Developing Flexibility in Assembly Environments

By

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Submitted to the Mechanical Engineering Department and the Sloan School of Management in partial fulfillment of the requirements for the degrees of

Master of Science in Mechanical Engineering
and
Master of Business Administration

In conjunction with the Leaders for Manufacturing Program at the
Massachusetts Institute of Technology
June 2007

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1.0 Abstract

Manufacturing flexibility has been a topic of interest for both researchers and practitioners for several decades. Despite the amount of attention that flexibility receives, it remains a nebulous concept to those in industry trying to develop flexibility within their firms. This thesis attempts to act as a guide to practitioners, bridging the gap between the idealistic academic literature and the pragmatic concerns that are encountered when actually implementing flexibility projects.

It is very difficult to develop recommendations for the implementation of flexibility projects from outside of an organization. Therefore this thesis introduces two separate flexibility implementation case studies that were performed while the author was employed by the firm in the case study. Through offering this unique perspective, it becomes apparent that without knowing the cultural and political climate of the firm, poor recommendations can be made. Often implementation failure can be traced back to this root cause.

Flexibility is often thought of as a manufacturing problem. While flexibility is an important tool in combating increased uncertainty and variability within the manufacturing environment, there is great opportunity to utilize flexibility in other environments as well. In particular flexibility can be a key source of competitive advantage if properly applied to the launch of new products. Typically most organizations divide the manufacturing and design functions through organizational boundaries resulting in vastly disparate entities. Therefore increased focus around the hand-off between these two functions, particularly with respect to flexibility can provide significant opportunities.

Keywords: Manufacturing Flexibility Implementation

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ACKNOWLEDGEMENTS

I would like to thank Dell for sponsoring this internship and its continued support of the LFM program. I'd like to specifically thank several people at Dell for an exceptional LFM internship experience.

I would like to thank Steve Cook for his sponsorship of the flexibility internship project. His energy and leadership were instrumental in providing a challenging opportunity that fueled the research of this thesis topic.

Matt Snyder and Jennifer Smith deserve recognition for their tireless patience and guidance throughout the project. Their contributions were invaluable to both the project and my personal development.

I'd like to acknowledge Rick Anthony, Jen Felch, Cale Holman, Jessica Dolak, Michael Hoag, and Becky Fearing for creating a strong LFM support network and providing key insights that helped me navigate through Dell's rich culture.

On the MIT side, much gratitude goes out to my thesis advisors, Dave Hardt and Jeremie Gallien. Their views have demystified the intellectual quagmire that I found myself in during the early stages of the project.

Thank you to the LFM Program and Staff, who have worked so hard to provide a life changing opportunity to so many students over the years. I will never look at the world the same again.

Thank you to all my friends in LFM who have made the two years in Boston such a memorable experience. In particular I'd like to thank Nima and Leigh, my thesis coaches, whose tireless persistence jump started the writing effort, and helped me to achieve greater things than I could have by myself.

Finally, I would like to thank my family, who are the reason that I have found my way here. Particularly I'd like to thank my wife, Jessica, for her love, patience, and guidance during my internship and throughout my time at MIT. Without you none of this could be possible.

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2.0 Introduction to Flexibility

2.1 Why is this Thesis Relevant?

Much has been written about the importance of flexibility in industry. Many view flexibility as a key strategic weapon along with the classic dimensions of cost and quality. A quick review of the literature in this space (Upton (1995), De Toni and Tonchia (1998), and Slack (2005)) shows both the benefits of developing flexibility and the challenges in obtaining flexibility. With the potential of adding another dimension to a firm's competitive advantage, attention has been given in academia with the hope of understanding this key competency while developing flexibility theories, measures and taxonomies. Rather than revisiting the all too common story about the business problems firms face today (i.e. shortened product lifecycles, removal of the safety nets provided by buffers, and increased variability in demand) to support the importance of flexibility (and this work), I offer a simple observation: despite the importance of the subject and the volume of work produced, a key question remains: How does a firm effectively develop flexibility?

This thesis is designed to address this need by acting as a practitioner's guide to the development of flexibility within a firm. The remainder of this chapter focuses on an extensive literature review of the current body of knowledge, to provide a suitable foundation for practitioners in the hope of avoiding the common confusions associated with discussions of flexibility. Once a baseline is established, Chapter 3 will introduce how flexibility fits into the larger picture of business strategy and how flexibility influences the more familiar strategic levers of cost and quality. Chapter 4 introduces change implementation frameworks and addresses those organizational hurdles that are often ignored in the academic literature that often define the difference between a business success and failure. Once armed with an understanding of flexibility, how it fits in with an organization's greater goals and a framework for implementation, Chapter 5 introduces case studies where the flexibility implementation was conducted by the author while working inside the firm. The goal of Chapter 5 is to highlight not only the application and benefits of additional flexibility, but to also demonstrate the importance of a holistic view of implementation, specifically tailored to a given firm's situation.

2.2 Literature Search Review

While discussions of the importance of flexibility have been around for quite some time (some would argue beginning in the 1930's or earlier), the subject began to attract significant attention in the late 1970's and early 1980's. Despite the effort devoted to this area, significant effort still persists today. One reason for the subject's persistence is the combination of the subject's importance and its ambiguity. For example Suarez et al. (1994) observed this fundamental challenge associated with flexibility: *"The confusion and ambiguity about a concept that often represents a critical competitive capability seriously inhibits its effective management."* The ambiguity referenced by Suarez can become apparent through a short conversation about flexibility with practitioners in industry. Through his extensive research in the paper production industry, Upton's (1995) observations are still relevant today based on the author's personal experience at a build to order computer manufacturer: *"Flexibility means different things to different people. At the plant level, flexibility is about the ability to adapt or change. But there are many ways to characterize such an ability. One manager might be talking about the cost of changing from one product to the next. Another might be talking about the ability to ramp production volumes up and down to fit the demand of the market... these abilities might be called flexibility, but they require very different courses of action to develop."* Despite the work produced by academia regarding the subject of flexibility, there are few firms that have achieved the mastery required to make the flexibility a key source of competitive advantage. Subsequent chapters of this thesis will attempt to diagnose potential root causes of this gap and attempt to offer a perspective to begin to address the shortfall.

To organize the current body of knowledge regarding flexibility, the subsequent sections will deal with the following topics from a very general base: the definition and taxonomy of flexibility, the reasons for developing flexibility, measurements of flexibility, and broader implications of flexibility. The goal of this literature review is to set a basis for nomenclature and to frame the future discussion of developing flexibility in practical applications at a firm's operational level.

2.2.1 Definition and Taxonomy of Operational Flexibility

The first lesson learned in researching the topic of flexibility shows that there is no one generally accepted definition of flexibility. In fact the more research that is performed with the goal of developing a unified definition of flexibility, the longer the diverging list of competing definitions becomes. Knowing that hunting for a definition may be a frustrating exercise is futility, developing a taxonomy system is useful for providing a foundation for future flexibility discussions. Once the taxonomy of flexibility is identified for a given exchange, all parties can align their perspectives to avoid confusion while conversing. While the ambiguity of the subject makes the dominance of one taxonomy classification unlikely, there are four basic methods of organizing flexibility that have been found to be relatively comprehensive (along with their hybrids): horizontal taxonomy, vertical taxonomy, temporal taxonomy, and exhaustive criteria taxonomy.

Kim (1991) popularized a horizontal taxonomy, which considers flexibility drivers along a value chain. This view can be simplified from the firm's perspective into "internal flexibility" and "external flexibility" depending upon whether a given position in the value chain is under the direct control of the firm. This self-centric view of flexibility is useful as the approaches used in achieving each type of flexibility differ significantly. Often internal flexibility is attained through investment in equipment and process improvement, while external flexibility is built through relationship building and information sharing along the disparate firms of a value chain. The horizontal taxonomy research thread is responsible for much of the current supply chain flexibility research that appears in recent journal articles.

Slack (2005) noted, in revisiting his earlier work, that the vertical method of taxonomy provides an effective way of linking the strategic directions of the firm to individual resources. This hierarchy of flexibility includes four distinct positions in the taxonomy: the specific production resources, the production strategy, the production functions, and finally the whole company. The vertical flexibility hierarchy helps to ensure alignment with respect to flexibility throughout the firm. At the firm level there is a goal that requires flexibility and then each lower piece of the hierarchy develops the necessary flexibility to support the goal. At the macro level, this view supports alignment between the business strategy and the operational strategy.

The third common taxonomy involves the temporal designation of flexibility capability. Barad and Sipper (1988) note that *"There is a mutual correspondence between the nature of the change and the time span during which the system is expected to adapt…"*. According to De Toni and Tonchia (1998), this classification strategy utilizes the required time horizons of achieving the flexibility benefit. The literature goes further to define several time horizons during which flexibility can be expected to be implemented and effective:

- Instantaneous Flexibility (Ability to select the optimal path for a product to navigate)
- Short Term Flexibility (Mobilization of preexisting flexibility range)
- Medium Term Flexibility (Addition or elimination of product mixes from production line or change to production capacity by adding or removing equipment)
- Long Term Flexibility (Adaptation of existing system to new types of products, mixes or volumes)

As each of these temporal taxonomies could reach across any of the other taxonomies, it is important to be aware of the time horizon requirements during the development of flexibility within a firm. It is not effective to address an urgent flexibility need by trying to adapt an existing system to new requirements (a long term flexibility strategy). While this observation is fairly obvious in a vacuum, the author has personally observed this behavior in Fortune 500 companies.

The final unique taxonomy organizes flexibility according to a collectively exhaustive, mutually exclusive set of criteria that is offered by Azzone and Bertele (1989). This system identifies six elementary flexibilities:

- *"Routing Flexibility – The ability to operate with one or more machines out of order; it is measured by the manufacturing system's availability (i.e. the ratio between its expected production and the production of the fully operating system).*
- *Process Flexibility – The ability to operate product changes among a given mix with low set-up times. It is measured by set-up times.*
- *Product Flexibility – The ability to introduce new products into production with low costs. It is measured by the expected costs of fixtures and CNC programs*
- *Production Flexibility – The probability that the manufacturing system will be able to process a new product*
- *Volume Flexibility – The ability to operate with a low reduction of the operating margin during decrease in market demand. Its indicator is the operating leverage.*
- *Expansion Flexibility – It is measured by the cost difference between acquiring a machine at the starting time and adding it afterwards."*

While Azzone's approach seems specific to flexible manufacturing systems (FMS), it can be generalized to be relevant to wider applications. This list is often simplified to the four categories of flexibility that Suarez (1994) mentions: Volume Flexibility, Mix Flexibility, New Product Flexibility, and Delivery Time Flexibility.

When entering into any discussion of flexibility it is important to identify a common taxonomy to be used as a foundation for the exchange. This initial starting point will help to avoid confusion and minimize wasted effort due to misunderstandings and communication gaps. It will become apparent that the four basic taxonomies are not mutually exclusive and often the taxonomies will overlap, which further expresses the need for a common starting point. While there are many other competing taxonomies that exist within the literature, the most relevant alternatives are captured by the four presented here, or by hybrid taxonomies that combine the ideas of these four basic classification systems. With all parties beginning from the same point, the chances for successful implementation improve significantly by avoiding misunderstandings during implementation execution.

2.2.2 Demand Drivers for Flexibility

Once a reasonable understanding of flexibility is developed, it is important to explore the needs for flexibility. These categories that fuel the demand for developing flexibility are useful and can be used in discussions in lieu of a definition to assure that all stakeholders are talking about the same types of flexibility within a given taxonomy. This alignment is important as the different types of flexibilities often require different resources to develop. More importantly, the different flexibility types may negatively impact the others or present trade-offs between competing flexibility types during implementation. Based on De Toni and Tonchia's literature review (1998), five discrete conditions were identified that need flexibility to address:

- Variability
- Accelerating life-cycle of products and technologies
- Wider range of products
- Increased customization
- Shorter delivery times

With the identification of the basic drivers of flexibility, there is an impulse to begin measuring each flexibility need or benefit to be compared. The following section investigates the prevailing thoughts on the subject of flexibility measurement.

The need for good measures of operational flexibility (regardless of the taxonomy used or need generating the demand) is required to properly value flexibility improvements and the prioritization of projects.

2.2.3 Measurement of Flexibility

Chen (1996) notes that *"Without the development of flexibility measurements and, consequently, a better understanding of the relationship between different flexibility levels and system performance improvement, it could be quite difficult for firms to position manufacturing flexibility as one of their competitive priorities."* There are several challenges in achieving this end. The most formidable challenge is the inherent conflict between developing measures of flexibility for each individual piece in a system and developing flexibility measures based on improved system performance. Developing flexibility measures at the subsystem level allows an individual to compare the flexibility merits of a subsystem based on equipment and operational choices between different applications, separate of the complexities that the entire system introduces. While the benefits of this approach allow a direct comparison between competing methods or machines, it tends to reinforce local optimization and may introduce double marginalization during process improvements. The competing method of defining flexibility benefits from the system level is useful in decision and project guidance but is not transferable to other situations. To be most useful, measures are needed for each case with a transform method to be able to translate the measures between local and global system perspectives.

Apart from the scope of the measure, another issue shrouding accurate estimates of flexibility benefits is the ambiguity demonstrated in the earlier definition and taxonomy sections of the literature review. Because of the degree of latitude available to characterize flexibility enhancements, it is very unlikely that subsequent projects would adhere to the same definitions, let alone assumptions surrounding valuation. Therefore even if it were possible to accurately value two flexibility projects, it is likely that these two valuations would exist as an "apples to oranges" comparison. Therefore much of the literature that proposes methods of measuring the flexibility of a system becomes irrelevant from a pragmatic industry perspective. Such a perspective would view little value from a flexibility measurement that is not directly tied to the valuation of the flexibility implementation. Therefore it is recommended as a practitioner's guide that flexibility improvements be directly tied to business performance to determine a value of the flexibility improvement.

This insight is particularly relevant when valuing using a global system perspective in a traditional cost analysis. Since operational units are typically treated as cost centers, projects are typically valued based on a payback period, or in more sophisticated organizations by an internal rate of return based on the cost reduction potential of the project. The major issue with the cost based method of valuation stems from the difference between what Slack (2005) refers to as flexibility range and mobility. For example, a flexibility project may be implemented, resulting in an increase in the potential flexibility of the process (i.e. an increase the range of flexibility as the flexibility benefits were left unutilized (as in a real option)). The same flexibility project may also be immediately exploited, utilizing the added flexibility in the process (i.e. mobilizing the flexibility within the developed range). From the cost perspective, each of these projects would be valued identically, but the latter project, which mobilizes the available flexibility, will certainly be worth more than the project that was undertaken to increase the flexibility range of the process. In other words, the latter project actually realizes the projected cost savings, while the former project does not. Seeing this typical cost based path as problematic, valuing projects through the revenue generating side shows more promise.

In theory, if the revenue gains resulting from the added flexibility capability are known, calculating the benefit based on expected implementation costs would be straight forward. More specifically, the added revenue from mobilized flexibility is known and an option value can be calculated using a real option approach for the option to capture future revenue in extending the flexibility range of a process. Unfortunately today in most organizations, there are often organizational disconnects between cost centers and profit centers. This organization disconnect often bolsters the gap between market share and operational capability. Table 2A shows examples of relevant profit center measures for different flexibility types, using the fundamental flexibility taxonomy.

Fundamental Flexibility Type	Example of Profit Center Measurement
Product Mix	N/A (Cost Center Based Metric)
New Product	Additional Revenue from New Markets
Delivery Time	Additional Revenue from Exisiting Markets
Volume	Additional Revenue from Exisiting Markets

Table 2A: Examples of Revenue Based Flexibility Measures

In more concrete terms if an operational person is valuing a project to reduce delivery time of a product, a sales or marketing representative may be asked how the market values getting the product one week earlier. The response is typically "no idea." In their defense, these profit centers usually operate with a perspective of fixed constraints and efforts not intimately linked to incentivized behavior (i.e. sales targets or commissions) such as a market study to estimate such gain, are not given priority. With a general inability to estimate revenue generating benefits, it becomes difficult to value a project based on flexibility benefits.

