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Abstract

The concept of factory focus has enjoyed considerable academic endorsement as well as industrial adoption, but has *not seen much rigorous research.* The consequent research gaps result in severe limitations in the theory and practice of focused manufacturing that are becoming increasingly important with changes in the competitive environment. Contrary to a frequent misconception, the new environment does not diminish the relevance of focus, but requires an even better grasp of the issue.

The lack of research, as well as the apparent rarity of successful realization, can both be traced back to conceptual limitations (for example, denotation, measurement, etc.,) in the notion of focus. This paper develops a *conceptual framework for factory focus* by departing from the existing literature in significant ways. The framework addresses the conceptual research gaps by considering focus from a different perspective, and at a different level, while still concentrating on the notion of a limited manufacturing task.

Filling the conceptual research gaps facilitates rigorous, quantitative research on factory focus. The framework is applied to a real factory in what we believe is the *first examination of focus and its impact on the production lines and the manufacturing infrastructure.* Specific hypotheses are supported regarding, i) Relationship between focus and performance, ii) The structural nature of focus, iii) Capability trade-offs in focusing, and, iv) Longer-term competitiveness of the focused factory.

Thus, significant progress is made towards filling the conceptual as well as empirical research gaps left unaddressed since the advent of the focused factory concept.

1. MOTIVATION AND OBJECTIVE

1.1. MOTIVATION

1.1. The concept of the focused factory has enjoyed considerable academic support as well as industrial acceptance. The focused factory, *based on excelling in a limited manufacturing task*, was proposed by Skinner (1974). Academic support for focused manufacturing begins with Skinner (1974) and remains strong. Skinner believes that the focused factory will outperform the conventional plant and can be a formidable competitive weapon. Ten years later, Hayes and Wheelwright (1984, pp. 108-114) argue that focusing can have significant benefits in improving plant-performance. Hill (1994, p-142) believes that focused manufacturing enables a company a greater control of its competitive position, and results in an improved overall performance. Desirability of focus is also supported by Miller (1991.) The concept has found its place in textbooks of Operations Management, has strong intuitive appeal, and has been adopted by many manufacturing companies. Several articles citing specific companies and locations of focused factories are found in the practitioner literature [Funk (1989), Huber and Vasilah (1988), Kapoor (1989), Oliver (1989), Sheridan (1990), Willis and Shields (1990), Harmon (1991), and others.]

1.1.2. Focus, however, is rarely realized in practice for its full competitive benefits. In spite of such support and adoption, factories that have achieved the full competitive benefits of focus are not commonplace. It is important to note here that Skinner (1974) *discovered*, rather than *invented* the concept of focused manufacturing. Based on a study of about fifty factories, he *found* that the more competitive ones could be described as having concentrated their manufacturing resources on a limited, explicit manufacturing task. He called such factories focused factories. Skinner says that in spite of their advantages, focused manufacturing plants are surprisingly rare. Twenty years later, Hill (1994, p-142) comments, "In most plants the recognition, let alone the achievement of a meaningful level of plant focus, is rarely understood." Indeed, an examination of the above-mentioned practitioner accounts of about two thousand, 'focused factories' indicates that focus has mostly been interpreted only in a partial sense, preventing full realization of the competitive advantage of concentrating on a key task.

1.1.3. A long-felt, but unmet research need has resulted in significant research gaps. Hayes and Wheelwright (1984, p-117) suggest that focus can be one of the most important factors to influence factory performance, and deserves additional research. Five years after that, the Operations Management Association (Skinner, 1989) designate the question of focus versus flexibility among the top ten research agenda of the nineteen-nineties. *Even by 1995, however, there is little rigorous research examining the focused factory.* This lack of research has resulted in significant research gaps, discussed in Section-2, but summarized below.

Table 1.1. Research Gaps

1. Empirical Research Gaps	
	1.1. No quantitative assessment of relationship of focus with performance
	1.2. No detailed study of capability trade-offs made in the focused factory
	1.3. No systematic examination of long-term competitiveness of the focused factory
2. Conceptual Research Gaps	
	2.1. Definition more conceptual than operational
	2.2. No well-developed classification system for types of focus
	2.3. No Measure of focus
	2.4. Static perspective on focus

1.1.4. It is important today to fill these gaps, because of the following two factors.

i) Today, capability trade-offs in focusing must be considered explicitly. Sweeping economic, technological, political, and regulatory changes over the last twenty years have redefined competition (Jensen, 1993.) Consequently, new competitive factors [Clark, (1989), Winger and Zakon, (1990)] require that manufacturing delivers in an increasingly dynamic environment. While the focused factory concept has been considered as more applicable to a stable product/market situation (Hayes and Wheelwright, 1984, p-90), manufacturers today need to consider focusing factories within this changing environment. The issue before strategists is not whether to focus, but of understanding how focusing decisions affect the long-term manufacturing capabilities of a factory (Hayes and Pisano, 1994.) Consequently a focus framework that takes a dynamic perspective, and makes manufacturing capability trade-offs explicit is called for if the concept of focus is to achieve its full potential in this environment.

ii) Today, available flexible technology makes focus more realizable. Availability of flexible technology has been identified as one of the major forces of change shaping the competition of the nineteen-nineties and beyond (Clark 1989), with economic flexibility empirically observed to be a top objective of leading manufacturers [DeMeyer et al (1989), Ferdows et al (1986).] Specific examples of the new flexible technology being used to build focused factories are found at firms such as Motorola (Sheridan, 1988), and Briggs and Stratton (Burgert, 1988.) Maller (1984) argues that to be flexible, a manufacturing process must first be simplified and focused. Hayes and Jaikumar (1988) find that the new technology encourages factories to break-up into smaller units - plants within the plant [akin to Skinner (1974)] - of cells. Drucker (1990) argues in favor of using modularity to make manufacturing more responsive. Indeed, Harmon's (1991) report on 'focused factories' reveal that the notion of focus have been understood in these factories to be similar to what Hayes and Jaikumar suggests. Later Venkatesan (1992) describes how manufacturing cells divide a factory into focused mini-factories at Cummins Engine.

Thus, availability of *flexible technology seems to have increased the importance of focused manufacturing* by making the prospect of focusing much less restrictive than without such technology.

1.2. OBJECTIVE and SCOPE

The aim of this thesis is to,

i) Build a new framework towards a better understanding and successful practice of focus today, by filling the conceptual research gaps, and,

ii) Demonstrate that the framework can fill the empirical research gaps through systematic research on the focused factory in the real world.

The framework is developed in Section-3 , the research design is discussed in Section-4, and the validity of the framework through its application in the real world is established in Sections 5, 6, and 7. A small-sample survey is then conducted to support the need for such a framework to help manage focus better. Future research will undertake multi-site examination of focus towards integrative theory development.

2. REVIEWING PRIOR RESEARCH ON THE TOPIC

2.1. Manufacturing Task

The notion of the manufacturing task is the key element of focused manufacturing, because the other elements of the definition and much of the later work on this approach to manufacturing management emanate from this concept of a limited set of tasks in one of the following two ways.

2.1.1. Consistency of the Manufacturing Tasks with a Corporate Strategy: The manufacturing task, says Skinner (1974), must be derived from an explicitly defined corporate strategy. The need for this consistency has been argued time and again in the literature and does need not further elaboration [Wheelwright (1978), Hayes and Schmenner (1978), Hayes and Wheelwright (1984), Fine and Hax (1985), Cleveland, Schroeder and Anderson (1989), and specifically about the focused factory, by Hill (1989, p 99.)]

2.1.2. Configuring the Manufacturing Support Functions to Accomplish the Key Manufacturing Task*:* As a means to accomplishing the limited manufacturing task, Skinner (1974) recommends, "Learning to structure the basic manufacturing policies and supporting services so that they focus on one explicit task." That the organization of the support functions to expressly execute the manufacturing task has a major impact on manufacturing competitiveness has further been argued by Schmenner (1978), Miller (1981), and Hayes and Wheelwright (1984, p 32, introducing the terms 'structure and infrastructure'.)

2.2. Dimensions of Focusing

The ways of focusing are termed as 'dimensions' of focusing by Hayes and Wheelwright (1984, p 90). These dimensions of focusing have strong similarities with the perspectives of Hayes and Schmenner (1979), Schmenner (1979), and Schmenner (1982). Based on the research cited, a table is constructed below capturing possible ways of focusing factories, along with examples. An important point to note here is that the dimensions are viewed as *alternative* ways [Hayes and Wheelwright (1984), p 102; Hill (1989), p 103] to focus.

Table 2.1. Literature-based dimensions of factory focus

Focusing Dimensions	Description	Example
Product	Products assigned to plants using product-based criteria	Appliances Consumer Electricals Canned Food Medical Instrument
Market segment/ Customer	Individual product-focused plants dedicated to specific markets/customers	Beverages Bottling Industrial Equipment
Process	Segments of the production process assigned to different plants based on process-based criteria	Automobiles Consumer Electronics Heavy Chemicals Rubber products Apparel
Volumes	High, low and medium volume products assigned to different plants	Industrial Equipment Consumer Durable
Geographic Region (Raw material based)	Each plant procures from a specified geographic region	Paper and pulp Lumber Meat Processing Agricultural products Mineral Processing
Geographic Region (Market area based)	Each plant produces for a specified geographic region	Energy Generation Printing Glass Asphalt

2.2.1. Dimension-Based Focus: Intent versus Reality

The above classification system for focusing factories essentially examines the firm's portfolio along a chosen dimension, and then assigns concise sections of the portfolio to separate factories. For example, an appliance manufacturing firm may view its portfolio as making refrigerators, washers, dryers, and dishwashers, and 'product-focus' its factories by assigning each of the products to a separate factory.

Is such a factory focused as we understood from the definition of focus? Not necessarily.

All that can be said with certainty about the factory making dishwashers is that it is making dishwashers and only dishwashers. Nothing is known, however, about whether the 'one central focus--the one key manufacturing task' necessary for competitive success (Skinner, 1974) has been even determined, let alone accomplished. What this firm has achieved is a way to focus the manufacturing resources of each factory to concentrate on a limited product-line, not necessarily on a limited manufacturing task.

What then, is the difference between a limited product-line, and a limited manufacturing task? Broadly speaking, a limited set of products is but one of the many determinants of a limited manufacturing task. The product-focused factory making dishwashers can make it for several markets that have different price expectations, regulatory standards, and delivery requirements. It can make several models that are produced in different batch sizes on the same equipment. That is, it might still have a very complex set of manufacturing deliverables, and does not, just by the virtue of making only dishwashers, automatically organize its manufacturing support functions towards a congruent, competitive purpose. It does not become a 'focused factory' as Skinner describes such a factory to be. *The difference is not semantic, but substantial with significant competitive implications.*

It is a *research gap* in the literature that beyond Skinner's (1974) original article, focusing dimensions has been almost exclusively looked at as alternate ways to specialize plants within a multi-plant network (Hayes and Wheelwright 1984, p 102; Hill 1989, p103). While limiting the demands made on a factory is recognized to be the key to the success of focused manufacturing, [Skinner (1974), Hayes and Wheelwright (1984, p 99), and Hill (1989, p 90),] allocation of the portfolio along one of the alternative dimensions does not necessarily eliminate the conflicting demands. In this paper, we take the perspective that focusing dimensions are *complementary--rather than alternative--dimensions along each of which a focused factory needs to make choices.*

2.3. Measure of Focus

No universally accepted measure of focus exists in the literature. Indeed, Hayes and Wheelwright (1984, pp. 90-108) illustrate with an example that measures of focus are usually case-specific in their usefulness. The only published attempt to measure focus rigorously is by Pesch (1990), using Likert-type numerical scales. The author observes, however, that the validity, applicability and the reliability of the measure is not established.

Thus, there exists a significant *research gap* in our ability to measure focus.

2.4 The Focused Factory: Evidence of Benefits

Much of the writings on performance benefits of focusing are based on broad observations of factories [Skinner (1974), Hayes and Wheelwright (1984), Ruwe and Skinner (1987), Harmon (1991).] There is no rigorous quantitative assessment of the impact of focus on performance available in the literature. This creates a significant *research gap.*

There exists, however, a small but emerging body of literature that looks empirically at the impact of variety on plant or firm performance. Note that these studies do not consider whether the factories that comprise their units of analysis have attempted focusing or not. Most of the studies are cross-sectional, and provide statistical evidence of relationship between cost and product-variety. The correlations range from negative (Hayes and Clark, 1985), (McDuffie, Sethuraman, and Fisher, 1993), through zero (Foster and Gupta, 1990), (Krafcik et al, 1990), to positive (Kekre and Srinivasan, 1990.) In a longitudinal study, Anderson (1993) find a negative correlation between attribute-based product variety, and performance. Since product variety can be one of the determining dimensions of factory focus, cross-sectional or longitudinal statistical *approaches* similar to these studies may be suitable for a quantitative assessment of the impact of focus on performance.

2.5. Concern about Competitiveness of Focused Factories

Academic literature has, time and again, raised concern about the longer-term implications of focusing factories. These concerns can be grouped into two broad categories:

2.5.1. Maintaining Focus: This can be interpreted as a concern over a time period over which the manufacturing environment, and hence the task necessary to succeed in the environment does not change, but additional *incompatible* tasks may be added to the focused factory [Skinner (1974), Hayes and Wheelwright (1984, p 108)] through 'focus regression' [Hill (1994, p 152)].

Why would managers of focused factories introduce incompatible manufacturing tasks to the factory? Is it possible that they are not *knowingly* adding incompatible tasks, that in fact, they do not have a systematic way of knowing what new tasks are incompatible with the factory's capabilities. Further, since the ability or inability to perform a task is determined by the structural and infrastructural configuration of the focused factory, is it possible that *managers do not have a systematic way of knowing what tradeoffs are made* in the structure and infrastructure of a factory during the exercise of achieving focus?

2.5.2. Ability to Change Focus: Concerns in this category take a dynamic view of focus, and point out that a manufacturing system must retain the ability to change its task when the competitive environment changes [Stobaugh and Telesio (1983), Hayes and Wheelwright (1984, p 90), Abernathy and Wayne (1974).] By Skinner's (1974) description, accomplishment of a chosen manufacturing task involves choices in establishing manufacturing policies (i.e., in configuring structure and infrastructure.) A new manufacturing task would, then, require a new set of managerial choices about the elements of structure and infrastructure. Thus, in order to respond to the demand of a new task, a focus factory will need to retain the capability to easily change its structure and infrastructure.

