ADAPTATION OF A FOCUSED FACTORY TO A MISSION CHANGE: THE INFLUENCE OF MANUFACTURING REQUIREMENTS AND CAPABILITIES

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ABSTRACT

This paper examines how a focused factory adapts to a change in its manufacturing mission. We use the organizational nature of production operations to suggest that the effectiveness of adaptation will depend on how well the manufacturing requirements of the new mission match manufacturing capabilities at the production line level. We test our hypotheses using primary data from a well-known focused factory of the Copeland Corporation. The results suggest that the factors that influence adaptability derive from individual and organizational competence, and that the direction and extent of their influence depends on the systemic nature of the operational activity concerned. The results highlight important roles of carefully designed complexity in operations and of process-oriented decision making on the shopfloor in successful adaptation. This work contributes to our understanding of how factories and, more generally, business organizations overcome impediments to successful change.

ADAPTATION OF A FOCUSED FACTORY TO A MISSION CHANGE: THE INFLUENCE OF MANUFACTURING REQUIREMENTS AND CAPABILITIES

This paper examines the effectiveness with which the production lines of a focused factory adapt to new manufacturing objectives. Recent conceptual arguments suggest that an organization's absorptive capacity will affect the success or failure of the organization's attempts to adapt (Cohen and Levinthal, 1990). Results supporting this proposition arise in several contexts, including development of new technological capabilities of a firm (Cohen and Levinthal, 1990; Gambardella, 1992), knowledge transfer in inter-firm alliances (Mowery, Oxley and Silverman, 1996), knowledge transfer within firms (Szulanski, 1996), and information technology implementation (Boynton, Zmud, and Jacobs, 1994). In a previous study, Mukherjee, Mitchell, and Talbot (1999) show that the productivity and quality performance of production lines of a focused factory decline when lines lack absorptive capacity relevant to a new objective. The current study identifies factors that may affect absorptive capacity and, in turn, might influence the success of focused production lines in adapting to a change in manufacturing objective.

We use the concepts of absorptive capacity and organizational routines to develop two sets of hypotheses concerning how manufacturing requirements and manufacturing capabilities influence the success of an attempted change in manufacturing mission of a factory. The predictions emphasize the view that organizational routines tend to constrain change within path dependent lines. We consider two elements of manufacturing requirements, including similarity of routines and magnitude of change. We consider five elements of manufacturing capabilities, including the number of production line routines, the number of routines that individual employees have experience with, the extent to which a line has mastered its old routines, availability of slack resources, and greater horizontal information processing. Together, manufacturing requirements and manufacturing capabilities lie at the intersection of the need for change and the ability to change to fulfill a factory's manufacturing mission.

This work contributes to our understanding of how factories and, more generally, business organizations overcome impediments to successful change. Hayes and Clark (1985) note that confusion tends to prevail when focused factories lose their focus. More generally, many convincing theoretical and empirical studies in organization theory, economics, and business strategy show that firms face strong social and economic inertial barriers to organizational change (e.g., Cyert and March, 1962; Nelson and Winter, 1982; Hannan and Freeman, 1989). Nonetheless, although many organizations do not respond successfully to changes in their competitive environments, some firms do adapt successfully over time. We seek to understand how factories and, more generally, firms can balance their needs for reliability of current activities with their needs to reshape business capabilities. Our results indicate that the role of focus in this context is to prevent the complexity of meeting this dual need from degenerating into confusion.

Our empirical analysis examines productivity trends for sixteen production lines over a 48 month period (768 productivity data points) during which a focused factory underwent significant changes in its manufacturing mission. We use data for 1,300 parts in measuring changes that took place during the four years of the study period, combined with a survey of plant personnel. This is a moderate-sized data set that provides an effective opportunity for the analysis owing to the fine-grained detail available concerning the nature of the changes and the effectiveness with which the factory adapted. The empirical results support several hypotheses, while rejecting others. The predictions tend to take a relatively simple starting point for examining adaptability, reflecting the underlying assumption that the greater the change, the greater the difficulty in adaptation. The rejected hypotheses increase our understanding of situations in which seemingly difficult changes may actually be viable. We believe that the interpretation of the results help us understand how routines and absorptive capacity do indeed constrain some changes, but may also assist some forms of organizational change.

1. THEORY AND PREDICTIONS

Our goal is to understand why some production lines adapt with greater or lesser effectiveness to a change in their manufacturing objective. We will first define several key terms derived from a 'top down' model of business strategy that has strong intuitive appeal and is widely used in practice. Corporate strategy largely defines business unit strategy which largely defines functional (e.g., manufacturing) strategy. From manufacturing strategy flows facility (e.g., factory), discipline (e.g., engineering) and interdisciplinary (e.g., product development) missions. A factory mission (what Skinner [1974] would refer to as a 'manufacturing task') is translated into manufacturing objectives for specific operations or production lines. We argue that how well a production line meets its manufacturing objective depends on two factors: the manufacturing requirements of the objective and the manufacturing capabilities of the line. Manufacturing requirements are the manufacturing routines that the firm needs in order to achieve the manufacturing objectives. Manufacturing capabilities are the manufacturing routines that the firm currently has available. We develop two sets of hypotheses concerning how manufacturing requirements and manufacturing capabilities will influence production line adaptability to new production line objectives.

Our argument derives from applying the organizational theoretic concepts of routines and absorptive capacity to the context of production lines. First, consider the role of organizational routines in organizational change. Organizational change in response to changed objectives, whether change involves production line changes or other changes, necessitates the creation of new organizational routines. Routines are identifiable patterns of activity embodied in human and capital assets (Winter, 1990; Dosi, Marengo, and Fagiolo, 1996). In this sense, routines are the skills of an organization that span individuals in ways that no one person can fully understand or control (Nelson and Winter, 1982; Hannan and

Freeman, 1989). Examples of production line routines include technological processing routines, information flow routines, material flow routines, and manufacturing support routines. Organizations can either create routines from new resources or recombine existing routines in order to achieve new purposes (Galunic and Eisenhardt, 1996).

Second, consider the relationship between the creation of new routines and absorptive capacity. A firm's ability to create new routines, whether by acquiring new resources, by recombining existing routines, or through some combination of new resources and routine recombination, will tend to depend on a firm's absorptive capacity. Absorptive capacity is the ability to recognize, evaluate, assimilate, and utilize new knowledge (Cohen and Levinthal, 1990). New knowledge, in this context, may be basic skills, a shared language, shared understanding of technical developments, or, for our purposes, shared understanding of new manufacturing objectives. Prior related knowledge confers an ability to recognize the value of new knowledge, as well as to assimilate and utilize the knowledge. In the manufacturing context, Abernathy (1978) and Rosenberg (1982) note that direct manufacturing experience helps a firm recognize and utilize new information relevant to a specific product-market, especially when the new information builds cumulatively on the firm's experience. Similarly, the absorptive capacity of a production line tends to develop cumulatively. The capacity may develop through transfer of knowledge among the members of a line, as well as through the interface of the line with its environment including other lines and functions within the factory and external agents such as suppliers of parts to the line. Thus, absorptive capacity is path dependent, in that it builds cumulatively on past experience in a particular organizational context. Moreover, creation of new routines is an organizational process that involves understanding what new routines are necessary, identifying candidate component routines within the current portfolio, evaluating alternatives, and creating the needed responses through re-combinations. This process of creating new routines must address manufacturing requirements and manufacturing capabilities.

1.1 Manufacturing Requirements

We use the concept of manufacturing requirements to define the routines that a production line needs to achieve its manufacturing objectives. Such routines may include activities such as transmission, interpretation, planning, handling, processing, and controlling functions. Manufacturing requirements derive from the objective at hand. Changing the manufacturing objective of a production line is similar to organizational innovation at a micro-level. Research on organizational innovation suggests that the characteristic of an innovation will influence its success (Abrahamson, 1991; Damanpour, 1988, 1991; Poole and Van de Ven, 1989). Some researchers explain knowledge transfer success by stressing attributes of the knowledge transferred (Winter, 1987; Zander and Kogut, 1995). Lower manufacturing requirements of a new objective imply less stretching of the current routines. Accordingly, we propose the following hypothesis.

> **Hypothesis 1**: The greater the additional manufacturing requirements of a changed objective, the less effectively a production line will adapt to the change.

We operationalize change in manufacturing requirements using two elements: routine deficiency, and magnitude of change. We propose a testable hypothesis concerning each element.

First, we examine the concept of routine deficiency. Cohen and Levinthal (1990) note that successful assimilation of new knowledge depends on how closely the new knowledge is related to the old knowledge. Mowery, et al. (1996) operationalize the concept of closeness of relationship in terms of resemblance, which for their study is the technological overlap between allying firms. For a production line that faces a changed objective, resemblance arises with the similarity of the routines needed for the old objective and those of the new objective. The less the similarity, the greater the deficiency of the old routines to meet the new requirements. A greater degree of deficiency of routines increases the additional manufacturing requirement that the change creates, and therefore, results in less adaptability.

> **H1A**: The greater the deficiency of existing routines needed to achieve a changed objective, the less effectively a production line will adapt to the change.

The logic underlying H1A assumes that managers will either not recognize the routine deficiencies or will not be able to address deficiencies that they do recognize. If, instead, managers tend to recognize and address inadequacies when they change manufacturing objectives, then there may be little or no negative relationship between prior deficiency and adaptability. We believe that firms do tend to recognize and address many potential problems when they undertake changes. Nonetheless, we propose H1A as a relatively simple baseline prediction that is consistent with the current conceptual tendency to view organizational routines as presenting strong constraints on managerial action. Support for H1A would be consistent with the current conventional wisdom in organization theory, while rejection would reflect greater support for arguments that credit managers with substantial adaptive incentives and ability.