2.2.4 Flexibility Implementation Perspective from Literature Review

This literature review would not be complete without a discussion of the research that has been conducted in supporting flexibility development. Jaikumar (1986) shares the general consensus within the literature by alluding to two strategies for the implementation of flexibility within a firm. The first strategy deals with design and equipment choices and is often referred to as technological, plant, or hardware choices. A lot of attention in the literature addressing the technological choices investigates the notion of flexible manufacturing systems (FMS). The second strategy deals with organizational choices, and is also referred to as managerial or software choices. During the late 1980's and early 1990's large amounts of capital were invested based on a technological flexibility strategies with the expectation that FMS would replace human inputs into the manufacturing system. Many of the firms that were lured by this vision were ultimately disappointed in their FMS deployments. Retrospectively, these firms ignored the second source of flexibility. Upton (1995) observed that *"Operational flexibility is determined primarily by a plant's operators and the extent to which managers cultivate, measure, and communicate with them. Equipment and computer integration are secondary."* Upton's work summarizes the backlash caused by the failure of these investments to generate favorable returns as well as the importance of balance between a technological and organizational strategy to flexibility. Later in Chapter 4, this insight will be further developed, and an alternate implementation framework is proposed that is more able to capture firm specific attributes critical to a successful flexibility implementation.

Given these seemly comprehensive sources of flexibility, the literature fails to adequately address (independently of flexibility definition or taxonomy) the practical aspects of implementing flexibility in such a way that yields the benefits that management desires. Instead, the literature typically investigates two dimensions of studying flexibility as shown in Figure 2A. The goal of this thesis is to fill the void that exists in the center intersection of Figure 2A's axes.

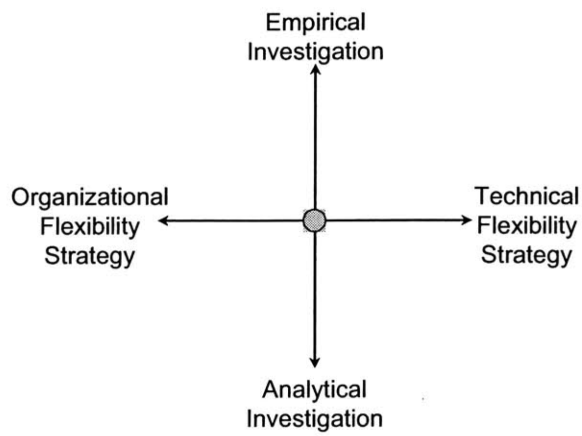

Figure 2A: Flexibility Research Focus Space

The horizontal axis shown in Figure 2A represents the sources of flexibility that Jaikumar acknowledged. For example, the bulk of the FMS literature focuses on the technical implementation of optimizing part routing, change-overs, or arbitrary flexibility measurements (right end of horizontal axis). However the literature often begins its study at a point where the equipment is already defined and installed, and the goal is to improve its performance in isolation ex post facto. Upton's (1995) work is a classic example of the study of an organizational (left end of horizontal axis) approach to achieving flexibility. It is interesting to note that at the extremes of the horizontal axis, researchers often view research into each of the strategies as mutually exclusive while implicitly understanding the connection between the two strategies for a successful implementation.

The vertical axis shown in Figure 2A represents the dichotomy in the approach for the research of flexibility. At the upper end of the vertical axis the researcher chooses to propose a hypothetical system and then investigates the variations of several variables on the performance or measurement of the system's flexibility. Kahyaoglu and Kayaligil (2002), Van Hop (2004), and Chan (2003) are all examples of this approach. These studies are rarely followed by a practical implementation where the analytical model is compared with actual financial business benefits with a discussion of the variance between predicted and actual performance. The lower end of the vertical axis involves empirical studies over a large number of firms to try and identify and draw conclusions about the flexible capability of an industry or technology type. Upton (1995), Vickery (1999), and Das (2001) offer examples in this space. A common feature of these empirical studies is the attempt to improve or benchmark the machine or system flexibility for flexibilities sake rather than to fulfill a specific business goal or objective. To be fair, the purpose of these publications is to improve intuition about the costs and benefits of flexibility and when flexibility should be employed, and not to improve the intuition of how to successfully develop flexibility.

Consistent with the preceding conclusion, while there is significant coverage of flexibility concepts at the extremes of Figure 2A, it appears that research at the origin of the axes is underserved. A hypothesis is offered for this observation: Since this area encompasses such a wide range of previous segregated areas, it would be difficult to gather the necessary data that would be needed to complete such a study from outside of an organization. Additionally, most of the intuition surrounding the potential benefits, and when flexibility is an adequate response to a business problem have already been developed by one of the research threads existing at the extremes of the flexibility space defined by Figure 2A. Therefore while of great interest to practicing managers in industry, the combination of difficulty in getting access to confidential information from within a firm along with the fact that the potential for the development of new theories is limited acts to limit the interest in the origin of the Flexibility Research Focus Space within academia.

2.2.5 Future Areas of Academic Research

Despite the volume of work completed in the area of flexibility, there still remains a significant research effort in furthering the state of knowledge in this area. For example several authors including Zhang (2006), Sami and Berman (2007), and Vickery (1999) are continuing the thread begun by Kim (1991) in the investigation of horizontal flexibility throughout a firm's supply chain. Other authors including Jack and Powers (2004) and Netessine et al (2002) are exporting the body of knowledge developed in relationship to manufacturing systems to health care and service operations respectively. Finally, research is currently underway to increase the depth of the manufacturing knowledge base, particularly around the technical implementation strategies of next generation production systems (NGPS) and intelligent manufacturing systems (IMS). Examples of the current topics of interest are shown by Wong et al. (2007), da Silveria (2006), and Adler et al (1999).

3.0 Role of Flexibility in a Firm's Operational Strategy

3.1 Brief Review of Processes

While not intended to be a remedial lesson, it is important that a common view of a process is adopted at this point in the thesis to ensure that the following ideas are built from a common foundation. For the purpose of this thesis, the definition of a process will be based off of van Ryzin's (2000) observation: a process is a unified system consisting of inputs, outputs, resources, and activities. *"As a unified system, processes have their own characteristics, such as capacity, efficiency, speed, flexibility, consistency, etc., that can be quite independent of the product or service they produce and often depends in complex ways on the interactions between all the various components of the process. As a single system, the process itself must be designed, developed and improved over time to achieve the mix of characteristics necessary to support the business objectives of the firm."*

Using this definition, flexibility is a characteristic of the given process. Like characteristics of other objects, they can be developed or atrophied, and exploited or ignored. Therefore, it is likely that in implementing a process, it will contain some inherent flexibility. The degree of flexibility available is often characterized by the choices made during process implementation. For example in general, processes requiring manual labor are generally more flexible than automated processes (although not always the case). Using this process view, one can conclude that there are a few ways of influencing the flexibility of a process including implementing an entire new process, modifying parts of an existing process, and changing the design of the object affected by the process. The case studies included at the end of this thesis include successful examples of the implementation of flexibility in each of the methods listed here.

3.2 The Theory of the Product-Process Matrix

Recall that in Chapter 2, flexibility was explored and a broad view of flexibility was presented. In the previous section, the notion of flexibility was linked to an operational process as one of its characteristics. This section of Chapter 3 will discuss the importance of tying processes (a characteristic of which is flexibility) to the bigger picture of corporate strategy that is advocated by the vertical taxonomy of flexibility. By the end of Chapter 3, a perspective will be developed to show how flexibility fits into the larger picture of a firm's strategy, and more importantly how developing flexibility can help a firm achieve a given strategy.

Hayes and Wheelwright (1979a) introduced the concept of the product-process matrix as a framework to match the operational strategy of a firm with its corporate strategy. In this paper, Hayes and Wheelwright argue that for a given position of a product on its product diffusion curve (S-Curve), a dominant operational or process strategy exists. Figure 3A shows this representation.

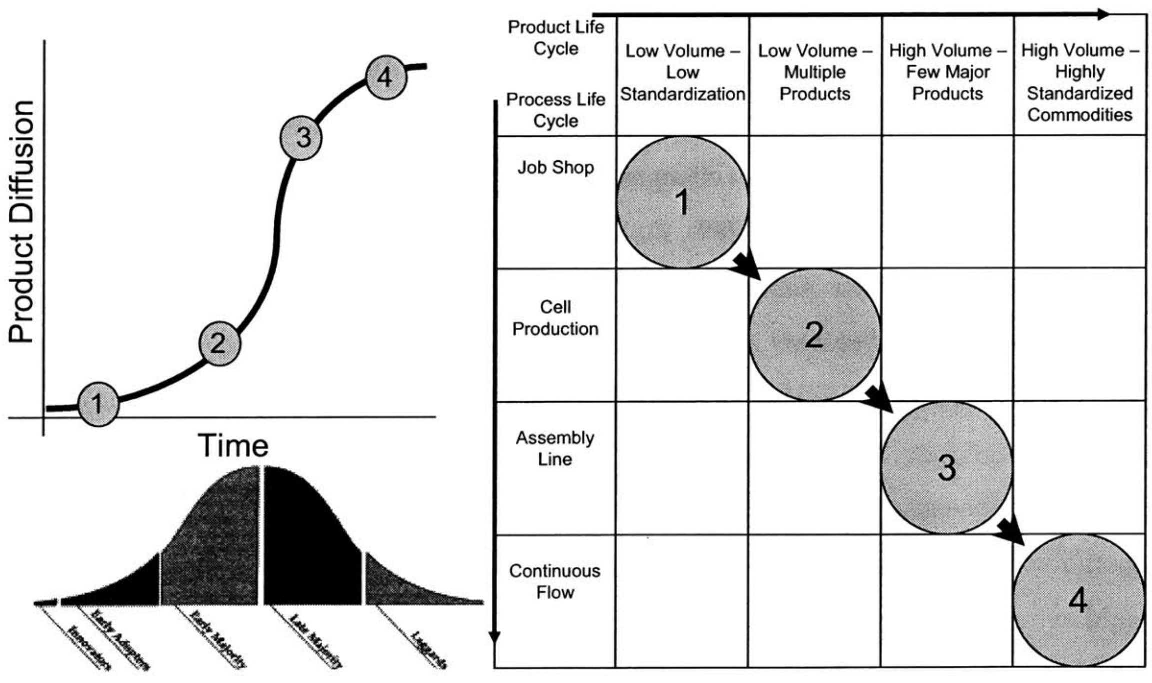

Figure 3A: Product – Process Matrix Linked to the Product Diffusion "S" Curve

The diagonal of the product-process matrix represents the composite industry average of firm behavior, also referred to as the dominant strategy. It is important to note that the matrix labels represent a progression along a continuum rather than four discrete possible positions along an axis. Firms can then choose to position themselves on this continuum in relation to the dominant industry strategy to try and gain competitive advantage. For example, a firm positioned on the matrix in an area above the industry's dominant strategy is relying on a flexibility strategy to meet underserved stakeholders who have higher willingness to pay. A firm operating in an area below the industry's dominant strategy is relying on standardization and is positioning itself to take advantage of a lower cost structure as it gains volume and market share at the expense of its margins.

In a subsequent paper Hayes and Wheelwright (1979b) discuss the dynamic aspect of the product-process matrix. As a product moves along its market adoption curve, the dominant strategy of the industry evolves as the preferences of its customers change due to more conservative consumers joining the market. Moore (1999) divides a given market into five populations of customers based on the time the consumer group enters a market: Innovators, Early Adopters, Early Majority, Late Majority, and Laggards (as shown in Figure 3A). The requirements that the market demands will change over time as the composition of the market changes with new customer groups entering. For example according to Moore (1999), the Early Adopters are *"driven by a 'dream'. The core dream is a business goal, not a technology goal, and it involves taking a quantum leap forward in how business is conducted in their industry or by their customers..."* Because of this predisposition, the Early Adopters demand a highly specialized product that is tailored specifically to help in achieving this goal. Based on this market knowledge (because of the market's immaturity) it would be foolish to have an operational strategy based on a capital intensive system that is highly inflexible but will yield extremely low average costs if given adequate volume. Those customers in the Late Majority, on the other hand, expect the product to perform, but are especially concerned with cost and dependability. The previous operational strategy that would have resulted in ruin in a younger market now becomes the dominant strategy in an older market. This example highlights the need for a firm to reevaluate its operational strategy as the needs of its customers evolve the market. While it is important to match the operational strategy to the market, it is equally important to have coordination between operational and business strategy. For example if a market is mature and the operational strategy is correctly based upon a standardized mass production process (from Hayes and Wheelwright's perspective), but the business is selling highly customized products, not only will the volume to efficiently utilize the production equipment not be sufficient, but the operational processes will be too rigid to accommodate the added complexity required by specialized products. This uncoordinated combination will result in disaster for the firm.

At this point attention should be brought to a couple of issues with Hayes and Wheelwright's conclusions. While generally accepted at the time of the papers' publish date, the advent of modern flexibility has brought up several issues with the theory. Since the late 1970's several studies have been completed that suggest that an update to the product-process matrix is needed. Many of these studies site the need for this update is directly related to changes in process technology and more specifically the advent of modern flexibility (see McDermott and Fischer (1997), Ariss and Zhang (2001), Ahmad and Schroeder (2002), and Spencer and Cox (1995)).

Issue #1: Hayes and Wheelwright (1979a) bolster the then commonly held trade-off between cost and quality when talking about dominant competitive modes. If quality is interpreted as the lack of defects then there has been evidence since the publish of this work that, if done correctly, cost and quality can be positively correlated rather than inversely related. It is safe to assume that everyone in the practice and study of operations are familiar with Toyota and other organizations practicing lean manufacturing in which this trade-off is consistently proven to be false. Several direct examples are shown through Adler, et al. (1999), Spear (2004) and Spear and Bowen's (1999) work with Toyota. If however, quality is more broadly interpreted as an indication of a customer's willingness to pay, then argument can be made that the trade-off between cost and quality still holds true.

Issue #2: The product-process matrix structurally supports the dichotomy between efficiency/cost advantage and flexibility. Since the diagonal of the matrix represents the industry baseline, those firms lying above the diagonal have a flexibility advantage at the expense of a cost disadvantage, and vise versa with firms lying below the diagonal. At the time of its publication, it was a common practice that automation was employed with the end goal of substituting capital for labor, thus fueling the common precondition of inflexible automation. With this frame of reference, it is understandable that the efficiency/cost benefits that were realized from automation were a result of replacing the expensive but flexible manual labor content. Since the late 1970's there has been a paradigm shift with respect to automation and flexibility as noted by New (1992) *"The new focus is a complete reversal: 'Use technology to achieve flexibility.'"* Ahmad and Schroeder (2002) concluded after an empirical study of 128 manufacturing plants: *"These groups of plants (MSOP and LBC) were able to minimize trade-offs by producing products with custom option and customized products without sacrificing efficiency. The cluster comparison suggested that the reduction /elimination of the trade-offs was possibly due to the proactive efforts regarding innovative initiatives, processing technology, product design and perhaps the use of management practices, in these plants."* Using the definitions and taxonomies developed in Chapter 2, many of the "management practices, processing technologies, and innovative initiatives" cited in could be classified as developed flexibility.

Despite the controversy surrounding the product-process matrix, it still provides a good framework in which to think through the coordination of operational strategy and business strategy. This tool also highlights the power of flexibility. Without developing flexibility as defined in broader terms (as in Chapter 2, not Hayes and Wheelwright's more narrow definition), a firm's overall choice of successful strategies are constrained to a relatively narrow envelop of possibilities. In fact it is plausible that modern flexibility could be a third dimension of the product – process matrix. With flexible processes, one could imagine that a mature industry could offer a customized product, breaking the "either or" paradigm implicit in the product – process matrix.

3.3 Role of Flexibility within an Operational Strategy

Given the fact that it is important to develop an operational strategy (or process strategy) to support a firm's broader business strategy, this section will provide a thought construct on the application of flexibility to meet these ends. A key challenge in achieving operational strategies in industry is the introduction of variability into a firm's processes during the tactical execution of its strategy. For example, a firm may have an operational strategy that seeks to support a firm's business goal of being the market leader in the supply of Christmas wrapping paper. Drawing insight from the business strategy, we can infer that this firm's operational strategy must have a low cost structure and mass produce standardized products (in this case standard size rolls of wrapping paper). The low cost structure is a necessity in achieving volume market leadership for a standardized, commodity product. Further understanding that this is a relatively mature industry, Hayes and Wheelwright would expect that the dominant production process be a high volume continuous flow line. From a high level operational analysis, one would expect to find a high fixed cost/low variable cost structure, and with sufficient volume, having an average cost advantage over other firms with a less capital intensive operation. Therefore successful execution of this operational strategy requires significant volume to amortize the fixed costs to achieve a low average cost. With achieving adequate volume being important, the firm's operational strategy is vulnerable to demand fluctuations. There are two opposing factors in achieving stable demand: since this product is mature its annual demand is predictable based on past demand, but the demand is highly seasonal, introducing demand variability. This seasonal demand yields significant changes volume, and the production line would be unable to operate efficiently during the demand troughs. The lack of flexibility in this production process prevents successful execution of the operational strategy and subsequently the business strategy.