Why would managers of focused factories compromise the capability of their factory to adequately change itself with the changes in the environment? Again, is it possible that they are not *knowingly* conceding that capability to change, but that they do not have a systematic way of knowing how to retain that capability? Indeed, if they do not have a way of recognizing the trade-offs in the first place, as it was argued before, less likely are they to think about guarding against the trade-offs.

2.6. Focus Frameworks and Research Gaps

2.6.1. The Existing Frameworks: Academic Literature provides us with four frameworks, one by Skinner(1974), two by Wheelwright (1979), and one by Hill (1989), that help decide how to focus a manufacturing plant. In addition, practitioner literature includes a framework by Taylor (1987) which follows Skinner's closely.

2.6.2. Intents and Limitations: An examination of these frameworks reveals that they are all generalized and broad. Skinner (1974) himself mentions that his framework risks oversimplification of an inevitably complex set of issues. Specifically, the intent to provide a generalized framework seems to come in the way of making the notion of focus more operational than conceptual. Wheelwright's models seem to concentrate on the issue of adoption of a market-driven versus an operations-driven approach to focus depending on firm's length of experience with focused manufacturing. Hill's framework follows Skinner's, but additionally emphasizes continued managerial awareness of the power of focus as a key element of successful implementation of the concept.

Let us examine what these frameworks do, and do not do, for a manager trying to achieve manufacturing focus at a plant.

First, all the frameworks recommend deriving the key manufacturing task from an understanding of the link between that task and an explicit higher level strategy. While the necessity of that link is of paramount importance, arriving at a concise manufacturing task based on that link remains more a conceptual than an operational issue. Such a broad directive does not help identify managerially controllable levers that can be used to derive the precise task in a given situation.

Second, since the frameworks are broad rather than detailed, they do not provide either a quantitative measure of focus, or a quantitative way to relate focus with performance.

Third, the frameworks emphasize configuring (or reconfiguring) the structural and infrastructural elements of manufacturing to accomplish the key manufacturing tasks. While such congruent configuration is crucial for the accomplishment of the chosen focused task, there occurs an error of omission in not making explicit the trade-offs made in the manufacturing capabilities of the factory in the process of that coherent alignment.

Fourth, the intent of the frameworks is to achieve, (or at best achieve and maintain) a chosen focus. Both the derivation of a manufacturing task, and the configuration of the structure and infrastructure are done with the aim of 'achieving' focus. This perspective on focus is static. The frameworks do not take a dynamic perspective that, i) explicitly recognizes the potential need to change the focus when the environment changes, and then, ii) provides guidelines for doing so.

Finally, note that the paucity of rigorous empirical studies noted earlier in this chapter can be attributed to the above limitations of conceptual thinking about focus. Indeed, a concept without a measurable, operational definition does not render itself well to empirical investigation.

The research gap, therefore, is of a framework that does what the current frameworks do not do. Specifically, a new framework for focusing facilities should:

1. Fill the conceptual research gaps identified above, and thereby,
2. Make possible systematic empirical research on the focused factory.

This thesis aims to provide such a framework in Section-3, and then demonstrate its validity in the real world of business in the subsequent sections.

3. CONCEPTUAL FRAMEWORK AND RESEARCH HYPOTHESES

The new focus framework will comprise a few interrelated *building blocks* which will be discussed first in Sections 3.1 through 3.5. These building blocks will then be put together to construct the framework in Section 3.6. Finally, specific research hypotheses will be proposed in Section 3.7 to check the validity of the framework in a real world application.

The framework consists of the following building blocks.

1. Positioning the factory on complementary dimensions of focus.
2. Identifying managerially controllable determinants of focus.
3. Establishing a hierarchical linkage, and thereby enabling a measure of focus.
4. Making explicit the structural and infrastructural trade-offs in the focused factory.
5. Retaining designed unfocus.

Each of the five building blocks is discussed below, and then combined into the new dynamic framework for factory focus.

3.1. Positioning the Factory on Complementary Dimensions of Focus

Consider a captive heat-treatment plant (Factory F) of a firm. Suppose that all this plant does is annealing one machined component coming in large batches from one factory, and sending the annealed component to one assembly plant. Let us think about factory F in terms of the dimensions of focusing identified in the literature (Section 2.2), but treating these dimensions as complementary rather than alternative. Factory F is positioned along each of these complementary dimensions in Table-3.1 below.

Focusing Dimension	**Factory F's Position**	**Description of the Position**
Product	Produces one product	The annealed component
Process	Employs one technology	Annealing
Customer	Sells to one customer	The assembly plant
Geographic Area served	Delivers to one location	The assembly plant
Volume	Homogeneous volumes	Large batches
Supplier	One major supplier	The machining plant

Table-3.1. Factory F

Factory F provides a useful way of thinking about how a factory can limit what it has to operationally do. As we can observe, factory F has a narrow operating range on *each* dimension. Note that *any* factory, by its sheer existence, is positioned over some operating range along a continuum on each of these dimensions. These dimensions, therefore, become *complementary dimensions* for describing the demands placed on a factory--any factory. Since focus involves limiting the demands placed on a factory, the first step in focusing can be seen as limiting the operating range of the factory on the continuum along each of these complementary dimensions of factory focus. We can represent this notion through a multi-dimensional 'focus diagram' as shown in figure 3.1.

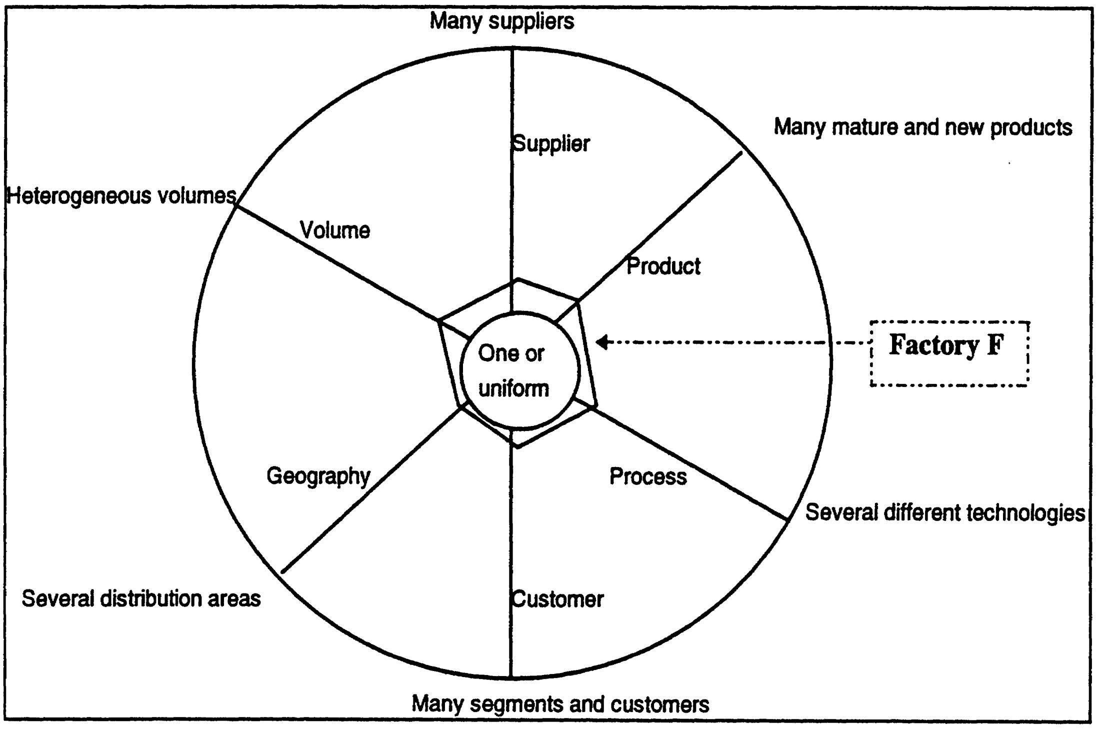

Figure-3.1. Focus Map for Factory F

Along any dimension, a point closer to the center represents greater uniformity of demands than a point further away from the center. Factory F, for example, will occupy a position close to the center of the diagram, since it occupies positions close to the center along each dimension as depicted in Table-3.1. There are many ways in which these demands may increase. The map provides a good way to illustrate the increased demand. Instead of its focused positions (Table-3.1), factory F can have alternative operating ranges along each of the focusing dimensions as shown in Table-3.2 below.

Dimension	Focused Position	Possible Defocusing
Product	One product, the annealed component	Annealing an additional component
Process	Employs one technology, Annealing	Begin tempering in addition
Customer	Sells to one customer, The assembly plant	Accepting orders from outside the firm
Geographic	Delivers to one location, The assembly plant	Also sell to a distant downstream plant
Volume	Homogeneous volumes, Large batches	Accepting small orders
Supplier	One major supplier, The machining plant	Accepting parts from outside the firm

Table-3.2. Defocused Factory F_1

Each of the alternative positions places the factory radially outward on the corresponding dimension. The effect of wider operating ranges along all dimensions can be represented by the larger map (figure-3.2) corresponding to a larger set of demands. *Focusing the resources of the factory on meeting a precise demand, then, means limiting the operating range of the factory on a continuum along each of a set of complementary dimensions.*

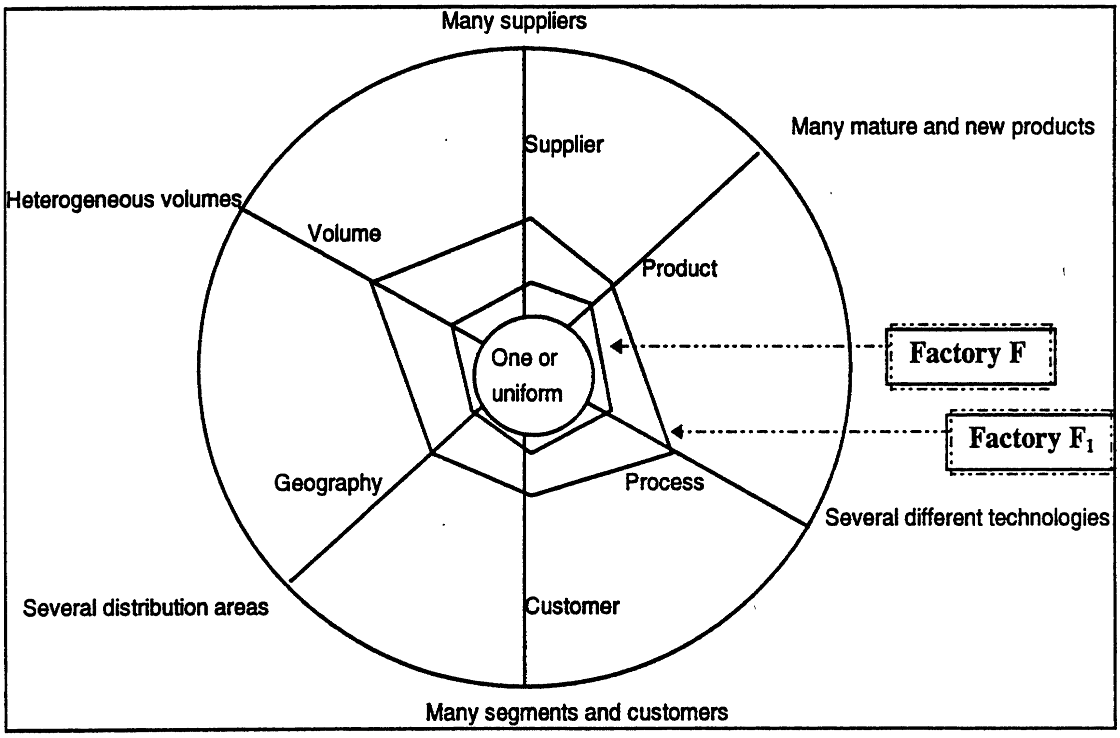

Figure-3.2. Focus Map for Defocused Factory F_1

Note that sometimes this narrowing down of the operating range along a dimension may be accomplished by *default* by the realities of technology and economics, while sometimes focusing will involve choosing the dimensions along which a managerial *design* will be exercised to narrow down the operating range of the factory, as illustrated below in Table-3.3.

Focusing Dimension	Decision Variable	Industry	*'Focusing' by*
Process	Process-types employed in a plant	Sugar Factory	*Technology*
Process	Process-types employed in a plant	Industrial Machinery	*Management Option*
Geographic	Distribution Area	Power Generating Plant	*Technology and Economics*
Geographic	Distribution Area	Automobile Assembly	*Management Option*

Table-3.3. Focusing: By Design and Default

The notion of complementary dimensions can help refine the idea of manufacturing task as it is currently understood. In a survey of focused factories, this author found that the idea of the manufacturing task is often interpreted very broadly by manufacturing executives (e.g., 'Low cost', 'High quality', 'Higher productivity', etc.) The concept of the complementary dimensions can be used to place such a broadly perceived task in a perspective that is more specific to the factory in question. Factory F, for example, may have a manufacturing task of, 'High yield.' Using the complementary dimensions, however, we can state its task as, 'High process-yield in annealing one machined component in large volumes for our own downstream plant.' Such a description is much more specific than the perception of 'high yield.' To differentiate it from the broad manufacturing task, let us call this specific task the *operational deliverable* of the factory.

3.2. Identifying Managerially Controllable Determinants of Focus

The dimensions by themselves are not very useful to manufacturing managers unless they know the levers they have in controlling the operating range along these dimensions. What does it mean, for example, to limit the demands on a factory along the customer/market dimension? How does one know what to limit? A firm making automobile hub-caps, for example, can significantly limit the demands on its factories by limiting the, 'number of customers' served by each factory. This is done simply by limiting the number of automobile assembly plants served by each hub-cap factory. On the other hand, the same 'number of customers' approach to factory focus may not be very meaningful for a bar-soap manufacturer. Along the same market/customer dimension, the soap-maker, rather, would focus factories by targeted market-segments.

Along each dimension, therefore, management must identify specifically what needs to be and can be limited. We call these the, 'controllable determinants' of focus. Without claiming to be exhaustive, we provide below a list of possibilities (Table-3.4.)