The second prediction concerning manufacturing requirements needs fewer assumptions of limited managerial rationality. The old and the new objectives can differ not only in the nature of their routines, but also in the magnitude of the requirements. While the nature of the change affects how similar the new routines will be to the old ones, the magnitude of the change will tend to determine how easily and quickly the routines reach a state of efficient execution. The efficiency with which a production line executes new routines affects the performance of a line, and hence, adaptability. A lower level of change facilitates adaptability by providing lower hurdles to efficient execution of routines. In contrast, a greater magnitude of change will increase the extent of additional requirement, and will make adaptation more difficult (Barnett and Carroll, 1985). Accordingly, we propose the following hypothesis.

> **H1B**: The greater the magnitude of a changed requirement, the less effectively a production line will adapt to the change.

1.2 Manufacturing Capabilities

The concept of manufacturing capabilities provides the second general component of our approach. We view manufacturing capabilities as the production-line level equivalents of competencies. This argument follows the discussion of resources in the strategy literature (Penrose, 1959; Wernerfelt, 1984; Barney, 1986; Prahalad and Hamel, 1990), as well as in the manufacturing strategy literature (Hayes and Pisano, 1994). When a manufacturing mission changes over time, the problem of production line adaptation parallels the problem of developing firm-specific dynamic capabilities (Teece, Pisano, and Shuen, 1997). The capability of a production line comprises the skills and knowledge embedded in the systems, technologies and structures of a line, plus the tacit knowledge embedded in the human skills of individual employees (Polanyi, 1962: 49) and groups of employees (Winter, 1987; Kogut and Zander, 1992). This definition is consistent with Cohen and Levinthal's (1990) argument that absorptive capacity is a characteristic of the recipient of new knowledge. Thus, capability is a function of the current state of the line, rather than of the new manufacturing objective. The current state of the line, in turn, depends on its prior states, due to the path-dependent nature of absorptive capacity. Because adaptability depends on the extent of matching between capabilities and requirements, greater capability facilitates better matching by widening the scope of the ability to match requirements.

> **Hypothesis 2**: The greater the manufacturing capabilities of a line, the more effectively the line will adapt to a changed objective.

We operationalize manufacturing capabilities in terms of five elements, including the number of production line routines, the number of routines that individual employees have experience with, the extent to which a line has mastered its old routines, availability of slack resources, and horizontal information processing ability of employees. We propose a testable hypothesis concerning each of the elements.

The availability of a greater number of existing routines provides a broader array of elements for recombination purposes. Mowery, et al. (1996) use this argument in proposing that a larger scale of operation provides greater absorptive capacity, since larger firms will tend to undertake a greater span of activities. A solution to the changed objective at a production line, for example, might involve establishing new patterns of information and material flows among existing subroutines that the line performs within and across production lines. Production lines that learn, practice, and remember a greater variety of production and planning routines within their regular scope of operation have more combinations of routines with which they can create new flows. Therefore, it is possible that lines with more routines will tend to be better able to adapt to a changed objective. We will state the hypothesis to reflect the value of routine recombination, taking the view that greater experience of any kind will help adaptation to future changes. An alternative outcome is possible, however, if the presence of more diffuse past experience instead confuses attempts to adapt to future changes, especially if much of the past experience is not relevant for the new objectives. If such confusion arises, then the need to use greater routines in the past might actually contribute to less adaptability, rather than greater. The empirical analysis will help address these conflicting possibilities.

> **H2A**: The more routines that a production line uses for its existing objective, the more effectively the line will adapt to a changed objective.

In addition to the influence of organizational routines, the scope of recall of the individual employees who work at the line will influence the creation of new routines at a line. The ability of individual employees to create new routines may determine how well the line as a whole responds to the new objective. In turn, the ability of an individual to create new routines will depend on the variety of his or her endowment of routines. For example, Boynton, et al. (1994) examined an organization's absorptive capacity for information technology through the conjunction of its two component managerial skills, information technology-related knowledge, and business-related knowledge. Thus, H2A and H2B differentiate between the organizationally-embedded experience of a production line (H2A) and the personally-embedded experience of individual employees (H2B).

> **H2B**: The greater the repertoire of routines that individual employees have experience with, the more effectively a line will adapt to a changed objective.

The degree to which members of an organization understand how to combine old routines in order to create new routines will also influence the success of adaptation. As Nelson and Winter (1982: 31) state, adaptive efforts take place most effectively if the organization has the old routines 'fully under control.' Developing an effective new combination is easier when the employees can use the elements of the combination, the old routines, without difficulty or ambiguity. A production line with its current routines under control will adapt better to a new objective than a line that does not have adequate control.

> **H2C**: The greater a production line's mastery of its old routines, the more effectively the line will adapt to a changed objective.

In the context of organizational information processing, Galbraith (1977) views organizational performance as the extent to which an organization's information processing requirements match its information processing abilities. We draw a parallel between the matching in the context of information processing and in our context of manufacturing mission. Consequently, we can expect that two mechanisms that Galbraith prescribed for facilitating the matching will help production lines adapt as well. The first mechanism is resource-slack. Research on new product development and on organizational innovation generally supports slack resources as a facilitator of change (Nonaka, 1989, 1991; Damanpour, 1991). If there are slack resources at a production line before change, then the line can use the slack to absorb the uncertainties and the increased manufacturing requirements of the new objective.

> **H2D**: The greater a production line's slack resources, the more effectively the line will adapt to a changed objective.

Although slack provides the ability to respond to uncertainties by absorbing them, an alternative response may be to actually meet the additional manufacturing requirements of the uncertainties. Thus, Galbraith's second mechanism is increased information processing ability, which may come through direct investment in information systems or through organizational mechanisms. Most specific to our case, an information processing perspective suggests that one way a production line can adapt more easily to a changed objective is through having horizontal modes of decision-making (Galbraith, 1977). Horizontal modes of information-processing and decision-making help an organization or sub-unit of an organization adapt to a changed objective by avoiding information overload of the decision hierarchy. The organization will be more resilient if decisions that need greater information processing can be made at lower hierarchical levels.

> **H2E**: The greater the horizontal information processing ability of employees at a production line, the more effectively the line will adapt to a changed objective.

In summary, we argue that manufacturing routines and absorptive capacity will influence the effectiveness of production line adaptation to new manufacturing objectives. Figure 1 summarizes the conceptual model. Our argument suggests that production lines develop routine-specific absorptive capacity and capabilities as a result of their prior activities. In addition, the overall set of resources that the firm possesses may provide additional general capabilities. When faced with a change in objectives, the routine-specific and general capabilities will influence the effectiveness of adaptation. In addition, the manufacturing requirements of the changed objectives will influence the effectiveness of adaptation, where requirements may be either absolute requirements or relative requirements taken in the context of the lines' existing capabilities.

********** **Figure 1 about here** **********

We develop two sets of hypotheses, concerning manufacturing requirements and capabilities. First, lines will adapt most effectively to new manufacturing objectives that require routines that are similar to old routines (relative requirements) and have a lower magnitude of change (absolute requirements). Second, lines will adapt more effectively if their prior experience provides greater routine-specific capabilities (many prior routines, extensive individual employee experience with different routines, mastery of old routines) and greater general capabilities (slack resources, horizontal decision making ability). We now describe the empirical context of the study.

2. EMPIRICAL METHODS

Testing our hypotheses entails observing manufacturing requirements and manufacturing capabilities at the production line level. This paper studies sixteen production lines within a well-known focused factory of the Copeland Corporation at Hartselle, Alabama, that underwent substantial changes in manufacturing objectives.[1] Although the emphasis on a single factory limits the generalizability of the results, we chose this approach because of the need for detailed data collection in order to identify our measures. Moreover, measuring our variables across production lines of more than one factory would introduce unobserved heterogeneity in the characteristics of manufacturing requirements and capabilities, which, in turn, would reduce the reliability of the results. We believe that our single factory approach is appropriate on both empirical and conceptual grounds.

Mukherjee, Mitchell, and Talbot (1999) found general relationships between absorptive capacity and production line performance following a changed mission at this focused factory. In this paper, we seek additional empirical evidence examining adaptability of production lines from the factory. We held meetings with the corporate and plant management and found that the factory is an appropriate empirical site for the current study. First, the factory and its production lines changed their mission and objectives, respectively. Second, primary data are available to examine production line performance and changed objectives. Third, the presence of sixteen production lines with available data provides an opportunity to identify comparative differences in the capability of the lines to adapt to change. Finally, initial discussions with plant management also suggest that lines experience different degrees of difficulty in adapting to changing objectives. We provide a brief description of the evolution of the manufacturing mission at the site below. Mukherjee, et al. (1999) contains a more detailed description.

2.1 Evolution of Manufacturing Mission at Copeland Hartselle

Copeland established its 256,000 square feet flagship focused factory at Hartselle, Alabama in 1979 at a cost of $30 million. The company designed the factory to manufacture one million units a year of a refrigerant compressor. The focused factory served the market with a few compressor models assembled from multiple combinations of a few parts produced in large batch sizes with the minimum of factory complexity. The facility included two areas, machining and assembly. Machining is where metal

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[1] Our primary sources for information on the Copeland Hartselle facility include Copeland Corporation internal reports, documents, and archives, plus interviews with several Copeland managers between 1991 and 1994. In addition, we collected information from several public sources including HBS Case # 9-686-088 and HBS Film # 9-887-527.

removal processes such as milling, turning, drilling, and grinding occur. There are eight machining lines, which we designate as ML1 (Machining Line 1) through ML8. The assembly lines are where workers put together machined and purchased parts to form a complete compressor. The assembly operations comprise several fastening, fitting, welding, and brazing processes. There are a total of eight assembly lines, which we designate as AL1 (Assembly Line 1) through AL8. We were able to obtain monthly productivity data for each line over a four year period. Therefore, we have productivity information for 16 lines, which we analyze over 48 monthly time periods.

