Determining the Value of Volume and Process Flexibility in Market Driven Manufacturing Operations

by

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Submitted to the MIT Sloan School of Management and the
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Abstract

Manufacturing flexibility is wide field of research that lacks a clear and concise definition. It has been described by some to be a source of competitive advantage. Others have described manufacturing flexibility as analogous to quality as a critical measure of manufacturing capability. This thesis considers the role of manufacturing flexibility as it applies to a manufacture of luxury products. A specific definition of flexibility is applied to this firm based on its particular industrial evolutionary stage and operational objectives. Probabilistic modeling, linear optimization and iterative simulation is used to show that volume and product mix flexibility can substantially improve the ability to respond to customer demands while improving capacity utilization. Network flow modeling illustrates that significant benefits can be achieved with limited flexibility. The full benefits of this flexibility are detailed and the organizational barriers to change are explored.

Thesis Advisors:
Nelson Repenning, MIT Sloan School of Management
Chris Magee, MIT Engineering Systems Division and Mechanical Engineering Division

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Introduction

This thesis is based on research and analysis of a major US manufacturing company during a six month internship at the company. This company, hitherto referred to as the Open Road Manufacturing Company (ORMC), is a domestic manufacturer of recreational vehicles that require significant fabrication and assembly manufacturing based in multiple locations. This multi-echelon supply chain consists of fabrication and assembly facilities with raw material externally supplied and the majority of sub-component fabrication occurring within ORMC facilities. The long history of ORMC manufacturing is based on a variety of manufacturing strategies throughout the company's existence. This heritage is a defining feature of ORMC's products and the maintenance of and devotion to this heritage is a defining cultural element within the company.

History

Open Road Manufacturing began as a custom fabrication shop specializing in recreational products. Early technical innovation and design success resulted in ORMC becoming the largest manufacturer in their industry during the first half of the 20th century. Production of recreational products was halted to support the US military during both world wars and served to establish both a sound manufacturing base for the company but also provided a brand recognition and loyalty in the servicemen that used their products during the war.

The ORMC customer base proved to be highly loyal to the brand and this continues to be a distinguishing feature of the company and its customers. In the 1970's the company went through a period of intense competition, stagnant design and poor manufacturing quality which eroded their market share dramatically. The customer's loyalty was challenged but its strength may have been the reason ORMC was able to rebound. During this time the company greatly increased its internal production capabilities and expanded its manufacturing network. While this expansion enabled strong growth in infrastructure it also resulted in greatly increasing the defects within the products. This, in turn, put pressure on the existing customer base while they continued to lose market share to entrants into the market.

In the early 1980's the company faced extinction but instead mounted a dramatic turnaround with a highly leveraged buy-out, reinvigoration of innovation and implementation of improved manufacturing principles. The focus turned toward measuring and maintaining quality, reducing wasted effort and inventory, and employee involvement. This manufacturing strategy complemented the efforts to regain market share and reestablish credibility with customers by reducing defects and increasing the availability of products in the market. Building on this momentum the company began to increase the product offering and introduced new models and new variations to its existing product lines. These new models relied heavily on two significant advancements in technology. The first innovation increased the comfort of the customer while maintaining the aesthetics of the product. The second was innovation in the power train design, quality and performance. These advancements established a product portfolio that opened its product base to new customers while maintaining appeal to the existing customer base. In addition the company began aggressively marketing their products to both the existing customers and to new market segments. By the 1990's the demand for

ORMC products was greatly exceeding its ability to deliver products from the single plant ORMC was using to produce all models.

The long term goal set at this time was to increase supply in order to meet demand without compromising quality. A focused manufacturing strategy was implemented. This strategy was based on product platform or families with each family manufactured on a dedicated assembly line. Product variation within a family is a significant reduction in complexity compared to product variation between families. The construction of new manufacturing facilities and the implementation of this focused manufacturing strategy enabled production to increase by ~15% annually until 2003. Between 1983 and 2006 yearly production increased by greater than fourteen times while quality was maintained. During this time of volume growth the complexity growth kept pace, two new product platforms, 2.7 times the number of models and two additional production facilities were introduced by the company. Figure 1 show this historic volume growth and growth of product variants.