Table-3.4 Controllable Determinants of Focus

Focusing Dimension	Controllable Determinant
Product	Product-line breadth (Kotler, '86) Product-line depth (Kotler, '86) Product feature variety Product attribute variety Product Customization Stability of Design Packaging Variety Product-life cycle stages
Volume	Range of Order Sizes Delivery lot sizes for blanket orders Allowable disruptions of production runs
Customers	Number of customers Relative size of customers (clout) Product application Delivery requirements Inspection Requirements Quality levels Market segments Demand Forecast Reliability
Process	Life cycle stages Number of different technologies Nature of difference in technologies Materials processed Skills required Process yields Set-up requirements
Geographic	Procurement area Distribution Area Standards Regulations (govt.) Delivery requirements Shipping requirements Packaging requirements Delivery lead-time
Suppliers	Number of suppliers Supplier size range Relationship mode (Shapiro, 1985) Incoming inspection requirements

Identification of the appropriate determinants in a specific situation will depend on management's understanding of focus, the relevant dimensions, and a knowledge of the determinants. This is not to say that the determinants cannot be chosen methodically. On the contrary, the determinants *must be chosen very methodically* to be of relevance in explaining the demands placed on a factory. An idea of the rigor involved in arriving at the appropriate determinants can be had from Anderson (1993.) In the textile industry, the author shows that simple 'number of products' fails to capture the demands placed on the production system along the 'product' dimension. The relevant determinant in this case is found to be product-attribute variety, derived through factor analysis of engineering parameters of textile design and manufacturing. Also, McDuffie et al (1993) experiment with several possible such determinants of automobile assembly operations.

The point is that the appropriate determinants within each dimension must be identified with rigor if the determinants are to truly capture the demands placed on the production system. Otherwise, management *runs the risk of trying to focus the factory by controlling an arbitrary parameter* which may have no effect on factory performance. Admittedly, the effort requires in-depth knowledge of several aspects of business (corresponding to the dimensions of focus.) On the other hand, this foundation of in-depth, business-specific knowledge is arguably necessary if focus is to achieve its full potential in providing competitive advantage.

3.3. Establishing a Hierarchical Linkage, and thereby Enabling A Measure of Focus

While the literature cited in Section-2.3 demonstrates the difficulty of measuring focus, we believe that the approach we describe below can overcome much of difficulties faced by researchers in the past, and can measure focus in a way that is meaningful and applicable in many situations of factory focus.

In a major departure from existing literature, we propose to measure focus not at the factory level, but at the production-line level, while maintaining an explicit link between the two levels. The notion that focus operates at multiple levels was proposed by Hayes and Wheelwright (1984). They describe these levels as: Business Focus, Factory Network Focus, Individual Factory Focus, and Production-Line Focus. Since a factory consists of its production lines, narrowing the demands at the factory level will likely limit the demands on the production lines. Each production line within a manufacturing facility can be described as possessing specific processing capabilities to manufacture products within given ranges of specified design parameters. At its simplest, this will mean production of just one type of plastic molding on an injection molding machine, for example. A production line for a gear wheel, on the other hand, may comprise broaching, milling, and honing operations in sequence to produce a variety of gear-wheels.

3.3.1. Increasing the number of parts at a line is one way in which the demands placed on the production line increase. Within the process engineering system of a factory, every part with a different physical characteristic or requiring a different process parameter is generally indicated with a new part number, or, in technical terminology, a new bill-of-material.

The number of bills of material on a production line provides a more meaningful measure of variety then the number of products produced in the factory. The 'number of products' measure at the plant level does not consider the nature of the difference between the products [Anderson (1993), McDuffie et al (1993).] The parts on any given production line, on the other hand, have largely common design and processing characteristics. A new bill of material on that line indicates change of a rather limited nature, mostly on values of design dimensions and processing parameters. For example, on a gear-shaping line producing two gears, the addition of a third bill of material will typically indicate another gear that goes through the same shaping operations in the same sequence as the other two, only with changes in process parameter values. While the 'number of products' measure at the factory level provides little information about the extent to which these products place different demands on the system, the 'number of bills of material' on a production line capture much more adequately the variations placed on the line.

3.3.2. Increasing the heterogeneity of volumes is a second way in which the demands placed on a production line increase. On the shop-floor, this will be measured in batch-sizes. Even if the number of bills of material on the line remains same, the same number of parts can be produced in large, medium, or small volumes. A wider range of volumes can be seen as generating more demands on the production line. A greater degree of homogeneity, and therefore a lower level of complexity is provided by "large only", as well as "two's and one's only" situations, for example. Uniformity of batch-sizes helps a production line adopt the economically and technologically appropriate elements like tooling, jigs and fixtures, material handling systems, production planning and quality control systems, and work-routines. Two compressor manufacturing plants of Copeland Corporation at Alabama and North Carolina (HBS Case # 9-686-091) exemplify successful focusing of these elements on large-only and small-only batches respectively. Non-homogeneity of volumes stretches the designed capabilities of these elements, and therefore, increases the demands placed on the line.

The two measures of focus at the production line level--number of bills of material, and homogeneity of part-volumes--can therefore be used meaningfully to capture the extent to which the demands placed on a production line varies.

3.3.3. The Hierarchical Linkage

The real power of these measures center, however, not only in their ability to capture the variations in demand at the production line level, but also in their ability to represent the variations in demand at the factory level through those at the production line level using a hierarchical linkage. Since a factory comprises production lines, an activity along any of the determinants of factory focus will likely manifest itself at the production line level. Let us consider the several ways of depicting factory focus as per Table-3.4. Corresponding to each controllable determinant along each dimension, we now employ the hierarchical linkage to describe the manifestation of factory focus at the production line level (Table-3.5.)

Table-3.5 The Hierarchical Linkage

Focusing Dimension	Controllable Determinant Activity	Production Line Implication
Product	Product-line breadth Product-line depth Product feature variety Product attribute variety Product Customization Packaging Variety Product-life cycle stages	# of BOM's on most lines # of BOM's on most lines # of BOM's on some lines # of BOM's on some lines # of BOM's on some lines # of BOM's on packaging lines # of BOM's on most lines
Volume	Range of Order Sizes Delivery lot sizes for blanket orders Allowable disruptions of production runs	Heterogeneity of volume on most lines Heterogeneity of volume on some lines Heterogeneity of volume on all lines
Customers	Number of customers Relative size of customers Product application Delivery requirements Inspection Requirements Quality levels Market segments	Likely volume heterogeneity Likely volume heterogeneity New BOM's Volume heterogeneity BOM's resulting from Change Orders BOM's resulting from Change Orders New BOM's
Process	Process Life cycle stages Number of different technologies Nature of difference in technology Materials processed	BOM's, Volume heterogeneity New BOM's -- BOM's on some lines
Geographic	Procurement area Distribution Area Standards Regulations (govt.) Delivery requirements Shipping requirements Packaging requirements lead-time	Volume heterogeneity upstream Volume heterogeneity downstream Additional BOM's on some lines Additional BOM's on some lines Volume heterogeneity downstream BOM's on downstream lines BOM's on downstream lines Volume heterogeneity downstream
Suppliers*	Number of suppliers Supplier size range Relationship mode Incoming inspection requirements	Volume heterogeneity upstream Volume heterogeneity upstream -- --

* As the table shows, unlike the other dimensions the supplier aspect of defocusing is not captured very well through line-level measures. This is not unexpected, since complexities of supplier management are usually taken care of by the Materials function, and production lines are often insulated from accompanying variations. We will, therefore, take this up in our analysis of the impact of focusing on the Materials function.

The basic notion behind the linking is that a change in the operating range along a dimension of factory focus will also manifest itself at the production line level. Through the linking, a majority of the examined changes in focus at the factory level map onto mainly two types of change in focus at the production line level: change in the number of parts, and change in the homogeneity of volume. Note that a possible third effect, establishing an additional production line, simple involves employing these same two measures on this additional line. This linking, therefore, enables us to monitor just two measures of focus at the production line level rather than having to deal with an unwieldy set of determinants at the factory level. While it may be possible to find exceptions, we observe from the above discussion that this linking procedure can be used to effectively collapse most of focusing activity at the factory level to the two measures at the line level (Figure-3.3.) This link is very powerful, and can bypass much of the difficulty associated with measuring factory focus.

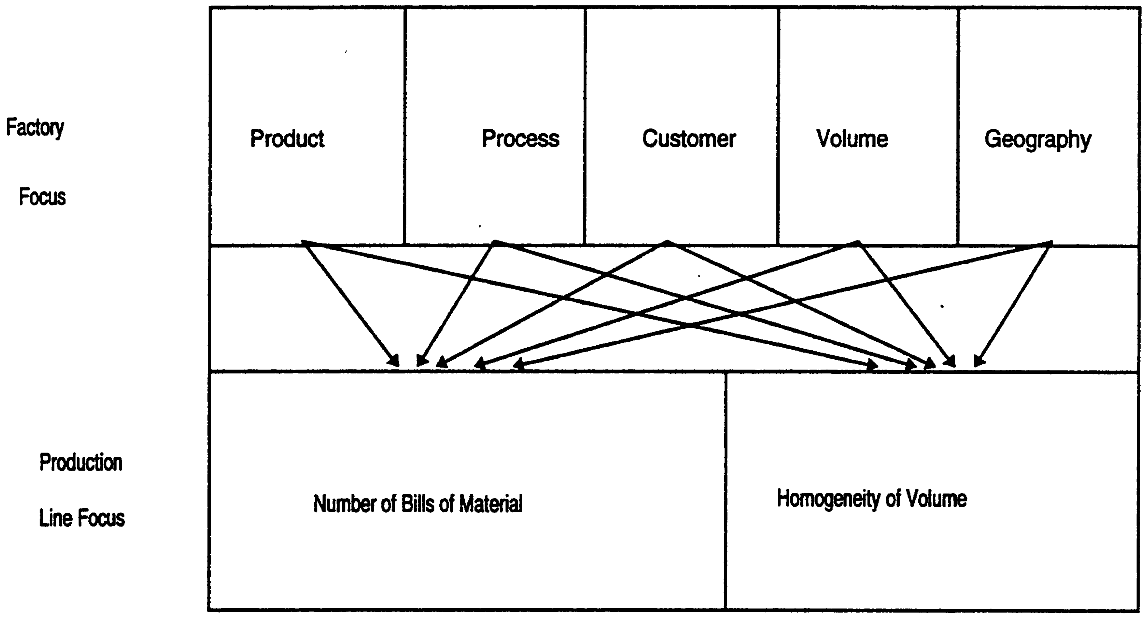

Figure-3.3. Hierarchical Linkages

3.4. Making Explicit the Manufacturing Capability Trade-offs

We have seen in Section-2.5 that the literature addresses explicitly the issue of aligning the elements of manufacturing support functions with the manufacturing task of the factory. We propose that what needs to made explicit, in addition, is the trade-off between such alignment and alternative manufacturing tasks. While it may be impossible to develop an exhaustive set of alternative tasks, the 'Focus Map' can help the process substantially.

Parallel to identifying (or narrowing) the current position of the factory along each determinant, management can also engage in the exercise of anticipating potential changes along these determinants over the life of the plant. This exercise will help define a well-articulated set of possible 'Alternative operational deliverables' which, in turn, can be examined for their effects on the production lines just as described for the current deliverable.

The approach helps not only in anticipating potential changes in demands on the system, but also understanding the implications of such changes as and when they do occur. Once the factory is in operation, any attempt to ask the factory to do anything else can be easily recognized as a shift in the operating range along a dimension. *Every time the company takes a new step, either proactively to seize an opportunity, or reactively to meet a demand, it can identify the accompanying new demand on its factory through the focus map.* Demands made on the system by the current and alternative deliverables can then be contrasted. Specifically, operational policies and procedures of manufacturing decision-categories such as Production Planning and Control, Quality Control, Engineering, Human Resources Development, Materials Handling, Sourcing and Supplier Relations, Costing, and, Maintenance can be examined for their capability to respond to the different sets of demands arrived at through the focus map. The capability trade-offs, thus, will be made explicit so that future decisions do not suffer from past errors of omission.

3.5. Long-Term Capabilities and Retaining 'Designed Unfocus'

In order for the factory to retain the capability to change its deliverable, management must enable each element of the structure and infrastructure to retain the capability to change accordingly. Note that a normative guideline prescribing how each element of structure and infrastructure can retain flexibility is neither within the scope of this study, nor its purpose. Instead, the framework can help conduct an empirical investigation discovering factors that help these elements respond to a new deliverable.

Specific designs of elements of manufacturing hardware, systems, and organization have been identified by the literature [Browne et al (1984), Gerwin (1989), Kolodny et al (1990), Sethi and Sethi (1990)] as conducive towards providing manufacturing flexibility. Although not examined in the context of the focused factory before, it is expected that these designs will also help a focused factory retain the ability to change its operational deliverable. It is possible that such designs may require deviation from the aimed simplicity of focus. We propose that a focused factory makes a conscious choice along each of its controllable determinants to design in a degree of variation around the focused position. Let us call this, 'Designed unfocus'. The designed unfocus will force the focused factory not to become too rigid in the configuration of its structure and infrastructure. Depending upon the relevant controllable determinants of a focused factory, this unfocus needs to be designed in very carefully--through a component modification, part routing difference, lot size variation, etc.,--so as to enable the factory to respond to the variation without disrupting its operations. This is no easy task. This thesis aims to only demonstrate that such unfocus helps in the long-run. A normative guideline for designing the requisite unfocus in a given situation is left to future research.

3.6. The Dynamic Framework for Factory Focus

Combining the above elements, we construct a dynamic framework for factory focus.

1) Identify relevant controllable determinants along the complementary dimensions.
2) Determine the specific hierarchical linkages.
3) Compare the implications of alternative operational deliverables for manufacturing structure and infrastructure, and thereby identify capability trade-offs explicitly.
4) Implement focus with designed unfocus.
5) Measure and monitor focus and its impact on performance regularly, for signals of change along the determinants identified in step-1 above.

3.7. APPLYING THE FRAMEWORK

The proposed framework for factory focus needs to be applied to the real-world to test its validity. It needs to be recognized up front that while the framework is built generically, application at a particular site inevitably involves site-specific concentration on chosen dimensions and controllable determinants of focus. Through studies of published instances of factory focus, this author believes that focus has been mostly interpreted and implemented as product-focus, and will proceed accordingly.