Newman et al. (1993) also observed that: *"...manufacturing flexibility is the most obvious response to external uncertainty, because of its accommodating nature."* Revisiting the overly simplistic example of the Christmas wrapping paper manufacturer and substituting uncertainty with variability, an obvious solution to our firm's dilemma can be reached. The firm can develop product mix flexibility, allowing it to augment seasonal demand troughs for Christmas wrapping paper with other types of wrapping paper (wedding, birthday, St. Valentine's Day, etc.). In addition, it would be wise to implement a certain amount of volume flexibility as the demand these other products is likely to be lower than the demand required for the Christmas product. With the development of product mix and volume flexibility, the line could still operate at a nominal level of efficiency, and the operational strategy would still be able to support the overall business strategy. In summary, flexibility in the production line enabled the firm to operate through the variability in its demand while allowing it to operate in a relatively extreme off-diagonal position in the product – process matrix.

Newman et al. developed a simple yet insightful model for demonstrating the relationship between variability, flexibility, and buffers within a manufacturing system, shown in Figure 3B. Figure 3B has been adapted to reflect consistent nomenclature developed in Chapter 2 of this thesis.

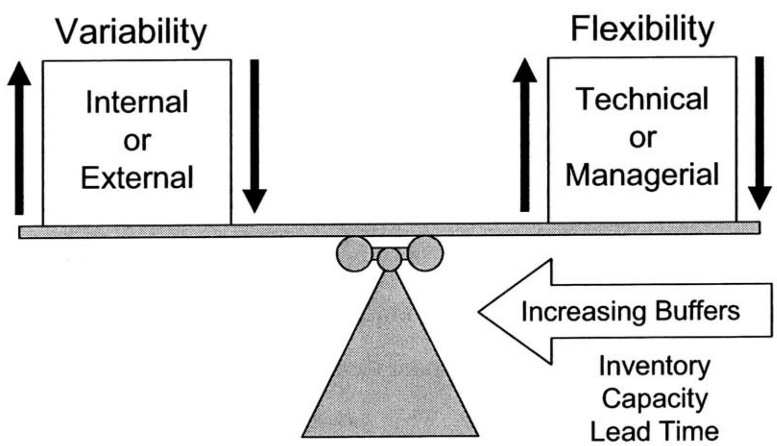

Figure 3B: Balance between Variability and Flexibility

This model shows that in order for an operational strategy to remain in balance with an increase in variability a response is required. While more difficult to implement successfully, increasing manufacturing flexibility through process improvement is an effective way to balance out an increase in variability. To truly achieve a balance in Figure 3B, the economic costs of developing the flexibility must be favorable when compared with the additional revenue (or avoidance of lost revenue) that the firm experiences. Otherwise the system would be too heavy on the flexibility side and the operational strategy may evolve into "flexibility for flexibility's sake" rather than supporting the overall business strategy.

Figure 3B shows three methods for adjusting the equilibrium of the system. Level of variability and level of flexibility have already been discussed and are fairly straight forward. The final variable is comprised by the buffers that exist within a manufacturing system that act as the fulcrum of the balance. The interaction between buffers and the remainder of the system is a little more complicated than the interaction between variability and flexibility discussed earlier. The main difference is the possible consequences attached to increasing buffer levels to reduce instability caused by increasing variability. For example, if the lead time requirement for a product was lowered by a firm's customers, the producing firm would experience variability in its lead time requirements, causing instability in the production process. The firm could refine its production processes to reduce its cycle time to accommodate the lead time improvement (pushing on flexibility), or it could increase its inventory levels and fulfill orders out of stock rather than as a build to order supplier (moving fulcrum towards variability). While the latter of these options allow the existing flexibility within the factory to deal with the increased variability, the increased inventory levels have negative effects including increased internal complexity and increased inventory holding costs. The former of these, may actually increase the instability in the system due to a myriad of issues such as increasing congestion in the system, obsolescence, and fire fighting. This secondary effect reduces the effectiveness of the balance action. In an extreme case, the problem could worsen with increased complexity causing further instability, resulting in a reinforcing viscous cycle. Figure 3C shows these interactions using a system dynamics representation made popular by Senge (1990).

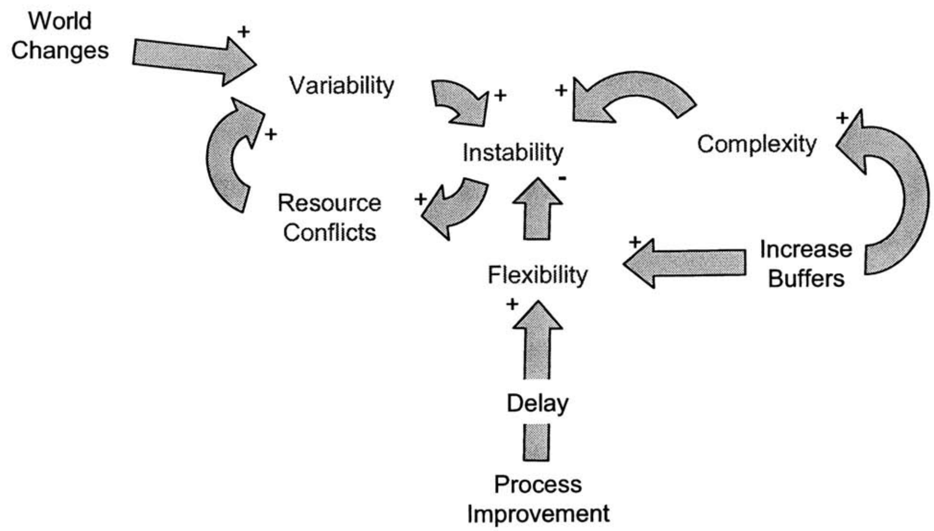

Figure 3C: Dynamic View of Balancing Variability with Different Sources of Flexibility

While it would be ideal to address all external factors upsetting the strategic balance with improving the flexibility of the plant, it isn't always possible. In Section 2.1 of Chapter 2 the taxonomy describing the temporal nature of flexibility improvements was discussed. Several events that increase the variability of the system may warrant a buffer increase provided that the disruption is short in duration, or immediate in threat. For example, a shortage in the supply of a key component could be countered with developing the flexibility of in-house capability to make the part, developing supply chain flexibility to activate an alternate source or developing more coordination with the supplier to reduce supply side variation. These approaches would not address the immediate problem of satisfying preexisting customer orders. Instead a policy of temporarily increasing the product lead time (moving the fulcrum) as a near term solution, while addressing the longer term flexibility issues in parallel to prevent future occurrences may prove to be the best policy.

4.0 Implementation Tools and Techniques

Chapters 2 and 3 have discussed flexibility and how it fits within the larger picture of a firm's strategy. It has also been established that flexibility is an ambiguous and complex characteristic of a process. Since a process is built of several components, including resources (further comprised of people, procedures, and equipment), successfully developing flexibility within a process is similar to creating a change within an organization. Based on this observation, an organizational change framework was chosen to bridge the gap between Jaikumar (1986) and Upton (1995) while further developing the notion of organizational flexibility. While this approach to implementing flexibility is fairly unique, there are several examples (Upton (1995), among others) within the literature of flexibility implementations that have failed to obtain the expected returns, despite the rigorous economic analysis that would be required through corporate capital allocation processes. Based on these failures, a hypothesis is developed (and tested through the subsequent case studies): to increase the success of flexibility development, it must be tailored specifically to the organization to which it is implemented. More specifically, a holistic vision of the firm must be satisfied including the strategic, cultural and political perspectives. In order to test this hypothesis against the case studies discussed in Chapter 5, a framework is offered to structure an organizational change approach to flexibility development. This framework addresses the key gaps of the failed implementations presented in Section 2.2.4. This novel approach ensures that the technical analysis is weighted equally with other concerns that would be unique to the specific organization implementing the change (i.e., culture and politics).

4.1 The Three Lenses Approach to Organizational Analysis

The preceding section offered a hypothesis that suggests there is more to the development of flexibility than just analyzing the economics, technical content of the change, and executing the implementation. One likely explanation for the failure of so many flexibility initiatives is that while the concept of flexibility is very complex, the bigger challenge is having the flexibility implementation fit in context with the organization. Ancona, et. al. (1999) presents the Three Lens approach to organizational analysis that will be summarized over the next sections. The root of the Three Lens approach is the perspectives that must be considered during an implementation analysis: Strategic, Political, and Cultural. The metaphor of using each of these models as a colored lens to view the organization is developed.

One interesting conclusion supported by this metaphor is that stacking all three lenses together to get a comprehensive view of the organization will yield a distorted view. Instead the three lenses must be used independently to analyze a problem, and then all three perspectives must be used as decision criteria (which may require trade-offs between perspectives) in choosing an appropriate solution. The implementation of the resulting solution, since tailored specifically for the organization requiring the change, will be more successful than a solution developed with just any one perspective (as those summarized in Section 2.2.4's literature review).

4.1.1 The Strategic Design Lens

The strategic design perspective can be likened to a viewing the organization as a machine that has been carefully designed to achieve specific goals through its operation. Carroll (2001) describes the view through this lens: *"The approach is highly rational and analytical. People, money, equipment, and information are moved around a strategic and operational chess board using logical principles of efficiency and effectiveness. The model assumes that, with the right plan and information flow, the organization can be rationally optimized to achieve its goals."* Ancona, et. al. (1999) further clarifies this view *"Efficiency involves accomplishing strategic goals with the least possible expenditure of resources; effectiveness involves ensure that the goals are accomplished to the standard necessary for the organization to succeed."*

The strategic perspective is characterized by examining the field of potential solutions and analyzing each one against the goals of efficiency and effectiveness. Once the analysis is performed, the best solution from the strategic perspective delivers effective results with the minimal amount of resources. The strategic perspective is the prevailing mental model seen in most academic literature. In fact, the technical approach advocated by Jaikumar (1986) is very similar to the strategic perspective presented here. Consequently, most of the studies that appear in the bottom half of the Flexibility Research Focus Space (Figure 2A), particularly the bottom right quadrant, share this mental model.

The strategic perspective is often useful to investigate the boundaries of a problem, as it provides the best theoretical solution to a given problem (i.e. the solution in an organizational vacuum). In knowing the best possible outcome, the project can then be evaluated. For example if product mix flexibility is required, but the best solution from the strategic perspective has an unacceptable pay-back period, then the project can be scrapped or a different approach can be explored.

While the strategic perspective provides a great way to bound the solution set of a problem, it alone is usually not sufficient, since organizational vacuums are rare. The consequence of this realization is that for effective implementation, the required solution must be tailored specifically to the organization. To successfully achieve this end, the perspectives in the following sections must be considered.

4.1.2 The Political Lens

Ancona, et. al. (1999) provides an excellent description of the perspective of the political lens: "*The political aspects of an organization are simultaneously the focus of much of the attention (and even more of the gossip) of those working in and leading the organization, and the least accepted. When people say, "That was a political decision," they are usually implying that it was a bad decision made on the wrong criteria. If decisions are to be effective, however, they must be political – good decisions as well as bad. They must have the buy-in of those who have the power to implement or to block action. Power and interests, coalition building and negotiation, conflict and conflict resolution are essential aspects of organizational life. If the formal design of the* *organization is the equivalent of the skeleton of the organization, the political system is the musculature. It is essential to action.*"

While the major influence exerted by the political perspective is power, the source of this power can be derived from many different sources. Common sources of organizational power include (but are not limited to) an individual's personal characteristics, scarce and valued expertise, track record, formal position in organizational hierarchy, and informal network position. Since the source of organizational power is so diverse, but also necessary in successfully delivering results within an organization, it is helpful to understand who holds the power with respect to a project, and how those power sources are likely to influence the project implementation. It is often useful to employ tools such as stakeholder mapping, network diagrams, etc. to understand the potential allies and enemies of an implementation. Roberts and King (1989) illustrate the use of these tools for those readers interested in supplemental material on the subject.

4.1.3 The Cultural Lens

The cultural lens provides a complex perspective on the limitations of formal channels within an organization. Everyone that has worked in an organization has seen cultural forces at work (i.e., there is a way things are supposed to be done, and then there is the way that things are actually done). One way of thinking about this paradigm is the formal channel acts as course roadmap of how to achieve progress within the organization. The tactical turns required to avoid obstacles that do not show up on the roadmap are how the organization actually operates. A new member of an organization armed with only the road map is likely to operate less efficiently than an organizational veteran. The difference is that the veteran understands the organizational culture and uses it to aid in organizational navigation to avoid the issues that are present but not formally addressed. Organizational culture is the tacit knowledge, operational norms, and informally reinforced behavior that is developed over time based on the leadership and people that operate within the organization. Ancona, et. al. (1999) further develops the cultural contrast against the other perspectives when observing that "*People are thus more than cogs in a machine, nodes in a network, sources of intellectual capital or self-*

interested political actors. They are more importantly meaning makers, identity carriers, moral actors, symbol users, story tellers who are actively engaged in organization life and, through interaction with one another, they continually create, sustain and modify organizational events, processes and products."

In viewing a problem or solution from the cultural perspective, it is important that its fit within the existing organization is considered. For example, a firm whose culture reinforces the behavior of employees staying late at the office through peer pressure will be ineffective if it chooses to implement a policy to help avoid burnout that encourages employees to leave the office each day by 5pm. While in the best interest of the employee is to leave early per the policy, the culture of the organization provides a greater incentive for the employee to act against their best interests. The employee will realize that in order to "fit" into the system, they will have to stay late. Another example is common in production environments where production rates are enforced. Often in this environment, a culture develops that encourages mediocrity. Those workers who produce greater than rate are chastised in the name of the cultural norms of the group for inflicting unprovoked pain upon the group by overachieving. The underachievers are often bolstered up by the group even though it is against the interests of the individuals of the group by requiring more effort from the rest of the team.

The following case studies will examine a problem through each of the three perspectives introduced in Chapter 4 and discuss the trade-offs that each present in adopting a final solution.

5.0 Flexibility Implementation Case Studies

In Section 2.2.4, the body of knowledge around the research of flexibility implementation was reviewed. It was discovered that the majority of the work in this area focused on the study of implementations of flexibility in a theoretical environment or the retrospective examination of previously implemented flexibility across a large number of firms. Within each of these approaches, the researchers typically focused on either the technological choices or managerial approaches to achieving flexibility (also as defined in Section 2.2.4). There has been very little work in the practical application of developing flexibility. While some papers attempt to address this gap (Jack and Raturi (2001)) with a more "centered" view (in the Flexibility Research Focus Space), to the author's knowledge all applicable studies are performed from outside the organization. The goal of this work is to unite some of the past work along different threads and incorporate new frameworks to fulfill the underserved needs of practitioners. In the following sections, this thesis will introduce case studies that address flexibility development by studying actual projects performed within a firm, by employees of the firm. Because of the unique ability to present this experience, this paper will give an insight into how firms value flexibility during its development and implementation.

5.1 Developing Flexibility at Dell

Experiences at Dell Inc., the host of a six month internship, are used as a basis for the first case study to closely examine practical implications of developing flexibility in an assembly environment. This case study focuses on a project to improve the product mix and volume flexibility at an existing plant in order to help align its manufacturing strategy to its business strategy as the mission of one particular factory evolves. Many operational challenges are discovered in gaining this alignment.

From a high level, Dell pursues a build to order operational strategy, in order to keep alignment with its direct business model. While it is difficult in general for a firm to create this alignment, it becomes significantly more difficult to execute such a strategy. A direct business model is particularly challenging with respect to capacity planning and product mix allocation, as the customer decides on any given day which types of products that are produced. Those readers not intimately familiar with Dell's operations are encouraged to peruse Paxton's (2004) work, which gives a good overview of Dell, its manufacturing strategy, and its operational model. This knowledge will provide a good foundation for the subsequent chapters.

5.1.1 Case Study Background

While it would be ideal to meet the challenges of the direct business model by developing completely flexible manufacturing processes that would allow single piece flow of all product types down the same manufacturing line without the requirements of change-overs between products, in practice this is very difficult to achieve. Consequently, Dell operates multiple production lines that have limited capabilities with respect to the variety of product produced. The goal of this study is to develop the volume and product mix flexibility of an existing production line within a desktop manufacturing factory that represents one node within Dell's manufacturing network.