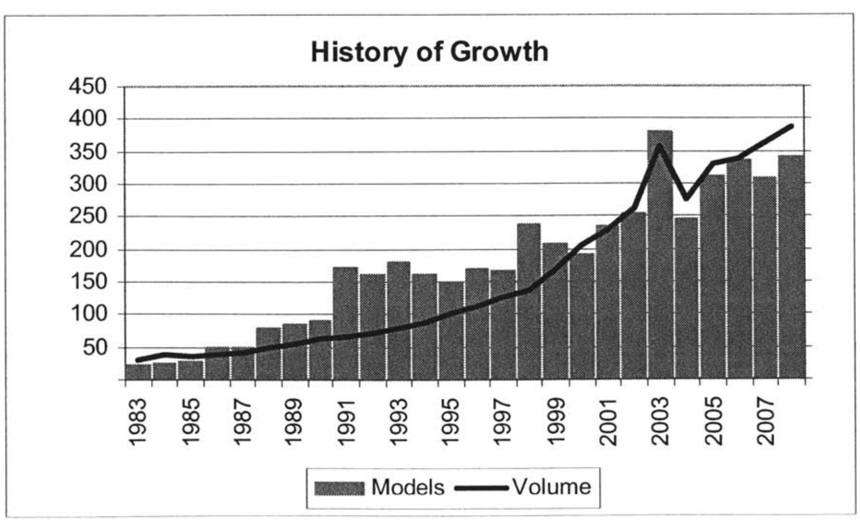


Figure 1. Historic growth in volume and complexity.

Shifting Priorities

Open Road Manufacturing Company enjoyed numerous operational advantages due to having such strong demand. Virtually every product produced was sold. In fact, customer waiting lists were actively maintained with backlogs of up to two years in some cases. Customers exhibited amazing flexibility with regard to product options and product platforms. The lack of market feedback combined with the dedication to the company's heritage combined to reinforce a mass manufacturing mentality initially instilled by the focused manufacturing strategy. Styling and engineering changes occurred slowly, new product introductions were handled conservatively, and manufacturing systems evolved slowly and steadily. Furthermore, this change occurred within each product family with minimal cross-family sharing. Figure 2 illustrates this with a system dynamics model.

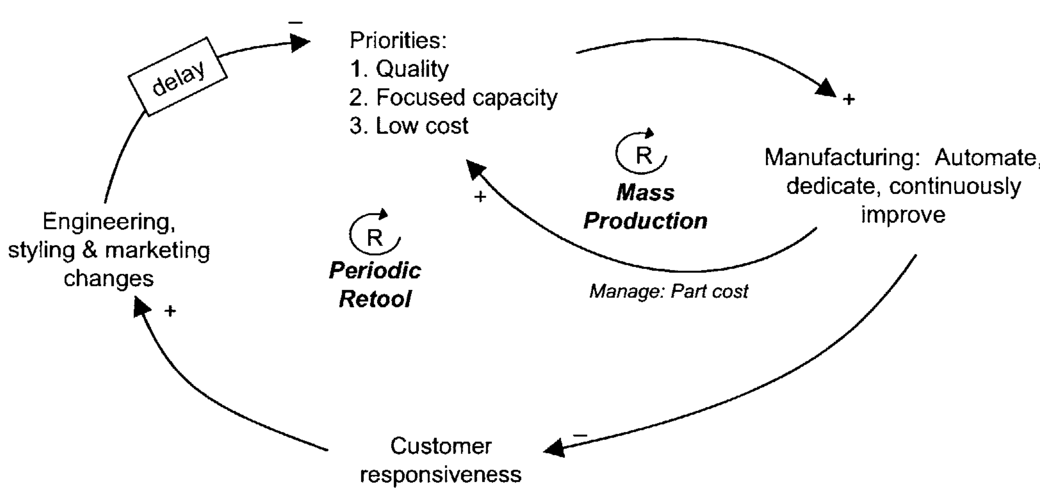


Figure 2. Mass Production Cycle.