The original focused manufacturing mission of Hartselle was to achieve the lowest cost position in their industry, with at least equal quality to their competitors, through high-volume production of a restricted mix of components and end products. The original manufacturing objective of the machine shop was to excel in high volume, high precision machining of a narrow mix of components. The initial manufacturing objective of the assembly shop was to build variety through multiple combinations of the relatively few basic components. In order to achieve the flexibility, Copeland designed the assembly lines with less restricted set-up time and many more manual operations compared to the machine shop lines.

With the focused factory approach, Copeland achieved tremendous success with customers and transformed itself from an industry follower into the undisputed industry leader. The focused factory became a showpiece and a marketing tool for the company. However, market pressure for broader product lines and customized modifications coupled with Copeland's aggressive marketing strategy gradually caused Copeland to defocus Hartselle's product line. After the defocusing, the manufacturing mission of the facility continued to call for achieving low cost and high quality, but now with a wider component and product range, which needed greater range and volume fluctuation in component machining and end-product assembly. Mukherjee, Mitchell, and Talbot (1999) identify the impact of a changing plant mission on production line performance at this site. They show that the productivity and quality performance of production lines of the factory declined for lines that lacked absorptive capacity relevant to new objectives. Specifically, the study found statistically significant detrimental relationships between volume heterogeneity of parts produced at a line and the direct labor productivity of the line. This result implies that part volume heterogeneity was a key aggregate determinant of manufacturing requirements. We use the volume heterogeneity result from the prior study in defining our operational variables and developing our model, which we discuss next.

2.2 Operational Variables

This section operationalizes the conceptual variables that we used to state the hypotheses in sections 1.1 and 1.2. Table 1a summarizes the variables.

************ Table 1a about here **************

We first operationalize the dependent variable. The conceptual dependent variable for the study is a production line's adaptability to a changed objective. We operationalize the dependent variable as the degree to which the statistical association between part volume heterogeneity and labor productivity changes over time, where a greater positive association indicates greater adaptability. Our rationale for this choice is that a more effective adaptation to a change implies that the production lines learn to execute the new routines of the changed objective more efficiently over time. Labor productivity of a line reflects the efficiency of execution of routines by employees at the line. Consistent with Upton's (1995) usage of non-deterioration of performance in the face of change as a measure of manufacturing flexibility, we define adaptability to a change as non-deterioration in labor productivity with respect to the change. We concentrate on productivity of direct labor so as not to confound our results by the implications of the changes for indirect production support functions such as set up changes and material handling.

We now operationalize the independent variables within the setting of the empirical site. Operational variables for the hypotheses H1A and H1B measure aspects of the change in manufacturing objectives. For testing H1A, we measure the deficiency of the old routines for the new objective through the degree of difficulty of processing batches of heterogeneous volumes on lines designed for processing batches of homogeneous volumes. For testing H1B, we measure the magnitude of the volume heterogeneity through the mean value of volume heterogeneity over the time-period of change. [2]

The operational variables for H2 consist of characteristics of the lines and the people who work on the lines. For testing H2A, an operational element at the site that represents carrying out of a variety of routines at a line is the difference in routings of the parts manufactured at the line. The greater difference in routing that the parts follow, the greater the variety in routines that will be available for recombination. For testing H2B, an operational element at the site that can increase the variety of routines from which an individual worker can draw is the extent of job rotation of workers at a line. We expect that the variety of routines with which an individual employee has experience will increase with the number of jobs through which the employee rotates. For testing H2C, a way to examine if the employees have mastered existing routines is to assess the training levels of the workers on a line, with the expectation that greater adequacy of training reflects greater mastery of routines.

For testing H2D, we use two metrics of resource slack that are observable at the production line level at the site, capacity cushion and equipment set-up time. Capacity cushion indicates the unused capacity at a line relative to the used capacity. In addition, less time lost in set-up changes indicates more available slack.[3] Finally, for testing hypothesis H2E, we use the worker-to-supervisor ratio as a measure of horizontal information processing. Greater worker-to-supervisor ratios indicate greater horizontal

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[2] We considered using the degree of temporal fluctuation of the change as a measure of change magnitude, but found that it correlated highly with the mean HINDEX variable.

[3] We considered using set up ease as a third measure of slack, but found that it correlated highly with capacity cushion.

information processing ability, consistent with arguments concerning span of control and hierarchy (Keren and Levhari, 1979).

This section converts the hypotheses from conceptual to operational form. Although the operational variables are specific to the Hartselle site, the conceptual variables are general and consistent with guidelines for case-based research (George, 1979). Moreover, the site-specific operational variables that we have chosen will be common to many different sites. In the next section, we describe the model and the methodology we use to test the hypotheses.

2.3. Model and Estimation

We use a two-step process to test our hypotheses. First, we measure the adaptability of the different lines to volume heterogeneity. For this purpose, at each line we propose the following general model for direct labor productivity.

(1a) $\text{LaborProductivity}_t = B0 + B1\text{LogT} + B2\ \text{Het}_t + B3\ \text{Het}_t \times \text{LogT} + e_t$ (for the t_{th} time period)

where B0 is the intercept, B1, B2, and B3 are multiple time-series regression coefficients, and e_t is the residual term. We explain the independent variables below.

> *LogT* : The base-10 logarithm of time, where T represents time. We expect that in addition to the focal variables of interest, unobserved variables that influence the learning that takes place at a line over time will influence absorptive capacity and hence performance. Consistent with the logarithmic nature of the learning curve, we represent the time variable in logarithmic form.
>
> *Het_t*: The heterogeneity of volumes of products processed at a line at time t, as we discussed in Section 4.2.
>
> *$Het_t \times LogT$*: The dynamic adaptability of a line to a changed objective. Our rationale is that the independent variables assist a line adapt to a change, and that this assistance develops over time. Hence, we use LogT as an interaction variable to determine the extent of this time-dependent assistance to adaptability.

The focal variable of our interest is the B3 coefficient of the interaction term $Het_t \times LogT$. We include the LogT and Het_t variables in the equation in order to separate the interaction effect from the main effects of the two variables.

We estimate equation (1) for each of the sixteen production lines. Since we are testing with time-series data, we tested for auto-correlation during each estimate using the Durbin-Watson d-statistic and residual plots, finding substantial auto-correlation. Therefore, we re-estimated the equation using a time-series transformation of the data based on first differences of the Labor Productivity dependent variable. First differencing reduces the sample size to 47 periods and eliminates the intercept term from equation (1a), resulting in equation (1b).

(1b) $\Delta\ \text{LaborProductivity}_{t-1,t} = B1\Delta\text{LogT}_{t-1,t} + B2\ \Delta\text{Het}_{t-1,t} + B3\ \Delta(\text{Het} \times \text{LogT})_{t-1,t} + e_t - e_{t-1}$

Consistent with many time-series analyses, first differencing removes most auto-correlation in our testing. The resulting sixteen B3 adaptability coefficients are the values of the dependent variables for the adaptability analysis. Because of scaling difficulties arising out of the lines manufacturing different products using different nominal unit labor hours, we use the standardized regression coefficients for better comparability across production lines.

We then examine the pattern of the adaptability coefficients in each shop and try to explain their differences in terms of the independent variables for manufacturing requirements and capabilities. We estimate pair-wise cross-sectional correlation between B3 as the dependent variable and all the independent variables. To obtain the correlation estimates, we estimate Spearman's rho, which treats the variables as non-parametric rank order measures. Owing to the small number of cases, the nonparametric Spearman approach is likely to introduce less bias than alternative parametric and partially-parametric correlation measures such as Pearson correlation estimates that treat B3 as either a continuous or rank order variable[4].

The correlation approach to the hypothesis testing has the restriction of examining each influence on adaptability singly. To some extent, the individual variable approach allows us to infer how the plant makes trade-offs when faced with conflicting influences. With a larger sample, we would prefer to determine the additive and joint effects of different influences on adaptability. As we noted earlier, though, the current small sample study is appropriate for the detailed degree of information that we need for the study. Therefore, we will base our primary interpretation of the analysis on the individual results, attempting to tease out the separable influences and likely trade-offs.

In addition to examining the unitary influence of each variable, the correlation results also help us select sub-groups of the independent variables that we can use in multiple regression estimates with adaptability as the dependent variable. Because we are limited to sixteen units, we are limited to regressing at most three independent variables at time. Consequently, we cannot use the regressions for extensive multivariate hypothesis testing, but we use the multiple regressions as exploratory analysis to examine which of the correlation results tend to hold when we include several influences.

2.4 Measurements and Data Sources

In addition to listing the variables, Table 1a summarizes measures and data sources that we use for the variables. The data for the dependent variable come in the form of primary production data on 1,300 parts and fifteen cost centers of the factory recorded on a monthly basis over a 48-month period. Measuring the dependent variable, which is the association of labor productivity with volume heterogeneity, entails measuring productivity and heterogeneity and then calculating their association.

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[4] For sensitivity analyses, we also calculate correlation coefficients using Pearson estimates, finding similar results.

For each line, we measure the direct labor productivity as the ratio of the monthly aggregate volume in the numerator, and the monthly direct labor hours worked in the denominator. We use primary unit production data for all part numbers, and then aggregate them for each production line. To measure the second element of the dependent variable, volume heterogeneity, we consider parts with the same part number as homogeneous and parts with different part numbers as heterogeneous. At each production line, we aggregate the production volumes of each homogeneous part. We then employ the Hirschman Index (HINDEX) as a measure of volume heterogeneity. For n variables $x_1, \ldots\ldots, x_n$, the HINDEX = $\Sigma x_i^2/(\Sigma x_i)^2$, for all $i = 1, \ldots, n$ (see Tirole, 1989: 221-222). For a given number of parts on a production line, a higher HINDEX indicates a greater heterogeneity of volume.