5.1.1.1 Evolution of Dell's Eastgate Factory's Mission

Within the broader context of Dell's position in the PC industry, its low cost business strategy supports the undying pursuit of continual improvement with the goal of operational perfection. It is important to understand that most opportunities addressed in this document stem from the evolution of the mission of this facility that occurs in the pursuit of such operational perfection. As the mission and subsequently the affected manufacturing processes change, there is often opportunity in updating and changing the legacy systems that were optimized for older mission profiles. The following sections discuss the evolving mission of EG-1 from the plant's opening to the most recent changes at the time of this thesis publication to provide a foundation for the forces driving the need for the flexibility enhancements.

5.1.1.2 New Consumer Desktop Factory Commissioned

In 1999 a new plant located on Eastgate Boulevard, outside of Nashville, TN (internally, this plant is designated as EG-1) was opened as the second major desktop manufacturing facility within Dell's Americas Operations. EG-1's mission was to produce Dell's line of consumer desktops. Due to the immediate need of additional desktop capacity, an existing building was retrofitted with Dell's production equipment, rather than designing and building a true greenfield plant.

Dell makes a commitment of shipping only complete orders to customers (i.e. all pieces of that order must be present before shipment). This commitment prevents a customer from receiving a new computer without its monitor or display unit, which would understandably be a source of customer dissatisfaction. Since the typical consumer order is comprised of 1-2 items, the need for accumulation space and systems is minimized in a facility like EG-1 which focuses primarily on consumer orders. Therefore the precious space in EG-1 was used to maximize throughput capacity rather than accommodate accumulation requirements. In fact, because of the restrictions of the existing floor plan, EG-1 exhibited some of the first "3-D" production processes within Dell where some processes were moved to a mezzanine level of the facility to fully utilize the volume of the production facility (i.e. building up). It is also important to note that during this time a key operational metric was "units/square foot of production area", and therefore minimizing floor space was a priority. During this era, EG-1 enjoyed large volumes of orders spanning very few platform types as another Dell facility satisfied most of the demand for commercial products.

5.1.1.3 Advent of GEO-MAN Changes EG-1 Mission

As the demand for Dell desktops increased after the PC industry settled from the high tech crash of 2001, capacity became an issue again for Dell across its plant network. Since the majority of Dell's business is with the commercial market, the demand for additional commercial capacity was felt throughout the Dell manufacturing network. Faced with the need to deviate from the line of business paradigm, Dell decided to determine plant order fulfillment allocation by optimizing outbound logistics costs. The majority of Dell's cost variability is comprised of the final shipment cost to the customer so an outbound logistics optimization was designed. This optimization was subsequently named the Geographic Manufacturing Rules or GEO-MAN for short. With an updated mission, Dell was faced with the challenge of operating EG-1, designed to build and ship customer orders with low multiples of packages, with an operating mission that requires greater order accumulation demands prior to shipment (the average commercial order has 6-10 items). Around the same time, the governing metrics that guide Dell operating decisions also evolved, and local managers are forced to adapt the new requirements with the legacy systems that were built under a different set of operating rules. In the case of EG-1, the macro operational strategy clashed with the previous decisions to limit floor space as additional accumulation capacity was needed, but the floor space to do so was not available. The result is an operational challenge to incorporate product mix flexibility within a facility with fairly rigid systems. Heaps-Nelson's (2005) thesis documents the improvements that were made to add the required product mix flexibility to the system in order to enable EG-1 to be aligned with the new operational strategy of serving commercial customers. Despite the mission change to produce additional product lines, the overarching problem facing EG-1 management lies with increasing its capacity.

5.1.1.4 New Capacity Refines EG-1's Operational Mission

In 2006, Dell ramped its third US based desktop assembly plant located in Winston Salem, NC (internally known as WS-1) to its minimum operational scale. WS-1 is more than twice the size of its existing plants according to Null (2005). The primary reason for the creation of additional capacity was the fear that the capacity of the system would be exceeded within the subsequent couple of years. During the lag between breaking ground and commissioning in 2006, consumer preferences in the PC market have begun to move away from desktops and toward laptop form factors. Bossong-Martines and Coda (2006) show that the US based desktop market grew at less than 5% year over year (markets served by all three of Dell's US based assembly plants) and during the same time Dell's US market share declined slightly. Using conservative assumptions that WS-1 increased Dell's desktop network capacity by 50% and the network previously operated at 100% capacity; it is easy to see that Dell is currently operating at a state that is far under the capacity of the overall network. With the GEO-MAN rules in effect, the demand for desktop products will be split among the three plants and all plants (including EG-1) could be faced with the unfamiliar problem of idle capacity.

Since the risk of operating beyond the capacity of the system was so strong over the previous several years, many of Dell's current operating metrics were chosen to reward productivity within the plant network. Knowing that key operational metrics are influenced by volume within the plant (these metrics will be discussed in a future section), local plant management is now challenged with finding ways to increase volume through the plant to stay competitive within the Dell factory network. Since GEO-MAN controls which plants receive volume from the desktop line of business, servicing other product lines will be required to increase the plant productivity. Product mix flexibility must be developed to enable EG-1 to service other product lines, while utilizing the existing idle production resources. The product line that was chosen to be accommodated, while optimal for Dell as a company, provides some particularly challenging temporal volume fluctuation. This fact requires the development of volume flexibility (or referred to as flexible capacity within Dell) in addition to product mix flexibility.

5.1.2 Dell Operating Metrics

The previous sections showed the power of metrics in influencing behavior in the execution of an operational strategy. Due to their importance, this section will include a brief look at the key operational metrics within Dell. In subsequent sections, competing solutions to the product mix and volume flexibility challenges will be measured against both the flexibility requirements and the operational metrics described in this section. While there are several more metrics that are measured than discussed in this section, this study will mention a few of the important ones. It is important that Dell keeps the types of metrics measured up to date as the mission of each manufacturing plant evolves. For example, Upton (1995) noticed that "*Most managers at the plants I studied were still clinging to measures that had no connection to flexibility... ...To expect a plant both to be flexible and to continue to focus solely on the utilization of its equipment and the cost of production makes no sense.*" when referring to an unrelated industry. The end of this section will include a discussion of how Dell may need to evolve its metrics to improve the chances that the flexibility development will succeed.

Using the three lens framework developed in Chapter 4, metrics will be used to represent the stakeholders from the strategic perspective when alternative designs are considered in future sections. The three lens approach will be particularly insightful as typically choices are made considering such strategic perspectives only, and may subsequently fail by neglecting the cultural or political fit of such a solution. Therefore solutions that may provide the best strategic solution (using the 3 lens nomenclature) may be disregarded in favor of a more balanced solution that better fulfills cultural or political implications, which will have a better likelihood of successful implementation.

The organizational structure within a Dell plant holds different levels of the organization accountable for different metrics. In other words as the responsibilities of the positions increase, the inclusiveness of the guiding metrics also increase. Figure 5A shows a simplified version of typical plant reporting structure at a Dell manufacturing facility.

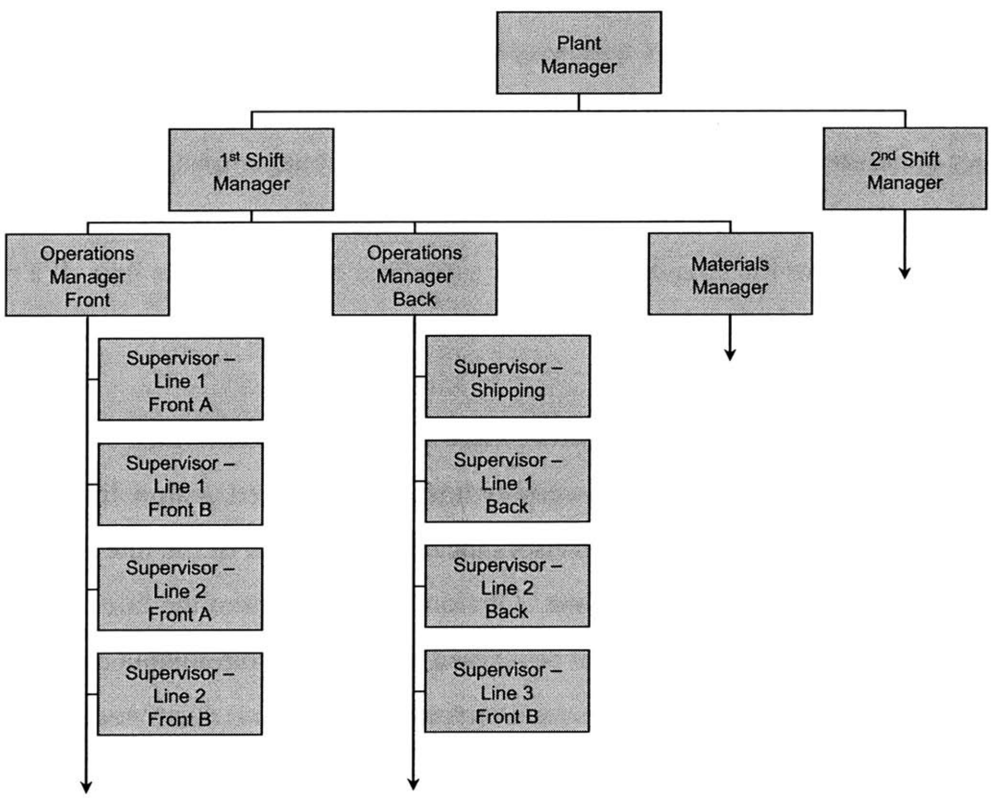

Figure 5A: Simplified Organizational Structure of a Dell Manufacturing Plant

5.1.2.1 Throughput

During the time period described in section 5.1.1.2 and 5.1.1.3, plant capacity was often the major challenge in achieving customer satisfaction. A facility that is limited by capacity has a direct impact on a customer receiving an order on or before its promised date (due to the direct business model). Because of this direct interaction with customer satisfaction and the capacity limited operating mode over the last several years, product throughput became an important metric within Dell.

At Dell, throughput or perhaps more accurately stated as throughput attainment, is the main metric by which production supervisors (at the bottom of the management chain in Figure 5A) are measured. Throughput is calculated by comparing the actual production line output with the output that the line was designed to attain. For example, if a given production line was designed to produce 1000 computers/hour and over the previous hour the line actually produced 1100 computers, then the throughput is calculated to be 110%. Subsequently, the line supervisors will be rewarded for outstanding performance. The power of this metric is that it is simple to calculate and at any point in the day, each supervisor understands how their line is performing against upper management's expectations. In addition to rewarding high amounts of production, supervisors are indirectly rewarded for the attendance of their associates working on the line. If a line experiences several absences, it is unlikely to hit its throughput goals.

Despite the power of the throughput metric, there are downsides that must be considered prior to its adoption. Because Dell's assembly lines are structured as flow lines, this metric places the success of those supervisors located in the back of the line at the mercy of the performance of the front of the line. Obviously if the front of the line underperforms, the back of the line will be starved and meeting throughput attainment will be difficult. Therefore supervisors (and operations managers) must work together between the front and back of each production line. One frequently observable behavior that supports this cooperation is the flow of line associates between the front and back of the line to account for absences that may lead to the back of the line being starved, or conversely the back of the line backing up into the front of the production line. While this metric encourages good behavior, it can also encourage supervisors to behave badly (such as creating waste through overproduction and overstaffing). Typically, a plant that is capacity constrained and configured with flow lines can avoid the problem of overproduction. Overstaffing, on the other hand, is an issue and is dealt with by the next echelon of metrics.

5.1.2.2 ULH

The next level of Dell management (operational managers) is judged based on a productivity metric known as Units per Labor Hour (or ULH). This metric is slightly more complex than the throughput metric used by supervisors, as the number of actual productive hours must be calculated, depending upon several factors including the number of absences on the line, line downtime, break structure, etc. As resources are shifted between lines to balance production, the actual ULH that a line runs at is often unknown until the end of the shift. This fact explains why supervisors aren't required to actively manage using the ULH metric; it's too slow. For example, assuming that the theoretical line used in the previous section that produced 1100 units in an hour, did so using 22 people that each contributed 5 hours of productive labor (after breaks, line downtime, etc.) the ULH is calculated to be 10. If the line was designed to operate with 25 people each contributing 6 hours of productive labor, then the operational manager would be rewarded for producing a ULH of 10 on a line that is designed to produce a ULH of 6.67.

ULH directly addresses the bad behavior of over staffing that supervisors may be tempted to engage in. Just like each line is designed to achieve a certain level of output, each line is also designed to be operated by a certain number of associates. By holding the operational manager accountable for ULH, tension is created around the issue of staffing levels on a given line. If properly managed, the operational manager would not allow her direct reports to overstaff to make throughput attainment as it would reflect badly upon her when ULH is calculated.

While addressing the issues that the simple throughput metric introduced at the supervisor level, ULH does not include the cost of bad quality or waste. In fact, the operational managers may be driven by ULH to make bad decisions surrounding exceptions or quality issues that may slow down the production line. For example, an operational manager is not incentivized by ULH to fix quality issues once discovered. If driven solely by ULH, the operations managers would allow product defects to be passed down the line and fixed via an off-line (and therefore out of ULH) process. To avoid these unwanted behaviors, the next echelon of metrics addresses this weakness of the ULH metric.

5.1.2.3 CpB

The level of shift management is measured against a productivity metric of Cost per Box (or CpB). This metric is essentially the same metric as ULH (labor cost per hour is substituted for productive labor hours, ignoring overhead and depreciation) if the plant is running perfectly. Since perfection is very difficult to achieve, the calculation of this metric becomes fairly complicated. As waste is accumulated in the plant (through downtime, reprocessing, reworking, etc.) the ratio of productive hours to paid hours becomes smaller, which pushes CpB up. As material issues are encountered (quality issues, inventory inaccuracies causing obsolescence, etc.), other cost of goods sold (OCOGS) is increased and the facility CpB follows suit. Since the impact of many of these waste sources is difficult to calculate immediately, it becomes difficult to understand the current CpB of a facility at a given point in time. Often the CpB is calculated at the end of financial reporting periods, making it a poor daily management tool, but ideal to be used for course corrections, and as an indicator for focusing on areas of improvement.

CpB is an important metric for the plant. It represents the transformation cost of a facility. The title of "Lowest Cost Plant" is given to the plant with the lowest CpB metric within the Dell manufacturing network. An organization like Dell that bases its core business strategy on controlling cost makes this title extremely important to the careers of the managers within a given facility. Additionally if GEO-MAN is indifferent in placing a customer order based upon outbound logistics cost, it is reasonable to assume that the work is given to the plant that has the lowest CpB. CpB will become increasingly more important as GEO-MAN evolves to consider a more complete view of transformational costs while determining where to allocate demand. This dynamic relationship between CpB and volume is represented in Figure 5B.

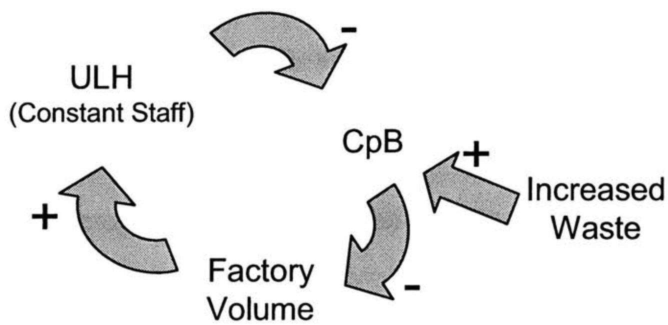

Figure 5B: Dynamic Relationship between CpB and Volume

Figure 5B also demonstrates that if CpB increases, the cycle may become vicious as reduced volume will lower ULH (assuming all other factors remain constant), and raise CpB further.

5.1.2.4 Need for Flexibility Metrics

It is apparent that the metrics that Dell has chosen work well in an environment in which each factory is operating at full capacity while building similar products. With the recent changes in the plant network, Dell should update its metrics to address the issues that develop with evolving missions. More specifically, as EG-1 diversifies it product mix from the other factories, the ULH metrics will no longer be comparable across different factories. This will become misleading as the title of the "Lowest Cost Plant" may evolve into the "Plant Producing the Simplest Product." Such evolution may be acceptable provided that these old metrics are no longer used to allocate the demand to plants.