The reinforcing loops of mass production and periodic retool were effective means of maintaining the relentless march towards meeting demand and resulted in periodic expenditure to increase capacity. Figure 3 shows a single ORMC manufacturing location's expenditure over time to sustain this strategy. The most recent expansion project exceeded $100M and took over two years to complete.

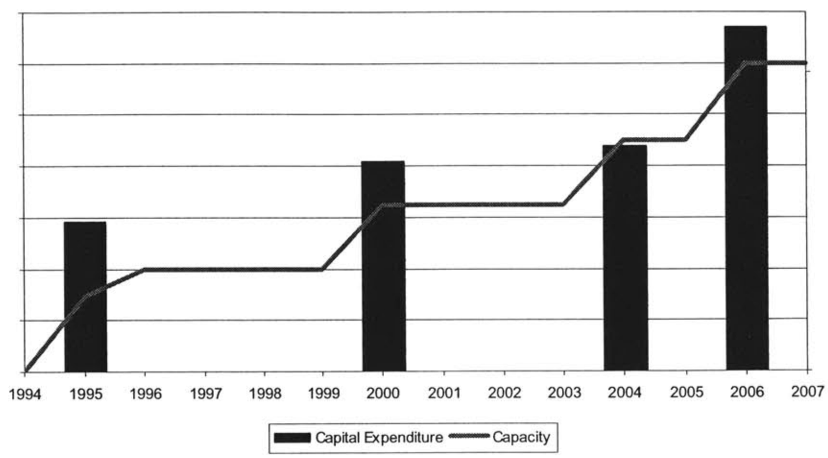


Figure 3. Capital expenditure over time to maintain capacity.

Focused manufacturing was the strategy employed to increase supply to meet demand. ORMC was highly effective in achieving this objective and in 2003 a growth in product inventory indicated that they had reached saturation and growth was no longer needed. Market feedback was now available. With short supply it appeared that whatever ORMC made was accepted by the market. Now that customers had a choice of available products their voice could now be heard.

The high cost of maintaining a growth strategy and ORMC's inability to respond quickly to fluctuations in demand are driving strategic changes. The following section will analyze the changes and provide a context for understanding why they are occurring as well as what course of action should be taken.

Motivation for Change

The business strategy of ORMC is currently in flux. The leadership structure established in the mid-1990's was based on a consensus model centered on three major areas of focus: producing products, creating demand and support. This fit with the focused manufacturing policy and provided clarity of purpose to every employee. A business unit either maintained a close relationship to the customer, produced the highest quality product or supported one of these functions. In 2006, this leadership model was redesigned to include four focus areas: produce products, design products, sales and marketing and provide support. This might be described as clarification of responsibilities. The cultural and political ramifications of this change will be considered in later sections. As part of this change the CEO challenged every business unit to become more flexible. The next section will cover four aspects of ORMC and analyze why these changes are occurring. Market dynamics, product innovation, three phases of industrial innovation and projected market demand will provide a strategic analysis that will form the basis for justifying the need for ORMC's change. Finally, flexibility will be defined as it pertains to manufacturing in ORMC.

Market Dynamics

One of the fundamental motivations for change for ORMC is the current stage of their lifecycle. One model for industry life cycles is the S Curve (Christensen 1997). Figure 4 shows the basic structure of the S curve. There are three key phases in this model: Ferment, take-off and maturity. It is proposed that ORMC's transition from ferment to take-off occurred in 1983 and that the inflection point between take-off and maturity occurred in 2003. The period from 1903 to 1983 can be classified in very general terms as a period of ferment where their dominant design was taking shape. There are a number of smaller S curves during this early time period corresponding to both the evolution of the product and the complete lifecycle of now obsolete products through this time. However, this time period can aggregately be thought of as a long fermentation period.