Following building-blocks 1 through 3 of the framework, the extent of focus in the product focused factory can be measured at the production-line level through, i) Number of bills of material, and, ii) Non-homogeneity of volumes. Since focusing derives its benefit from its homogeneity and simplicity [Hill (1994), p-146], and since ability to respond to change can be noted by non-deterioration of performance in the face of change [Upton (1991)], the following hypothesis is proposed.

> ***Hypothesis 1:*** *Performance of production lines deteriorate with increasing defocusing at the lines.*

The above hypothesis proposes a relationship between production-line focus and performance measures. Such relationships, however, are symptomatic. The underlying cause for these expected declining relationships can be traced back to the support functions of the focused factory. First, let us seek numerical evidence. Support functions have a factory-wide span. If these elements resist defocusing, such resistance will have plant-wide manifestations. Specifically, defocusing in one part of the factory may cause a decline in performance at another part which is not defocused itself, but linked with the defocused part through a common manufacturing structure and infrastructure. Thus, the following hypothesis is proposed.

> ***Hypothesis 2:*** *Even if the production-lines maintain their own designed focus, performance of the lines is negatively related to defocusing elsewhere in the factory.*

Beyond numerical evidence, following building-block 4, we propose that individual elements of the support functions be examined for their rigidity subsequent to focusing. Within the current notion of focus, since these elements are configured in a pattern to achieve the focused mission, they are likely to be incompatible with a defocused task. Configuration of these elements is often a lengthy, difficult and costly management exercise, and merits a detailed analysis for an understanding of if and how trade-offs are made. The following hypothesis is proposed.

> ***Hypothesis 3:*** *Capability trade-offs in a focused factory can be explicitly identified in the operating policies of its manufacturing support functions.*

Finally, we apply the framework to examine what the focused factory can do to respond to defocusing. When a focused factory is defocused, all of its production lines may not respond equally to defocusing. Lines may be different in their configuration, and some of these configurations may be more responsive than others. Following building-block 5, we propose that, *__Hypothesis 4:__ Lines with 'Designed unfocus' perform better then others when defocused.*

In the next section, we will describe a research design to scientifically test our hypotheses. Establishing support for the hypotheses will validate the new conceptual framework for factory focus that we believe manufacturing of today needs.

4. RESEARCH DESIGN AND METHODOLOGY

4.1. Nature of this Research

Research design must follow research objective. Therefore, the *nature* our research objective has to be first defined within the three fundamental research tasks of description, prediction, and explanation (Emory, 1985.)

This research will *describe* the focused factory, i) From a different perspective (complementary rather than alternate dimensions) and, ii) At a different level (production-line rather than factory) to make the notion operational and measurable rather than conceptual. *Predictive* empirical research on focused manufacturing faces the severe problem of conceptual violations of all of the three basic tenets of definition: Denotation, Clarification, and Measurement (Lachenmeyer, 1971). From the perspective of theory-building research, therefore, this work will aim at fulfilling the criteria of, i) Making possible systematic relationship-building (Dubin, 1969,) between variables and/or attributes of focused manufacturing and, ii) Imparting an explanatory understanding of the phenomenon (Scriven, 1962.) Any attempt at further theory-building through the relationships among the variables and/or attributes of focused manufacturing in such exploratory work can only lead to incompleteness (Gale, 1976), and should be avoided as a method of theory development (Hunt, 1991.)

4.2. Searching for the Appropriate Methodology

Experts within Operations Management (OM) have commented time and again about the inadequacy of traditional OM research methods in achieving research objectives of the nature undertaken here. [See for example: Ackoff (1979), Anderson et al (1979), Buffa (1980), Chase (1980).] They have also argued in favor of adopting new perspectives and methodologies to enable OM research to address such questions [Miller and Graham (1981), Hax (1981), Sullivan (1982), Chase and Prentis (1987), Hill et al (1987), Meredith et al (1989).] It is not clear, however, how much progress have been made in that direction. For example, even today there is virtually no standard, validated survey research instrument for Operations Management.

We, therefore, go outside OM for designing our research with requisite rigor. Specifically, research designs and methodologies of Anthropology, Political Science, Psychology, Sociology, and Business Policy are examined to seek the appropriate design for this work. To maintain the context of Operations Management, however, the framework of research methodologies in operations by Meredith et al (1989) is used as a reference in the discussion below. The nature of this research may require employing one or more of the several available interpretive and logical positivist/empiricist methodologies. To arrive at the appropriate methods within this subset, we consider the following criteria.

Context-dependence: The logical positivist/empiricist perspective assumes context-independence of an object or behavior, and therefore aims at absolutist inferences, while the interpretive perspective includes the context, explore meaning rather than behavior, and make relativistic inferences. Due to the violation of the above assumption of independence, however, the quest of absolute truth in empirical studies may result in inferences that are either simplistic or tautological [Campbell (1975), Cronbach (1975).] For OM research, some limitations of the empiricist perspective has been noted by Hill (1987.)

Validity versus Reliability: In general, empirical methods seeking perceptional information (e.g., surveys) allow for detailed statistical analyses, and are popular among academicians for this reason [Meredith et al (1989).] Two critical issues of concern with such methods are the reliability and validity of the test instrument. Most such research tend to *emphasize reliability by increasing sample size* without examining the effect on validity while *high reliability may well be associated with zero validity* [Emory (1985), pp. 94-98.] The lack of a universal, measurable definition of focus makes this roadblock unavoidable. Interpretive research, on the other hand, has been used successfully to investigate specific phenomenon through in-depth, but limited-scope study (e.g., Ethnography.)

Primary versus Secondary Source: Research based on perception of object reality assumes uniformity and reliability of secondary source knowledge. A reading of the practitioner literature convinced this researcher about the potential fallacy of that assumption regarding focused manufacturing. Consequently, primary source methods emerge as more desirable. Desirability of primary source methods for exploratory studies has also been discussed by Lijphart (1971 and 1975.), and interestingly, in the very first issue of the Harvard Business Review, by Donham (1922.)

Practicality: Some methods of socio-technical research are perhaps impossible to replicate in Operations Management due to the intensity and length of involvement required. (e.g., Becker, 1970 - living with subjects for several years.)

The above examination of alternatives logically concludes that the most appropriate methodology to fulfill the stated research objective is the interpretive, primary-source method of case-study.

4.3. What type of case study?

Since the basic tenets of definition prescribed for socio-technical research (Lachenmeyer, 1971) are violated by our the state of our knowledge of focused manufacturing, controlled comparison case studies of Lijphart (1971) to develop explanatory generalizations become infeasible. This difficulty is not unique, but mirrors those faced in similar efforts in other fields, as discussed by social science scholars as distinguished as Donald Campbell (1975) and Sidney Verba (1976.) Such difficulties led researchers in several fields to recognize the importance of the single-case, rather than comparative cases, as the desirable research method in such situations [Lasswell (1968), Naroll (1962), Raser (1969), Becker (1970), Russet (1971).] We follow these observations made by researchers in other fields over about the last thirty years, and adopt the single-case method. Following Eckstein's (1975) typology of case-studies for theory development, the case for this research can be classified as a *plausibility probe* case-study. The critical requirement for such a study is to formulate the explanation for the case in terms of general rather than idiographic variables (George, 1979.) Further, since the units of analysis in this phase of the research are production lines and support functions *within* a factory, the research objective will be served well due to the availability of several such units within one case.

4.4 Site selection

Following the guidelines for site-selection (George, 1979), and through a survey of the literature and subsequent dialogue with company management, the flagship factory of the Copeland Corporation at Hartselle, Alabama (HBS Case # 9-685-091) qualified as the study-site due to its experience with a successful focus, and a subsequent defocusing, as described below.

4.4.1. The Factory

Copeland established its factory at Hartselle, Alabama to manufacture a new, high-efficiency, CR model refrigerant compressor in 1979. The market was to be served with a few compressor models assembled from multiple combinations of a few parts to be produced in large batch sizes with the minimum of factory complexity.

4.4.2. Manufacturing Task

At the center of focused manufacturing at Hartselle is the machine shop that manufactures precision components. The *manufacturing task* of this shop, and in fact of Hartselle, was established as excelling in high-volume, high-precision machining of a narrow mix of components to attain the world's best cost position. The plant was very successful in implementing this focus, and the machine shop became a showpiece for the company in the early eighties. The seven lines of the machine shop are designated hereafter as ML1 (Machining Line 1), ML2, ML3, ML4, ML5, ML6 and ML7.

Management recognized that the market demand for end-product variety will not be very narrow. The manufacturing task of the assembly shop was to build variety through multiple combinations of the relatively few basic components. The assembly lines were designed with much lower set-up time and much more manual operations compared to the machine shop lines, to achieve the desired flexibility. Of the eight production lines, four are subassembly lines, and are designated as AL1 (Assembly Line 1), AL2, AL3, and AL4. The other four, the main assembly lines, designated as AL5, AL6, AL7 and AL8.

4.4.3. Focusing the Support Functions

Copeland management carefully configured the architecture of factory to carry out the focused task. Product design was changed to make parts amenable to high-volume production. The superior cost goal dictated that the high volume production of these few models be made on dedicated machine tools of dial index or transfer line type. Going further with focus, several operations requiring manufacturing technologies other than high-volume, high-precision machining were sub-contracted, and so were many routine jobs. The focus on long production runs of high volume, high precision components on dedicated machines also gave rise to specific batching and scheduling guidelines, accompanying off-line quality assurance systems, and specific procedures of other infrastructural elements like maintenance, material handling, and human resources.

With the focused factory on line, Copeland achieved tremendous success at the marketplace, and was transformed from a me-too player to the undisputed industry-leader.

4.4.4. Tradeoffs in Capability

It was recognized that by focusing on superior competence in high-volume, high-precision machining of relatively few components, what was being conceded was the ability to handle product proliferation, and the factory would find it difficult to accommodate changes in products, or the addition of a new product line. The factory has gone through two concentrated efforts to maintain and sharpen its focus, first in 1982, and then again in 1984.

4.4.5. Defocusing

Market pressure for broader product lines and customized modifications coupled with Copeland's aggressive marketing strategy gradually necessitated that Hartselle proliferate its product-line, i.e., defocus the plant. Defocusing at Hartselle came in two phases:

Incremental Defocusing: Between about 1985 and 1990, while the machined components were not proliferated, the end-products were. Minor model changes were made through the introduction of a new product--CR4.

Radical Defocusing: In 1990, a completely new line of compressor--the CR6--was introduced. It was very different in design from the previous products, and was accompanied by an increase in the number of components, often new from a processing perspective.

4.5. Research Methods at Site

In keeping with tenets of heuristic/plausibility probe (Eckstein, 1975) case-studies for hypothesis-generating (Lijphart, 1971), the objective at this stage is to *formulate potentially generalizable relationships* through the application of the framework to the chosen case. Validity of the hypotheses across the production-lines and support functions can be tested through the analyses described below.

4.5.1. Gathering and Analyzing Perceptional Data

Unstructured interviews have been noted to be a very effective method in descriptive and exploratory phases of research [Dexter (1970), Schatzman and Strauss (1973), Murphy (1980).] Several such interviews were conducted with corporate and plant level managers over the first three months of the research (October through December, 1991.) These were followed by unstructured interviews, on-site studies, and internal surveys of managers, supervisors, and staff over about one year (January to December, 1992,) examining performance as well as support functions. Unstructured interviews, by design-requirement, are pre-empted from using a standardized instrument. Following an on-site study for site-specific relevance of the factors identified in the literature (Section 3.5), the following elements of manufacturing hardware, systems and organization--shown in Table-4.1 below as explanatory variables--are examined in a cross-sectional analysis of production lines. Table-4.2 in Appendix shows the constructs used to measure each variable through an internal survey of supervisory staff. Respondents provided either primary data, or perceptional data on a Likert-type scale, as appropriate.

EXPLANATORY VARIABLES
Equipment and Parts Capacity Constraint, Set-up Time, Set-up Difficulty, Routing Difference
Incoming Material Quality, Delivery Reliability
Human Resources Issues Job-Rotation, Job-Discretion, Training, Supervisor-Worker Ratio

Table 4.1. Potential Explanatory Variables

4.5.2.Gathering and Analyzing Primary Data

Following the research design, our thrust in the statistical analysis is to formulate explanation in terms of general (rather than idiographic) variables, showing that the framework meets the unmet research need of making possible systematic research on the focused factory. In a plausibility probe study, the variable definition and potential generalizability of relationships are of prime concern. Such a study, therefore, seeks simple relationships between variables, and does not stand to gain from advanced statistical methods (George, 1979), particularly since the state of our understanding of focused manufacturing commits conceptual violations of definition prescribed for such work (Lachenmeyer, 1971.) Using multiple regression under such conditions, for example, can lead to dangerous misconclusions about hypotheses, as observed by Ryan (1960), Scheffe (1953), Selvin and Stuart (1966), and other statisticians. Accordingly, this research will employ Ordinary Least Square (OLS) regression models.

4.5.3. Variables, Constructs, and Data Sources

For the purpose of hypotheses testing, OLS regressions were performed at each of the fifteen production cost centers and the supporting functions of maintenance, materials handling, shop inspection, chemical inspection, receiving inspection, and toolroom. The two variables of interest, performance and defocusing, were captured following the requirements of our framework.

Variable	Construct	Data Source
Defocusing Variables[1]		
Product-mix	o Number of Bills of Material	1985-1992: Actual production volumes, by month, for each of the 1,300 part numbers.
Volume diversity	o Hershman-Herfindahl Index* (HHI)	Same as Above
	o Variance of part-volumes**	Same as above
Performance Variables		
Cost	o Direct Labor Hours per Unit o Indirect Labor Hours per Unit	1985-1992: Actual Direct and Indirect Labor Hours by month, by cost center.
	o Standardized Direct and Indirect Labor Hours per unit	Above actual hours, and work standards by year
Quality***	o Defects in parts per million	1990-1992: Actual parts per million levels, by cost center, by month
		1985-1990: Actual parts per million levels, by cost center, by year
	o Rework hours per unit output	1986-1988: Actual labor hours, by month
	o Scrap treatment hours per unit output	1986-1988: Actual labor hours by month

1: Both the measures of defocusing, product-mix, and volume-diversity, are measured by grouping together production volumes of parts. Grouping is done by production-line.