Another challenge is presented when Dell's business and operational strategy are compared using the product-process matrix introduced in Section 3.2. According to

Hayes and Wheelwright (1979a & 1979b), it can be argued that Dell's market is positioned between locations 3 and 4 on Figure 3A, due to the commoditization of the PC (thanks in part to Dell). The consequence is that the operational strategy should focus around a few standardized products made through the use of a high volume continuous production system. In fact, the metrics described in the previous sections support this view. The glaring problem with this conclusion is that Dell also offers significant value to its customers by allowing customers to configure their own systems. This behavior would position Dell between positions 1 and 2 on Figure 3A where a large variety of products are demanded by the market. Therefore Dell appears to be operating in two regions of the product process matrix. A useful way to think about this contradiction is by thinking about these positions as two separate markets rather than along a product lifecycle. Since these markets are so different, one would expect that different business strategies are needed to service the customers in the different groups. A disciple of Hayes and Wheelwright would then argue that two types of production facilities should exist, one focused on a standardized product to be produced at the lowest possible cost, and one that is flexible, and able to meet the needs of a more sophisticated (and richer) customer. Similarly from the product perspective, two product architectures would be required. Skinner (1974) argues that without such separation, operational complexity will be introduced, which may become too significant to manage efficiently. The result is a myriad of compromises that leaves a complex system, incapable of producing any product type at the most efficient level. To mitigate the complexity that the lack of focus introduces, the concept of Plant Within a Plant (PWP) is advocated. This PWP concept resolves the discrepancy between the Hayes and Wheelwright model provided that separate reporting structure and metrics (such as those discussed later in this section) are utilized for the different PWPs. Figure 5C shows the two disparate markets graphically using the techniques discussed by Saloner et. al (2001).

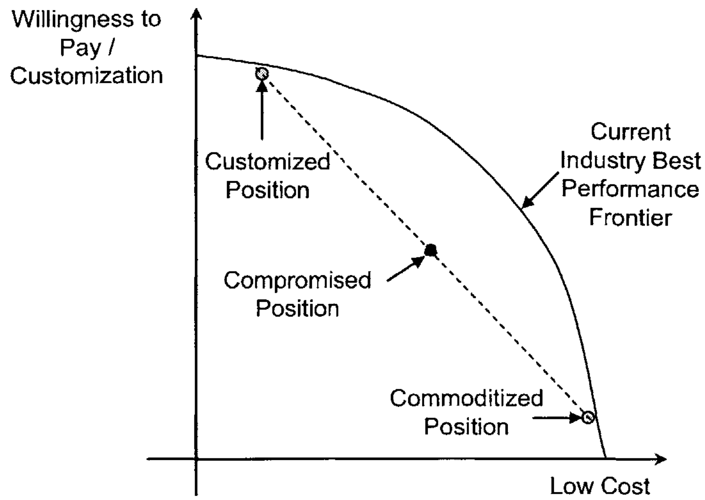

Figure 5C: Advantages of Adopting Plant Within a Plant Structure

The arc shown in Figure 5C represents the efficient performance frontier of the industry (i.e. the best possible combination of low cost and customization that is attainable within an industry). The performance frontier implicitly shows the necessary trade off that firms experience when positioning a business strategy between customization and low cost. Such a trade-off exists and is well documented by many including New (1992). Therefore, in order for alignment between business and operational strategy to be attained, separate structures should exist to support the focus on each different market. In doing so, it is possible to position each focused product near the efficient frontier of the industry (as shown for both the commoditized position (low cost) and customized position (high value)). The dotted line and point (shown as the compromised position) represents the probable outcome if both products were produced without the separation advocated by Skinner's PWP concept. Notice that this compromised position is well inside the efficient frontier due to the complexity that arises from the lack of a focused operation. Saloner et. al. (2001) argues that a firm, provided that it can reach the industry efficient frontier, will dominate a firm located in the interior of the frontier.

While superficially it seems as though Dell is diluting its focus by serving both markets of very different customers, Skinner suggests that this strategy is sustainable provided that each separate production area is treated as its own focused factory with separate reporting structures and guiding metrics. Opportunity lies in the development of a flexible plant environment with a new set of metrics to encourage the productive behaviors required to service the customized market. The operational execution of the commoditized product is already well positioned through the existing metric structure. The challenge is then developing a system that differentiates the need of flexibility to support its discriminating customers while it reinforces and rewards appropriate behavior.

Most of this problem can be addressed through a separate reporting structure and a new set of metrics that are thoughtfully implemented. It is naïve to think that such recommendations could be made from outside the organization; as there are several characteristics that must be considered to guide the choice of metrics. First, a tiered metric structure, similar to the current metrics should be used so that a simple, easily calculated metric is used for the lowest tactical level of management. Then each successive tier is held to a more complicated metric that addresses the shortfalls of the previous metric tier. The metrics should reinforce those characteristics that are important to the customer. In the case of the standardized product, the customer is price sensitive, and therefore metrics that reward low costs were utilized. In the case of the specialized product, new metrics are advocated for the three major management levels: supervisor, operations manager, and shift manager.

5.1.2.5 Flexibility Based Metrics for Supervisor Level

At the lowest management echelon, it is advocated that platform throughput attainment be substituted for the traditional throughput attainment. The concept of platform based metrics treats each platform requiring product mix flexibility to be treated separately. For example if during the last hour, a production line produces 80 Product X, 350 Product Y, and 350 Product Z, while throughput attainment for Product X, Y, & Z respectively is equal to 500/hr, 900/hr and 1000/hr, the platform throughput can be calculated knowing the run times of each product. If Product X, Y, & Z were run for 10, 30, and 20 minutes respectively (ignoring change-overs), platform throughput is calculated to be 96%, 78%, and 105% respectively. In this case, management would be pleased with product X and Z performance, but concerned about the performance of Product Y on this line.

Subsequently, the supervisor would be required to present a plan to address the shortfall at the production meeting. This metric addresses several of the weaknesses of the throughput metrics, but share some of the same fundamental weaknesses. While throughput attainment is solely a function of the average of platform rates based upon the design of the production line, platform throughput attainment differentiates between the required labor content of each platform that is run on the same line. Therefore a labor intensive, highly customizable platform has a lower platform throughput metric than that of a simpler system. Without this distinction, there would be a tendency of a supervisor to avoid running a platform which requires more labor, as the throughput attainment metric would be more difficult to obtain. Ironically, those more customized systems, while offering higher margins to the business, would wait longer in queue to be built. The platform throughput attainment metric also requires supervisors to develop a highly flexible workforce. Currently, some employees that work on certain lines are not proficient in producing all platforms types that the facility builds. With the new metric, the supervisor would be incentivized to train all their employees on all platforms, now that the throughput attainment of each platform is measured. The speed of calculating the throughput metric is retained after transitioning to the platform based metric because the existing systems are capable of supplying the necessary information. Therefore the platform based throughput metric is a useful tool in managing the tactical day to day line operations.

With the introduction of more product mix flexibility on a production line, quality must be measured as customized computers serve a more demanding market. The more platforms run on a given line, the more difficult it may become to track the source of quality issues. Therefore, it is advocated that supervisors are held accountable to a first pass yield metric. First pass yield is defined as the percentage of computers that require no rework prior to passing a first stage quality check. While platform throughput will identify training gaps in the form of speed and productivity, first pass yield identifies training gaps in the form of consistency and accuracy. Dell's current data warehouse enables first pass yield to be calculated as quickly as throughput, making it a good hour to hour management tool for the supervisors. By measuring both speed and accuracy at the lowest level in the organization, the tendency to "pass the buck" to other parts of the organization will be limited.

While these new metrics improve many of the shortfalls that the former metric suffers from, many of the fundamental weaknesses are still present. These include the familiar problems of overstaffing and overproducing. An additional bad behavior of resisting platform change-overs also appears as supervisors can produce better metrics with fewer platform types. Over time this resistance will act to erode the product mix flexibility that was so painstakingly developed. To address these issues, an updated set of metrics is proposed for the next level of management.

5.1.2.6 Flexibility Based Metrics for Operations Manager Level

While ULH no longer accurately measures the productivity of a line producing many platform types, platform ULH will. For this reason it is recommended that operations manager level is held accountable for platform ULH for many of the same reasons that the supervisor level is measured on platform throughput. This metric will fight the overstaffing tendency that supervisors may exhibit.

The new bad behaviors introduced at the supervisor level also need to be addressed by the operations manager level. This can be accomplished through a platform cycling metric. This metric will encourage frequent cycling of platforms, which will address the over production issues, and resistance to platform cycling from the supervisor level. Additionally with a quality metric pushed to the lowest level of management, less time will need to be spent on tracking quality issues.

The new platform cycling metric will encourage management at this level to cycle platforms regardless of order urgency. Therefore it is important that the next management level prioritizes platform cycling and orders based upon customer importance.

5.1.2.7 Flexibility Based Metrics for Shift Manager Level

Obviously from the shift manager level, cost is still an important metric that must be tracked. Therefore platform CpB should be tracked in the same way aggregate CpB was tracked prior to the flexibility implementation. Recalling that Dell has a build to order operational strategy, this level of management should also be measured on ship to commit attainment. Ship to commit attainment is defined as the difference between the date the customer order is actually shipped and the ship date that the customer was promised when they placed their order. This metric is the ultimate measure on customer delivery timeliness. Ship to commit attainment will pressure the operations managers to cycle platforms as needed to ensure that the correct platforms are built depending upon customer commitments.

5.1.3 Problem Definition

To this point Section 5.1 has focused on developing the background and demonstrating the importance and need for flexibility at Dell. The remainder of this section will detail the project that was undertaken to develop product mix and volume flexibility to accommodate the addition of the new product line. To protect sensitive information, the new product line will be referred to generically as Product X and the data presented will be normalized.

The new product line was chosen to be adopted by EG-1 for primarily three reasons. The first reason is that the US based production capability of Product X is nearing its network capacity. Secondly, the adoption of this product provides an opportunity to eliminate the use of a reverse logistics loop that will save Dell millions of dollars per year. Finally, Product X can utilize the existing idle production assets that formerly served desktops at EG-1 after the implementation of this flexibility product. While the new product line requires similar process steps to the current product lines serviced by EG-1, the complexity of these steps is multiplied due to the greater number of materials that could be required to meet customer needs.

The goal of this project is to enable the production of Product X at EG-1 using an existing idle production line (add product mix flexibility). The capacity of the new Product X line must be scalable to double in capacity within 12 months if required. Finally, line changeover between Product X and desktop products must take less than 48 hours of person-effort. The metrics of capital expenditure and Product X platform ULH & CpB will be used to compare competing flexibility solutions from the strategic perspective.

5.1.4 Designs for Developing Flexibility

Based on the project scope set by the problem statement in Section 5.1.3, designs to develop product mix and volume flexibility were required to introduce Product X into EG-1. Of the two required flexibility types, product mix flexibility proved to be less complicated to solve, so it will be addressed first. Of the competing designs that will be detailed in the future, the product mix flexibility approach remains constant.

5.1.4.1 Product Mix Enhancements

There were two main challenges in developing the required product mix flexibility to allow Product X to be produced at EG-1. The first challenge was in introducing the required production information systems required to allow the production equipment to communicate with the inventory, shipping, and production planning systems. These challenges were purely technical in nature, so they will not be discussed further. The second problem was derived from the added complexity that Product X introduced into the standard desktop process steps. The most prominent of these problems centered on the increased number of materials required on the production line to satisfy the myriad of customer options. The number of materials on this line would have to be increased by a factor of 6 while using the existing pick to light (PTL) rack structure (due to the maximum change-over requirement time). This problem was addressed through clever planning and analysis of material attach rates. For example, the high attach rate parts were stocked on the line PTL racks per normal desktop procedure. The medium attach rate parts were stocked on an additional rack system that was added to an offshoot spur coming from the main production line (referred to as a second pass material stop). The offshoot spur would be active when the line serves Product X and would be left unutilized during normal desktop production. The low attach rate parts (typically included in less than 1% of orders) are stocked off the line. Orders needing a lower attach rate part are removed from the process flow and accumulated until the part can be added to the product. While removed from the process flow, such orders are still included in platform throughput and ULH calculations to encourage timely processing.

5.1.4.2 Volume Flexibility Designs (Flexible Capacity)

As mentioned earlier, Product X introduces more complexity with its introduction in the form of volume variability. Figure 5D shows the average expected temporal variability in Product X demand serviced by EG-1. There are five issues that make the Product X demand variation particularly challenging to address. First, Figure 5D represents the average demand levels over the subsequent months organized by the days of the week. This indicates that additional daily variation is likely to occur. Historical data for Product X suggests that the demand distribution will exhibit a coefficient of variation between 20 and 40%. Secondly, the fluctuation in the demand of Product X is expected to vary by over 400% during the course of any given week. Due to Dell's 24 hour order fulfillment culture resulting from the build to order business plan, the ability to mitigate the demand variation through increased buffers (moving the fulcrum of Figure 3B through accumulation) is significantly hampered. An additional challenge is introduced as Product X demand is introduced into the factory at different times, depending upon the day of the week. The arrival rate variability is shown by Figures 5E-H. Finally the solution must be scalable to accommodate peak demand of twice that shown in Figure 5D during the next 12 months.

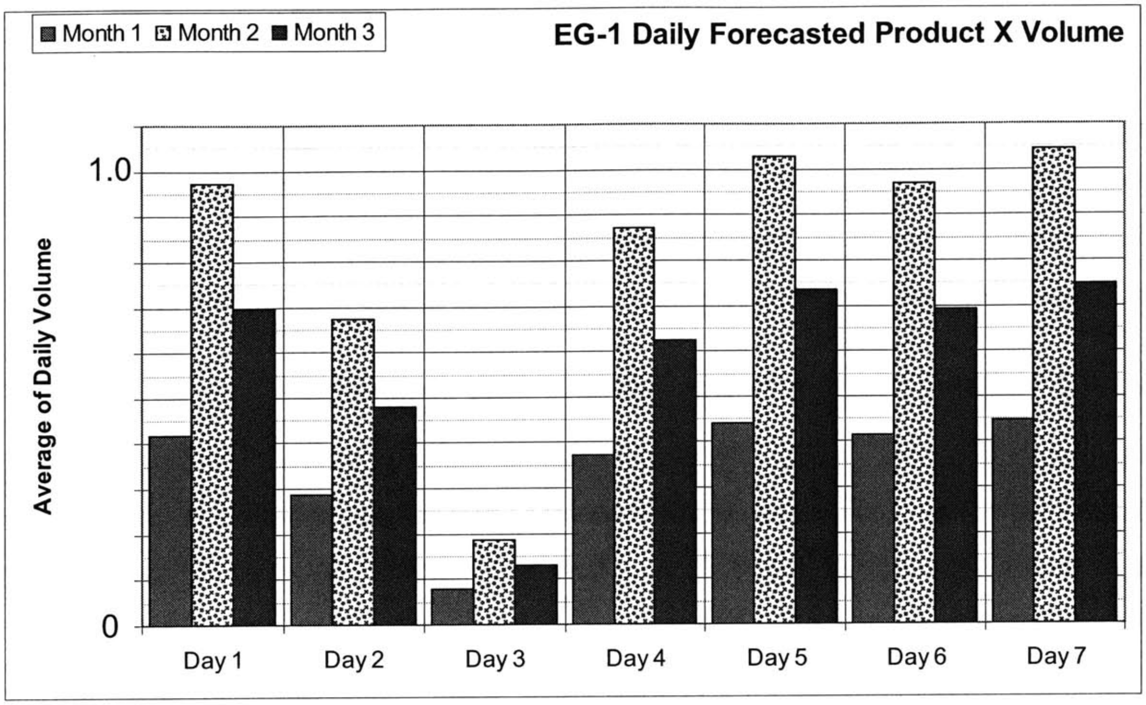

Figure 5D: Temporal Demand Variation of Product X

Recall that Section 2.2.4 discussed the importance of balancing the technical solutions to flexibility problems with the organizational solutions to the same problem. In order to successfully address the volume flexibility needed by Product X, both must be addressed.

Two competing technically based designs dominated the solution to the product mix flexibility piece of this problem. The first of these designs (referred subsequently to as Design TA) used the strategy of minimizing capital expenditures in favor of higher variable costs. The competing design (referred subsequently to as Design TB) leveraged capital equipment to address a key bottleneck in the existing line design, resulting in more efficient use of variable resources. Both alternatives were designed with expansion flexibility and are scalable to achieve double volume by introducing a parallel line when such an expansion is required. The alternatives presented by TA and TB represent a classic design tradeoff that many firms experience. The difference is that while most firms trade-off automation for flexibility, both Design TA and TB rely heavily on the organizational sources of flexibility, and keep the trade-off between variable and fixed costs. While design TB requires slightly lower staffing levels, it also increases line throughput, significantly lowering the labor cost per box portion of the variable costs. It should be noted that Dell operates nonunion factories, and is therefore is able to enjoy benefits of organizational flexibility that may be unavailable to those firms with a collective bargaining agreement. Table 5A shows how both of the competing technical designs score against several operational metrics discussed in Section 5.1.2.