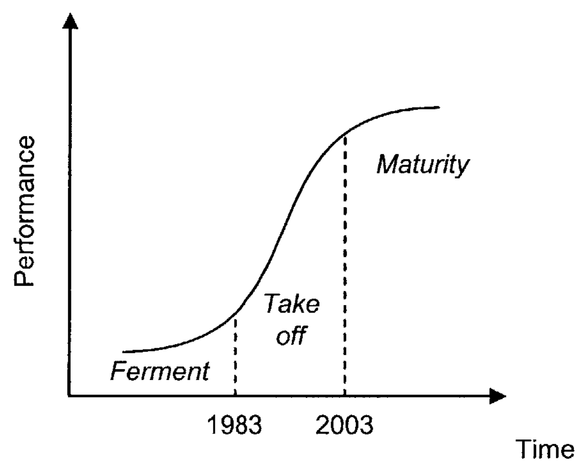


Figure 4. Structure of S Curve.

During this ferment stage ORMC established the dominant design that continues to define their product aesthetically but they had not yet tipped into the rapid growth phase experienced in the take-off phase of this life cycle model.

A number of factors came together to tip ORMC from a producer for a small stable niche of customers to an iconic product with broad appeal throughout the market. Significant but smaller events occurred, each one alone may not have been sufficient to tip (Galdwell, 2002). Indications that a tipping point had occurred are: customers were willing to wait for extended periods to time to take delivery of product, a robust resale market emerged that enabled customers to resell products for more than retail, and an industry segment emerged based on parts and accessories dedicated to the customization and personalization of ORMC products. This tipping point marks the inflection point between ORMC's fermentation stage and take-off stage. The tipping elements include:

- The symbolic recovery of ORMC from near bankruptcy as a dramatic storyline for an American manufacturer during a time when American manufacturing was losing to foreign competition.
- The styling and engineering groups within ORMC successfully updated the suspension of their vehicles through an innovative design that maintained the aesthetic elements of the product but provided significant comfort which made the product more accessible to a wider range of customers.
- ORMC redesigned the vehicle power train such that it dramatically improved quality and performance. ORMC's reputation for poor quality in the vehicles immediately proceeding this time period was legendary and the vehicle often required maintenance prior to initial sale.
- A focused and widespread marketing campaign known as "close to the customer" was initiated. This close to the customer strategy started in 1983 with an established ORMC membership club. This not only stimulated interest in their products it also gave executives, engineers and employees throughout ORMC an opportunity to meet and interact with customers. In addition, ORMC began a highly focused brand management effort that included branded clothing, general merchandise and product accessories. This branding has, at times, been extended as far as cafes and cross-branding with other companies.

Together these elements created phenomenal demand resulting in a greater than 21 fold increase in revenue from 1983 to 2006, and between 1989 and 2002 this increase was constrained by capacity. The magnitude of the impact on potential revenue growth due to lost customers is unknown.

From the S curve framework this period of rapid growth coincides with the take-off phase as shown in Figure 5. The question of whether the inflection point between the take-off and maturation phase exists within this timeframe is easier analyzed with a different set of data. The aggregate revenue of ORMC is a function of the primary product sales and the network effects of their complementary assets.

