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University of Michigan Business School Research Paper

Analysis of Manufacturing Strategy Involving Flexibility and Centralized Manufacturing

By
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A research paper submitted in fulfillment of the requirements for 3 credits, GRADUATE INDEPENDENT RESEARCH PROJECT Summer Term 1999, Professor J. Ettlie, Faculty Supervisor.

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<u>Faculty Comments</u>

JUN 26 2000

Sanjay did a great job of weaving a complex thread through a complex subject here. New plants are the wave of the future. How should they be organized? What strategy will drive their location, scale, scope, and workforce level? He has done a credible job of answering these questions.

Signature of Faculty Supervisor

Associate Professor

Title

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1. Introduction

In recent years, automotive industry has seen some of the most fundamental changes in its competitive landscape. Companies are not only acquiring potential competitors but also using technological innovations to streamline their internal operations to provide best value to their stakeholders. In order to deliver superior shareholder returns in this ever-changing marketplace, Ford Motor Company has redefined its vision from being a leading automotive company to becoming world's leading consumer company providing quality automotive products and services. To help achieve the new corporate vision, Manufacturing & Plant Engineering organization of Ford Powertrain Operations has proposed a new manufacturing strategy involving flexibility and centralized manufacturing of cylinder heads, one of the most critical components of an internal combustion engine.

The purpose of this paper is to explore various strategic issues that would be associated with the proposed strategy. The paper is organized as follows. First, management's rational behind the new strategy is presented. This is followed by a literature review in the area of manufacturing strategy, flexibility and centralized manufacturing. Next, analysis of cylinder head manufacturing at Ford Powertrain Operations is discussed. Benchmark data on engine manufacturing at Honda and Toyota follows this analysis. Finally, major action items are recommended to management of Ford Powertrain Manufacturing and Plant Engineering organization to successfully implement the proposed manufacturing strategy.

2. Rational for New Strategy

Cylinder head is one the five strategic components of an internal combustion engine[1]. Except for connecting rods and camshafts, these strategic components have traditionally been manufactured by automotive original equipment manufacturers (OEMs) in-house and in the same plant where engines are assembled. Further, majority of the machining lines in these engine plants are modular transfer machines dedicated to certain engines types only. Any change in engine design or mix that these machining lines have to handle is not only expensive but also time consuming due to retooling of the dedicated equipment. This generally causes the capacity utilization to vary across different engine plants. For instance, a truck engine plant at Ford would generally run at 120% of the capacity due to high demand for trucks where as plant making engines for cars would exhibit a low capacity utilization of 60% owing to poor demand for cars. Yet due to dedicated equipment, manufacturers cannot switch production of truck engines from truck engine plants to car engine plants. This not only increases cost of manufacturing but also prevents OEM from responding quickly to changes in the market.

The objective of the proposed strategy is to improve capacity utilization of Ford's engine manufacturing facilities while reducing cost through economies of scale and scope and improving manufacturing's ability to handle changing consumer requirements. Since cylinder head exhibits frequent changes in its design due changing market needs, management believes that consolidating the manufacturing of cylinder heads for various engines in a centralized flexible facility will help them achieve their strategic goals.

[1]Strategic components of an internal combustion engine are camshaft, connection rod, crankshaft, cylinder head, and cylinder block. Collectively they are called 5Cs.

3. Literature Review

This section presents a summary of the published work in the area of manufacturing strategy, manufacturing flexibility, and centralized manufacturing. In particular, it focuses on major enablers for manufacturing flexibility, outlines pros and cons of centralized manufacturing, and provides framework to successfully implement an innovation such as flexibility (See Exhibit 1 and Exhibit 8). Findings of the literature review are used in the next section to analyze cylinder head manufacturing at Ford Powertrain Manufacturing.

3.1. Role of Manufacturing Strategy

Skinner [16] is one of the first authors who recognized the strategic role of manufacturing function in business and corporate competitiveness. Since then, several authors have published their viewpoints regarding manufacturing strategy. Despite differing opinions, there are few common constructs that have emerged from the published literature. First, authors agree that prime aim of manufacturing strategy is to support the organization's achievement of a long term sustained competitive advantage. Second, they suggest that development of manufacturing strategy should follow a top-down approach where corporate strategy drives business strategy, which in turn drives strategies for manufacturing and other business units. Third, manufacturing strategy provides competitive advantage to organization by helping it excel on five key competitive priorities: cost efficiency, product quality, delivery speed, delivery dependability and flexibility. The relative importance of these objectives of manufacturing strategy depends upon the market in which organization competes. Finally, manufacturing strategy can be characterized as a consistent pattern of individual decisions in certain key strategic areas such as capacity, facilities, technology and the likes. Exhibit 3 shows manufacturing priorities and decision areas of manufacturing strategy according to some selected authors.

3.2. Flexibility

In most of the cited manufacturing strategy work, flexibility has been regarded as having an important role in organization's manufacturing strategy. It is not only one of the aforementioned competitive priorities but also influences other the competitive priorities (dependability, cost, speed and quality). In a recent census by Industry Week [15], companies ranked flexibility and agility as their #1 manufacturing strategy for 21st century, ahead of cost reduction (ranked #2). Although benefits of manufacturing flexibility have been well understood, managers have often found themselves frustrated with their inability to make their plants realize these benefits. This section highlights some of the major enablers managers need to concentrate on while formulating plans to implement flexibility in their plants. These enablers include nature of flexibility desired, nature of resources required, internal processes, measuring flexibility, and management attitude towards flexibility.

3.2.1. Nature of flexibility desired

One of the most fundamental roadblocks to incorporating flexibility in a plant is the failure to properly establish the nature of flexibility required. Flexibility means different things to different people. For instance, one manager might call the ability to seamlessly change from one product to the another as flexibility while another manager might refer to the ability to ramp up volumes to meet market demand as flexibility. There is no general consensus among leading authors on the classification of flexibility. Exhibit 5 gives various dimensions and types authors have proposed in the literature to classify flexibility. However, classification by Upton [17] is found to be most comprehensive and relevant to the scope of the current research. He suggests that whether one is referring to products, production volumes or manufacturing processes, flexibility in any plant be about increasing range, increasing mobility or achieving uniform performance across a range. Range refers to the ability to make different types of products in different volumes. For instance, it could mean small volume of highly dissimilar products or large volumes of slightly different products. In other words, range refers to product or volume or manufacturing process flexibility. Mobility refers to plant's ability to change nimbly from making one product to another. This kind of flexibility is associated with quick response time. It allows plants to minimize long runs and follow demand without excessive inventory. Uniform Performance refers to plant's ability to continue to perform well as it moves away from its most favored set of parameters. For instance, some plants perform well when making some particular product or when operated at some particular volume. Their performance falls off steeply if the operating pattern deviates sharply from the norm.