Design	TA	TB
Required Headcount	1.27	1.00
Design ULH	0.61	1.00
Design Throughput	0.77	1.00
Design CpB	1.62	1.00
Capital Cost	0.10	1.00

Table 5A: Metric Comparison of Product X Technical Design Solutions

Based on the two technical design alternatives, four staffing (organizational based volume flexibility) scenarios were investigated based on heuristically developed scenarios that focused on cost, demand arrival, fulfillment time, and flexible options. Figures 5E-H, show the representative staffing plans (Organizational Flexibility Scenarios 1-4) and shift schedules derived from the heuristic process.

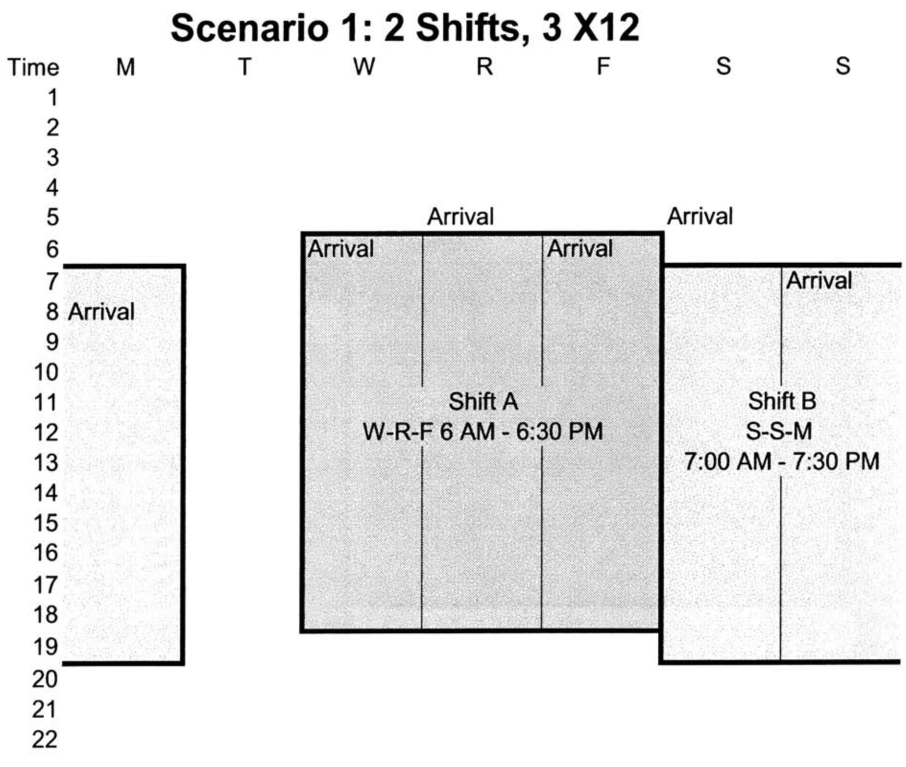

Figure 5E: Organizational Flexibility Scenario 1 (O1)

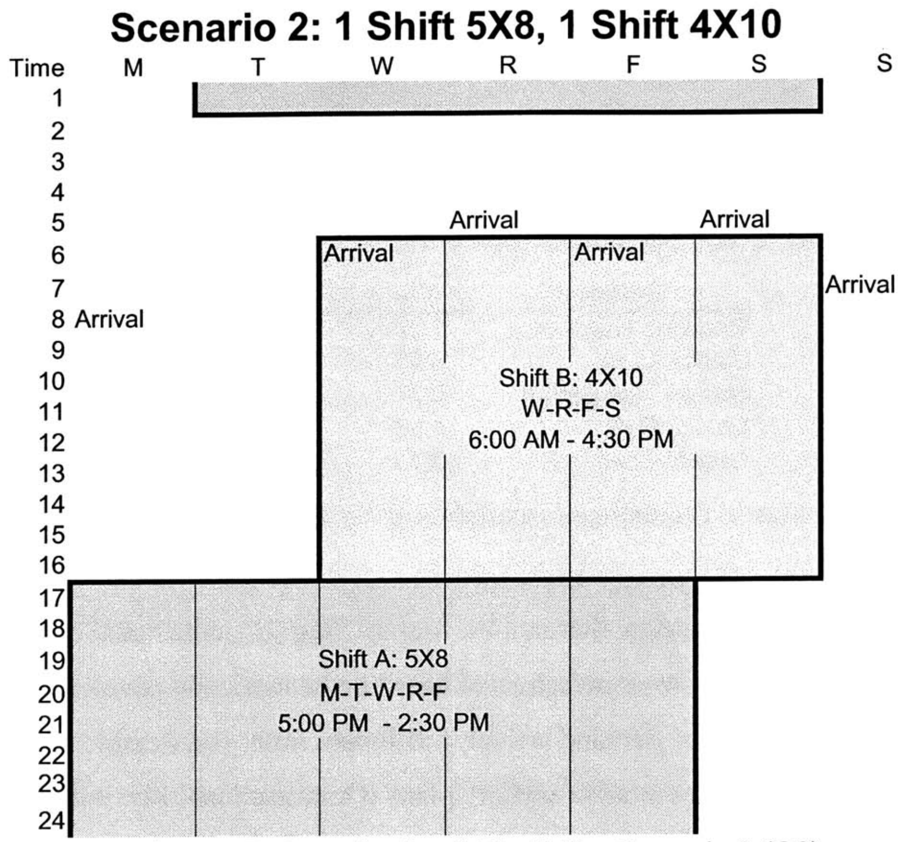

Figure 5F: Organizational Flexibility Scenario 2 (O2)

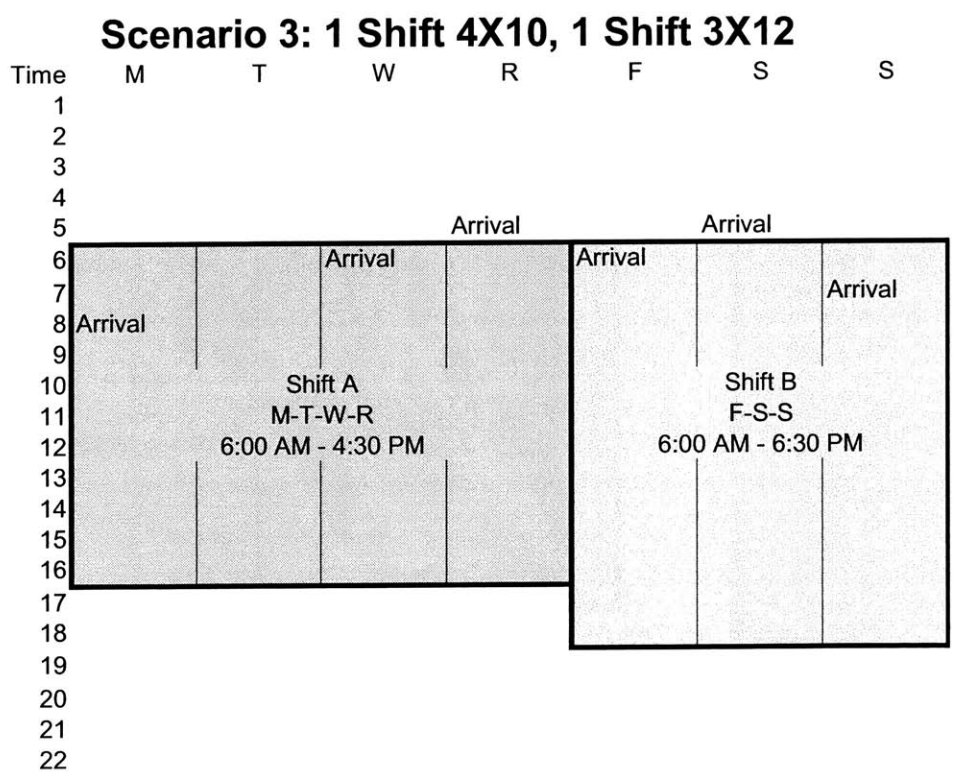

Figure 5G: Organizational Flexibility Scenario 3 (O3)

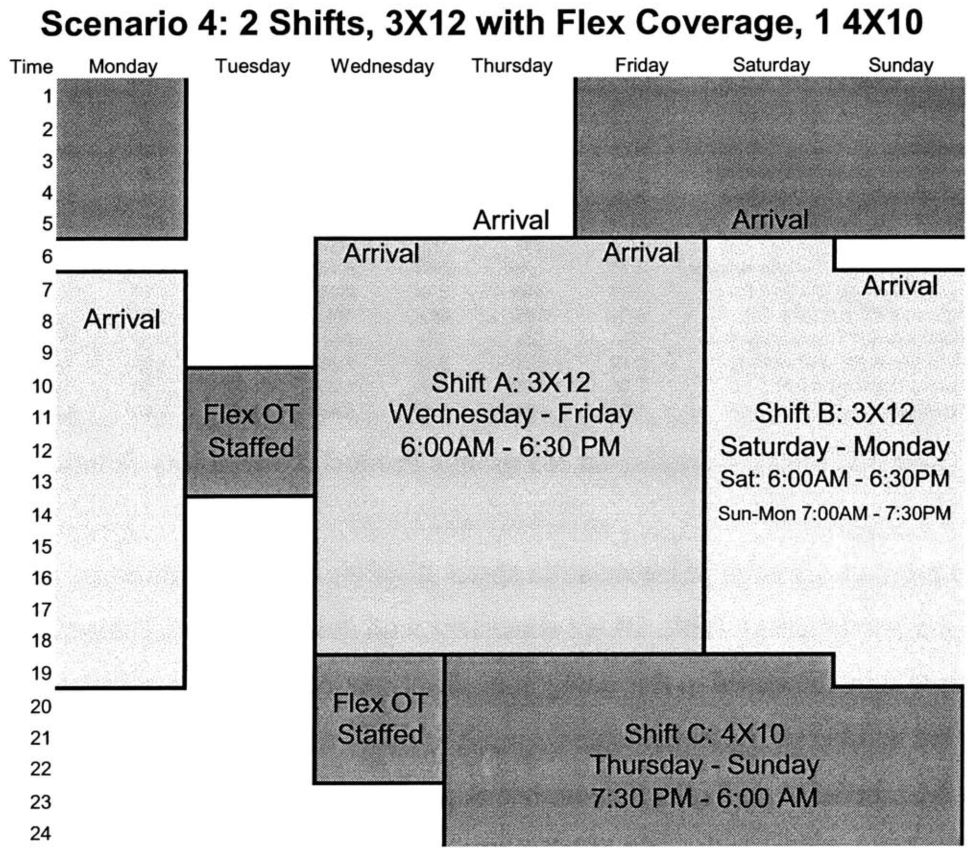

Figure 5H: Organizational Flexibility Scenario 4 (O4)

Table 5B shows the performance of the organizational flexibility scenarios as applied to each of the technical flexibility designs. The performance measures in Table 5B have been normalized using the same datum used to develop Table 5A. Product X utilizes the same support services that are used throughout the rest of the factory (i.e. production control room resources, materials receiving, shipping, etc.). While there is enough capacity in those support functions to accommodate the addition of Product X, if the Product X line runs while the rest of the factory is not scheduled to be operating, additional support staff will be required. More specifically, EG-1 does not currently operate a night shift on Saturday, nor any shift on Sunday. Therefore, those operational flexibility scenarios that require Sunday or late Saturday operation have the added burden of additional support staff (i.e., O1, O3, and O4). This explains the additional required headcount for those designs (along with the "staffed" vs. "design" metric designation) shown in Table 5B when compared to Table 5A.

Design	TAO1	TAO2	TAO3	TAO4	TBO1	TBO2	TBO3	TBO4
Staffed Headcount	1.34	1.27	1.34	1.50	1.08	1.00	1.08	1.23
Staffed ULH	0.53	0.56	0.53	0.47	0.85	0.92	0.85	0.75
Staffed Throughput	0.77	0.77	0.77	0.77	1.00	1.00	1.00	1.00
Avg Demand Staffed CpB (W/O Overtime)	2.13	1.79	2.01	2.79	1.36	1.27	1.36	2.34
Avg Demand Staffed CpB (W/ Overtime)	2.22	1.87	2.10	2.79	1.36	1.27	1.36	2.34
Overtime Required Avg Demand (%)	27%	14%	20%	0%	0%	0%	0%	0%
Avg Hours Management Opportunity (%)	0%	0%	0%	24%	2%	13%	8%	38%
Peak Demand Staffed CpB (W/O Overtime)	2.13	1.79	2.01	2.13	1.33	1.11	1.26	1.67
Peak Demand Staffed CpB (W/ Overtime)	2.32	2.03	2.24	2.18	1.40	1.17	1.33	1.67
Overtime Required Peak Demand (%)	78%	59%	68%	7%	37%	22%	29%	0%
Peak Hours Management Opportunity (%)	0%	0%	0%	0%	0%	0%	0%	13%
Staffed Capacity/Week (W/O Overtime)	0.79	0.88	0.83	1.31	1.02	1.15	1.08	1.61
Average Required Capacity/Week	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Peak Capacity/Week	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40

Table 5B: Metric Comparison of Possible Product X Flexibility Solutions

Table 5B presents a wealth of information about all of the potential solutions. While many of the row labels of Table 5B are consistent with those shown in Table 5A, the new categories will be discussed in this paragraph. Overtime percentage is calculated by dividing the number of overtime hours required to fulfill demand for a given week (beyond the scheduled shifts) by the number of productive hours available during that week. Overtime increases the cost of labor content by a factor of 1.5 during the overtime periods, which increases the CpB metric. The difference between the CpB without overtime and the CpB with overtime represents the cost of under allocating capacity for a given Product X demand profile. The Hours Management Opportunity Percentage is calculated by dividing the hours of excess capacity that is allocated based on a given staffing scenario by the number of productive hours available in a given week. Hours Management Opportunity Percentage represents the costs of over allocating capacity for a given Product X demand profile. These hours can be recaptured in some cases by shutting down the line early as Product X demand is exhausted for a given day and sending temporary labor home, and reassigning Dell employees to other areas within the plant. Table 5B shows CpB, overtime, and hours management opportunity as a function of the peak demand (similar to the Month 2 Demand shown in Figure 5D), and average demand (calculated by averaging the demand of all months together).

As previously discussed, the two technical solutions (A&B) shown in Tables 5A&B provide a trade off between fixed costs and variable costs. In order to help in the selection the best technical solution, a Net Present Value (NPV) analysis is performed to determine the NPV of the capital expenditures required for investment over one year of operation. Dell often uses a one year payback hurdle with an annual weighted cost of capital that is consistent with the computer hardware industry as a decision criterion when choosing projects to fund. While a one year payback period would be an overly aggressive hurdle for most businesses, the speed of change within the PC industry requires such short time horizons in order to guarantee a return on an investment. The industry speed can be easily observed through the discussion of the significant mission changes that EG-1 experienced in section 5.1.1 over relatively short periods of time.

12 Month NPV	Product X Volume
$360,989	1.00
$683,726	1.40
$0	0.12

Table 5C: NPV Benefit of Technical Solution B Over Technical Solution A

Table 5C shows the results of this analysis based on the initial extra required capital costs and CpB advantage of TB's approach to achieve technical flexibility. Therefore the analysis determines how the variable cost benefits (i.e., the labor savings from lower staffing levels and increased throughput) offset the added capital costs during the implementation of TB. This analysis assumed different volume levels of Product X moving through the factory. The major conclusion of Table 5C is that as volume of Product X increases, the return on the investment grows as well. More importantly, at least 12% of the average Product X volume predicted by Figure 5D must be attained in order for Technical Design B to be superior to Technical Design A from an NPV analysis. These results are not surprising, considering this classical trade-off between upfront investment and more efficient subsequent operations that many firms face.