With respect to the independent variables, the independent variable for testing H1B characterizes volume heterogeneity. We measure the variable using the average value of the Hirschman Index, which we described above. Data on the volume heterogeneity independent variable come in the form of primary production data on 1,300 parts that the factory produced, which the company recorded on a monthly basis over a 48-month period.

We collected data on the other independent variables, including the remaining manufacturing requirement variable and all capability variables, through a survey that we administered within the plant. We administered the survey when we gained access to the plant in early 1993, about a year and a half after the end of the 48-month period for which the data is relevant. Because the unit of analysis is the production line, we selected the supervisor of each line as the respondent to the survey about that line. We asked the supervisors to assess several dimensions concerning the state of their lines at the beginning of the change period. The appendix describes the constructs and scales we used in the survey instrument. We followed the supervisory survey with unstructured interviews with some of the respondents in order to clarify questions they had about the survey questionnaire. Subsequently, we conducted unstructured interviews with managers, supervisors, and manufacturing support staff to learn more about the implications of the empirical results.

Table 1b and Table 1c report the summary statistics for each independent variable and the correlation coefficients between the independent variables. The reported correlations show that there are substantial statistical relationships among some of the covariates, but that there is at least moderate independent variation among them. Given the variation, it is useful to examine the relationships between adaptability and each of the covariates.

********** **Table 1b and Table 1c about here** **********

3. RESULTS

We present the results in two phases. We first measure adaptability by calculating the B3 coefficient in equation (1b) for each line. We then assess the influence of the independent variables on B3.

3.1. Measuring Adaptability Over Time

The first step is to determine the adaptability of the production lines to a change in manufacturing objective. Table 2 lists the results of estimating equation (1b). For each estimation of equation (1b), the table shows the regression coefficients and their significance, plus an overall model summary including the Durbin-Watson d-statistic and multiple-R values.

************ Table 2 about here ************

We first consider the basic time trends of productivity. The results in Table 2 show that in both shops, most B1 coefficients associated with the time variable are negative. Most B1 coefficients in the assembly shops are statistically significant. In the machine shop, though, few B1 coefficients even approach significance at the 90% level. We will address these differences across the assembly and machining lines in the discussion section of the paper. The overall negative signs and the distribution of significance of the coefficients indicate that costs tended to rise over time, particularly in the assembly shop, as the plant became increasingly unfocused. Based on our discussion with managers, we believe that the plant was becoming increasingly unfocused on several dimensions during the period of the study and was struggling to respond effectively to the change in its manufacturing mission.

We next consider the main effects of heterogeneity. Table 2 shows that in both shops, the B2 coefficients associated with heterogeneity of part volumes are mostly negative. Again, the results are more likely to be significant in assembly than in machining. The results indicate that productivity tended to decline with greater heterogeneity of volume, especially in assembly. This trend is consistent with the results that Mukherjee, Mitchell, and Talbot (1999) report. The result is also consistent with our argument here that volume heterogeneity is a change in requirements that tends to reduce production line performance.

Finally, we consider the measure of adaptability. Table 2 shows that in both shops, the B3 coefficients associated with the interaction of time and heterogeneity are mostly positive, often at statistically significant levels in the assembly shop. The generally positive sign of B3 indicates that, over time, many lines became increasingly better able to deal with volume heterogeneity. Nonetheless, there is substantial line-by-line variation in the extent of the adaptability. Our task now is to determine how the independent variables that we predicted will affect adaptability tend to associate with differences among the B3 coefficients, that is, with differences in the degree to which different lines were able to adapt over time.

3.2 Results of Hypothesis Tests

We now discuss the detailed testing of the individual hypotheses. Table 3 reports the estimates we derive by correlating the adaptability measure (B3 from the regression model) with the independent variables that measure elements of manufacturing requirements and capabilities. We report the results separately for the assembly and machining shops, because of the differences that were apparent in Table 2, as well as for the factory as a whole.[5] For each pair of variables, we list the non-parametric Spearman correlation coefficient as we discussed earlier.[6]

************ Table 3 about here ************

Table 3 reports mixed results for hypothesis 1, which predicted that greater manufacturing requirements will lower adaptability of production lines to the new objective. The results reject H1A, but provide moderate support for H1B. Hypothesis H1A predicts that greater deficiency of old routines for a changed objective would reduce adaptability. The results reject the hypothesis strongly and significantly for the assembly lines. The machining line results also take the unexpected positive sign, but at non-significant levels. Factory-wide, the results take the unexpected direction and are moderately significant. One possible explanation for this unexpected result is that people and organizations adapt better under greater challenges, especially if they recognize the challenges and have resources available to address them. We discuss further the counter-intuitive result for H1A later in the paper.

Hypothesis H1B predicts that lower magnitude of change assists adaptability. The coefficients take the expected sign in assembly, machining, and across the factory, with the correlation being significant in the assembly shop. Overall, the results of testing H1B support the notion that greater magnitude of change at least somewhat interferes with adaptability. The results of H1B corroborate the general assumption that the greater the change, the greater the difficulty in adaptation (Barnett and Carroll, 1995).

Table 3 provides mixed support for Hypothesis 2, which predicted that greater manufacturing capabilities assist adaptability to a changed manufacturing objective. The results vary substantially among the operational variables.

H2A, which predicts that the availability of more old routines available at a line assists adaptability, receives moderate support. The results take the expected direction in both assembly and

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[5] To respect the confidentiality agreements, we report the summary correlation relationships, rather than the line-by-line values of the independent variables against B3.

[6] We report significance at the 90% and 85% levels of confidence, basing these choices on the sample size (Leamer, 1978).

machining. The results are moderately significant at the machining lines and across the factory. This result is consistent with Nelson and Winter's (1982) argument that routine variety promotes adaptability.

H2B, which predicts that adaptability will tend to increase with the extent of the repertoire of routines that individuals have experience with, reveals dual influences. The hypothesis is strongly supported among the machining lines but strongly rejected among the assembly lines. We will discuss the counter-intuitive result for assembly in the next section. The equally strong opposing results in the two shops prohibit any factory-wide inference.

The results support H2C, which predicts that greater mastery of old routines by employees of a line assists adaptability. The support is strong in assembly, moderate in machining, and strong across the factory overall. The results suggest that greater mastery of old routines often assists adaptation to new requirements. This result is consistent with Nelson and Winter's (1982) argument that routine familiarity promotes adaptability. The somewhat greater strength of this result, when compared to the routine variety influence in H2A, suggests that mastery of routines may be more critical than simply the number of routines available for potential recombination.

H2D, which predicts that greater available slack will assist adaptability, receives mixed support. We tested the hypothesis with two measures of slack: capacity cushion and set up time. The capacity cushion results significantly support the prediction at the machining shop but significantly reject the prediction in the assembly shop, where lower cushion rather than greater capacity cushion seems to assist adaptability. The set up time results are non-significant, individually in both shops, as well as overall, indicating little effect of set up time on adaptability. Overall, our testing of hypothesis H2D produces a mix of expected and unexpected results concerning the role of slack resource vis-à-vis adaptability. We will discuss the counter-intuitive results in the next section.

H2E, which predicts that greater horizontal information processing ability assists adaptability, receives moderate support. We tested the prediction with worker-to-supervisor ratio as the information processing measure. The results are significant in assembly. Although the coefficient for this hypothesis in the machine shop is non-significant, the factory-wide results are statistically significant. In general, this result is consistent with organizational design arguments concerning the contributions of horizontal decision-making to adaptability (Galbraith 1977).

4. DISCUSSION

The results provide support for several hypotheses while rejecting others. Overall, six out of eight tests provide at least partial support for the hypotheses. Adaptability often declines with requirements created by greater magnitude of change, especially in assembly. Adaptability often increases with capabilities that derive from routine variety (especially machining), routine experience in machining, routine mastery, slack capacity in machining, and horizontal information processing in assembly. Several notable rejections are also apparent. Among the manufacturing requirement influences, adaptability often increases with greater routine deficiency. Among the manufacturing capability influences, routine experience and slack capacity lead to reduced adaptability in assembly. We believe that both the support and rejections provide useful insights.

We noted the some of the direct implications of each result in the previous section, when we presented the results for each hypothesis. In this section, we consider some of the more interwoven implications. We first discuss implications of the bivariate correlation results. We next present exploratory multivariate analyses. We then outline general managerial implications.

4.1 Bivariate Implications

We find an important distinction between the assembly and machining line results. Overall, assembly line adaptability has stronger association with the independent variables than does machining line adaptability. The assembly results are significant for six of eight hypotheses, with three of them taking the expected sign and three taking the unexpected direction. In machining, meanwhile, four of eight hypotheses are significant, with two of the four achieving significance only at the 85% level. Unlike the assembly results, though, all four significant machining hypotheses take the expected sign. In general, then, the assembly lines were both more strongly affected and more likely to face conflicting influences than machining lines. Recall, too, that the productivity trends in Table 2 tend to be stronger in assembly than in machining. A key question, then, is why the adaptability of the assembly lines was so much more variable than the adaptability of the machining lines.

A key difference between the assembly and machining shops is that while the focus of the machining operations is on automation, that of the assembly operations is on manual skills. It is likely that the lower level of automation in assembly provides greater opportunities for learning and action by individuals, because people often have greater adaptive potential than machines. This is consistent with Upton's (1995, 1997) findings that the key to flexibility is the human factor, in that workers with more experience and greater skills are willing and able to 'stretch the envelope' to explore new possibilities. At our site, the differential emphasis of the two shops on individual skills and automated skills likely underlies many of the differences in the adaptability results, as we discuss below.

