cost	110.80	105.26	0.95	see Table 5-7
Prod. + Dev Cost	100.67	107.72	1.07	see Table 5-12

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