The choice of the flexibility should come from the objectives of manufacturing strategy, which in turn are driven by the corporate business strategy of the company. In general, manufacturing managers should concentrate on the flexibility that would provide long term sustainable competitive advantage to their company.

3.2.2. Nature of Resources Required

The nature of the resources required in the plant would depend upon the type of flexibility desired. The two most important resource types managers need to focus on are workforce and technology.

Workforce

Building the right workforce is one the most important tools managers can use to make their plant flexible. Upton [17], in his research, reported that workforce experience is an important factor in determining the operational flexibility of a plant. He found that long service was correlated positively with the range and negatively with mobility. His argument was that experienced crew held very rigid views about the way the plant should be operated and regarded any switching from those established parameters as making improper demands on the plant. Also, experienced crew was better at handling product variety simply because of their extensive knowledge base. On the other hand, younger crew viewed change as defining part of their jobs and was much amenable to switching from one job to another. In short, if one is looking to manufacture highly customized products, i.e. increasing range, it will need highly experienced workforce to make these products. Similarly if response time (mobility) is desired, one will need to build a work force that is less traditional and more apt to changing environment.

Another aspect of proper workforce is training and generally most overlooked by manufacturing managers striving for plant flexibility. Training is an important tool for building operational flexibility in a plant because of several reasons. First, it provides necessary skills required for carrying out news tasks. (For instance, ability to run different types machines, monitoring different types of manufacturing processes, setting up machines for different types of products etc.). Second it helps to change old non-flexible mindset through proper communication and education. Training should be used to emphasize the importance of flexibility to the workforce. Third, it helps to build confidence especially when people are afraid that trying new and different things might expose their ignorance. Fourth, it provides a sense of common purpose. Finally, it can help negotiations with unions especially when flexibility might be reducing the number of workers.

Technology

Likewise workforce, proper technology is another key driver to achieving plant flexibility. Today, managers have wide range of technologies to pick from - conventional or flexible transfer machines, flexible high speed machines or manufacturing cells, high speed machining centers, conventional manufacturing cells, or standard machining centers. Although the discussion about various systems is beyond the scope of this paper, there few key issues that managers need to keep in mind while selecting such systems. First, managers should base their decision for the technology on the nature of flexibility that they desire. For instance, one type of equipment may be capable of making large range of products while another may possess quick-changeover capabilities. However, former is of no use if product variety is minimal. Second, managers should be prudent in deploying flexible machining systems. For instance, instead of making every machine on production line flexible, they should use flexible machines only for those operations that see frequent product variation. This also obviates the risk of over investing in the technology. Similarly, unbridled implementation of automation should also be viewed critically especially considering that such a deployment has been found to negatively effect flexibility [17]. Technology should be viewed only as a tool to achieve flexibility rather as a total solution in itself. Third, managers should work with machine tool manufacturers to standardize both current and future components (internal and external) of the machine tool. This not only makes the expansion of the current machine easier and economical but also helps worker seamlessly move from one machine to another.

Japanese manufactures are the epitome of prudent machine tool selection. Toyota, for instance, facilitates flexibility in their machines is by mutually agreeing with machine tool suppliers on a long-term architecture for machines. This helps them to economically and easily add or delete modules to their existing machines. Also, it invests in machines that helps worker in carrying his job efficiently rather merely automating the operation.

3.2.3. Internal Processes

In addition to proper workforce and technology, management also needs to streamline various internal plant processes that might need changes due to new emphases on plant flexibility. These processes could include work practices, incentive systems, production planning and management, quality inspection procedures, tool changes, and the likes. Since, quite a few of these internal processes are direct consequence of company's production system, changing them would be hard.

Kaplan [9] also suggests changing internal cost accounting system, primarily due to increased content of machine hours used within flexible plants compared to labor hours in traditional plants. Improper allocation of overhead could result in transfer pricing issue especially when the plant is considered a profit center. This implies that no longer plants could rely on standard costing system to properly cost different products they manufacture in their plants especially if they produce lots of different products for external or internal customers.

3.2.4. Measuring Flexibility

In addition to right workforce, pertinent technology and streamlined processes, managers also need to find ways to measure flexibility they are seeking and need to emphasize the importance of these measures to their workforce. Upton's [17] research indicates that managers at most plants, where flexibility didn't produce desired results, relied primarily on financial measures (such as capacity utilization, total cost etc.) that had no connection to flexibility. On the other hand, plants that were flexible in terms of range and mobility tended to have clear non-financial measures (such as changeover times, lead times, process range etc.) to guide them. This is not to say that financial measures should be abandoned. Rather, they should be modified and (or) supplemented with those emphasizing the importance of flexibility as well.

Kaplan [9] in his research identified a handful of companies that institutionalized new ways to measure their manufacturing performance and productivity especially due to influx of new manufacturing practices such as JIT, factory automation, CM and the likes. For instance, GE identified externally focused measures that give value to its customers and support the goals of the business. Exhibit 6 shows the hierarchy which GE management selected to measure its manufacturing excellence. It is important to understand that these measures originate from customers and shareholders both of which are essential for company's survival.

customers, and loss of customers due to customer's preference for better service provided by a competitor. Finally, management of shipment logistics gets more complicated causing additional expenses to be incurred.

In addition to shipping disadvantages, there could also be an increased inventory cost. This is made worse when a centralized facility manufactures different parts for different downstream plants. Unless managed properly, it generally results in increased inventory both at the centralized location and at the downstream plant. At the same time, there could also be an increase in pipeline inventory as governed by Little's Law[4]. As company moves manufacturing of an upstream component from a collocated location to a centralized facility, the transportation distance and the quantity of the products to be shipped from the single plant increases, thereby causing average inventory in the pipeline to increase. Increased inventory results in higher working capital requirements and moves plant from pull inventory system to push inventory system.

3.3.2. Bureaucratization Diseconomies

Bureaucratization diseconomies occur when an increase in the size of the plant is accompanied by a concomitant increase in the payroll (workers, supervisors, managers etc.) required to support it. The large size of the organization makes communication and coordination more difficult and, thus, causes response time and quality for the whole plant to deteriorate. Any efforts to make plant flexible get jeopardized.