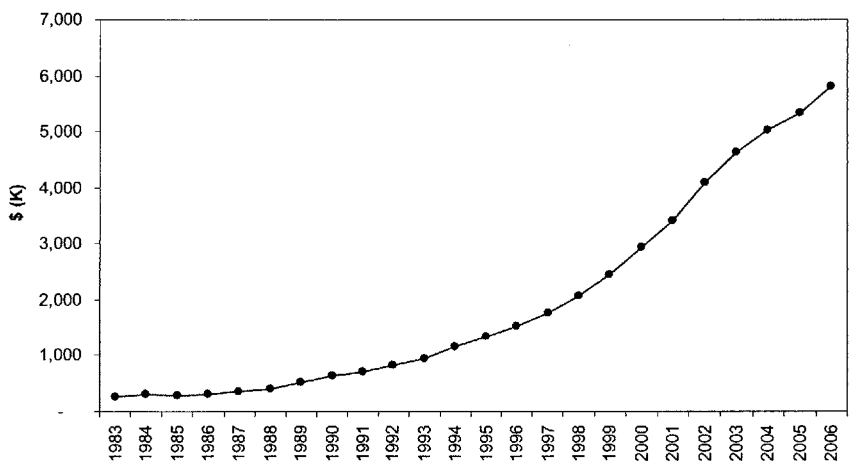


Figure 5. ORMC Gross revenue. Curve represents over a 21x increase in net income over this time period. (Source: Annual reports)

This includes the major categories of parts and accessories, domestic and international product sales and general merchandise. When product sales in these markets are isolated and the domestic and international sales are separated a clearer picture emerges. The rate of increase in domestic product sales has started decreasing as shown in Figure 6.

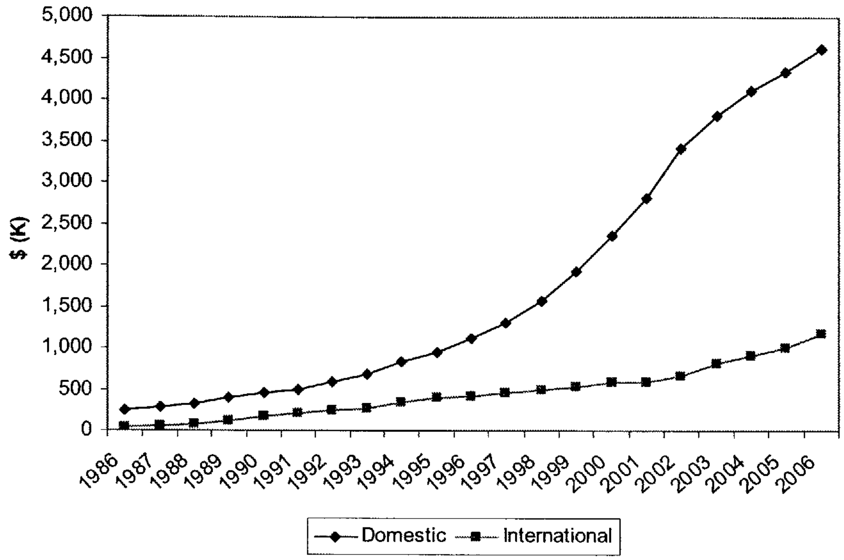


Figure 6. Revenue from product sales domestic and international. (Source: Annual reports)

The indication that the domestic market is entering a maturity phase is the dominant feature of ORMC's market because the domestic revenues have consistently represented between 70-80% of the company's yearly revenue during this time period.

On an aggregate level ORMC product performance in the market follows the behavior of the S curve model. The ferment stage of this evolution is marked with a high number of variations in the product itself with a growing base of customers and market share. The inflection point between the ferment and take-off period is marked by a tipping of the market from a slow and steady growth to a dramatic increase in market performance and dramatic increase in production and an overall growth in the market itself. The transition from take-off to maturation may be segmented by customer base or geography as ORMC begins to grow its target customer base. However, the maturation of the domestic market appears evident and as such it is strong indication that this inflection point has been reached.

This is one indication of the emerging changes in ORMC business strategy. Additional evidence points to why ORMC is transforming its strategic plan. An analysis of the product innovation and the dynamics of this innovation over time will illustrate this.