Implications concerning the differential relative importance of individual and automated skills arise from both the manufacturing requirement and capability influences. Among the manufacturing requirement influences in Table 3, the relationship between routine deficiency and adaptability (H1A) is interesting in terms of both its being positive, that is, counterintuitive, and in its being significant in assembly, but non-significant in machining. That the relationship is counterintuitive suggests that lines where managers recognize the difficulties of handling variable batch sizes adapt better. Thus, this routine deficiency result highlights how cognitive approaches may characterize production-line decision-making. An important factor in carrying out routines is the ability to know which routines to perform when. For an individual, this entails the ability to receive and interpret a stream of incoming external messages. For a production line, this amounts to the first line of management performing the activities of processing external information such as demand and delivery requirements, and then translating it into a form such as a work center production schedule that line workers will understand and act upon. Thus, the line managers are actors at the interface between the line and entities such as other sub-units of the factory, other parts of the firm, and the external environment. To the line managers, the activities of receiving and processing information, and then formulating and sending messages are the performance of routines. When external events such as heterogeneous batch sizes challenge these routines, one response is to remain firmly committed to the existing way of doing things, which are based on homogenous batch sizes. Not recognizing the difficulties with variable batch sizes can be a manifestation of such response. A greater resistance at the interface will likely make the line less responsive to adapting to the change, since the messages sent from the interface will not favor adaptation. Messages sent from the interface can be critical in creating specific managerial emphasis, which Upton (1997) finds to be associated with outcome in the context of flexibility. An example at the site is that of small batches being treated as 'a nuisance.'

Next, the finding that the routine deficiency relationship is positive and significant at assembly, while still positive but not significant at machining, suggests a greater effect of this variable on assembly lines. We have already argued that adaptability may require that managers recognize the potential difficulties which will arise from handling batches of variable sizes at particular lines and devote substantial attention to addressing the problems. The results suggest that greatest success in this regard came for the lines at which individually-based skills are the most important, that is, in assembly rather than machining. The likely reason is that people often possess greater potential for adaptation than machines, so long as they recognize the need to adapt, have appropriate resources, and undertake efforts to change. More automated situations, by contrast, involve greater rigidity and offer fewer potential individual options for effective responses, leading to greater managerial resistance. Thus, we would expect to see lesser adaptability over time in machining, consistent with the trends in Table 2. At a general level, therefore, the difference in automation of assembly and machining may lead to cognitive differences in how managers view the need and potential for adaptation.

The manufacturing capability results in Table 3 also provide striking implications concerning the difference between personal adaptation and automation adaptation. The variables that derive most strongly from attributes of people have the strongest influence on the assembly lines. Notice, particularly, the somewhat greater impact of training (H2C) and the substantially greater impact of worker horizontal information processing (H2E). By contrast, the variables that derive more from attributes of the line, such as routine variety (H2A) and slack (H2D) associate more with adaptability of the machining lines. The straightforward implication of this comparison is that personal experience has greatest influence on adaptation when the adaptation involves activities that rely on manual skill, while line experience has greatest adaptation influence for activities involving automated skill.

At the same time, though, greater reliance on human skill may also produce counter-productive influences on some attempts to adapt. Note, in particular, the negative relationship between individual routine experience gained through job rotation for assembly adaptation, while, by contrast, rotation has a positive relationship with machining line adaptation (H2B). A possible explanation for these divergent results is that machining provides a more stable, defined environment owing to automation, so that rotation may provide cumulative development of skills that individuals can apply to new machining activities, especially if the new machining-line activities build cumulatively on the prior activities. By contrast, rotation among less-automated assembly activities may lead to a more fragmented set of skills that have less cumulative value, particularly since the lower degree of assembly automation means that adaptation may involve more discrete changes than in machining. Table 1c illustrates additional implications concerning this point, reporting a positive correlation between training (routine mastery) and rotation (individual routine experience) in machining ($r= 0.74$), but a negative correlation between training and rotation in assembly ($r= -0.50$). Again, the more automated machining environment may allow rotation among related activities to support training activities. By contrast, in the more idiosyncratic assembly environment, rotation among differentiated activities may actually conflict with training activities. Overall, then, the greater idiosyncrasy and fragmentation of assembly activities that rely on individual skill may reduce the cumulative value of rotation experience when workers attempt to adapt to changed activities.

The rotation results for the assembly lines conflict with the current conventional wisdom that multi-tasking will promote flexibility. Despite the conventional wisdom, though, Upton (1997) finds a negative impact of multi-tasking on product range flexibility. Our assembly line results are consistent with Upton's results. Upton explains his results behaviorally. In parallel, we suggest that within the technical and cognitive limits of how many skills a person can master, the difficulty of remembering an overly-extensive set of skills will make ready adaptation more difficult. Such problems will be particularly pronounced in situations that involve greater individual skills, such as the assembly lines, rather than cases that tend to involve programmed machine-tending, such as in the highly automated machining lines.

The negative results for capacity cushion slack (H2D.1) among the assembly lines might also arise from problems based in the emphasis on individual skills in assembly. Individuals working at assembly lines with greater available capacity slack may have tended to develop a degree of laxness in production and found it difficult to adapt when faced with new objectives. By contrast, individuals working on assembly lines that had little slack may have developed a discipline that helped them adapt. Conversely, in machining, where the predicted positive relationship between slack and adaptability emerged, the more highly automated machining lines may have required the presence of substantial slack in order to revise automated procedures. Consistent with the argument that underlay H2D, machining lines with little slack may simply have been too constrained to both achieve ongoing production and make necessary changes to the mode of production. The implication here is that human-based skills can often change more quickly than machine-based skills, but need the presence of disciplined humans to undertake effective changes.

4.2 Multivariate analysis

We used the bi-variate correlation approach that Table 3 reports due to the relatively small number of production lines available for the study. However, in addition to the bivariate tests, we undertake exploratory analysis with a limited set of multivariate regression analyses. Table 4 reports these multivariate analyses, based on the factory-wide pooled sample of sixteen production lines. We excluded slack and rotation as independent variables from the factory-wide regressions because of their significant opposing influences in the assembly and machining shops.

************ Table 4 about here ************

Table 4 first compares the influences within the sets of manufacturing requirement and capability variables. Row 1 reports a model with the two manufacturing requirement variables, showing that routine deficiency continues to retain its significant influence, while change magnitude remains negative but with a non-significant coefficient. Row 2 then reports a model with the three capability variables that had consistent factory-wide individual influences, showing that routine variety, routine mastery, and information processing all retain their positive influence on adaptability, with routine mastery having a significant effect. Note in Table 1c that the three factory-wide capability variables are only moderately correlated with each other (r=.36 to .44). Among the capability influences, then, routine mastery, which we measured in terms of worker training, appears to have the strongest influence on adaptability. Note, too, that the manufacturing capability variables provided substantially greater adjusted R-square than the manufacturing requirement variables (.266 versus .075), suggesting greater overall influences of manufacturing capabilities.

Table 4 next combines the manufacturing requirement and capability influences. Row 3 combines the routine deficiency variable, which was significant in row 1, with the three capability variables. None of the four variables in model 3 is significant and the adjusted R-square drops substantially from model 2 to model 3, however, due to the small sample size. Therefore, we refined the analysis further.

Intriguing inferences arise when we refine the analysis, as we show in row 4 of Table 4. Model 4 drops the capability variable that had the weakest influence (routine variety) in model 3. Model 4 reports that the routine mastery variable returns to statistical significance and information processing takes a near-significant coefficient. Routine deficiency, meanwhile, not only fails to return to significance in model 4, but now takes the negative sign that H1A predicted. The change in the routine deficiency sign is partly a statistical phenomenon, because there is a substantial factory-wide correlation between routine deficiency and routine mastery (r=.71 in Table 1c). Nonetheless, the results in row 4 are intriguing, because they suggest that the apparent counter-intuitive effect of routine deficiency might arise because the lines at which workers have the greatest training also are those that supervisors expected to have the most difficult adapting to the new batch size demands. In turn, this relationships suggests that the plants' recognition of where the potential difficulties would be greatest led them to undertake additional training for workers at those lines. The training then led to greater ability to adapt. As we noted earlier, the adaptation was most successful in the assembly lines, where training provided the greatest potential for individual adaptation.

Finally, model 5 of Table 4 drops the routine deficiency variable and assesses the impact of routine mastery and information processing. Routine mastery continues to be significant, while information processing remains near statistical significance. This set of two capabilities variables provides the best overall fit, based on the adjusted R-square. Overall, Table 4 suggests that substantial influences on adaptation arise from capabilities variables that involve line level employees, particularly training and, to a lesser extent, horizontal decision making abilities.

4.3 Managerial implications

What, then, are the managerial implications of this study? That is, how might managers of a focused factory most successfully guide a change in the activities of the factory? The summary results that we present in Table 5 suggest several inferences. Table 5 differentiates between activities that emphasize individual activities (assembly) and activities that emphasize automation activities (machining). The table then lists the influences that tended to associate with greater adaptability in each case. The table also notes the reasons that appear to underlie the source of each association.