Also, it has been observed that plants, which are too big in relation to the local population, are more likely to attract successful unionization efforts, resulting in

[4] $L = \lambda W$, where L is the inventory in the pipeline, λ is shipments per unit time, and W is the transportation delay.

additional bureaucratization, compared to plants that are reasonably sized. This is because of the increased dependence of neighboring communities on the plant's payroll causing them to influence plant's internal decisions.

3.3.3. Confusion Diseconomies

Confusion diseconomy is associated with increased overhead from having to deal with increased product and processes complexity. If two plants manufacture different products using dissimilar processes, consolidating them under one roof would usually make the new plant more complex than individual plants. Literature suggests that the number of people whose role is primarily one of coordination across functional or departmental boundaries tend to increase more than proportionally with the number of separately managed units (departments, functions, process stages, etc.). This phenomena is analogous to one often observed in large networks where the supervisory costs increase in rough proportion to the number of units but the coordination cost increase with the number of links[5]. For instance in a network of 4 units and 6 links, addition of another unit increases the number of links to 10. Thus, supervisory costs increase by 25%, in proportion with the number of units, but coordination costs increase by 67%, in proportion with the number of links. It is important to note that application of information technology, such as Enterprise Resource Planning (ERP) System, integrated product and process knowledge-bases etc., can significantly reduce some of the coordination costs.

In addition to the cost of coordination, there could also be a cost of quality attributed to increased complexity of the operation. This could emanate either as

[5] In general the number of links between n nodes in a network is equal to $\frac{1}{2}n(n-1)$

increased scrap or reworks or warranty or as increased overheads to maintain the existing level of quality.

3.3.4. Risk Diseconomies

The more a firm centralizes its manufacturing, the more it is dependent upon the successful operation of that plant. Should a natural disaster (flood, fire, hurricane, earthquake, etc.) or a human calamity (labor strike, accident, management demise) or any other breakdown strike the plant, the performance of the whole company will be seriously hurt. Thus companies should prevent "too many eggs in one basket" situation by allocating the production of certain critical components or products into two or more separate locations.

3.4. Effect on Quality, Cost and Timing

No definite conclusions could be made on the effect of flexibility or centralized manufacturing on quality, cost and timing in the published literature. However, few empirical observations have been made. For instance, in a recent survey of manufacturing plants, Industry Week [15] reported that companies who focused on enhancing their flexibility and agility experienced less scrap and rework, higher first pass yield, and less late delivers compared to those who focused solely on improving their cost structure. Similarly, an empirical study by O'Leary-Kelly et al. [12] indicated that new product flexibility had a positive effect on product quality and negative effect on cost while volume flexibility helped lower unit manufacturing costs and late deliveries. These authors hypothesized that new product flexibility is most often accompanied with deployment of computer aided design (CAD) systems and implementation of simultaneous engineering techniques, both of which tend to increase quality, however, at additional costs. Further, authors argued that volume flexibility help companies avoid inventory build up (and the associated cost) while enhancing their capability to adjust their production to meet demand in timely manner.

3.5. Innovation Management

Since flexible manufacturing is an innovation, analyzing its adoption and implementation as a "strategic management of innovation" can also yield good insight to potential roadblocks firm could face. Afuah [1] suggests that firms generally face several economic and organization challenges when implementing the decision to adopt an innovation. Economic roadblocks include fear of loss of revenues, lack of incentive to invest in the innovation, fear of being stranded in a small network, and large exist costs. Organizational impediments include obsolesce of existing capabilities, political power coalitions, emotional attachment to old technology, firm's dominant logic, and fear of losing a competence builder in the old technology. As shown in Exhibit 7, firms can expect different roadblocks to be in effect depending upon the impact of innovation on firm's capabilities and products.

Afuah also suggests that firm's abilities to overcome these roadblocks and successfully implementing the decision to adopt innovation depends largely on the fit between its strategy, structure, processes and systems, and people (S^3P), as shown in Exhibit 8. For instance, a firm, whose strategy is to rapidly introduce new products, would need to have an organization that promotes creativity, where people can effectively articulate market needs and where incentive system rewards employees for new ideas. It is important to understand that fit needs to exist only within the realm where innovation will be implemented. For instance, a strategic business unit of big corporation, in order to innovate, might exhibit strategies, systems and people that fit quite well within that business unit but the same S^3P could depart from the company's norm (e.g. GM versus Saturn).

4. Cylinder Head Manufacturing

As mentioned earlier, Manufacturing and Plant Engineering management at Ford Powertrain Operations is considering a new plant strategy that will consolidate the manufacturing of cylinder heads in a centralized flexible facility. This section presents an analysis of this strategy highlighting critical areas that would need management attention. In particular it discusses major decision areas and competitive priorities associated with this manufacturing strategy, as shown in Exhibit 9.

4.1. Overview

Cylinder head is one of the most critical and frequently changed components of an internal combustion engine. Its design varies not only within a particular engine family but also across different engine families. Within each family, variations occur primarily in terms of feature locations whereas across the families variations occur in terms of overall dimensions. For instance two cylinder heads, despite belonging to same engine family (V6 six-cylinder engine), could differ in terms of cylinder size and oil hole locations. However, the overall topology of the cylinder head doesn't change much. Cylinder heads can also vary in terms of their material (cast iron, steel or aluminum). Final variation can come from tolerances that are required on the manufactured component. Tolerances generally depend upon the overall design of the engine. Differences in material and tolerance most often cause changes in the process needed to manufacture cylinder heads. However, these process variations are generally limited to just a handful of operations.

Under the current manufacturing strategy, cylinder heads are manufactured in the same plant, though in a different department and line, in which the engine is assembled. Different engine plants build one or more different engine families. These plants are located both in United States (primarily in Midwest) and in Europe. Further, cylinder head lines in each plant are composed of dedicated transfer machines. Any design change generally requires substantial time and capital investment to retool these machines.

4.2. Nature of Flexibility

As mentioned earlier, the product variety for cylinder heads is low. Thus range flexibility is not important in the current scenario. However, since majority of current and future cylinder heads will be manufactured in the new facility and since demand for different engines can vary substantially within the cycle plan, it is imperative that the centralized plant exhibit both the ability to switch production among different types of cylinder heads[6] and maintain uniform performance at different volumes and mix. This will help achieve the objectives of the new manufacturing strategy (improve capacity utilization while responding rapidly and economically to changing consumer demands).