Product Innovation

Numerous innovative product improvements have been introduced by ORMC throughout the years as both incremental improvement and in response to competition. Figure 7 shows a the pace of product innovation for a single product component along a single dimension, engine horsepower. This is not the only product innovation ORMC has achieved but it exemplifies the predominate adherence to incremental innovation. In 1909 ORMC introduced an engine architecture that continues to be used in 96% of its current production. There have been significant performance improvements to this design but these are refinements and incremental innovations to this product.

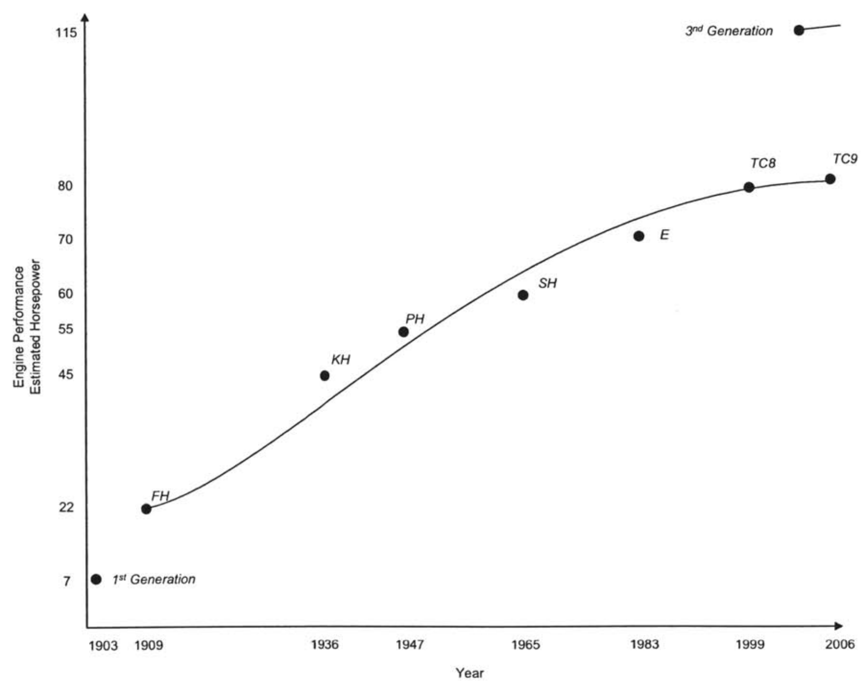


Figure 7. Innovation evolution for ORMC's major market engine design. Each point on the line represents an incremental innovation of the core architecture.

The ability to continue this incremental product evolution may be limited within the current design constraints. Material properties, engine geometry and passenger comfort from heat generation all pose limiting constraints for this technology..

Another way to view the product innovation of ORMC is to view this through the product family evolution over time. Figure 8 shows the major product families as they evolved over time. This is shown as the cumulative evolution of each family over time as determined subjectively by the author. In the previous section the time period prior to 1983 (outside the dashed region in the figure) was generalized as a single ferment phase.