5.1.5 Best Flexibility Solution to Accommodate Product X

5.1.5.1 Strategic Implications

Based on the analysis in the preceding section, one would expect that flexibility scheme TBO2 to be adopted, as it offers the lowest cost solution for the fulfillment of Product X. This conclusion would be correct, considering only the metric performance and NPV analysis (from the strategic perspective), however; the political and cultural perspectives must also be considered (recalling the 3 lens implementation framework developed in Chapter 4). It is often true that the best strategic solution is usually superior in a vacuum; however, it is often suboptimal when the broader cultural and political systems of a firm are taken into account. Furthermore, it is often very difficult to understand the implications of these non-strategic perspectives when viewing a firm from the outside.

5.1.5.2 Cultural Implications

There are two major cultural implications at Dell that must be considered when choosing a flexibility scheme that will be successfully implemented. The first involves the requirement to fulfill a customer order within 24 hours of receiving the demand at the factory. Due to its direct business model and build to order operational strategy, a big part of Dell's culture supports the notion of providing an excellent customer experience. Therefore, any solution that does not provide staffing during a day where there is an arrival (see Figures 5E-H) will violate this promise, and therefore, may be difficult to implement despite the cost advantages. The natural question to be asked is how much is this cultural norm worth in monetary means. For example, if such a solution existed that fulfills customer demand within 25 hours of receiving the demand at the factory and saved $1M per day, then one would presume that the compromise would be acceptable. On the other hand, a solution that would satisfy demand within 100 hours of receiving the demand at the factory in order to save $1k per day would probably be unacceptable. Unfortunately the point of indifference between savings and fulfillment delay is currently unknown (and even if known would be likely to change). Therefore, most decisions needed in this realm are made through negotiation and consensus between the key stakeholders (which once again explains the difficulty in predicting successful implementation from outside of a firm). Since there is not a known trade-off point in which sacrificing 24 hour fulfillment is acceptable, it becomes part of the "undocumented" norms of operation within the firm. Similarly without such an important parameter addressed explicitly, it is left to the culture of the organization to decide such acceptable thresholds.

The second cultural implication surrounds the major source of Dell's operational flexibility: the work force. In order to continue the level of continuous improvement that Dell enjoys from its workforce, it must make a credible commitment to respect its people. Therefore Dell uses a rule of thumb in which the overtime percentage is limited to preserve its workforce's quality of life. In a similar respect management also has an informal contract with the workforce to limit the hours management that is practiced so that Dell employees are able to meet a minimum threshold of work hours per week. These related limitations preclude the organizational flexibility scenarios of 1, 2, & 3 for both technical solutions (particularly if peak demand conditions are achieved).

5.1.5.3 Political Implications

The previously discussed cultural norms at Dell have limited the viable solutions to TAO4 and TBO4. The political perspective will help in determining the solution that was recommended as yielding the greatest possibility for success. Two political considerations influenced the optimal design for the implementation of Product X at EG-1. The first consideration is the availability of capital funding. Classic business thought teaches managers to invest in any project that yields a positive NPV. Obviously, firms do not have infinite funding and often positive NPV investments are not made due to budgeting constraints. Therefore managers are encouraged to minimize capital expenditures, unless such expenses are explicitly budgeted for. In the case of Product X implementation, some capital funding was secured during the budgeting process; however, its use is closely monitored and management is encouraged to minimize such spending.

The second political consideration is a closer examination of one of the key assumptions used in the development of this project. The development of the problem (Section 5.1.3) stated that the US capacity for Product X was beginning to become saturated. The development of Product X capability at EG-1 provides overflow capacity within the plant network. This flexibility development provides a real option to the centralized production planning group in the event that the network capacity becomes saturated. Recall that in its prior history, EG-1 faced capacity saturation in several instances, and in each case was able to expand its capacity through local improvement projects. It would be a major oversight not to expect the same behavior from the existing plants servicing Product X. In fact, once the EG-1 Product X project was significantly underway, it was learned that a significant expansion project was in process at a plant currently servicing Product X. The management in the locations with existing capacity is incentivized to expand their capacity if possible, as they have all support processes in place and are more likely to fulfill demand in a more productive manner than one line worth of new capacity at another plant. Similarly, the management of EG-1, after being directed to place Product X capacity in EG-1, must accommodate this request in the event that the central planning organization requests that the capacity be activated. Combining these actions together creates a capacity race between existing plant and EG-1. Coupling this knowledge with the assumptions surrounding the NPV shown by Table 5C, and the minimum volumes that were certain to be available are now more doubtful. Since it would be judged as a poor decision for management to invest significant capital into a project that may not be fully utilized when an alternate avenue was available, EG-1 management is more likely to embrace a less capital intensive solution that will provide the required flexibility. It is likely that the implementation of the technical solution will be done in such a way that allows the upgrade of TA into TB once the volumes are sustained at a minimum level. In practice, the design of this flexibility, although not discussed here, is what Azzone and Bertele (1989) refer to as expansion flexibility.

5.1.6 Conclusion

As the three lens perspectives are examined, solution TAO4 was recommended to be pursued, despite offering the worst CpB out of all the solutions that were examined.

Notice that a different recommendation would have actually been presented had the firm specific cultural and political implications not been considered. A key takeaway discovered by this case study is the fact that the flexibility implementation was not viewed as a one time event. Instead it was approached as an evolutionary process; where the implementation contains enough expansion flexibility to evolve as the needs of the system evolve.

5.2 Achieving Flexibility through Product Development

The previous case study at Dell focused primarily on the traditional operational levers available to a firm in achieving flexibility. This subsequent case study investigates the power of product development in achieving a flexible assembly operation by examining a manufacturer of small utility vehicles. The author spent time working in this organization during this project in which many lessons were learned with respect to flexibility in an assembly environment.

5.2.1 Case Study Background

The small vehicle market is comprised of four main segments: industrial, golf, recreational, and commercial. The industrial segment demands solutions to move people and materials over the paved surfaces often found at developed industrial sites. The golf segment is mainly driven by the need to carry golfers and their equipment around the golf course, as well as to aid caretakers in turf management. The recreational segment is primarily comprised of individuals who are interested in traveling over rough terrain. The commercial segment serves the needs of construction sites, i.e., helping to move people and materials around a construction job site. Figure 5J shows an example of vehicle choices that were typically available to consumers of each respective market segment: industrial cycles, golf carts, 4-wheeler ATVs, and small pick-up trucks.

Figure 5J: Example of Small Vehicle Options Prior to the Utility Vehicle Introduction

Customers that needed a vehicle that could haul loads around a job site safely were often faced with the compromises that one of these four vehicle types represented. The industrial cycles shown on the left do not operate well in unpaved environments, have limited hauling capability and can only transport one person safely. A golf cart performs better on unpaved conditions and can carry two passengers, however; does not operate well in rough terrain and has very limited hauling capability. The 4-wheeler ATV operates well on rough terrain and has racks to secure some cargo, but is usually configured to carry only one passenger. The straddle configuration of this vehicle type is less comfortable, especially for older operators. Finally, compact pick-up trucks can carry large loads and multiple people over relatively rough terrain, but are relatively expensive and can be difficult to maneuver around tight job sites. To confront these problems, several innovators began offering kits to mitigate some of the limitations inherent in the 4 vehicle types discussed above. For example, kits were sold to add cargo beds to golf carts and 4-wheeler ATVs, to increase the ground clearance of the golf carts and industrial cycles, and to reduce the top vehicle speed of pick-up trucks and 4-wheeler ATVs (for work site safety). Firms offering vehicles to serve this market began recognizing these needs and began the investing in new vehicle designs. These events collectively served as the impetus to create new segments within the small vehicle market. In addition to serving unmet needs, small vehicle firms looked for growth opportunities as traditional markets stagnated, and speculation mounted over a probable price war for market share. The resulting new designs (called utility vehicles) were the perfect solution to the issues facing these firms. Utility vehicles combined the strengths of the four vehicle types shown in Figure 5J while addressing many of their weaknesses.

Providing firms with a new growth market, each firm's infant utility designs allowed the continued rivalry between firms to be focused on product differentiation (as opposed to price competition).

5.2.2 Problem Definition

Although the needs of the four individual market segments were similar, each utility vehicle design had to be optimized for its own market segment. For example a vehicle targeting the commercial segment will often have bright colors for safety and visibility while using tires with aggressive treads that are required for travel over rough terrain. This same utility vehicle would be extremely unattractive to the golf segment. The bright vehicle colors would be distracting on a golf course and the aggressive tread on the tires would rip up the turf that is so painstakingly cared for. The consequence of this specialization is evident in the proliferation of vehicle types. Instead of a firm introducing 5 new vehicles to address the new market opportunity, there were now closer to 20 different utility vehicles that were needed to fully serve the market. While the utility vehicle provided an emerging market with great growth potential, it also provided a challenge to this firm's operations. The volumes of these vehicles initially were not great enough to justify the introduction of new production capacity. In particular, the new production demands increased variability in several operational functions including production planning and material replenishment. Recalling the dynamics of the interactions between flexibility, buffers, and variability shown in Figure 3C, two flexibility based paths were available to pursue: increasing buffers and process improvement. Initially, increased buffers were utilized to address the instability introduced into the production processes in the form of longer lead times. It was quickly observed that while acceptable for the near term, increasing competition in the utility segment would quickly require reduced lead times to customers (requiring reduced buffers). This change in the market strategy required a congruent change to the operational strategy. Therefore a project was launched to develop product mix flexibility within the existing production processes.

5.2.3 Manufacturing Perspective

Due to the immaturity of the emerging utility vehicle market and the subsequent volumes demanded, only one preexisting production line was dedicated to the production of the new utility vehicle platforms. This was problematic because of the limited room for materials to be stored on the line. The subject of the case study utilized Just In Time (JIT) production techniques, and therefore did not require much space on the line to store materials for assembly. Figure 5K shows a generic diagram of the utility vehicle production line.

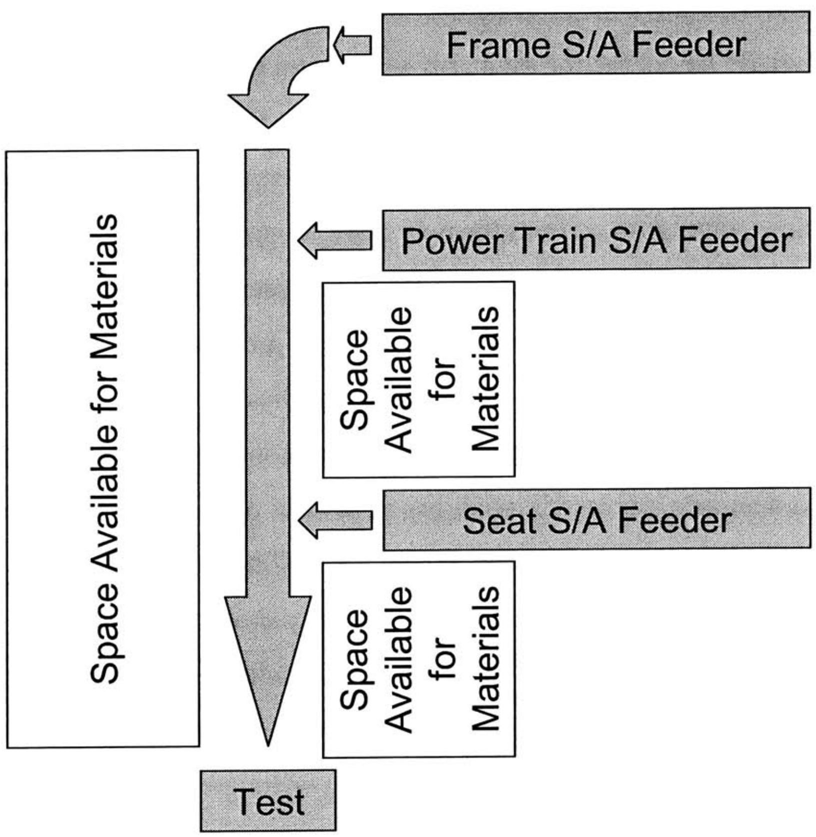

Figure 5K: Small Vehicle Production Line

The main assembly line is a moving line similar to those found in the automotive industry. Workers are stationed on either side of the line and are tasked with a specific group of tasks to complete. These tasks are generally grouped to achieve uniform work loads across every worker station. Major subassemblies are produced on feeder lines which merge into the main assembly line. Materials are continually replenished to the line in the material racks shown by the unshaded boxes in Figure 5K. Since there was inadequate space to store materials required for all of the different types of utility vehicles, production control typically batched vehicle production by platform and segment type. A line change-over was required in order to transition between batches. Consequently, a customer order sits in a scheduling queue until that specific vehicle is scheduled for a production batch. Many customer orders consist of several different vehicle types, requiring several batches to be scheduled and produced before a customer order is ready. The customer sees a ballooning lead time as a result. The tension between smaller batch sizes to reduce customer lead time and minimizing expensive line change-overs resulted in creation of a project to address both. This project was tasked with reducing change-over time (or ideally eliminating it) allowing shorter customer lead times. Table 5D shows the average line down time required for line change-overs between platforms and segment targets, as determined by averaged data gathered by the production routing data warehouse. This data was normalized to show relative improvement between the baseline case and a future improved case, while preserving the data confidentiality.

	To	1				2				3				4				5			
From	Segment	G	C	R	I	G	C	R	I	G	C	R	I	G	C	R	I	G	C	R	I
1	G		0.5	NA	0.5	0.7	1	NA	1	1.2	1.7	NA	1.7	2.7	3	3	NA	2.7	3	3	NA
	C	0.5		NA	0.5	1	0.7	NA	1	1.7	1.2	NA	1.7	3	2.7	3	NA	3	2.7	3	NA
	R	NA	NA		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	I	0.5	0.5	NA		1	1	NA	0.7	1.7	1.7	NA	1.2	3	3	3	NA	3	3	3	NA
2	G	0.7	1	NA	1		0.5	NA	0.5	1.2	1.7	NA	1.7	2.7	3	3	NA	2.7	3	3	NA
	C	1	0.7	NA	1	0.5		NA	0.5	1.7	1.2	NA	1.7	3	2.7	3	NA	3	2.7	3	NA
	R	NA	NA	NA	NA	NA	NA		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	I	1	1	NA	0.7	0.5	0.5	NA		1.7	1.7	NA	1.2	3	3	3	NA	3	3	3	NA
3	G	1.2	1.7	NA	1.7	1.2	1.7	NA	1.7		0.5	NA	0.5	1.5	NA	1.8	NA	1.5	1.8	1.8	NA
	C	1.7	1.2	NA	1.7	1.7	1.2	NA	1.7	0.5		NA	0.5	1.8	1.5	1.8	NA	1.8	1.5	1.8	NA
	R	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA		NA	NA	NA	NA	NA	NA	NA	NA	NA
	I	1.7	1.7	NA	1.2	1.7	1.7	NA	1.2	0.5	0.5	NA		1.8	1.8	1.8	NA	1.8	1.8	1.8	NA
4	G	2.7	3	NA	3	2.7	3	NA	3	1.5	1.8	NA	1.8		0.5	0.5	NA	0.7	1	1	NA
	C	3	2.7	NA	3	3	2.7	NA	3	NA	1.5	NA	1.8	0.5		0.5	NA	1	0.7	NA	NA
	R	3	3	NA	3	3	3	NA	3	1.8	1.8	NA	1.8	0.5	0.5		NA	1	1	0.7	NA
	I	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA		NA	NA	NA	NA
5	G	2.7	3	NA	3	2.7	3	NA	3	1.5	1.8	NA	1.8	0.7	1	1	NA		0.5	0.5	NA
	C	3	2.7	NA	3	3	2.7	NA	3	1.8	1.5	NA	1.8	1	0.7	1	NA	0.5		0.5	NA
	R	3	3	NA	3	3	3	NA	3	1.8	1.8	NA	1.8	1	NA	0.7	NA	0.5	0.5		NA
	I	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	

Table 5D: Average Downtime Required for Utility Line Change-Overs (Baseline)

The numbers located in the Table 5D headings represent each of the five new utility vehicle platform types. Following the platform numbers, four letters represent each of the market segments that were discussed in Section 5.2.1. Rows represent the current line configuration, while columns represent the assembly line configuration that is desired through the change-over. Therefore, the downtime that the assembly line experiences between any two vehicle configurations can be discovered. Table locations shaded and marked with NA either designate unavailable data, or an unutilized vehicle configuration. Therefore, if platform #1 for the golf market is currently running on the assembly line and the schedule dictates that platform #2 for the golf market will be run next, management would expect 0.7 time units of downtime during the transition.