[6]As mentioned earlier, the ability to change nimbly from making one product to another is also referred as mobility.

Although, current management knows that they need the ability to nimbly change from making one type of cylinder head to another while maintaining adequate performance, lack of coordination between product strategy and manufacturing strategy planning[7] could prove to be problematic. This is because manufacturing managers would need to establish the boundaries of product changes they could expect during the planning year. Thus, it is imperative that the current management focus on improving the integration of product strategy and manufacturing strategy planning to truly make their plants mobile.

4.3. Nature of Resource Required

Workforce

In terms of workforce, management would need to deal with a couple of major issues. First, the workforce would need adequate skills to operate and maintain the flexible equipment. In an internal pilot study involving high speed machining, lack of proper operator training was identified as a major cause of pilot failure. Second, the number of job classifications within the plant would need consolidation. This is because in the new flexible environment workers should be allowed to easily move from one job function (e.g. machine operation) to another (e.g. tool maintenance). Under the current system, machine operation and tool maintenance are two separate job functions that are performed by different individuals and can't be swapped among employees prior to union approval. Third, operators would need sufficient empowerment to make minor repairs and adjustment to machines instead of waiting for a formal machinist to come through so

Currently, powertrain product planning and manufacturing planning are part of two separate organizations.

as to keep high machine uptime. Finally, the policy of job assignment based on seniority would need modification to allow young and skilled employees to become machine operators as well. This is because there could be a likelihood that these younger employees are more adept at running new hi-tech machines compared to older employees.

It is important to realize that management doesn't have any strategy in place to deal with aforementioned issues. Further, management doesn't consider workforce to be an important tool in providing flexibility in the plant. The current view is very much focused on achieving flexibility through technology.

Technology

On the technology front, there are two major issues that management should concentrate on. First, they need to make sure that they don't excessively automate the manufacturing process. For instance, in the past, use of automated material handling systems (such as gantries) in engine plants was found to be the biggest inhibitor to modifying machines for manufacturing new cylinder head variants. Second, they should consult with the product strategy group to determine what type manufacturing capabilities they would need to handle possible future product variations.

4.4. Measuring Flexibility

Most of the current performance measurables used in Ford engine plants are either focused on cost (e.g. total cost, inventory turns etc.) or on operation efficiency (e.g. build to schedule, dock-to-dock, first time through quality, equipment efficiency etc.) and have no connection to flexibility. Thus, new measurables, such as changeover times, changeover cost, process lead-time, process range and the likes, need to be put in place to help management gauge the performance of flexibility. Unfortunately, in Ford Powertrain plants, new performance measures are received with skepticism and are considered flavor of the month. This can be, however, avoided through proactive plant involvement in setting these measurables and thorough proper workforce training and communication.

4.5. Internal Processes

As long as the new plant adheres to guidelines of Ford Production System, most internal plant processes will fall in place on their own. However, there are few that might need additional streamlining. For instance, in one of the internal Ford studies it was identified that a tool change, in addition to hardware changes, required updating 20 different documents in the system. Similarly, procedures for machine capability checking and for quality inspection might need changes due to the presence of flexible machines. Some of these procedures or processes can be easily handled with the help of information technology. The underlying issue is that although one might have best in class equipment and workforce, if the accompanying processes are still not efficient, the performance of the whole system would degrade especially relative to competition.

4.6. Management Attitude

The timing of the new strategy couldn't be better. Currently, there is universal acceptance among various managerial echelons to enhance plant flexibility. In addition, new and young management is much more open to new ideas and work practices. Also, management is convinced that they need to keep certain strategic assets on the balance sheet for long-term competitiveness.

4.7. Distribution Diseconomies

There are going to be handful of distribution diseconomies specific to this strategy. First, unit cost of cylinder heads, and hence engines, could increase due to added cost of transporting these heads from one centralized plant to network of various engine plants. For a simple of case of consolidating production of two different types of cylinder heads in a centralized plant, added transportation cost per unit was estimated to be 2% of the total per unit cost of the cylinder head. Considering that production volumes for cylinder heads could be huge (e.g. 600K - 1300K), this added cost can become substantial unless negated by cost reduction afforded by economies of scale. Second, addition of an extra link between engine and cylinder head could increase the response time to diagnose engine problems that are related to cylinder heads. This could be, however, addressed by having a liaison engineer coordinating activities between the engine plant and the cylinder head plant. Finally, there is danger of increased inventory both in the pipeline and in the plants. Pipeline inventory might increase because of added transportation delay (Little's Law Effect). The plant inventory might increase because of tendency to have safety stock in the engine plant to obviate any risk of keeping the plant idle. Although, having the entire inventory in one plant generally help reduce aggregate inventory level, it works only when majority of the inventory consists of similar parts. However, in the current scenario, cylinder heads going to different plants will be different and hence overall inventory levels won't decrease due to centralization as one might expect.

4.8. Bureaucratization Diseconomies

Bureaucratization won't be an issue because aggregate workforce and managerial levels won't change. On the contrary, centralized manufacturing will help reduce some of the bureaucracy. First, cylinder head section within central engineering will need to coordinate its activities only with one centralized plant instead of several engine plants. Second, the whole plant will be involved in activities related to cylinder head only, unlike previously.

The only bureaucratization that might manifest is the increased community involvement if plant happens to grow enormously. This can be addressed by choosing a location where plant payroll would be small compared to surrounding population or by having two smaller plants in two different locations.

4.9. Confusion Diseconomies

Since cylinder head variations are limited to a small set, confusion diseconomies won't be an issue. Also, the complexity of operating a single cylinder head plant is still far less than that of an engine plant where lot more dissimilar parts and activities need to be coordinated.

4.10. Risk Diseconomies

This is definitely an issue especially considering that cylinder head is a critical engine component and that it would be hard to have any supplier retool itself quickly to produce cylinder heads in case of any calamity. Even if the product boundaries of the centralized plant are confined to certain cylinder head types only (e.g. six-cylinder engines only) and there exists other engine plants with collocated manufacturing and assembly, it would be hard to retool these facilities quickly to produce different cylinder heads.

4.11. Innovation Management: S^3P Fit

In section 3 we noted that successful implementation of an innovation requires a fit between firm's strategy, structure, systems and people. The following discussion attempts to use this framework to spot any potential roadblocks to the proposed strategy.