* For n variables $X_1, ..., X_n$, the index is defined as, $HHI = \Sigma X_i^2/(\Sigma X_i)^2$ for all i = 1,........, n

** For n variables $X_1, ..., X_n$, this measure is defined as, $Variance = \Sigma(X_i - \Sigma X_i/n)^2 / n$ for all i = 1,......., n

***Since data on actual quality performance is limited, we use two surrogate variables which are recorded on a monthly basis:

1. *Rework labor hours per unit*: If assembled compressors are found to be defective, they are taken to the rework area to be taken apart and salvaged if possible. A higher proportion of defective compressors will, therefore, result in higher rework hours per unit of good product.

2. *Scrap Treatment labor hours per unit:* Defective parts contribute to the generation of more scrap in two ways. First, the defective pieces themselves, if not salvageable, contribute directly to scrap. Secondly, the need to produce a replacement generates more scrap material. Thus, a higher proportion of defective parts will result in higher scrap-treatment hours per unit of good product.

For testing hypothesis-1 (see Section 3.7,) all five cost and quality variables of each of the fifteen lines are regressed against all three defocusing variables of the monthly output of the same production line.

Note that the independent variables will comprise components, sub-assemblies, finished products for machine lines, sub-assembly lines, and final assembly lines respectively.

For testing hypothesis-2, all three cost variables of each of the fifteen lines are regressed against relevant defocusing variable(s) of the monthly production output of the next downstream production line.

Testing of hypotheses 3 and 4 are done through a combination of the above statistical tests, and analyses of data from on-site observations, internal survey, and unstructured interviews.

5. CASE STUDY RESULTS: NUMERICAL EVIDENCE OF IMPACT OF DEFOCUSING ON PERFORMANCE

Application of the framework successfully translated defocusing at the factory-level to the line-level, as anticipated in Table 3.5. This makes possible the potential validity of the proposed hypotheses. Following the research design, primary time-series production data for 1,300 parts and fifteen cost-centers by month are analyzed to determine statistical correlations between all the variable pairs indicated in section 4.5.2. We look at the numerical evidence (the Pearson pairwise correlation coefficients, and the corresponding t-values for levels of significance) of cost-impact, quality-impact, and structural impact of defocusing in sections 5.1, 5.2, and 5.3 respectively.

5.1. Cost Impact at Production Lines

We first examine the correlation between labor hours at a line, and the defocusing of the part manufactured at that line. Correlation coefficients and corresponding t-values are shown in table 5.1 for the machine shop, Table 5.3 for the sub-assembly area, and Table 5.4 for the main assembly area. Note that independent variables are measured at different levels for the three tables, as explained in Section 4.5.3. All three tables, and other tables not in the body of the text, are found in the Appendix.

5.1.1. Machine Shop Cost Impact

To measure the effect of defocusing without the potential confounding influence of new product introduction, we examine the performance of the machine lines during the period of incremental defocusing (1985-1989.) Table-5.1 documents the correlations between labor hours and defocusing at each machining line obtained through OLS regression. The results are discussed below, and then summarized in Table-5.2. (page 27.)

Table 5.1: Machine Shop Labor Hours versus Incremental Defocusing

Discussion:

ML1 shows no evidence of a desirable scale effect, and very strong deterioration in cost-performance with loss of volume-homogeneity, borne out by the strong correlations between all measures of labor costs and both the measures of non-homogeneity of volumes. Note that the numbers of bills of material cease to be an explanatory variable here since this line has always produced the same number of components.

ML2 shows detrimental impact of increasing number of bills of material on direct and indirect labor. The effect of volume non-homogeneity is mixed. A weak, positive impact is seen on direct labor, and an insignificant impact is observed on direct labor. Desirable scale effects are observed with indirect labor, but not with direct labor hours.

ML3 line shows desirable effects of scale on direct labor, but not on indirect labor. The number of bills of material affects indirect labor detrimentally, but shows no appreciable effect on direct labor -- actual or standardized. Effects of increasing Hershman-Herfindahl Index are seen to be detrimental and significant on all labor-hour measures.

ML4 does not lend itself to a systematic analysis due to the inadequacy of available data. ML4 has two distinct operations -- roughing and finishing. The part first goes through roughing, is then sent out to a subcontractor for heat-treatment, and is then brought back and finished. While the operations are distinct and have a time-lag, the recorded data considers ML4 as one cost center and captures the total labor hours for roughing and finishing. The difficulty is that at any given time, very different part-mixes are going through the two operations, while no separate labor hour record is kept. This makes any correlation between part-mix and labor hours irrelevant.

ML5 shows no desirable effect of scale. The effects of increasing number of bills of material are almost none, but this is explained by the fact that just like ML1, ML5 also manufactured consistently the same number of part-types every month. The correlations between all labor hour measures and volume variance are strong and significant, indicating deteriorating performance with increased non-homogeneity of volumes. The correlations with Hershman-Herfindahl Index are weakly negative, and are statistically insignificant.

ML6 stands out as an exception in the machine shop. It shows consistently desirable effects of scale, and almost no detrimental impact of defocusing except between standardized direct labor hours and the Hershman-Herfindahl Index. We make a note of this observation here, and examine it in detail in Section-7.

ML7 shows a detrimental impact of increasing the number of bills of material on indirect labor costs, but no other appreciable effect elsewhere. Also, standards for this component were not changed, and therefore, standardized direct labor hours are not calculated.

Inferences:

In Table-5.1 and the above discussion, we have looked at the effects of two kinds of defocusing: Defocusing through increasing the number of parts; And defocusing through increasing non-homogeneity of product-volumes. Accordingly, Table-5.2 (based on the statistical significance of the correlation between performance and defocusing observed in Table-5.1) shows the performance of the machining lines against the two types of defocusing.

Table-5.2. Deterioration in Performance at the Machining Lines

Rows: Deterioration of Performance with Increasing Non-Homogeneity of Volumes

	Observed	*Not Observed*
Not Observed	ML2 Indirect Labor* ML7 Indirect Labor	ML7 Direct Labor ML6 Direct Labor ML6 Indirect Labor
Observed	ML2 Direct Labor ML2 Standardized Direct Labor ML3 Indirect Labor	ML5 Standardized Direct Labor ML5 Direct Labor ML5 Indirect Labor ML1 Direct Labor ML1 Indirect Labor ML6 Standardized Direct Labor ML3 Direct Labor ML3 Standardized Direct Labor

Columns: Deterioration in Performance with Increasing Number of Parts

*Example: Indicates indirect labor hour performance of Machine Line 2 (ML2)

Note that out of the sixteen dependent variables measured, eleven exhibit deteriorating cost-performance with increasing non-homogeneity of volume. Of the five that do not, two belong to one line, ML6. We make a note of this inference of Table-5.2, and come back to it after we look at the assembly shop below.

Assembly Shop Cost Impact:

OLS regressions are run between assembly shop variables of interest in pairs, and the results are noted in Tables 5.3 and 5.4, discussed below, and then <u>summarized in Table-5.5. (next page.)</u>

Table 5.3 here: Subassembly Labor Hours vs. Incremental Defocusing

Table 5.4 here: Assembly Labor Hours vs. Incremental Defocusing

Discussion:

At AL1, scale has almost no impact on direct labor hours, the number of bills of material has a strong negative correlation, while the variance of volumes has a strong positive correlation with labor hours. Thus while the line seems to have the flexibility to accommodate an increasing number of parts, it cannot handle the defocusing of large, homogeneous volumes.

AL2 shows a strong, positive correlation between costs and volume-variance of its own, and does not show any statistically significant relationship between any other pair of variables.

AL3 shows a strong positive correlation between costs and its Hershman-Herfindahl Index. Since this index is a combined measure of variety and volume-variance, a combination of these two modes of defocusing seems to hurt, while individually none of the modes seem to have any impact.

AL4 is somewhat different from other sub-assemblies in two respects: First, it is the only sub-assembly line where indirect labor is a significant part of the total labor, and second, its next downstream level is the compressor with peripheral-variety, unlike core-variety for the other sub-assemblies. Both these aspects are considered in the analysis. Strong correlations, both positive and negative, are observed between several variables. Overall, both the number of bills of material and the volume variance appear to detrimentally impact direct as well as indirect labor. It is the only production line that shows deteriorating performance in terms of both types of flexibilities. We take note of this fact here, and revisit this production line later in our talk about sourcing in Section-6.

AL5 direct labor hours are strongly and detrimentally impacted by core defocusing as observed in the positive correlation coefficients with significant t-value. No significant effect is observed on indirect labor. The variance of volumes also has moderate, positive correlations with direct labor hours. This corroborates the notion that reduced volume-homogeneity hurts productivity.

AL6 exhibits very interesting correlations. It appears that increasing volume-variance has actually helped reduce costs, while increasing the number of parts hurt productivity. One may argue that this line exhibits excellent flexibility of handling non-homogeneous volumes, but shows marked inflexibility towards accepting an increased variety of parts, i.e., it exhibits product flexibility but no product-mix flexibility.

No significant impact of defocusing is observed on AL7. All of the correlation coefficients, positive or negative, are very weak and insignificant.

Inferences:

Table-5.5 shows the performance of the assembly lines against the two types of defocusing. The table is based on the statistical significance of the correlations between labor hours and defocusing observed in Tables 5.3 and 5.4.

Table 5.5. Deterioration in Performance at the Assembly Lines

Deterioration of Performance with Increasing Non-Homogeneity of Volumes		Deterioration of Performance with Increasing Number of Parts: *Observed*	Deterioration of Performance with Increasing Number of Parts: *Not observed*
	Not Observed	AL6 Direct Labor*	AL7 Direct Labor
	Observed	AL4 Direct Labor	AL1 Direct Labor AL2 Direct Labor AL3 Direct Labor AL5 Direct Labor

* For example: Indicates direct labor hour performance of Assembly Line 6 (AL6)

Note that five out of seven lines of the assembly shop (excluding packaging), AL5 and the four subassemblies, exhibit deteriorating performance with increasing non-homogeneity of volume. The two that do not, AL6 and AL7, are examined in detail later in Chapter-7. Let us combine this inference with that from the machine shop (Table-5.2), where we observed that eleven out of sixteen dependent variables show deteriorating cost-performance with increasing non-homogeneity of volume. Then the analysis supports **Hypothesis 1,** since,

Cost, measured in direct as well as indirect labor hours per unit, is observed to be an increasing function of the deviation from the factory focus on homogeneous volumes.

Further, such deterioration in efficiency is observed irrespective of whether the operation involves machining or assembly. It is observed from Table-5.5 that while five out of eight assembly line variables *do not* show any deterioration of performance with an increase in the number of bills of material produced, six out of eight assembly variables *do show* deteriorating performance with increasing non-homogeneity of volume. This is particularly important for the assembly shop since it was understood that these lines will have to produce variety by assembling multiple combinations of relatively few basic components, and 'flexibility' was provided through short changeovers and mostly manual operations. In interviews, management maintains that 'Changeover is a problem in the machine shop, not in assembly.' What we observe is that although the targeted flexibility was provided and has proven itself, defocusing put a demand for a different type of flexibility, that of adjusting to non-homogeneous production *volumes.* The lines did not possess this flexibility. This illustrates the importance of understanding the different types of flexibility and designing a system to possess the appropriate ones. Thus, we arrive at the following **corollary to Hypothesis-1.**

Corollary 1.1: Flexibility-types need to be specifically understood and implemented. The assembly lines were designed with the flexibility to adjust to multiple products, but they failed to respond to the need for a different type of flexibility: To adjust to non-homogeneous production volumes.

5.2. Impact of Defocusing on Output Quality

This section will look at the quality performance and the quality practices at Hartselle, and will examine if there is any evidence that quality performance has deteriorated with greater defocusing. First, we look at quality performance of the individual production lines over a 48-month period (Table 5.6.) The limitation of these data that they are available only on a yearly basis. Although this prohibits the use of regression analysis on this data, we can however, examine the data to see how output quality has behaved over the time period of incremental proliferation. The data shows that quality performance deteriorated both externally and internally. Defective rates at customer sites increased consistently through 1989, while internally, defective rates at a majority of production lines increased. In fact, at seven out of eleven quality check points, annual defective rates have increased in 1989 over 1988, and in six out of the same eleven, annual defectives rates have increased in 1989 over 1987. This precisely is the time period over which incremental defocusing occurred.

Table-5.6 here: Defective Levels at Quality Checkpoints; 1987-1990

Table-5.7 shows the correlations between the Hershman-Herfindahl Index (HHI) for each line with a quality checkpoint, and the labor hours consumed by the Rework and Scrap-Treatment for every good output unit.

Table 5.7 here: Cost of Quality versus Defocusing

As seen, per-unit Rework and Scrap-treatment hours have strong, positive correlations with the HHI of several components and sub-assemblies. Therefore, producing less homogeneous part-volumes at each line has a detrimental impact on the labor hours required for these two functions. Thus, by combining the greater defective proportions (from Table 5.6) over the time period of defocusing, and the increasing costs of Rework and Scrap (from Table 5.7) with defocusing, further, but limited support is found for **Hypothesis 1.**

5.3. Structural Resistance

In order to test structural resistance, we examine end-product proliferation at two levels: i) Compressor with peripherals (fittings, mountings, tubes, electrical, etc.); and, ii) Compressor without peripherals (the core compressor). Within Copeland, these two levels are represented by the 17-digit bill-of-material, and the 13-digit bill-of-material respectively. All the machined components, and all but one of the sub-assemblies go into making the compressor core. The AL4 sub-assembly and all assembly lines have the 17-digit compressor as the next downstream level of end-product. Results of correlations of labor hours at these lines with the appropriate end-product proliferation are depicted in Table-5.8.

Table-5.8 here: End-Product Proliferation versus Upstream Line Labor Hours

As observed from Table-5.8, the impact of defocusing downstream is very significant on upstream operations. In fact all machining lines (and also two assembly lines) show statistically significant and strong deterioration in cost performance with downstream defocusing, supporting **Hypothesis 2:**

In spite of not being proliferated themselves, unit-labor-hour cost at the machining lines is an increasing function of proliferation elsewhere in the factory, viz., at the end-product level.

In the next two sections we seek explanations behind the numerical evidence presented above.