********** **Table 5 about here** **********

Table 5 depicts striking similarities and differences between the two types of cases, depending on whether activities emphasized individual or automated activities. Successful adaptation for activities that emphasized individual activities required an activity of manageable individual scope, plus the presence of people with a range of personal attributes, including knowledge, responsibility, focus, and discipline. Thus, it seems that employees draw upon their knowledge of, as well as responsibility for, a specific activity to create responses to new requirements. We call such adaptation emergent adaptation. With emergent adaptation, all potential ramifications of a change need not be anticipated. Rather, adaptation occurs as the need arises, through improvisation of often fragmented and idiosyncratic individual skills. Such improvisation of individual skills is best supported when individuals have focused on those skills, and have the discretion to carry out some experiments with their idiosyncratic skills. Thus, managers of activities that primarily involve individual activities should emphasize developing employees with deep knowledge of their individual skills and establish organizational structures that allow those employees substantial responsibility and discretion in how they exercise their skills. Such a combination of people and structure will often permit effective ongoing adaptation to emergent new demands. Therefore, when skill is individual based, managers can best prepare for adaptation by taking advantage of the inherent potential of that skill-set for emergent adaptation.

For activities that emphasized automated activities, successful adaptation also required an activity of manageable scope and knowledgeable people, but differed in the emphasis on where the people drew their skills and focused their attention. In the automation-oriented activities, success tended to arise when employees' skills included extensive knowledge of other activities. The likely cause is that a change in the mode of activities on an automated line needs a carefully planned and coordinated change in other activities. Further, the multi-activity, multi-line nature of these changes necessitates that the responses be planned and coordinated over many activities and production lines. However, in an automated environment, employees and managers alike may be too constrained by automation to do extensive improvisation or experiments with processes. Without improvisation, adaptation in the emergent mode cannot take place. Rather, relatively little must be left to idiosyncratic endeavors in responding to changes that occur across activities and functions. Simultaneous cross-functional changes necessitate that responses be created with cross-functional considerations. Thus, cross-functional knowledge underlies these responses. Without the cross-functional knowledge, the employees will be unable to make effective choices about how to make substantial system-wide changes. Therefore, while managers of activities that primarily involve automated skill should also emphasize developing highly trained employees, in addition to knowledge of their individual skill, the employees need substantial knowledge of activities in other related activities. Unlike the case in which individual skills are most important, adaptation that attempts to rely on emergent understanding, rather than planned change, will often fail in an automated environment. Note in this regard that although changes at one assembly line undoubtedly required changes at other lines, the reliance on individual skills would allow greater emergent adaptation as the need for changes became apparent.

Another broad implication for managing change comes from the results related to the capability variables of part routing, job rotation, and worker-to-supervisor ratio. Greater magnitudes of these variables represent greater complexity of activities, skills, and responsibilities. In each case, we observe that greater complexity significantly correlates with adaptability, usually positively, with the one exception of the negative effect of rotation in assembly. In general, therefore, greater complexity often creates the basis for more effective adaptation. The implications of these results lie in the contingent benefits of managing complexity well. Management can make a conscious choice along relevant activities to design a degree of complex variation. The content of the adaptive variety will vary, though, depending on the nature of the activity. For example, a system-based complexity dimension such as greater part routing variety may be more effective in the automation-based machining lines, whereas an individual-based complexity dimension such as greater job responsibility may be more effective in the individual skill-based assembly lines. In general, therefore, some degree of complexity, contingent on the skill-type of a line, seems to be aid adaptability.

The exception to this rule is the result that adaptation at assembly becomes less effective with more rotation. There may be two reasons for this exception. First, as Table 1b shows, the degree of rotation in assembly (mean = 2.43) is much more than that in machining (mean = 1.00). This raises the issue of an appropriate limit beyond which additional complexity may be counterproductive. Second, it is possible that attempts to emphasize cross-functional activity will be counter-productive in settings that emphasize individual skills. One possible source of counter-productivity is that cross-functional activity may lead to a greater cognitive burden in an environment of fragmented and idiosyncratic skills rather than in structured jobs of the machine shop, and thus, may take time and attention away from focal activities. In addition, and possibly more importantly in an environment of emergent skills, the knowledge that employees gain through cross-functional activity may become obsolete once an objective or response changes. Despite the obsolescence, though, the employees may attempt to adapt based on an out-moded perception of appropriate changes. Finally, note that the effects of too much complexity and counterproductive cross-functional activity are mutually reinforcing in reducing adaptability.

The overriding managerial imperative here is to carefully incorporate complexity in the operations of a production unit, without crossing the limits where complexity turns into chaos. Whether an activity involves individual or automated skills, managers can gain by keeping the degree of routine variation under sufficient control that they can operate efficiently and, yet, develop a sufficiently varied repertoire of capabilities that they will be able to adapt effectively to changes. Managers must be careful in setting limits of this variation, so as to prevent a complex activity from degenerating into confusion.

5. CONCLUSIONS

We began the paper by asking what variables might influence the success of production line adaptability to a change in their manufacturing objectives. At a more general level, this question concerns the conditions under which organizations can change successfully. The results of the study offer a fairly simple but striking set of answers to these questions. Overall, the variables that influence the adaptability of production lines significantly appear to derive from both organizational and individual competence. Further, the direction and extent of the influence of a variable appear to depend on the nature of the operational activity that occurs at a production line.

At an organizational level, one aspect is most important. Change is most effective when firms have a wide variety of existing routines on which to draw when creating new routines as part of the change process. This result speaks to the growing interest and recognition of the value of being able to recombine existing routines in order to create new routines (Eisenhardt and Galunic, 1996).

At an individual level, three aspects stand out, involving people at managerial and operating levels in the organization. First, our strongest result is that adaptation is most effective when operating employees have adequate training, consistent with Nelson and Winter's view (1982:31) that recombination of existing routines is facilitated if these routines are fully under control. Second, adaptation is most effective when managers recognize problems that may arise as a result of the change, consistent with process-oriented explanations of behavior and decision-making (Simon 1986, Tversky and Kahneman 1988). Third, adaptation is most effective when operating employees have adequate autonomy to help undertake the adaptation, consistent with Galbraiths' (1977) argument that horizontal information processing is an enabler of meeting new requirements.

Together, these elements offer insights concerning successful change. Changes are most likely to succeed when individuals recognize problems, have requisite individual skills, have adequate autonomy to experiment and innovate with those skills, and are supported by a variety of organizational routines. However, while skill mastery appears to be a universal facilitator of adaptability, managerial problem recognition and employee autonomy seem to be more effective when operations involve more manual, individually-oriented processes than automated processes. In contrast, organizational routine variety is more effective when operations are more automated and involve closely-coupled system interactions. Thus, these elements differ in the degree of their impact on production line adaptability, depending on the nature of the operational activity of the line.

The organizational and individual variables vary in the extent of their influence on adaptability, but not in the direction of their influence across operation-types. In contrast, we find several cases in which the direction of the influence on adaptability depends on the nature of the operations that the line carries out. We find that organizational resource-slack and individual multi-tasking experience facilitate adaptability when the operations involve automated inter-line close coupling, and is thus consistent with Galbraith (1977) and Boynton, et al., (1994), but may hinder adaptability when the operations emphasize individually-based skills. Thus, the direction of the influence of variables such as organizational resource slack and individual routine variety seems to be contingent on the type of operations, particularly on the distinction between closely-coupled and loosely-coupled systems, rather than being universally applicable. In a real sense, this reinforces decades old ideas from Thompson (1967) and Weick (1976), who distinguished between the differential adaptive qualities of interwoven and independent systems.

The results also support the notion of contingent benefits of managing complexity (Chandler 1962). In the context of a factory, it adds to our understanding of how complexity of operational activities may not necessarily lead to the confusion that Hayes and Clark (1985) observe. More generally, while several researchers note the strong social and economic inertial barriers to organizational change (e.g., Cyert and March, 1962; Nelson and Winter, 1982; Hannan and Freeman, 1989), our results contribute to the understanding of how firms can sometimes balance their needs for reliability of current activities with their needs to reshape business capabilities through designing a carefully selected adaptive variety into its operations, where the content of the adaptive variety is contingent on the operational skills involved.

Two of these results have specific implications for research in Operations Management. First, we find that rationality of goals more than means may influence shop floor adaptability. This is consistent with experimental results of Lucas (1986) that the rational choice paradigm may not be applicable in a non-stationary environment, which a production line undergoing change is. This is also consistent with Upton's (1997) findings that 'managerial emphasis' is a determinant of flexibility. Under such conditions, decisions will be guided by managers' beliefs, expectations and utilities rather than by rational choice. Understanding such phenomena calls for research instruments that incorporate psychological and sociological components into economic research tools (Simon 1986). However, there is virtually no standard, validated research tool of that type in the Operations Management literature.

The second result of relevance here is the strong, positive influence of routine mastery on adaptability. The implication is that for several elements that the literature identifies as enablers of flexibility (Sethi and Sethi 1990, Gerwin 1993), the effectiveness of enablers may depend not only their presence in a production unit, but also on their degree of assimilation. Further, the transition flexibility of a production unit, called 'mix-change flexibility' in the above-cited literature from a product-based perspective, may be an important determinant of post transition performance, given the path-dependent nature of adaptability of production lines.

The evolution of adaptation at the Hartselle site after the period of our study has interesting implications for our results. We base the following comments on our discussions with Hartselle managers after the period of the study. We note that the discussions took place before we discussed our results with the company and, indeed, before we knew our statistical results ourselves. The following paragraphs note several initiatives that the firm undertook in order to implement its new mission. Overall, that process has been successful. Hartselle is a high performance plant in 1999, having undergone a successful adaptation process.

First, the managers note that they became aware of an organizational mindset that opposed product proliferation within the plant, despite the strategic change in the mission of the plant. In response, corporate management started a training program in 1992 to create a new mindset among workers and supervisors to accept future changes. This step is consistent with our findings that factories must overcome cognitive and behavioral resistance to volume heterogeneity in order to assist adaptability.