Strategy

Ford Motor Company's current corporate strategy focuses on improving shareholder value and responding swiftly to consumer needs. Since one of the objectives of the proposed manufacturing strategy is to have the ability to swiftly switch from manufacturing one type of cylinder head to another depending upon the market needs, there seem to be a good fit between the proposed manufacturing strategy and company's strategic vision.

Structure

Structure of an organization determines who reports to whom and who is responsible for what in order to successfully implement innovation strategies. In selecting right structure, we need to make sure that pertinent units within the firm have optimal amount of coordination and differentiation between them. One needs coordination because of the need of cross-functional interaction between the units. Similarly, differentiation is needed to focus on individual functional areas. The current structure within Powertrain Manufacturing comprises central engineering, managed by its own chief engineer and section supervisors, and manufacturing plants managed by their respective plant mangers. Central engineering develops long-term manufacturing strategy and support plants on general manufacturing issues (e.g. poor part quality, poor tool life, upgrading technology etc.). Plants are therefore customers of central engineering. This type of structure has provided right mix of interaction and differentiation that is needed to help each group specialize in what their competencies are. However, the missing link in the structure is the lack of cross-functional relationship between powertrain product strategy and manufacturing strategy planning. As discussed earlier, the existence of this link is essential to achieve manufacturing flexibility.

Systems

According to Deming [4], proper organizational systems are needed to keep employees motivated and informed to carry out the assigned tasks and responsibilities. Fortunately, for powertrain manufacturing, some of the corporate measures (such as performance bonus plan, spirit of ford etc.) will help keep employees motivated and informed about firm's grand vision. Despite that, manufacturing management still need to emphasize and communicate to its employee force the role of new manufacturing strategy as an important enabler to firm's overall objectives. Based on the current situation where we have undergone several changes in the organization and where employees have complained about lack of management communication, this could become an issue.

People

In addition to being motivated and informed, it is also essential that people have the competencies to carry out their jobs. As mentioned earlier, current workforce has limited experience with the technology that would be used in the centralized flexible facility.

Consequently, it is imperative that management put extra emphases on providing necessary machine operating and maintenance training to it prospective workforce.

4.12. Effect on Cost, Quality, and Timing

Cost

The proposed strategy has the potential to provide cost savings from two sources. First, savings will emanate from the economies of scale and scope net of the diseconomies discussed earlier. Based on an internal cost analysis[8], these economies should come from reduced number of machines and reduced labor. Overall, scale and scope economies have the potential to provide cost reduction for machined cylinder head in the neighborhood of 10%. Second, cost advantages will emanate from learning curve effects and from ability to change product mix and volume with minimal investment of capital and time. However, these cost savings are not quantifiable and will depend upon the overall execution of the strategy and advances in engine technology.

Quality

The product quality will remain at current level as long as centralized plant follows existing quality guidelines. For instance, according to the corporate quality initiative, all manufacturing plants (Vehicle and Powertrain Operations) within the company would adhere to various Ford Production System (FPS) disciplines, improve process capabilities to 1.67 or better, get Ql to QS9000 certification, and follow company's quality process system. Over the long run one can expect quality to improve because of learning.

[8] Since cost analysis data is company confidential, it is not included in the report.

Timing

Having flexible facilities with ability to retool quickly to manufacture different cylinder variants will certainly help improve the overall timing of the engine program. Despite the fact that management in powertrain product development is taking lead in simplifying product design and reducing product complexity, cylinder head, due to its strong influence on engine characteristics, would still exhibit most variations compared to other strategic components of the engine. Thus, flexible facility for cylinder head manufacturing would certainly help in improving launch time for new engine programs.

5. Benchmarking

This section presents benchmark data [7] on engine manufacturing at Honda Anna Plant and Toyota Georgetown Plant. The purpose of the discussion is to understand how these manufacturers have been able to handle flexibility and capacity utilization in their plants.

5.1. Honda Anna Plant

Honda Anna Plant produces both car and motor cycle engines. The plant manufactures five variants of four-cylinder engines (1.6L, VTEC and non-VTEC versions of 2.0L and 2.3L) and four variants of six cylinder engines (3.0L, 2.5L, 3.2L, 3.5L) for Civic, Accord, Acura and Minivan. Anna plant does not make all of its 5Cs in-house. Components, such as camshafts, connecting rods, crankshafts and sometimes heads, are sourced from outside suppliers or Honda of Japan. Actual production of four- and six-cylinder engines at Anna in 1998 approximates 900,000 units with plant-wide capacity utilization of 96%. Following are some key observations:

- Plant has three flexible machining lines that are shared by four- and six-cylinder heads. The head variations, however, are not as drastic as seen on Ford head machining lines. Also, to maximize equipment utilization, these lines are run on three-shift schedule.
- In V6 category, Anna Plant's productivity (measured in Hours Per Engine) is best-in-class at 3.22, ahead of Ford Lima at 3.80 and Toyota Georgetown at 3.6 [7]. Productivity depends upon factors such as product design complexity, machine automation management, number of variations, outsourcing of 5Cs, and amount machining performed in-house.
- Anna is much less automated than Toyota or Ford. The automation is used primarily for simple tasks such as loading and unloading heads. Honda believes that lower automation provides higher flexibility midst high level of product complexity.
- 80% of the machines at Anna have been designed and manufactured in-house by EGA, an engineering division within Honda Motor. As Honda moves forward with new designs, the same team of product and equipment engineers are together to create flexible equipment to handle current and future designs.
- Honda has developed its entire manufacturing system, including Anna, around batch size of 60. This type of batch build provides sequencing system in the line and helps Honda to get away with simple automation. Further, by building 60 units in row again

and again, Honda is able to build quality and error proofing into the routine of the process.

5.2. Toyota Georgetown

Georgetown is one of the two engine plants Toyota has in North America. Georgetown produces 2.2L four-cylinder engines for Camry and Solara, and 3.0L V6 engine for Avalon, Camry, Sienna and Solara. The total 1998 volume for engines is about 540,000 units with capacity utilization of 99%. Following are some key observations:

- Plant has two machining lines to manufacture heads.
- The technology for machines is tried and proven in Japan before being shipped to North America. This helps them in maintaining and launching equipment efficiently.
- Similar to Honda's Anna Plant, it also exhibits low level of automation in its engine plants compared to Ford.
- Unlike Honda and Ford, it manufactures all its 5Cs in-house.
- Toyota has long term contracts with their machine tool supplier on machine architecture.
- Toyota production system, which is the model for industry, is the key enabler to its ability to get flexibility and capacity utilization from its facilities. For instance, it builds minivans and sedans on the same system unlike any other manufacturer in North America. Principles of TPS that focus on leveling work load, standardizing work, making process visible and instituting low cost error proofing devices are just

some of the factors that enable it to efficiently produce highly different products together.