6. CASE-STUDY RESULTS: INVESTIGATING THE SUPPORT FUNCTIONS

To move from numerical evidence to possible underlying causes, the impact of defocusing on each manufacturing support function is examined in turn. One basic approach is followed in the analysis. For each function, it is noted what policies and procedures were established following factory focus. Then evidence is sought--statistical, perceptional or anecdotal--showing the operations of that function in the defocused environment. Table-6.1 shows some of the correlations that exist between the support function hours and defocusing. We draw upon this table for statistical evidence, and on the supervisory survey and the interviews (see Section 4.5.1) for perceptional and anecdotal evidence throughout this section. This evidence is then analyzed to examine if the initial policies and procedures may have led to later problems in the new environment. This process is repeated for the following manufacturing support functions (in alphabetical order): i) Maintenance, ii) Process Engineering, iii) Production Planning and Control, iv) Quality Control, v) Sourcing and Supplier Relations. For the sake of brevity, the analysis is reported here for only one support function: Maintenance.

6.1. Initial Focus

The maintenance function plays a crucial role if a factory focused as at Hartselle is to succeed. The focus is on achieving a low-cost position through high-volume, high-precision machining. In order to succeed at the desired focus, it was important to have minimal downtime on the sophisticated machine tools that performed the high-precision machining.

Management recognized this importance up front. Superior maintenance of sophisticated machinery require highly skilled maintenance people. An important factor in the factory location decision was the adequate availability of skilled maintenance labor in the Huntsville area (due to the presence of NASA). The skilled maintenance force was then given an explicit functional task, to achieve 'superior up-time of equipment.' We must recognize, however, that the maintenance task had to be carried out within a plant-level objective of long, uninterrupted production-runs of the machine tools. Implicitly, therefore, the maintenance task was to ensure superior up-time of equipment having long, uninterrupted production-runs. This task, in order, led to the following three operational procedures:

• Procedure 1	Off-shift detection and correction of maintenance problems so that production is not interrupted.
• Procedure 2	Preventive Maintenance schedules arranged around long-run production schedules.
• Procedure 3	Spare-parts inventory policies consistent with the above preventive maintenance schedules.

Table 6.2: Maintenance Procedures Subsequent to Focusing

6.2. Observations

Defocusing, measured by the Hirschman-Herfindahl Index (HHI), has a positive correlation with maintenance hours per unit produced (Table 6.1) indicating that maintenance costs increase with defocusing.

To measure the effect of CR6 introduction, the 12-month averages of monthly maintenance labor-hours were compared before-versus-after CR6 introduction. To keep the comparison free of disruption by new product introduction, we wait till six-months into the production of CR6. The results shows that the *average* *per-unit maintenance labor-hours increased 52%* after CR6 introduction compared to the levels before. Since CR6 introduction helped increase the number of 13-digit and 17-digit models considerably, it is plausible that the statistically significant impact that is observed with incremental defocusing above is *manifested further* with CR6 introduction. It is to be noted here that the plant underwent a maintenance overhaul in 1990, prior to CR6 introduction, suggesting that the problems persisted in spite of the management action.

A one-week study was performed on machine downtime at the individual machine level during the week of 5/16 - 5/21 of 1992. Total time lost due to, i) Line being down, ii) Mechanical failures, and, iii) Electrical failures, were recorded for 29 machine tools. Note that this lost time does not include time lost due to scheduled maintenance work. On an average, each machine had a downtime of four hours and seven minutes, or half-a-shift, during the week due to the above maintenance problems. Out of the twenty-nine, the top sixteen failing machines each had an average of about seven hours of downtime, or almost a shift. Typical quotes from plant-personnel are, "Machine downtime is a big headache", and "It (machine downtime) kills us".

6.3. Analysis

The findings above suggest that: i) Defocusing - incremental or radical - is associated with higher maintenance costs, and, ii) In spite of the management decision to respond to maintenance problems with a maintenance overhaul of the plant, the problems still persist. We explore likely causes below:

6.3.1. Hardware Failure

Maintenance, like any other manufacturing support function, carried out its task within a changing manufacturing environment of the plant. While production in the plant increased about 2.5 times, no major equipment capacity was added to the plant. Increased production was absorbed by increasing capacity utilization. This meant, i) Higher capacity utilization, and, ii) Addition of a third shift for most of the year. What is important here is that this rise in production volume was gained by proliferating the product line rather than producing more of the same models. Thus, while monthly production volume rose, individual production runs became shorter, leading to frequent starts and stops of machinery. This machinery, purchased for a factory with long runs, may not have been designed to absorb the frequent electro-mechanical surges of short runs. It is perhaps no coincidence electrical and mechanical failures are perceived as leading causes of downtime.

6.3.2. Procedural Failure

• **Procedure l: Off-shift detection and correction of problems:** Higher capacity utilization, frequent changeovers, and regularity of the third shift, made the availability of 'off-shift' time-slots much more scarce. The established operational procedure of problem-solving became inconsistent with the new reality. Maintenance problems now had to be attended to *within* production time, hurting output directly.

• **Procedure 2: Preventive Maintenance schedules:** The initial idea of arranging preventive maintenance schedules around long production runs worked well in an era of available capacity slack. With production-pressure ever-increasing, same-day repair became essential, leading to more *corrective* maintenance. Also, as we have argued, more frequent starts and stops may have caused the more frequent failure problems, leading in turn to *more frequent corrective maintenance.* Therefore, the dominant mode of maintenance is changing, i) from scheduled to unscheduled, and, ii) from preventive to corrective. Unscheduled corrective maintenance of more frequently failing machines would certainly result in much more maintenance costs than scheduled preventive maintenance of less frequently failing equipment.

• **Procedure 3: Spare-parts inventory policy:** The spare parts policy proved highly inadequate to meet the demands of the new situation. That policy was geared to meet the needs of a well-planned preventive maintenance schedule, and fell far short of keeping up with the far more heightened demands of parts-availability of a frequent, unscheduled corrective maintenance scenario. As a result, we find production being stopped because of lack of spare-parts for the failed machine tools. It is also possible that costs increase due to the expediting that follows such stockout.

6.4. Synthesis

Defocusing, and the consequent short runs, may have required the production equipment to operate in a way they were not designed to operate, resulting in frequent hardware failure. The initial focus on high-volume may have overlooked such details of machine tool design that were not relevant in a high-volume environment, but could have become important in a defocused factory.

It became impossible, upon defocusing, to follow the carefully designed maintenance procedures focused on the previous task. The inconsistency between the new demands and the old practices becomes clear in our analysis. All three operational procedures are seen to be out of synch with the new reality, interrupting production and increasing costs.

It is also observed that the management response to maintenance problems was well motivated but inadequate. What the 1990 maintenance overhaul did, of course, was to recondition the machines. But what it did not, and could not do, was to remove what appear to be strong reasons behind increased downtime: Obsolete operational procedures in a changed manufacturing environment. The new task still remains ensuring 'superior up-time', but the old way of operationalizing that task does not work anymore. Since product-proliferation is here to stay, management must redesign the policies and procedures of maintenance to enable that function to achieve its mission without incurring increasing costs or interrupting production.

6.5. A General Note on the Manufacturing Infrastructure

Through essentially similar examination of the other manufacturing support functions, we observe the emergence of a pattern. The policies and procedures consequent to focusing can be seen to lead to the problem symptoms after defocusing. The analyses suggest that the infrastructural configuration subsequent to focusing later became an impediment in the defocused environment, supporting **Hypothesis 3.**

Capability trade-offs in the focused factory can be explicitly identified in the operational policies and procedures of its manufacturing support functions.

Consistent with our framework, therefore, an examination of the alternative operational deliverables generated by the focus-map will make explicit this capability trade-off up front. There is a huge potential for future research on alternate infrastructural configurations that will help a focused factory retain such capabilities.

7. CASE STUDY RESULTS - RESPONDING TO DEFOCUSING

As seen in Sections 5.1, and 5.2, both in the assembly shop and the machine shop, some production lines have been more successful than others in responding to the deliverables of a new environment. As a next step, it is desirable to study what underlying factors may be observed in explaining the differences in the adaptability of different lines to defocusing. As per Section 4.5.1, elements of manufacturing hardware, systems, and organization were examined through the internal survey for potential relationships with the ability of a line to respond to the change. Survey results, measuring each element of each line on Likert-type scales (Table 4.2, Appendix), were compared with the observed flexibilities of the lines (Tables 5.2 and 5.5,) and a set of inferences are drawn about the role of the examined elements in responding to defocusing. For the sake of brevity, the results are not described in detail, but are summarized in Table 7.1.

TABLE 7.1. Elements that Help Respond to Defocusing

Evidence* whether an element helps in responding to a defocused task:	Elements of hardware, systems, or organization
Strong Evidence	1. Greater (perceived) capacity constraint** 2. Greater (perceived) difficulty of set-up** 3. Less (perceived) adequacy of worker-training**
Limited Evidence	4. Lower set-up time 5. Experience with several part routings 6. Higher (perceived) quality of incoming material 7. Greater extent of job-discretion 8. Greater extent of job-rotation
No Evidence	9. Higher (perceived) delivery reliability of incoming material 10. Higher ratio of supervisor to workers

* Evidence is sought in three categories:

Strong Evidence: One-to-one correspondence between presence of element (Tables 7.1 - 7.4) and observed flexibilities (Tables 5.2, and 5.5) on 80% to 100% of the lines.

Limited Evidence: Such correspondence on 50% to 70% of the lines.

No Evidence: No such correspondence.

** Counter-intuitive. See Section 7.1 for inferences.

7.1. Inferences and Strategic Implications

The set of elements that shows limited evidence of flexibility of responding, lends itself to further analysis for managerial implications. Two of them, lowering set-up time, and ensuring better quality of incoming material, are managerial tasks that conventional wisdom dictates, and need no stressing. As in almost any manufacturing environment, these two remain desirable in a focused factory as well, and help it respond to a defocused deliverable.

The other three--difference in part routing, job-rotation, and job-discretion--are more interesting in the current context because they play significant roles in enabling the focused factory to defocus effectively. All these elements have a common thread running through them--an ability to learn to deal with increased complexity. Whether it is through learning to handle the complexity of dealing with parts that take different paths through a production line, whether it is through learning to handle the complexity of rotating between tasks, or it is through learning to handle the complexity of making decisions, *these elements enabled the focused factory to learn to handle the very complexity that focusing so carefully tried to keep out.* It is no coincidence, therefore, that the presence of these elements is associated with an increased ability to handle a defocused task. The point here is not to concentrate on these three particular elements, but to recognize that it may be entirely possible for the focused factory, through possessing elements such as these by design rather than default (let us call it 'designed unfocus'), to learn to respond to a defocused task if and when needed in the long-term, without sacrificing its focus and the consequent benefits in the short run. That this is possible has been shown by the experience of the production lines of Hartselle. The task for management is to identify and systematically implement such channels of learning to handle complexity. This provides limited support for **Hypothesis 4.**

Operations with elements of 'Designed Unfocus' respond better to the defocused task.

Next, the three elements that are associated strongly with flexibility to respond to defocusing warrant closer attention. The inference about the perceived seriousness of these elements is very remarkable, because it is counterintuitive. Only on these lines, supervisors have perceived the capacity constraint as very tight, the set-ups as very difficult, the training as grossly inadequate. And only on these lines is observed non-deteriorating performance in terms of efficiency of direct and/or indirect labor in the defocused environment. In other words, only the lines whose supervisors perceive these problems as very severe have responded with flexibility. All these problems, tight capacity, difficult set-ups, and inadequate training, are expected, however, to lower the flexibility of a line. *What we see instead, is that a recognition of these problems is associated with greater flexibility.* What may actually be happening is that these problems are real for all the lines, not just these three. However, only the ones that recognize the problems can hope to address them, while the others, oblivious of the seriousness of the problem, cannot even get started in responding to them, and consequently experience falling performance.

This underscores the **criticality of recognition of production problems at the first-line-supervisor level.** For a production line problem to be addressed by management, the problem has to be recognized by the first line of management, the shopfloor supervisor. As the production environment gets increasingly complex in the factories of tomorrow, what may be called for, indeed, is a new breed of people to take up this position of first line supervisor, *a job the definition and scope of which must also change* accordingly to represent the new reality of dynamic manufacturing.

8. BEYOND PLAUSIBILITY PROBE

8.1. External Survey

Since one of the objectives of the framework is to provide a better understanding of focus, the extent of practitioner-understanding of the issue was assessed through a small-sample survey. A questionnaire (not repeated here) was sent to manufacturing executives of companies indicated in published literature as having focused factories. Results of the survey confirm a notion that motivated this study (Section 1.1.1), that 'focus' is not understood well enough for its competitive benefits to be realized. The idea is not of semantic conformity, but competitive advantage.

8.2. Future Work

In a logical extension of this study, future work will undertake decisive hypotheses testing through controlled comparison case-studies [Lijphart (1971)] towards development of integrated theory of focused manufacturing in a dynamic environment.

9. CONCLUSIONS

The entirety of this work is summarized below in a tabular form. Each of the column headings of the table corresponds one-to-one with the sections of the paper.