Second, several managers noted that new practices concerning temporary employment in the proliferated environment were counter-productive. They stated that adding and removing a large number of temporary workers created major problems in a proliferated environment, because proliferation needs a higher plant-wide skill base that the temporary employment practice obstructed. The problems that the temporary employment practices create are consistent with our finding that training has the strongest influence on adaptability, because temporary workers will typically have lower levels of training than permanent employees.

Third, we found the plant to be taking interesting steps regarding individual experience with routines, in the light of our findings that such experience helped the adaptability of the inter-dependent automated machining but hindered the adaptability of the individually-oriented manual assembly. The plant initiated a training program in the machining shop in 1992-1993 to cross-train workers on selected key machining jobs across the shop. In contrast, we found at least one assembly line stopped its prior practice of having three workers rotate between jobs and instead assigned each worker to a workstation.

In conclusion, our study offers several insights regarding the adaptability of factories, and more generally, businesses, to a change in mission. First, our examination of several literature-based elements of adaptability suggests a differential role for them in an emergent versus planned mode of adaptation. The results also suggest that the appropriate mode of adaptation may depend on the underlying type of operational activity of an organization, in that emergent versus planned adaptation seem to be more appropriate for changes in loosely-coupled versus closely-coupled operations, respectively. Second, while implications concerning the differential relative importance of individual and automated activities arise from both the manufacturing requirement and capability influences, the overall influence of the capability variables on adaptability turns out to be stronger. Third, cognitive rather than rational approaches tend to assume a larger role in decision making in non-stationary environments such as production lines undergoing change, and understanding them calls for appropriate, new research instruments. Finally, operations focus can play a crucial role in such environments by allowing the complexity necessary to create adaptive responses while preventing it from degenerating into confusion.

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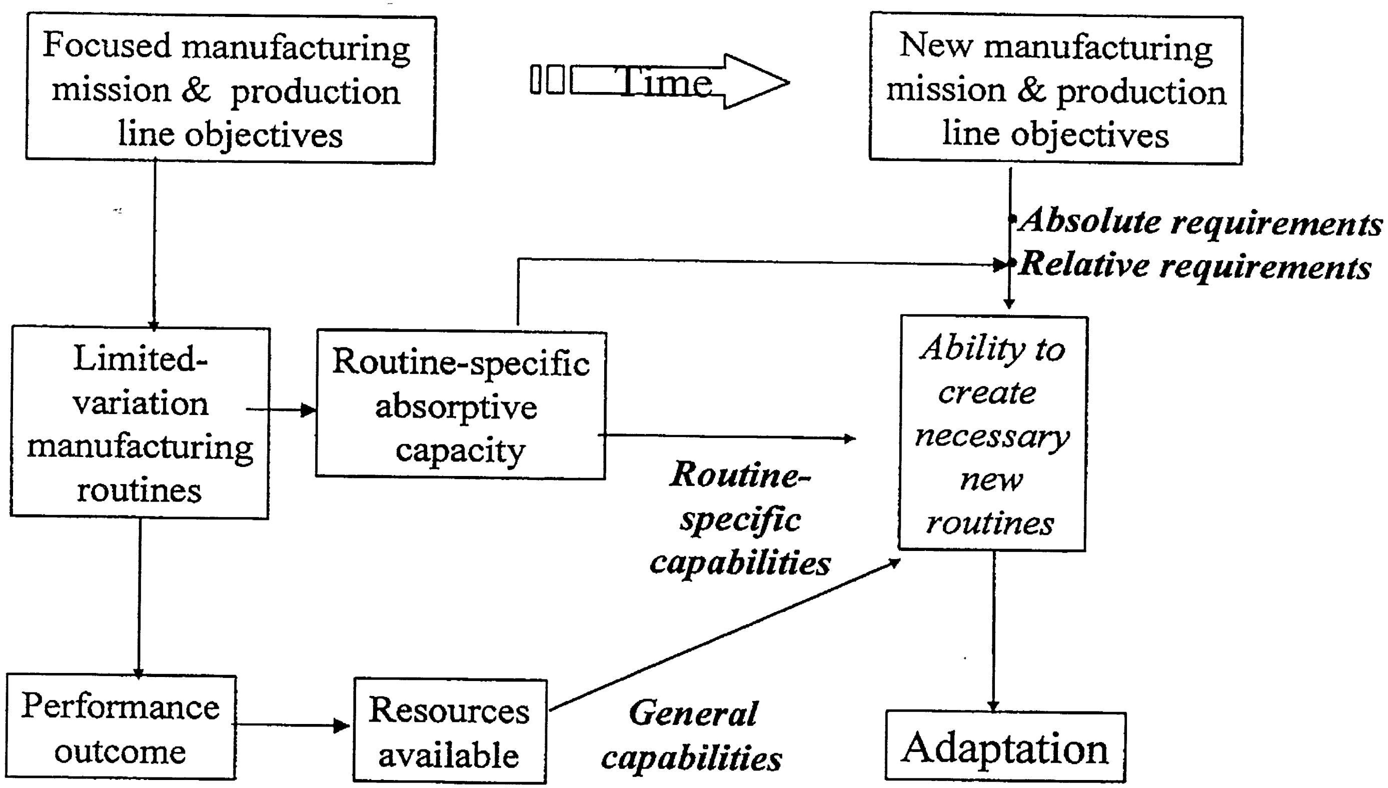

Figure 1. Conceptual Model

Table 1a. Variables, Measurement, and Data Sources

Dependent variable

Variable	*Measure*	*Data Source*
Adaptability to a changed production line objective, defined as the intertemporal association between direct labor productivity of a line and part volume heterogeneity	Dependent variable: B3 coefficient in equation 1 multiple regression; a larger positive B3 indicates greater adaptability, as we describe in the text. Δ LaborProductivity$_{t-1,t}$ = B1ΔLogT$_{t-1,t}$ + B2 ΔHet$_{t-1,t}$ + B3 Δ(Het x LogT)$_{t-1,t}$ + $e_t - e_{t-1}$	1986-1990, primary "Direct labor hours per unit product" and "Hirschman Index of part volumes" data, as we describe below.
Direct labor productivity of a line	LaborProductivity = Direct labor hours per unit product	Actual monthly direct labor hours by cost center, 1986-1990, and work standards by year.
Part volume heterogeneity (i.e., requirement change)	Het = Hirschman Index of part volumes (HINDEX)	Production volumes by month for each of the 1,300 part numbers, 1986-1990.

Independent variables

Hypothesis 1. The greater the additional manufacturing requirements of a changed objective, the less effectively a production line will adapt to the change.

Variables denoting the additional manufacturing requirements of a changed objective	*Measure*	*Expected correlation with B3*	*Data source*
H1A. Deficiency of existing routines needed to carry out a changed objective (Routine deficiency)	Difficulty in processing large and small batches on the same line; 5 point Likert scale: 1 = Not at all difficult, 5 = Very Difficult	-	Survey of production line supervisors
H1B. Magnitude of a changed requirement (Change magnitude)	Mean value of part volume heterogeneity (mean HINDEX)	-	Same as Part volume heterogeneity

Hypothesis 2. The greater the manufacturing capabilities of a line, the more effectively the line will adapt to a changed objective

Variables denoting the manufacturing capabilities of a line	*Measure*	*Expected correlation with B3*	*Data source*
H2A. Repertoire of routines that a production line uses for its existing objectives (Line routine variety)	"Part Routing Difference" at a line, 5 point Likert scale: 1 = No Difference, 5 = All Different	+	Survey of production line supervisors
H2B. Repertoire of routines that individual employees have experience with (Individual routine experience)	"Extent of Job-Rotation": Number of jobs through which workers rotate	+	Survey of production line supervisors
H2C. Production line's mastery of its old routines (Routine mastery)	"Adequacy of Training" of workers, 5 point Likert scale (scale reversed from questionnaire): 1 = Highly Inadequate, 5 = Highly Adequate	+	Survey of production line supervisors
H2D. Slack resources at production line			
H2D.1. Capacity cushion (Capacity slack)	"Capacity Cushion", 5 point Likert scale (scale reversed from questionnaire): 1 = Little Cushion, 5 = Large Cushion	+	Survey of production line supervisors
H2D.2. Time available after set-up losses (Set up slack)	"Average Time Available", less "Average Actual Time Required For Set Up", calculated in hours per month	+	Survey of production line supervisors
H2E. Horizontal information processing ability of employees at a production line (Horizontal information processing)	"Worker-Supervisor Ratio": Actual numerical ratio	+	Survey of production line supervisors

Table 1b. Summary Statistics for Independent Variables

		Assembly (N = 8)					Machining (N = 8)					Factory-wide (N = 16)				
Variable	**Measure**	Range	Min	Max	Mean	SD	Range	Min	Max	Mean	SD	Range	Min	Max	Mean	SD
Routine deficiency	5-point Likert scale	3	2	5	3.37	1.061	2	1	3	2.37	.744	4	1	5	2.87	1.06
Change magnitude	Mean value of HINDEX	.44	.04	.48	.129	.155	.61	.12	.73	.4624	.2103	.69	.04	.73	.296	.247
Line routine variety	5-point Likert scale	2	1	3	1.75	1.035	2	1	3	1.25	.707	2	1	3	1.5	.894
Individual routine experience	Number of jobs	1.5	1.5	3	2.43	.608	3	0	3	1.00	1.195	3	0	3	1.67	1.192
Routine mastery	5-point Likert scale	2	2	4	3	.756	3	2	5	4.12	1.12	3	2	5	3.56	1.09
Set up slack	Hours	12.6	3.4	16	7.27	5.468	28.67	1.33	30	16.29	12.25	78.67	1.33	80	26.33	22.94
Capacity slack	5-point Likert scale	1	2	3	2.56	.496	3	2	5	3.5	1.414	3	2	5	3.03	1.13
Horizontal information processing	Ratio	32	3	35	15.13	12.56	17	3	20	12.37	7.46	32	3	35	13.75	10.08