- Toyota's greatest strength is its excellent planning and execution.

There are few key points that have emerged from this benchmarking. First, OEMs shouldn't rely on total machine solution to achieve plant flexibility, as indicated by low level of automation in Japanese plants. Second, OEMs need to work with their product design community and suppliers in order to create flexible equipment to handle current and future design changes. Finally, in spite of world class workforce and equipment, company's culture greatly influences firm's ability to become flexible (e.g. Toyota).

6. Conclusions

The new strategy, involving flexible and centralized manufacturing, proposed by Manufacturing and Plant Engineering Organization of Ford Powertrain Operations has been analyzed. Various decision areas, which management would need to focus on, have been identified. Exhibit 10 provides a possible migration path to successfully implement the proposed strategy. Key steps of this path are summarized as follows:

> Integrate product strategy planning and manufacturing strategy planning both through joint reporting under the current matrix organization structure and through inter department rotations. This type of arrangement will provide right mix of interaction and differentiation that is needed to help each group specialize in their competencies. At the same it will help develop cross-functional relationship between these two

departments. Such a relationship is required to help manufacturing managers establish boundaries of product and volume changes they could expect during a planning year.

> Develop strategy for workforce training. The training should not only focus on providing required machine operation and maintenance skills but also emphasize the importance of the new manufacturing strategy to workforce. Also, negotiate with unions (either at local level or at national level) to reduce number of job classifications within the plant. Additionally, educate manufacturing managers, through executive level communications, to view human resources as an important enabler to providing flexibility in the plant. The current view is very much focused on achieving flexibility through technology.

> Prevent excessive automation of manufacturing process within the plant. In particular, extensive use of material handling systems, such as gantries, should be avoided. Japanese plants have very low level of plant automation yet exhibit high level of flexibility. Also, develop long-term supplier contract for the architecture of machine tools.

> Develop new plant measures, such as changeover times, changeover cost, process lead-time, process range and the likes, to gauge the success of flexibility. These measures are essential for organizational learning and for replicating the strategy to other components or plants. Involve plants in setting up these measures to prevent them from being flavor of the month.

> Streamline in-plant processes, which might need modifications because of new ways of doing things under the proposed strategy (e.g. documenting tool change, checking machine capability). Professionals, both internal and external, who have experience in running flexible machines, should be consulted to understand which plant processes would need modification.

> Consider two manufacturing plants, instead of one, and in different locations to avoid high involvement of surrounding community and risking everything under one roof. Additionally, have liaison engineer(s) either at the centralized plant or at the engine plant to coordinate activities between two plants especially considering the extra link between cylinder head manufacturing and engine assembly that the proposed strategy would create. Also, prevent excessive pipeline inventory and safety stock buildups through just-in-time manufacturing practices.

In closing, the proposed strategy certainly has potential benefits of reducing cost and improving response time for Ford Powertrain Manufacturing. However, unless management addresses key issues that have been identified, these benefits would be hard to realize.

Exhibit 1. Major enablers for manufacturing flexibility and pros and cons of centralized manufacturing.

Manufacturing flexibility enablers

- Nature of flexibility required

  Workforce

  Technology

  Internal Processes

- Measuring flexibility

- Management Attitude

Centralized manufacturing

Pros	Cons
• Economies of scale and scope • Learning curve effect	• Distribution diseconomies • Bureaucratization diseconomies • Confusion diseconomies • Risk diseconomies

Exhibit 2. Capacity utilization of engine plants of Ford Motor Company (1999 Harbour Report) [7].

Engine Plant	**1998 Capacity Utilization**
Chihuahua, Mexico (14)	**70%**
Cleveland #1, OH (V8)	**53%**
Cleveland #2, OH (V6)	125%
Dearborn, MI (14)	**80%**
Essex, Canada (V6)	120%
Lima, OH (14)	**62%**
Lima, OH (V6)	127%
Romeo, MI (V8)	100%
Windsor, Canada (V8, VIO)	140%

Exhibit 3. Manufacturing strategy priorities and decision areas according to some selected authors [3].

Priorities

	Skinner (1978)	Wild (1980)	Buffa (1984)	Hill (1985)	Fine & Hax (1985)	Hayes et al. (1988)	Slack (1991)
Cost	X	X	X	X	X	X	
Cost dependability		X					
Productivity		X					X
Product Quality	X	X	X	X	X	X	X
Range of Products				X		X	
Innovation						X	
Delivery Speed	X*	X		X	X	X	X
Delivery dependability	X*	X	X	X	X	X	X
Flexibility	X		**X**		**X**	X	**X**

Skinner mentioned only delivery

Decision Areas

Wild (1980) - design and specification of the process and systems, location, layout, capacity and capability, design of work and jobs, scheduling of activities, quality, inventory, maintenance, replacement of facilities, and performance measurement.

Buffa (1984) - capacity / location, product / process technology, workforce and job design, operating decisions, supplier and vertical integration, and positioning of systems.

Skinner (1985) - plant and equipment, production planning and control, organization and management, labor and staffing, and product design and engineering.

Hill (1985) - choice of alternative processes, tradeoffs embodied in the process choice, role of inventories in the process configurations, function support, manufacturing systems, control and procedures, work structuring and organizational structure.

Find and Hax (1986) - capacity, facilities, vertical integration, process/technology, scope and new products policy, human resources, quality management, manufacture infrastructure, and vendors relations.

Hayes et al. (1988) - capacity, facilities, technology, vertical integration, work force, quality, production planning and control, new product development, performance measurement, and organization.

Slack (1989a) - design of the manufacturing system, management of product response, management of material flow, long term capacity, management of demand response, and manufacturing control system.

Exhibit 4. Selected results from Second Annual IndustryWeek Census of Manufactures.