1. Progress towards Bridging Conceptual Research Gaps

Research Gap	*Conceptual Approach for filling the gap*	*Methodology*	*Results*	*Contribution*
1. Limitations of Current Frameworks	**New Conceptual framework**	See below	See below	**Significant progress towards filling the research gaps left unaddressed since the advent of the focused factory notion**
1.1. Lack of Operational Definition 1.2. No well-developed lassification system for types of focus	Dimensions of focus are *complementary*, not alternate Each dimension has several *controllable determinants*	Develop a 'Focus-map' of a factory Examine practice and literature to identify determinants by focus-type Cross-sectional small-sample survey	Derived an 'Operational Deliverable' for a factory Identified managerially controllable levers in focusing Focus-type not understood well in practice	Defined focus at an operational level Provided operational guidelines for achieving and monitoring focus
1.3. No Measure of focus	Establish hierarchical linkage between levels of focus	Measure focus at production-line level, not factory level	Quantitative measures of focus	Provided a way of measuring focus for the first time
1.4. Static perspective on focus	Requisite unfocus helps respond to a dynamic environment	Consider focus over the life of the factory in a changing environment, not at a point of time	Made explicit capability trade-offs in the manufacturing structure and infrastructure Demonstrated the importance of 'designed unfocus'	Examines focus within the context of longer-term manufacturing capabilities

2. Progress towards Bridging Empirical Research Gaps

Research Gap	*Empirical Approach for filling the gap*	*Methodology*	*Empirical Results*	*Contribution*
2. Lack of Rigorous Studies (Result of limitations of frameworks)	Apply new framework to a real-world focused factory	Plausibility-Probe case-study of a focused factory	See below	**First quantitative examination of focus at the production line and support function level**
2.1. No assessment of relationship of focus with performance	Examine quantitatively the impact of focus on performance in a focused factory	Analyze longitudinally primary data of a focused factory	Statistically significant relationships between defocus, and performance	First quantitative assessment of relationship between focus and line performance
2.2. No study of trade-offs made in the focused factory	Examine longitudinally the support functions of a focused factory for resistance to a new task	Primary data analysis, interviews and survey within a focused factory, conducted over a year	Statistical evidence and detailed understanding of how the structure and infrastructure resist a new task	Made explicit capability trade-offs in a focused factory
2.3. No examination of long-term competitiveness of the focused factory	Examine longitudinally a focused factory with a changing deliverable, f or responsiveness to a new task	As above	Strong association between responsiveness and certain elements of manufacturing structure and infrastructure	Demonstrated the importance of 'Designed Unfocus' in building long-term manufacturing capabilities Rethinking the role of first-line supervisors in operations management

APPENDIX

Tables

Table 4.2: Constructs and Scales for Explanatory Elements

EXPLANATORY VARIABLES	MEASURING SCALE
Equipment and Parts	
Capacity Constraint	[1: Not at all constrained, 2: Somewhat constrained, 3: Moderately constrained, 4: Quite constrained, and 5: Extremely constrained]
Set-up Time	Actual set-up times are recorded for each of the fifteen production lines.
Set-up Difficulty	[1: Not at all difficult, 2: Somewhat difficult, 3: Moderately difficult, 4: Quite difficult, and 5: Extremely difficult].
Part Routing Difference	[1: Not at all different, 2: Somewhat different, 3: Moderately different, 4: Mostly different, and 5: Different for each part]
Incoming Material	
Quality of Incoming Material	[1: Very dissatisfied, 2: Somewhat dissatisfied, 3: Neither satisfied nor dissatisfied, 4: Somewhat satisfied, and 5: Very satisfied].
Delivery Reliability of Incoming Material	[1: Very dissatisfied, 2: Somewhat dissatisfied, 3: Neither satisfied nor dissatisfied, 4: Somewhat satisfied, and 5: Very satisfied].
Human Resources Issues	
Job-Rotation	[0: No rotation, 1: Rotate once a quarter, 2: Rotate once a month, 3: Rotate every week, 4: Rotate every day 5: Rotate within a shift]
Job-Discretion	[1: Supervisor specifies every detail of daily task, no worker-discretion, 2: Supervisor specifies most of the work, but some worker-discretion, 3: Supervisor provides broad assignment, moderate worker-discretion, 4: Supervisor sets targets only, substantial worker-discretion, 5: Supervisor is a facilitator, full worker-discretion]
Training	[1: Much less than adequate, 2: Less than adequate, 3: Just about adequate, 4: More than adequate, and 5: Much more than adequate].
Supervisor-Worker Ratio	Actual ratios are recorded for each of the fifteen production lines and shown in Table 7.4., indicating the number of workers per supervisors.

TABLE 5.1. Machine Shop Labor Hours vs. Incremental Defocusing:

Pearson Pairwise Correlation Coefficients

	Component Defocusing			
Labor Hours per unit	Production Volume	Number of Bills of Material	Hershman-Herfindahl Index of Core-Volumes	Variance of Core-Volumes
ML1 Direct Labor	.281 (.93)	n/a	**.511*** (3.94)	**.669** (5.97)
ML1 Indirect Labor	.265 (1.82)	n/a	**.469** (3.52)	**.585** (4.79)
ML1 Standardized Direct Labor	.194 (1.31)	n/a	**.431** (3.17)	**.499** (3.82)
ML2 Direct Labor	.151 (1.02)	**.480** (3.37)	.233 (1.6)	.006 (.04)
ML2 Indirect Labor	**-.329** (2.3)	**.364** (2.38)	.106 (.71)	.107 (.65)
ML2 Standardized Direct Labor	.114 (.76)	**.464** (3.19)	.217 (1.48)	.015 (.09)
ML3 Direct Labor	**-.344** (2.45)	.03 (.19)	**.396** (2.9)	.043 (.27)
ML3 Indirect Labor	**.349** (2.47)	**.391** (2.59)	**.301** (.2.08)	.215 (1.34)
ML3 Standardized Direct Labor	-.199 (1.35)	.096 (.59)	**.298** (2.07)	-.118 (.72)

(Continued...)

* Example: Figures in this cell indicate that per-unit direct labor hours at Machining Line 1 (ML1) have a correlation coefficient of 0.511 (with a t-value of 3.94,) with the Hershman-Herfindahl Index of monthly volumes of all components manufactured on ML1.

Figures in bold indicate statistical significance at 0.01 level of testing.

n/a : not applicable

TABLE 5.1 (Continued): Machine Shop Labor Hour vs. Incremental Defocusing:

Pearson Pairwise Correlation Coefficients

	Component Defocusing			
Labor Hours per unit	Production Volume	Number of Bills of Material	Hershman-Herfindahl Index of Core-Volumes	Variance of Core-Volumes
ML5 Direct labor	.275 (1.89)	.040 (.25)	-.144 (.97)	**.370** (2.43)
ML5 Indirect Labor	.015 (.101)	.157 (.96)	-.145 (.97)	**.424** (2.85)
ML5 Standardized Direct Labor	**.360** (2.56)	.056 (.31)	-.187 (1.26)	**.416** (2.79)
ML6 Direct labor	-.249 (1.7)	-.242 (1.54)	-.007 (.04)	.029 (.16)
ML6 Indirect Labor	**-.378** (2.71)	-.191 (1.19)	-.002 (.011)	-.1 (.54)
ML6 Standardized Direct Labor	-.004 (.03)	-.3 (1.91)	**-.313** (2.16)	-.199 (1.09)
ML7 Direct Labor	.003 (.02)	-.049 (.3)	.010 (.07)	.116 (.711)
ML7 Indirect Labor	-.187 (1.27)	.285 (1.79)	.049 (.32)	.080 (.49)
ML7 Standardized Direct Labor	n/a	n/a	n/a	n/a

Note: Machining Line 4 is not amenable to statistical analysis, due to data limitations as explained in Section 5.1.

· Figures in parentheses indicate t-values in this and all subsequent tables. n/a: not applicable

TABLE 5.3

Sub-Assembly Labor Hours vs. Incremental Defocusing:

Pearson Pairwise Correlation Coefficients

	Sub-Assembly Defocusing			
Labor Hours per unit	Production Volume	Number of Bills of Material	Hershman-Herfindahl Index of s/a Volumes	Variance of s/a Volumes
AL1 Direct Labor	.097* (.65)	**-.433** (2.91)	-.006 (.04)	**.302** (1.93)
AL2 Direct Labor	-.032 (.21)	-.142 (.87)	-.153* (1.02)	**.466** (3.21)
AL3 Direct Labor	.122 (.82)	-.035 (.21)	**.427** (3.13)	.016 (.099)
AL4 Direct Labor	.186 (1.26)	**.292** (1.85)	.189 (1.28)	.234 (1.47)
AL4 Indirect Labor	-.016 (.11)	.13 (.79)	**.395** (2.84)	.247 (1.55)

* Example: Figures in this cell indicate that per-unit direct labor hours at Sub-Assembly Line 1 (AL1) have a correlation coefficient of 0.097 (with a t-value of 0.65) with the monthly production volumes of all sub-assemblies made on AL1.

Figures in bold indicate statistical significance at 0.01 level of testing.

TABLE 5.4

Assembly Labor Hour vs. Incremental Defocusing:

Pearson Pairwise Correlation Coefficients

	Compressor Core Defocusing			
Labor Hours per unit	Production Volume	Number of Bills of Material	Hershman-Herfindahl Index of Core-Volumes	Variance of Core-Volumes
AL5 Direct Labor	-.116 (.81))	-.08 (.52)	**.347*** (2.45)	.266 (1.83)
AL5 Indirect Labor	.107 (.77)	.194 (1.31)	.021 (.14)	-.208 (1.41)
AL6 Direct Labor	-.113 (.754)	**.291** (2.04)	**-.303** (2.11)	-.217 (1.47)
AL7 Direct Labor	-.06 (.44)	-.121 (.81)	.079 (.52)	-.142 (.94)
AL8 Direct Labor	-.176 (1.09)	**.297** (2.07)	.078 (.52)	-.179 (1.2)

* Example: Figures in this cell indicate that per-unit direct labor hours at Assembly Line 5 (AL5) have a correlation coefficient of 0.347 (with a t-value of 2.45,) with the Hershman-Herfindahl Index of monthly volumes of all core-compressors (i.e., at core level, see Section 5.3 for explanation) assembled on AL1.

Figures in bold indicate statistical significance at 0.01 level of testing.

· Figures in parentheses indicate t-values.

Table 5.6

Defective Levels at Quality Checkpoints; 1987-1991

(Defective levels measured in parts per million)

	1987	1988	1989	1990	1991
Quality Checkpoints					
Field Returns	467	591	723	806	945
Assembly Check 1	19436	19876	18498	21687	21456
Assembly Check 2	33980	41235	46781	40981	39387
Machining Line 1	16578	19873	21456	23792	24603
Machining Line 2	42567	47891	50929	52386	53476
Machining Line 3	11876	13258	15672	17653	16783
Machining Line 4, check 1	23985	21894	25672	28719	29871
Machining Line 4, check 2	9876	10115	9982	11265	10934
Machining Line 5	5879	6698	7438	7568	7769
Machining Line 6	17629	19276	21876	22063	23118
Machining Line 7	29876	34983	35876	38763	39815

Note: Data disguised for confidentiality

Table 5.7: Quality (Surrogates) vs. Incremental Defocusing: Pearson Pairwise Correlation Coefficients

Quality Surrogates	Hershman Herfindahl Index of monthly volumes of parts made on lines with quality checkpoints										
	Assembly Line 1	Assembly Line 2	Assembly Line 3	Machining Line 1	Machining Line 2	Machining Line 3	Machining Line 4 Operation 1	Machining Line 4 Operation 2	Machining Line 5	Machining Line 6	Machining Line 7
Scrap treatment hours per output unit	.018 (.07)	**.334** (1.37)	-.045 (.17)	**.375** (1.56)	.29 (1.18)	.301 (1.22)	**.486** (2.16)	.306 (1.24)	.034 (.13)	-.088 (.34)	**.561** (2.63)
Rework hours per output unit	**.531** (2.17)	.087 (.31)	**.358** (1.33)	-.252 (1.01)	.316 (1.16)	**.39** (1.47)	**.719** (3.58)	.092 (.32)	**.406** (1.54)	-.36 (1.34)	**.682** (3.09)

Note: Due to limitations of data availability, a level of significance greater than 0.10 could not be attempted. Figures in bold indicate significance at this level.

TABLE 5.8

End-Product Proliferation[1] versus Upstream production-Line Labor hours:

Pearson Pairwise Correlation Coefficients

	Direct Labor	Indirect labor	Standardized Direct Labor
Machining Line 1	**.654**, (5.72)*	**.475**, (3.57)	**.457**, (3.4)
Machining Line 2	**.564**, (4.56)	**.286**, (1.97)	**.559**, (4.47)
Machining Line 3	.101, (.67)	**.508**, (3.91)	.207, (1.4)
Machining Line 4	**.328**, (2.33)	.01, (.07)	.175, (1.18)
Machining Line 5	**.639**, (5.51)	**.412**, (2.99)	**.653**, (5.71)
Machining Line 6	**.284**, (1.96)	.151, (1.01)	**.504**, (3.82)
Machining Line 7	-.107, (.71)	**.368**, (2.62)	n/a
Assembly Line 1	-.047, (.31)	n/a	n/a
Assembly Line 2	.197, (1.33)	n/a	.145, (.99)
Assembly Line 3	-.004, (.02)	n/a	n/a
Assembly Line 4	-.042, (.27)	**.661**, (5.84)	n/a
Assembly Line 5	-..08, (.52)	.194, (1.3)	n/a
Assembly Line 6	**.297**, (2.06)	n/a	-.2, (1.38)
Assembly Line 7	-.121, (.59)	n/a	n/a

1: The end-product for machining lines (ML1 through ML7,) and sub-assembly lines AL1 through AL3 is the compressor without peripherals, while that for assembly lines AL4 through AL7 is the compressor with peripherals, as explained in Section 5.3.

* Example: Figures in this cell indicate that per-unit direct labor hours at Machining Line 1 (ML1) have a correlation coefficient of 0.654 (with a t-value of 5.72,) with the Hershman-Herfindahl Index of monthly volumes of all end-products (at appropriate levels as explained above) manufactured by the factory.

Figures in bold indicate statistical significance at 0.01 level of testing.

n/a : not applicable

Table 6.1: Manufacturing Support Hours vs. Incremental Defocusing: Pearson Pairwise Correlation Coefficients

	Component Core Defocusing[1]				Compressor Peripheral Defocusing[2]			
	Production Volume	Number of Bills of Material	Hershman-Herfindahl Index	Variance of Volumes	Production Volume	Number of Bills of Material	Hershman-Herfindahl Index	Variance of Volumes
Maintenance Hours	-.208* (1.41)	.069 (.47)	**.348** **(2.46)**	.047 (.31)	-.208 (1.41)	-.142 (.95)	.251 (1.72)	-.07 (.47)
Material Handling	**-.49** **(3.72)**	.153 (1.03)	.112 (.75)	**.299** **(2.1)**	**-.49** **(3.72)**	.073 (.49)	.021 (.14)	**.375** **(2.69)**
Machining and Assembly Inspection	**-.511** **(3.94)**	.135 (.91)	.105 (.69)	**-.327** **(2.29)**	**-.511** **(3.94)**	.068 (.45)	.012 (.081)	**-.373** **(2.67)**
Receiving Inspection	**-.61** **(5.1)**	.129 (.86)	-.09 (.57)	**-.56** **(4.48)**	**-.61** **(5.1)**	**.376** **(2.69)**	**-.395** **(2.85)**	**-.68** **(6.15)**
Chemical Inspection	**-.586** **(4.79)**	.106 (.71)	.266 (1.83)	**-.387** **(2.79)**	**-.586** **(4.79)**	.022 (.15)	.044 (.29)	**-.482** **(3.65)**
Toolroom	**-.767** **(8.12)**	**-.338** **(2.43)**	.14 (.96)	**-.547** **(4.43)**	**-.767** **(8.12)**	-.19 (1.31)	.074 (.51)	**-.54** **(4.37)**

1. Defocusing of the compressor without peripheral attachments. See Section 5.3 for explanation.

2. Defocusing of the compressor with peripheral attachments. See Section 5.3 for explanation.

* Indicates, for example, that per-unit maintenance labor hours have a correlation coefficient of -0.208 (with a t-value of 1.41,) with the monthly production volume of compressors measured without peripheral attachments.