Table 1c. Pearson Pair-wise Correlation Coefficients between Independent Variables

		1	2	3	4	5	6	7	8
	Assembly lines (N=8)								
1	Routine deficiency	1	-.278	-.293	-.553	.713	-.629	-.360	.425
2	Change magnitude		1	.337	.475	-.271	-.077	-.277	-.550
3	Line routine variety			1	-.201	.000	-.453	.756	.431
4	Individual routine experience				1	-.504	.412	-.108	-.696
5	Routine mastery					1	-.763	-.048	.526
6	Set up slack						1	-.151	-.538
7	Capacity slack							1	.666
8	Horizontal information processing								1
	Machining lines (N=8)								
1	Routine deficiency	1	-.299	.339	.000	.576	-.068	-.353	.306
2	Change magnitude		1	-.108	-.168	-.439	.038	-.334	-.572
3	Line routine variety			1	.676	.763	-.143	.452	.413
4	Individual routine experience				1	.743	.423	.192	.080
5	Routine mastery					1	.314	.055	.210
6	Set up slack						1	-.540	-.697
7	Capacity slack							1	.645
8	Horizontal information processing								1
	Factory-wide (N=16)								
1	Routine deficiency	1	-.520	.073	.189	.707	.054	-.043	.403
2	Change magnitude		1	-.120	-.530	-.602	-.288	-.481	-.465
3	Line routine variety			1	.362	.443	-.049	.706	.444
4	Individual routine experience				1	.616	.567	.315	-.024
5	Routine mastery					1	.308	.236	.361
6	Set up slack						1	-.012	-.377
7	Capacity slack							1	.644
8	Horizontal information processing								1

Table 2. Standardized Time-Series Regression Coefficients of Equation 1

Larger positive B3 coefficients indicate greater adaptability, that is, less detrimental impact of volume heterogeneity on productivity over time, while more negative B3 coefficients indicate lesser adaptability.
(Based on first-differences of LaborProductivity; N=47; t-statistics in parentheses; coefficients significant at 90% or higher are in **bold**.)

	Durbin-Watson 'd' *	Multiple R	B1 (t-values): LogT	B2 (t-values): Heterogeneity	B3 (t-value): LogT x Heterogeneity.
Machining lines					
ML1	2.35	.20	-.140 (.722)	-.624 (1.253)	.554 (1.124)
ML2	2.01	.08	-.019 (.116)	.080 (.146)	.001 (.002)
ML3	2.22	.26	-.108 (.707)	-.369 (.473)	.592 (.757)
ML4	2.31	.32	-.066 (.447)	**-.237 (1.433)**	-.107 (.645)
ML5	1.87	.22	-.958 (.740)	-.360 (.460)	1.077 (.709)
ML6	2.51	.27	-1.376 (1.134)	-.818 (1.173)	1.281 (1.062)
ML7	2.04	.50	-.213 (.312)	-.923 (1.192)	.786 (.856)
ML8	2.04	.24	.677 (1.105)	-.640 (.868)	.668 (1.115)
Assembly lines					
AL1	2.29	.25	.144 (.502)	.343 (.967)	-.119 (.365)
AL2	2.32	.21	-.159 (.500)	.199 (.369)	-.109 (.168)
AL3	2.53	.32	**-.284 (1.771)**	**-.842 (1.765)**	**.806 (1.661)**
AL4	2.16	.33	**-.385 (2.012)**	**-1.095 (1.935)**	**1.058 (1.813)**
AL5	2.43	.28	**-.287 (1.616)**	**-.998 (1.575)**	**.970 (1.501)**
AL6	1.88	.40	**-.434 (2.561)**	**-1.373 (2.203)**	**1.356 (2.203)**
AL7	2.15	.37	**-.376 (2.184)**	**-1.304 (2.124)**	**1.263 (2.018)**
AL8	2.11	.15	-1.100 (.943)	-.754 (.967)	.770 (.942)

* The acceptable range of d-statistic for this data set is between 1.63 and 2.37 (Durbin & Watson, 1951). Only three of sixteen cases fall slightly outside this range, suggesting little evidence of auto-correlation.

Table 3. Spearman Non-Parametric Correlation Coefficients between B3 and Independent Variables

Positive coefficients indicate greater adaptability. Coefficients in bold (**) are significant at the 90% level. Coefficients in *italics* (*) are significant at the 85% level. These significance levels are relevant for the size of the sample.

Hypothesis (expected sign)		*Assembly lines* (N=8)	*Machining Lines* (N=8)	*Factory Wide* (N=16)	*Hypothesis results*: Implications for adaptability to changed objective (We address the unexpected results in the discussion section)
H1	**Manufacturing Requirement Variables**				
H1A (-)	Routine deficiency (Batch size difference difficulty)	**.784 ****	.143	*.484 **	*Rejected*: Deficiency of old routines for new objectiuve assists assembly adaptability.
H1B (-)	Change magnitude (Mean HINDEX)	**-.781 ****	-.119	-.339	*Moderate support*: Greater magnitude of change often resists adaptability.
H2	**Manufacturing Capability Variables**				
H2A (+)	Line routine variety (Routing difference)	.169	*.577 **	*.438 **	*Moderate support*: More available old routines somewhat assists adaptability.
H2B (+)	Individual routine experience (Job rotation)	**-.767 ****	**.805 ****	.184	*Mixed support & rejection*: Greater variety of routines among employees has mixed effects on adaptability.
H2C (+)	Routine mastery (Training)	**.849 ****	*.587 **	**.622 ****	*Support:* Greater mastery of old routines often assists adaptability.
H2D.1 (+)	Capacity slack (Capacity cushion)	**-.782 ****	**.626 ****	-.055	*Mixed support & rejection*: Slack from capacity cushion has mixed effects on adaptability.
H2D.2 (+)	Set up slack (Available time)	-.289	.073	.034	*Rejected*: Slack from time gained in set up has little effect on adaptability.
H2E (+)	Horizontal information processing (Worker-supervisor ratio)	.723	.060	**.575 ****	*Moderate support:* Greater horizontal information processing somewhat assists adaptability.

Table 4. OLS Regression Models

Cell values indicate standardized regression coefficients with t-values in parentheses (n=16 cases) . Coefficients in bold (**) are significant at p> 90%.

Note: We did not include rotation (H2B) and slack (H2D) in the regression models, although they were significant explanatory variables in each shop individually, due to their strong opposing effects in the two shops.

	Manufacturing Requirements		*Manufacturing capabilities*				
	Routine deficiency (Batch size difference difficulty)	Change magnitude (Mean HINDEX)	Line routine variety (Routing difference)	Routine mastery (Training)	Horizontal information processing (Worker-supervisor ratio)	R-square	Adjusted R-square
	H1A (-)	H1B (-)	H2A (+)	H2C (+)	H2E (+)		
Model 1	**.439 (1.509) ****	-.013 (.044)				.198	.075
Model 2			.107 (.407)	**.473 (1.875) ****	.207 (.819)	.413	.266
Model 3	.056 (.146)		.130 (.412)	.429 (1.076)	.190 (.659)	.414	.201
Model 4	-.022 (.069)			**.522 (1.647) ****	.245 (1.001)	.405	.256
Model 5				**.508 (2.211) ****	.241 (1.052)	.405	.313

Table 5. Variables Associated With Greater Adaptability

	Variable	Individual Activities (Assembly)		Automated Activities (Machining)	
		Influence	*Reason*	*Influence*	*Reason*
	Manufacturing requirements				
H1A	Routine deficiency	Greater recognized deficiency	Knowledgeable line managers		
H1B	Change magnitude	Lesser magnitude of change	Manageable *individual* scope		
	Manufacturing capabilities				
H2C	Routine mastery	Greater training	Knowledgeable people	Greater training	Knowledgeable people
H2A	Routine variety			Greater routing differences	Cross-functional experience
H2E	Information processing	Greater worker influence	Responsible people		
H2B	Routine experience	Less rotation	Focused people	More rotation	Cross-functional experience
H2D	Slack	Less capacity cushion	Disciplined people	Greater capacity cushion	Manageable *system* scope

Appendix: Survey Questionnaire
(Administered in 1993; relevant hypothesis noted in parentheses)

Instructions:

a. *All questions pertain to the period 1986-1991, that is, to the years after CR4 introduction but before CR6 introduction.*
b. *Please indicate the best answer for each question.*

Question	Hypothesis	Response options
1. Sometimes parts are made in large as well as small batches. How easy or difficult is it to produce large and small batches together?	H1A	Scale: 1 = Very Easy 2 = Somewhat Easy 3 = Neither easy nor difficult 4 =Somewhat difficult 5 =Very difficult
2. You have different part numbers being made on this line. Do different part numbers follow different routing?	H2A	Scale: 1 = Not at all different 2 = Minimally different 3 = Somewhat different 4 = Mostly different 5 =All different
3. How many jobs have the workers on your line rotated through?	H2B	Actual number of jobs
4. Has the right amount of training been provided to the workers on your line?	H2C	Scale: 1 = Much less needed 2 = Less needed 3 = Just about right 4 = More needed 5 =Much more needed
5a. Do you have enough capacity on your line to meet the demand?	H2D.1	Scale: 1 = Much more than enough 2 = More than enough 3 = Just about right 4 = Less than enough 5 = Much less than enough
5b. How long does it take to change set up?	H2D.2	Actual time required in hours and minutes
6. How many employees are under the supervision of one supervisor?	H2E	Actual number of employees