Manufacturing strategies for 21st century T151

Strategy	% of all plants	% of all companies
Enhanced flexibility and agility	23.60%	30.40%
Cost reductions	27.40%	16.10%
Focus on more competencies	14.30%	14.60%
Streamlined production	13.60%	10.40%
Reengineering or restructuring	7.00%	7.9%
Integrated supply-chain management	4.90%	9.2%
Plant modernization	6.30%	5.10%
Enterprise integration	2.8%	4.40%

Quality, Cost, Timing Performance [141]

Scrap and rework costs: 47% of plants pursuing strategy of enhanced flexibility reported scrap and rework costs less than 2% of sales. Among these, 31% have scrap and rework less than .5% of sales and 29% have scrap and rework less than .5% and 1.99% of sales.

Warranty Costs: Plants following strategy of enhanced flexibility and agility represented 30% of the respondents with warranty costs less between .5% and .99% of sales and 18% of respondents with warranty costs greater than 10%.

Quality: 31% of the plants with a first pass quality of 99% to 100% are pursuing a strategy of enhanced flexibility and agility compared with 19% of plants with a first pass quality yield of 75% to 89.99%.

Timing: Plants pursuing enhanced flexibility represented just 11 % of plants respondents with on-time delivery rate of less than 70%.

Exhibit 5. Dimensions and types of manufacturing flexibility according to some selected authors [3].

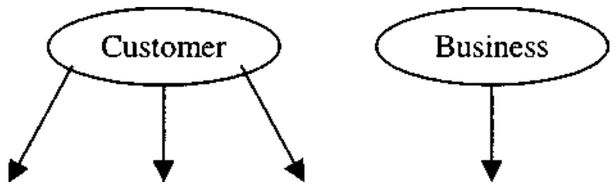
Dimensions

Mandelbaum (1978)	Slack (1983)	Gupta & Buzacott (1986)	Stecke & Raman (1986)	Carter (1986)	Gerwin (1986)	Dooner & De Silva (1990)
Action	Range	Sensitivity	Time	Time	Organizational Level	Range
State	Response	Stability				Switch-ability
		Effort				Modifiability

Types

Buzacott (1982)	Brown et al. (1984)	Gerwin (1986)	Slack (1983)	Dooner & De Silva (1990)
	Product	Mix changeover	Mix	Mix
		Modification	Product	Part
	Volume	Volume	Volume	Volume
		Sequencing	Delivery	
Machine	Routing	Re-routing		
	Machine			Machine
		Material		
	Process			
	Operations			
	Expansion			
	Production			
Job				

Exhibit 6. GE Performance Measures [9]



Key Success Factors	Quality	Dependability	Price	ROI
Internal Indicators	Defects	Schedule Realization	Cost	

New Product Line Performance Measures	Payroll $ / Units shipped per week
	Material $ / Units shipped per week
	Inventory in plant / Material $ in units shipped
	# Shipments on time
	Defects at final test/ Units shipped per week
	Field Repairs / Units shipped in the field
Old Product Line Performance Measures	Percentage of total direct labor $ applied to inventory
	Percentage of total overhead $ applied to inventory
	Inventory turnover
	Scrap rework

Exhibit 7. Roadblocks to implementing innovations [1].

Economic Sense	Incremental	Radical
Radical	• Fear of loss of revenues • Reduced incentive to invest • Fear of being stranded • Large exit costs • Political power	• Fear of loss of revenues • Reduced incentive to invest • Fear of being stranded • Large exit costs • Political power • Obsolete capability • Political power • Emotional attachments • Dominant logic • Technology drive
Incremental	Few roadblocks	• Obsolete capability • Political power • Emotional attachments • Dominant logic • Technology drive

Organizational Sense

Exhibit 8. Successful implementation of an innovation (S^3P Fit) [1].

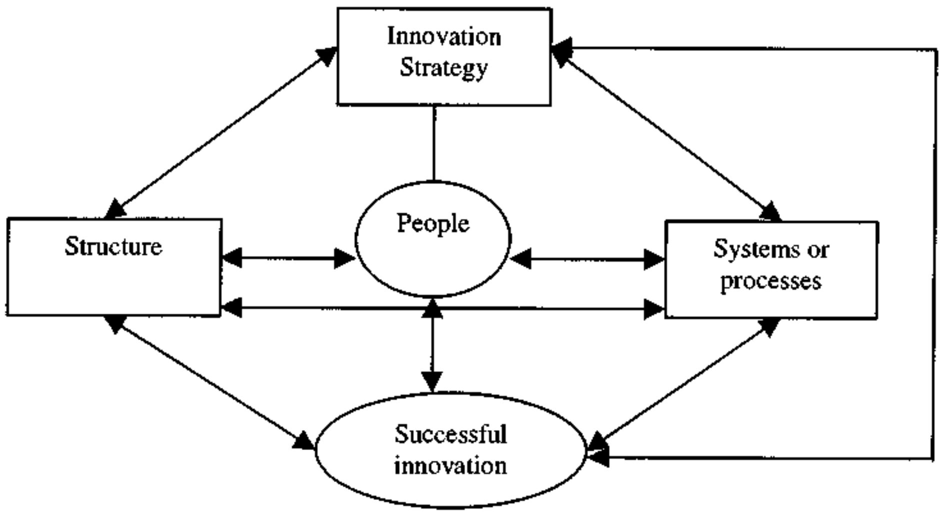


Exhibit 9. Decision areas and competitive priorities of the new manufacturing strategy.