Due to the availability of the information in Table 5D, it would be reasonable to believe that an optimization could be run based on an order profile to minimize the required line downtime. Following this logic, it would be expected that each platform would be cycled as required and then each segment within the platform would be run prior to changing-over to the next platform. Once a platform change is required, the segment should be matched to the next platform to be run. While forced to batch and cycle platforms and market segments due to the lack of space on the line to accommodate the required materials, it would be ideal if no line changeovers were required. The only way to achieve this would be either to create more space for materials (which was proved to be infeasible), or require less parts to be stored on the line (which was outside of the control of the manufacturing organization).

5.2.4 Product Development Approach to Achieving Flexibility

When studying the history of the product development organization, it has slowly evolved over time. To complicate matters, the new designs occurred over several years, meaning that different utility vehicle designs were completed under different organizational structures. One of the most significant organizational structures during this period was the split between the golf segment and the three other market segments. During this time, golf represented the largest portion of revenue for the business, so more resources were dedicated to it. This division resulted in subtle design differences between the different market segment versions of the same vehicle platform. While the manufacturing organization did not have control over limiting the number of parts required on the line, the product development organization did. Subsequently, a massive effort was organized to commonize parts across vehicles and platforms. For example, the golf segments, having higher volumes, could justify paying for prefabricated wiring harnesses with the connections already attached (special connectors were required for resisting the chemicals used in turf maintenance on a golf course). The same vehicle platform for the industrial market instead used cheap connections that were crimped onto wires during line assembly. While the volume from the golf segment could have subsidized the cost of the prefabricated harness for the industrial segment, the non-golf engineer was incentivized to make the lowest cost designs (based on the bill of materials) that were possible. Countless similar examples existed both within and across vehicle platforms, and were addressed during this effort.

This large, coordinated effort to commonize parts across segments and platforms helped the manufacturing organization reduce change-over time by limiting the number of parts required to be stocked on the line at any given time. While extremely successful, the project itself was not adequate to prevent future occurrences of this problem. Since a massive amount of product development resources were required to make the necessary engineering changes to commonize parts, the pace in new product releases slowed. Management, not wanting to have to make a similar sacrifice in the future, felt it necessary to put structure in place so that commonization became a lasting practice in the product development group. The following sections will investigate the flexibility implementation using the framework developed in Chapter 4 to obtain sustainable commonized output from the product development group to enable product mix flexibility in the operational group.

5.2.4.1 Strategic Implications

As mentioned earlier, a divide in the design organization allowed greater focus on a key business segment at the expense of allowing vehicle designs become inconsistent across a common platform for the different segment targets. In retrospect, this division also created a division between engineers in the product development group. It was thought that since the groups were divided, the engineers in the other group were working on separate, unrelated designs. The result is that communication broke down between engineers separated by the organizational barrier.

One way to address this issue is to remove the organization barrier and reorganize the engineering group by vehicle subsystem rather than by market segment. With groups responsible for subsystems, the likelihood of commonality between subsystems will increase. Additionally, organizing the different market segment teams into "trim package" subsystem teams provides the necessary differentiation across a given vehicle platform to address the needs of each market segment. Both the strength and drawback of this organizational structure is that it forces all engineers in the organization to communicate with many more people. Therefore, the platform system integration engineer must have excellent technical and communication skills. Figure 5L shows the proposed new organization structure of the product development group.

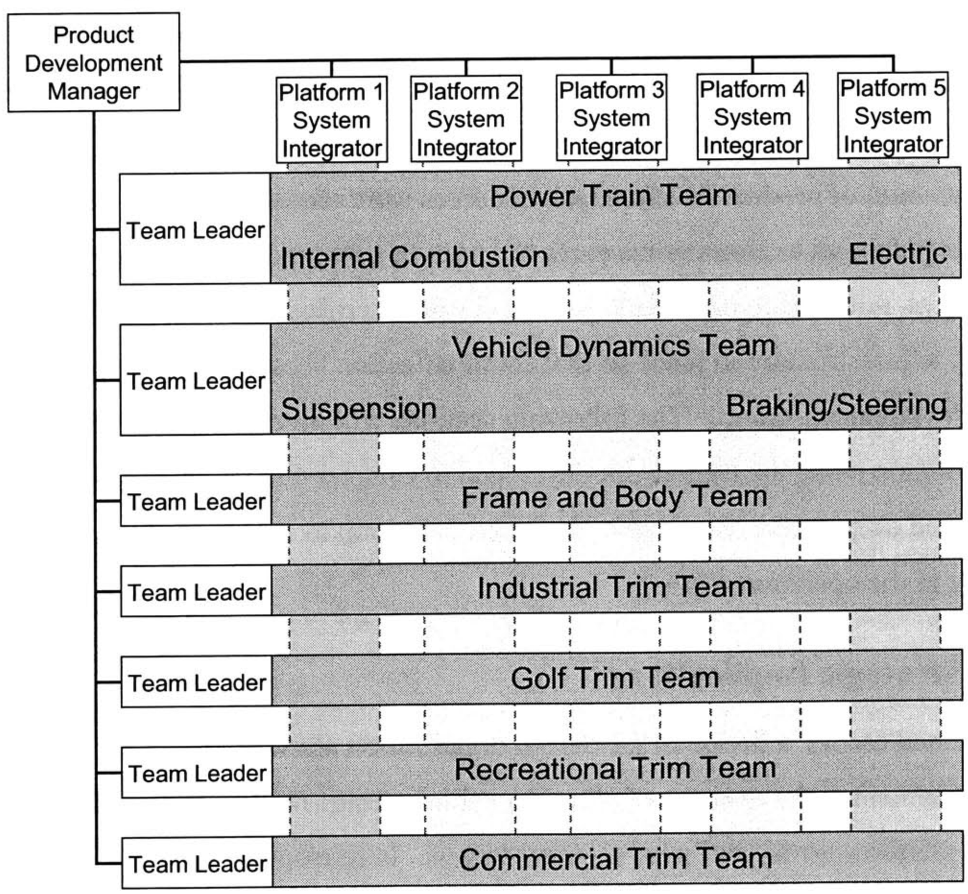

Figure 5L: Updated Product Development Organizational Structure

5.2.4.2 Cultural Implications

Prior to the massive commonization effort, there were no incentives that encouraged design engineers to use similar parts across platforms and segments. In fact, there was an incentive not to reuse parts. Within the development group, the engineers often felt great satisfaction in designing a part and seeing it launched into production. Additionally, reusing a part that is used on another vehicle often constrains the designer as changes to the form, fit or function of a part required every affected vehicle to be updated. This was a difficult task. Therefore, the path of least resistance was often to design a new part. Unfortunately, many of the engineers did not understand the extra work that was created in the sourcing, testing, and manufacturing organizations based on their decision to introduce a new part.

In order to help change the culture of the design function, the product development manager tied each engineer's performance review to the parts that were released by each engineer. Therefore, the engineer was responsible for the reliability of every new part that was released for several months after the part's production release. In this way, the product development manager attempted to measure the quality of the engineer's work. Indirectly, each engineer is now incentivized to reuse as many parts as possible to avoid the liability that a new part introduces into the engineer's performance review. This metric reinforces the desired commonization behavior that is needed, provided that the reused part allows the vehicle to meet its design specifications. The drawback to this incentive is the increased risk of stifling innovation at the design level. The tension that exists between the creative energy and coordination/control within an organization is a classic dilemma. To help offset this shift towards coordination/control, a design award and technical paper contest were introduced to showcase the creativity of the development engineers. These additions to the product development culture gave design engineers alternate avenues to be recognized by their peers and to develop the satisfaction that was previously felt through the frequent release of new parts into production.

5.2.4.3 Political Implications

With any large organizational change, there is always resistance expected from those who stand to loose power from the change. In particular, the divide between golf and other segments generated a tremendous amount of organizational power for those engineers in the golf camp. In fact, the golf group was often thought of as the "varsity" team and the other segments thought of as the "junior-varsity" team. Given this frame of reference, it was understandable to expect some reluctance from the golf group to reorganize. To immediately address this concern, the high performers within the golf organization were given the first preference to fill the new platform integration roles. Since these roles were at key organizational intersections, they provided an opportunity to retain their organization influence that had been built over time.

The new product development organization requires increased communication between its engineers to function properly. The product development management position also needs to have increased communication across several functions so that decisions are made for the good of the entire system rather than just one specific silo. The lack of this communication in the past has lead to many of the problems exposed by the flexibility project generated by the introduction of utility vehicles. In order to facilitate this understanding, an aspiring product development manager should be encouraged to spend time working in other organizations (i.e. production planning, purchasing, test, and manufacturing). In doing so, the new product development manger can correctly steer the development effort down the best path for the firm. Traditionally, the most technically competent engineer was rewarded by being promoted to engineering manager. Unfortunately technical competence is not generally the most important trait for a manager who must work with other functions. Instead, the new organizational structure introduced in section 5.2.4.1 provides a challenging technical role (i.e. platform integration) for those types of engineers to aspire to.

5.2.5 Conclusion

While the technical solution to the product mix flexibility was integral in achieving the improved change-over times shown by Table 5E, similar issues would be encountered in the future had the required organizational changes not been made.

	To	1				2				3				4				5			
From	Segment	G	C	R	I	G	C	R	I	G	C	R	I	G	C	R	I	G	C	R	I
1	G		0.3	NA	0.3	0	0.3	NA	0.3	0.7	0.7	NA	0.7	2.3	2.7	2.7	NA	2.3	2.7	2.7	NA
	C	0.3		NA	0.3	0.3	0	NA	0.3	0.7	0.7	NA	0.7	2.7	2.3	2.7	NA	2.7	2.3	2.7	NA
	R	NA	NA		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	I	0.3	0.3	NA		0.3	0.3	NA	0	0.7	0.7	NA	0.7	2.7	2.7	2.7	NA	2.7	2.7	2.7	NA
2	G	0	0.3	NA	0.3		0.3	NA	0.3	0.7	0.7	NA	NA	2.3	2.7	2.7	NA	2.3	2.7	2.7	NA
	C	0.3	0	NA	0.3	0.3		NA	0.3	0.7	0.7	NA	0.7	2.7	2.3	3	NA	2.7	2.3	2.7	NA
	R	NA	NA	NA	NA	NA	NA		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	I	0.3	0.3	NA	0	0.3	0.3	NA		0.7	0.7	NA	0.7	2.7	2.7	2.3	NA	2.7	2.7	2.7	NA
3	G	0.7	0.7	NA	0.7	0.7	0.7	NA	0.7		0.3	NA	0.3	1.5	NA	1.8	NA	1.5	1.8	1.8	NA
	C	0.7	0.7	NA	0.7	0.7	0.7	NA	0.7	0.3		NA	0.3	1.8	1.5	1.8	NA	1.8	1.5	1.8	NA
	R	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA		NA	NA	NA	NA	NA	NA	NA	NA	NA
	I	0.7	0.7	NA	0.7	NA	0.7	NA	0.7	0.3	0.3	NA		1.8	1.8	1.8	NA	1.8	1.8	1.8	NA
4	G	2.3	2.7	NA	2.7	2.3	2.7	NA	2.7	1.5	1.8	NA	1.8		0.3	0.3	NA	0	0.3	0.3	NA
	C	2.7	2.3	NA	2.7	2.7	2.3	NA	2.7	NA	1.5	NA	1.8	0.3		0.3	NA	0.3	0	NA	NA
	R	2.7	2.7	NA	2.7	2.7	3	NA	2.3	1.8	1.8	NA	1.8	0.3	0.3		NA	0.3	0.3	0	NA
	I	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA		NA	NA	NA	NA
5	G	2.3	2.7	NA	2.7	2.3	2.7	NA	2.7	1.5	1.8	NA	1.8	0	0.3	0.3	NA		0.3	0.3	NA
	C	2.7	2.3	NA	2.7	2.7	2.3	NA	2.7	1.8	1.5	NA	1.8	0.3	0	0.3	NA	0.3		0.3	NA
	R	2.7	2.7	NA	2.7	2.7	2.7	NA	2.7	1.8	1.8	NA	1.8	0.3	NA	0	NA	0.3	0.3		NA
	I	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	

Table 5E: Average Downtime Required for Utility Line Change-Overs (Improved)

Through the commonization of parts, changes within a given platform to other segments now require short change-over times and changes across similar platforms (i.e., between 1 & 2 and 4 & 5) within the same segments require no downtime.

The power of this change allowed a shift in the way production was scheduled. Instead of being driven by change-over avoidance, the production lots are now scheduled in smaller batches and the platforms are now cycled more frequently, reducing inventory holding costs and decreasing the delivery time to customers.

6.0 Conclusion

The majority of the confusion surrounding flexibility and its implementation within a firm is due to the fact that the term flexibility represents a genus containing several different species of flexibility. If two people are asked to describe an animal, the next natural question would be: what kind of animal? Similarly, flexibility must be treated as a broad topic that needs to be further classified to avoid confusion. This confusion can be compared to two people talking about an animal in which one person has a mental picture of an elephant, and the other a rabbit. While each animal may have big ears and large feet, the subsequent conversation would result in a frustrating exchange as each animal is completely different. Chapter 2 not only presented the observation that there is no one definition of flexibility, but the pursuit of one often leads to frustration along with an ever diverging set of candidates. Since flexibility can not be simplified into a singular idea, the four taxonomies presented in Chapter 2 are helpful in aligning expectations and perspectives. These four taxonomies along with their hybrids provide several dimensions to help in the classification of the species of flexibility that is required for a given situation. Because there is overlap between the different taxonomies, it is unlikely that one taxonomy will gain dominance over the others. Therefore practitioners are likely to encounter several of them during flexibility implementation.

For several decades, the importance of matching a business's overall strategy with its operational strategy has been advocated. Chapter 3 introduces the concept of the product – process matrix as a framework to help in thinking about this match. Expanding on the product – process matrix, the possibility of flexibility adding another dimension to this framework is investigated. Because of this potential, opportunities exist in using flexibility as a way to ensure and adjust the alignment between business and operational goals. Flexibility is particularly effective in addressing variability and uncertainty introduced into an operational process by the changing business climate. If flexibility is successfully implemented, it becomes possible to address a mature market with several customized product types, contrary to the original two-dimensional product – process matrix.

To successfully implement flexibility projects within a firm, it is important that a multidimensional approach be taken with respect to implementation. Chapter 4 introduces the 3 lens framework that is useful in implementing any change within an organization. This framework includes the strategic lens, cultural lens and political lens. Together, these lenses represent most perspectives within an organization. While much has been learned about flexibility through the academic publications on the subject, these works are primarily skewed towards the strategic perspective. Subsequently many of the recommendations made by these papers end in failures as Upton (1995) observed. The difficulty lies in understanding the cultural and political perspectives of a firm, as they are unique to each individual firm. Therefore, it becomes very difficult to make specific recommendations with the perspective of all three lenses from academia without being an insider in the firm. This thesis attempts to offer this perspective, as it is critical in making significant, lasting improvements to any firm.

In a continuation of the issues raised in Chapter 4, Chapter 5 details the importance of a holistic view during the implementation of flexibility improvements through two case studies. Since the author spent significant time within each organization, a complete perspective could be given to the respective flexibility implementations. Furthermore, it is apparent when looking at these case studies that the solution from the strategic perspective to the flexibility problem is often the easiest to arrive at. While optimal in a vacuum, the strategic solution is often the incorrect answer for the organization. Upton's focus on organizational sources, in addition to the technical (strategic) solutions, of flexibility shows similar insight. This thesis further segregates these organizational sources of flexibility into the cultural and political perspectives, and suggests how each can influence an implementation. Subsequently, many implementation failures stem from the difficulty in understanding all three perspectives.

The goal of this thesis was to develop a single source for practitioners to turn while trying to successfully implement a flexibility project within their firm. From this paper's perspective, there are four key steps to its successful implementation. First, it is imperative that all people involved in the implementation share a common origin and mental map of what is to be accomplished through the implementation of flexibility. This can be accomplished through classifying the scope of the flexibility project through the taxonomies presented in this paper. Secondly, it is important that the change is congruent with the business's overall strategy. Following a clear path aligned with the greater goals of an organization, the problem must be approached from a holistic perspective and tailored to the firm. More specifically, the strategic, political, and cultural implications of the project must be considered when choosing the implementation action. Through thoughtful analysis and using each lens as a perspective in choosing the proper plan of action, a project with the highest probability of success can be chosen. Finally, the project must be executed using standard, best practice project implementation discipline. While this thesis primarily focuses on how to pick the best course of action for a firm that needs flexibility, no improvements can be realized without the hard work that comes with thorough project execution.

7.0 References

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