Figures in bold indicate statistical significance at 0.01 level.

BIBLIOGRAPHY

BIBLIOGRAPHY-1: FOCUSED MANUFACTURING

Abernathy W. J., and Wayne, K.; Limits of the Learning Curve; *Harvard Business Review*; Sep-Oct; pp 109-119; 1974.

Anderson, S.; An Attribute-Based Model of Product Variety: A Study in the Textile Industry; *Working Paper,* University of Michigan, 1994.

Browne, J., D. Dubois, K. Rathmill, S. Sethi, and K. Stecke; Classification of Flexible Manufacturing Systems; The FMS Magazine, April, 1984

Burgert, Philip; Briggs to Build High-Volume FMS; *Manufacturing Week*, Issue 27, March 1988, p 1,24

Clark, Kim B., What Strategy Can Do for Technology; *Harvard Business Review*; Nov-Dec; pp 94-98; 1989

Clevelnd, G., R.G. Schroeder, and J.C. Anderson; The Content of Manufacturing Strategy: An Empirical Study. *Journal of Operations Management*, 1987, pp. 405-416.

DeMeyer, A., Nakane, J., Miller, J., and Ferdows, K.; Flexibility: The Next Competitive Battle, The Manufacturing Futures Survey; *Strategic Management Journal*; Vol. 10, pp 135-144; 1989.

Drucker, Peter F.; The Emerging Theory of Manufacturing; *Harvard Business Review*; May-June 1990.

Ferdows, K., Miller, Jeffrey G.; Nakane, J., and Vollman, Thomas E.;, Evolving Global Manufacturing Strategies; Projections into the 1990s; *International Journal of Operations and Production Management (UK)*; Vol. 6, no. 4; pp 6-16; 1986

Fine, Charles H. and A. Hax; Manufacturing Strategy: A Methodology and an Illustration. *Interfaces.* November-December, 1985, pp 28-46.

Foster, G., and Gupta, M.; Manufacturing Overhead Cost Driver Analysis; *Journal of Accounting and Economics*; Vol. 12; pp 309-338; 1990

Funk, Paul N.; Throughput Planning Instead of Capacity Planning Is The Next Logical Step After MRP II; *Industrial Engineering*, Vol. 21, Issue 1, Jan 1989, pp 40-44

Harmon, Roy; *Reinventing the Factory* (Book); 1991

Hayes R., and Clark, Kim B.; Exploring the Sources of Productivity Differences at the Factory Level; in Clark, Hayes and Lorenz eds.; *The Uneasy Alliance*; Boston, Massachusetts; Harvard Business School Press; 1985.

Hayes, R.H., and Jaikumar, R.; Manufacturing's Crisis: New Technologies, Obsolete Organizations; *Harvard Business Review*, Sep-Oct 1988, pp 77-85

Hayes R. H., and Pisano, Gary P.; Beyond World Class: The New Manufacturing Strategy; *Harvard Business Review*; Jan-Feb 1994

Hayes, R.H. and R.W. Schemenner; How Should You Organize Manufacturing? *Harvard Business Review*, January-February, 1979, pp 105-118.

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

Hill, Terry; *Manufacturing Strategy Text and Cases*; Irwin; 1994 (also see 1st edition, 1989)

Jensen, M.C.; The Modern Industrial Revolution, Exit, and the Failure of Internal Control Systems. *The Journal of Finance*, vol. XLVII, no. 3, July 1993.

Kapoor, V.K.; Just-In-Time and the Focused Factory: A Case History at Westinghouse; *Manufacturing Systems*; Vol. 7, Issue 12, Dec 1989, pp 47-49.

Kekre, Sunder and Srinivasan, Kannan, Broader Product Line: A Necessity to Achieve Success? *Management Science*, Vol. 36, pp. 1216-1231 (Oct. 1990).

Kolodny, H., M. Liu, and H. Denis; Organization Design for Technological Change. *Human Relations*, vol. 43, January 1990.

Kotler, Philip B.; *Marketing Management*, 6th Edition, 1986.

Krafcik, John F.; Triumph of the Lean Production system, *Sloan Management Review*; Fall 1990

Maller, R.J.; Integrated Manufacturing--The Structure: Simplify and Focus or Collapse. *Production Engineering*, September, 1984, pp. 62-65.

McDuffie, John P., Sethuraman, K., and Fisher, M. L.; Product Variety and Manufacturing Performance: Evidence from the International Automotive Assembly Plant Study; Working Paper, 1994

Miller, Jeff G.; Program Planning for World Class Manufacturing; *Manufacturing Systems*, Vol. 9, Issue 9, Sep. 1991, pp 21-26.

Oliver, Nick; Jitters in the Office; *Management Today*, Nov 1989 pp 142-149

Pesch, M.J.; *Defining and Measuring the Focused Factory*. PhD Dissertation, Minneapolis: The University of Minnesota. 1990.

Ruwe, D.M., and W. Skinner; Reviving a Rust Belt Factory. *Harvard Business Review*, vol. 65, no. 3, May-June, 1987, pp 70-76.

Schmenner, R. W.; Look Beyond the Obvious in Plant Location. *Harvard Business Review*, January-February, 1979, pp. 126-129.

Schmenner, R. W.; Multiplant Manufacturing Strategies among the Fortune 500. *Journal of Operations Management*, February 1982, pp 77-86.

Schmenner, R. W.; Every Factory Has A Life Cycle; *Harvard Business Review*, pp 121-129, March-April, 1983.

Sethi, A.K., and Sethi. S.P.; Flexibility in Manufacturing: A Survey; *International Journal of Flexible Manufacturing Systems*; Vol. 2; pp. 289-328; 1990.

Shapiro, R. D., Toward Effective Supplier Management; *HBS Working Paper* 9-885-062; 1985

Sheridan John H.; Whaddya Mean You're Too Small?; *Industry Week*, Vol. 239, Issue 11, Jun 1990, pp 12-14.

Skinner, W.; The Focused Factory; *Harvard Business Review*; Vol. 52, no. 3; pp 113-121; 1974

Skinner, W.; Report of the Operations and production Management Research Needs Committee; *Operations Management Review*; pp 18-23; Fall 1988 and Winter 1989

Stobaugh, R., and P. Telesio; Match Manufacturing Policies and Product Strategy. *Harvard Business Review*, March-April, 1983, pp 113-119.

Taylor, S.G.; Focused Production Systems. *Production and Inventory Management*. 1st Quarter, 1987, pp. 28-36.

Upton, D.; The Management of Manufacturing Flexibility; *HBS Working Paper* 92-050; 1991

Venkatesan, R.; Strategic Sourcing: To Make or Not to Make?; *Harvard Business Review*; Jan-Feb 1992

Winger, R. W., and Zakon, A.; Consumers Draw - from Mass Markets to Variety; *Management Review*; Vol. 86; pp 20-28; April 1988

Wheelwright, S.C.; Reflecting Corporate Strategy in Manufacturing Decisions; *Business Horizons*, February, 1978, pp. 57-72.

Wheelwright, Steven C.; Facilities Focus: A Study of Concepts and Practices Related to Its Definition, Evaluation, Significance, and Application in Manufacturing Firms; *Research Paper* #518, GSB, Stanford University; 1979.

Wheelwright, S.C.; Manufacturing Strategy: Defining the Missing Link. *Strategic Management Journal*, vol. 5, 1984, pp. 77-91.

Willis, T. Hillman, and Shields, Jerry D.; Modifying the ABC Inventory System for A Focused Factory; *Industrial Engineering*; Vol. 22, Issue 5, May 1990, pp 38-39, 73.

BIBLIOGRAPHY-2: RESEARCH DESIGN & METHODOLOGY

Ackoff, R.; The Future of Operational Research is Past. *Journal of the Operational Research Society*; vol. 30, no. 2, 1979, pp 93-104, 1979

Anderson, J.C., N.L. Chervanay, R. Narasimhan. Is Implementation Research Relevant for the OR/MS Practitioner? *Interfaces*, vol. 9, no. 3, 1979, pp 52-56

Becker, H.; *Sociological Work*, Chicago: Aldine, 1970.

Buffa, E.S., Research in Operations Management. *Journal of Operations Management*, vol. 1, no. 1, 1980, pp 1-8.

Campbell, Donald T.; Degrees of Freedom and the Case Study. *Comparative Political Studies*, vol. 8, July 1975, pp 178-193.

Chase, R.B., A Classification and Evaluation of Research in Operation Management, *Journal of Operations Management*, vol. 1, no. 1, 1980, pp 9-14.

Chase, R.B., and E.L. Prentis; Operations Management: A Field Rediscovered. *Journal of Management*, vol. 13, no. 2, 1987, pp 351-366

Cronbach, L.; Beyond the Two Scientific Disciplines of Scientific Psychology. *American Psychologist*. vol. 30, February 1975, pp 116-127.

Lasswell, H.D.; The Future of Comparative Method. *Comparative Politics*. vol. 1, 1968, pp 3-18.

Donham, W.B.; Essential Groundwork for a Broad Executive Theory. *Harvard Business Review*, vol. 1, no.1, October 1922, pp 1-10.

Dubin, R.; *Theory Building*. New York: The Free Press, 1969.

Emory, W.C.; *Business Research Methods*. 3rd Edition. Homewood, IL: R.D. Irwin, 1985.

Eckstein, H.; Case Study and Theory in Political Science, In F.I. Greenstein and N.W. Polsby (eds.), *Handbook of Political Science*. Reading, MA: Addison-Wesley, 1975, vol. VII, pp 79-138

Gale, George; *Theory of Science: An Introduction to the History, Logic, and Philosophy of Science*. McGraw Hill; New York, 1976.

George, Alexander, L.; Case Studies and Theory Development: The Method of Structured Focused Comparison. In P. Gordon-Lauren (ed.), *Diplomacy: New Approaches in History, Theory, and Politics*. New York: The Free Press, 1979.

Hax, A.; Comment on Production/Operations Management agenda for the 80's. *Decision Sciencse*, vol. 12, no. 4, 1981, pp 574-577.

Hill, A.V., G.D. Scudder, D.L. Haugen; Production/Operations Management Agenda for the 80's: A Progress Report. In *Proceedings of the 1987 DSI Conference. Boston*: Decision Sciences Institute, 1987, pp 840-842.

Hill, T.J.; Teaching and Research Directions in Production/Operations Management: The Manufacturing Sector. *International Journal of Operations and Production Management*, vol. 7, no. 4, 1987, pp 5-12.

Hunt, Shelby D.; *Modern Marketing Theory: Critical issues in the Philosophy of Marketing Science*. Southwestern Publishing Company, Cincinnati, OH, 1991

HBS Case # 9-686-091. *Copeland Corporation: Evolution of a Manufacturing Strategy--1975-82 (D)*, D.A. Garvin, and A. March. Boston, Massachusetts: HBS Publishing

Dexter, L.A.; *Elite and Specialized Interviewing*. Evanston, IL: Northwestern University Press, 1970.

Lijphart, A.; Comparative Politics and the Comparative Method. *American Political Science Review*, vol. 65, September 1971, pp 682-693.

Lijphart, A.; The Comparable-Case Strategy in Comparative Research. *Comparative Political Studies*, vol. 8, July 1975, pp 158-177.

Lachenmeyer, C.W.; *The Language of Sociology*; Columbia University Press, 1971.

Meredith, Jack R., Amitabh Raturi, Kwasi Amoako-Gyampah, and Bonnie Kaplan; Alternative Research Paradigms in Operations; *Journal of Operations Management*; Volume 8, number 4, October 1989, pp 297-326.

Miller, J.G., and M.B.W. Graham; (with J.R. Freeland, M. Hottenstein, D.M. Maister, J.R. Meredith, and R.W. Schmenner;) Production/Operations Management: Agenda for the 80's. *Decision Sciencse*, vol. 12, no. 4. 1981, pp 547-571.

Murphy, J.T.; *Getting the Facts*. Santa Monica, CA: Goodyear, 1980.

Narol, R.; *Data Quality Control: A New Research Technique*. New York: The Free Press, 1962.

Raser, J.R.; *Simulation and Society*. Boston: Allyn and Bacon, 1969.

Russet, B.; International Behavior Research: Case Studies and Cumulation. in M. Haas and H.S. Kariel (eds.) *Approaches to the Study of Political Science*. San Francisco: Chandler, 1970, pp 425-443

Ryan, T.A.; Significance Tests for Multiple Comparisons of Proportions, Variances, and Other Statistics. *Psychology Bulletin*, 1960, vol. 57, pp 318-328.

Schatzman, L., and A. Strauss; *Field Research: Strategies for a Natural Sociology*. Englewood Cliffs, NJ: Prentice-Hall, 1973.

Scheffe, H.; A Method for Judging All Contrasts in Analysis of Variance. *Biometrika*, vol. 40. 1953, pp 87-104.

Scriven, M.; Explanations, Predictions, and Laws. *Minnesota Studies in the Philosophy of Science*, vol. III. Minneapolis: University of Minnesota, 1962, pp 70-230

Selvin, H.C., and A. Stuart; Data-Dredging Procedures in Survey Analysis. *American Statistician*, vol. 20, 1966, pp 20-23.

Sullivan, R.S.; The Service Sector: Challenges and Imperatives for Research in Operations Management. *Journal of Operations Management*, vol. 2, no. 4, 1982, pp 211-214.

Verba, Sidney; Some Dilemmas in Comparative Research. *World Politics*, vol. 20, October 1976, pp 113-114.