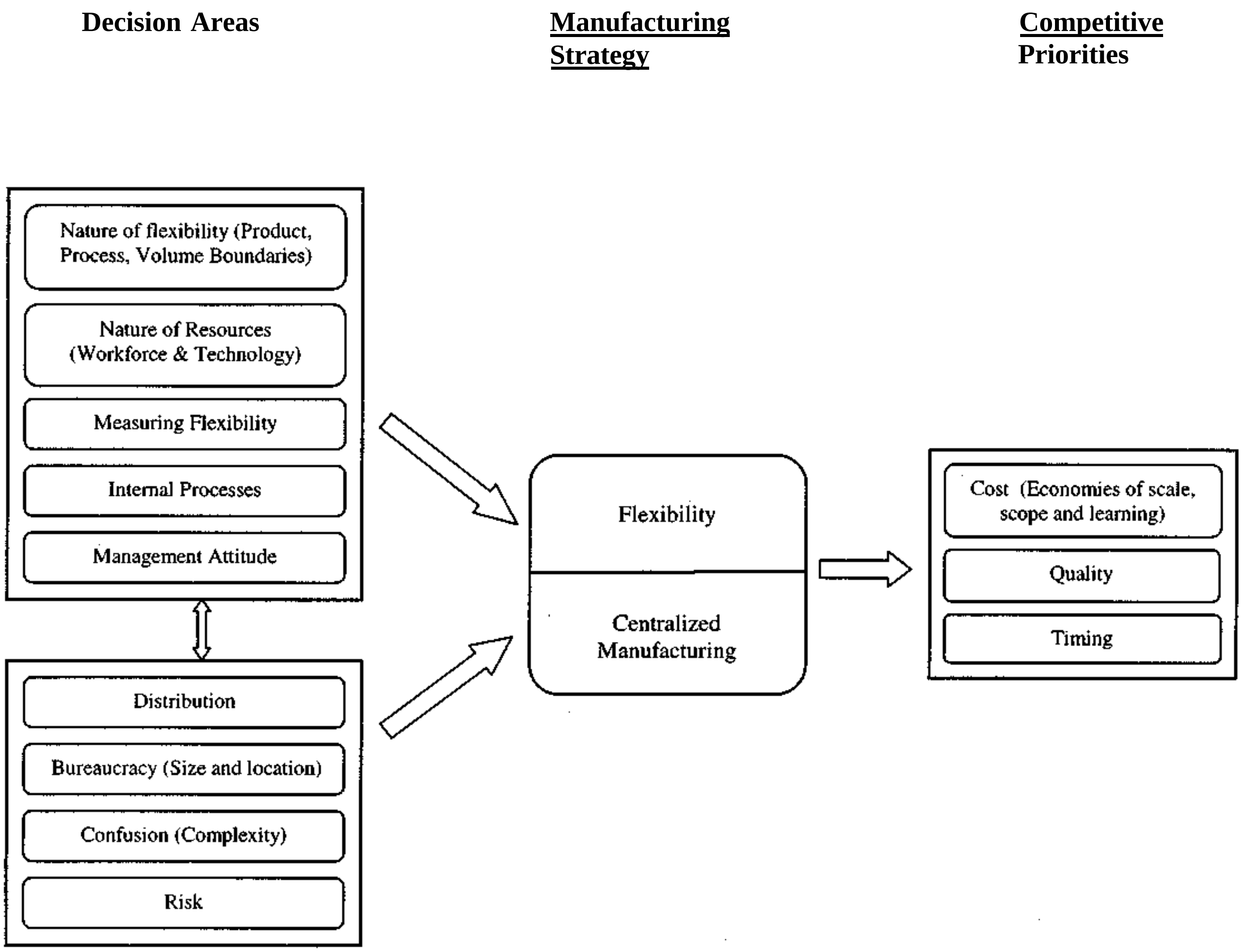
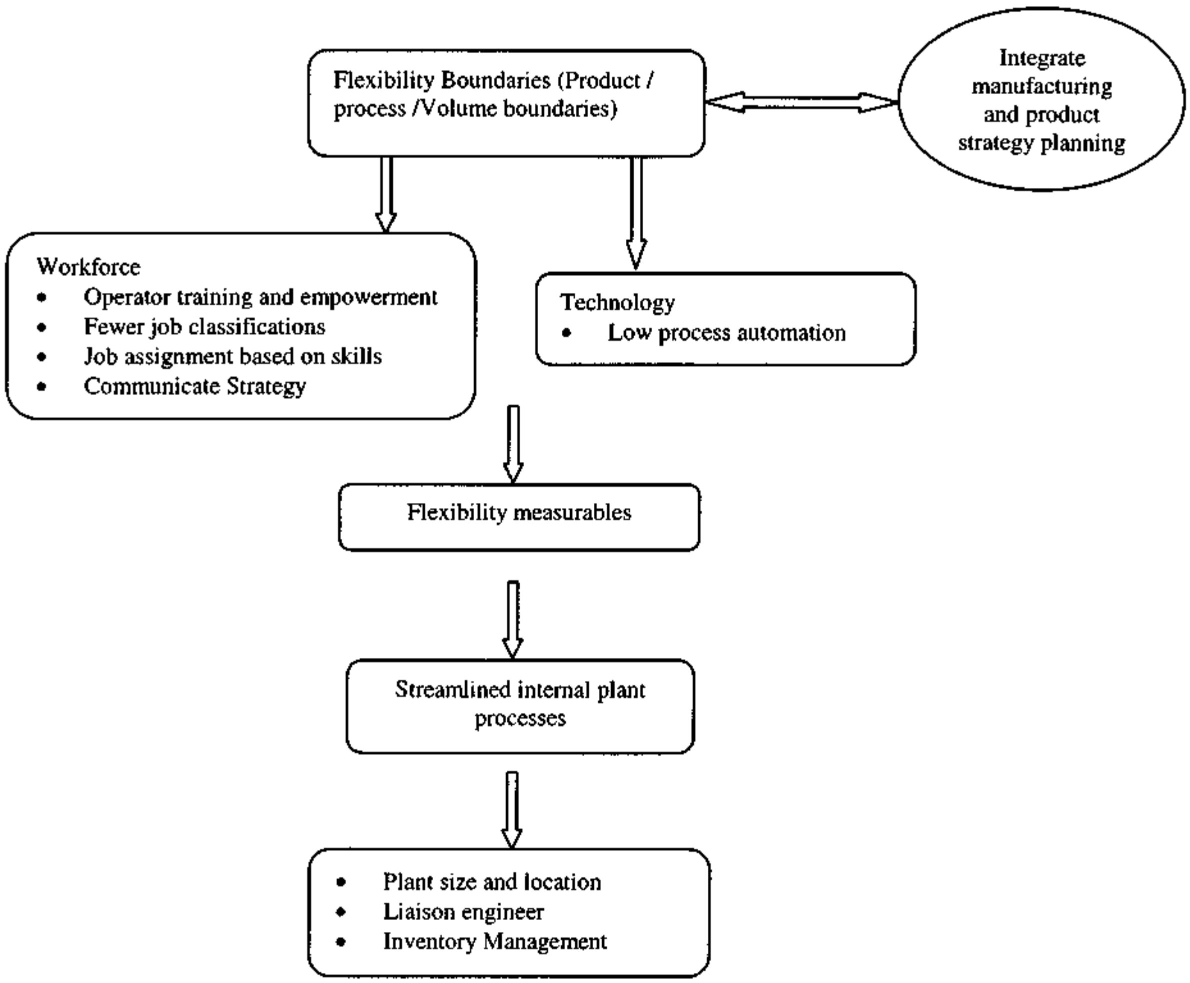


Exhibit 10. Roadmap to implement new manufacturing strategy.



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