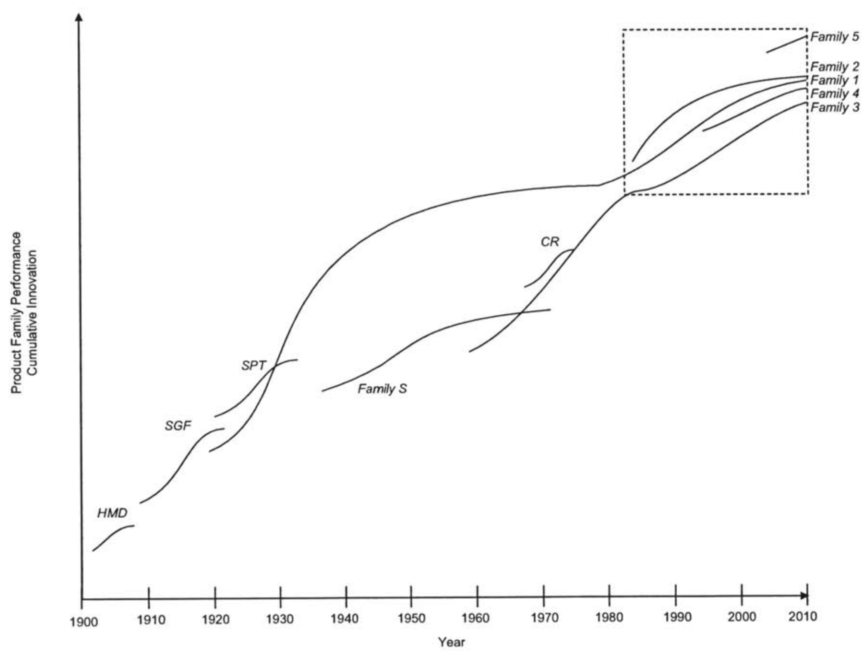


Figure 8. Product family evolution over time. The dashed region highlights the time period under analysis.

This is clearly not a single incremental evolution as presented in the S curve analysis. Rather this time period is an amalgam of numerous product variants and attempts to define and refine the dominate design. Given the emergence of a dominate design that is highly reinforced by ORMC and the discontinuity of performance between the distant and recent time periods this generalization does not detract from the previous analysis. Figure 9 shows the volume increase associated with the dashed region of Figure 8.

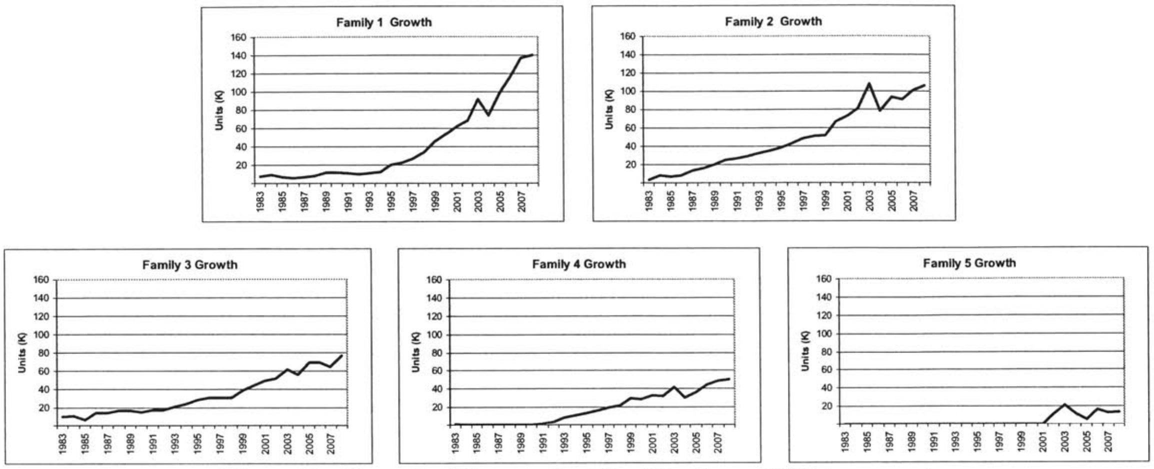


Figure 9. Growth of the product families from 1983 to present.

The convergence and leveling of the innovation occurring across four of the five product families is the second indication that ORMC has reached a new phase in their evolution. Taking another analytic perspective will reveal the third piece of evidence as to why ORMC is in the process of updating their strategic roadmap. This will explain why flexibility is the appropriate goal to define in the evolution of the manufacture of ORMC's products.

Three Phases of Industrial Innovation

Another model of the dynamic lifecycle of a firm that is closely related to the S curve is the general model introduced in (Abernathy 1978) and later refined in (Utterback 1996). This model includes both product and process innovation defined within a framework of three phases: Fluid, Transitional and Specific, as shown in Figure 10. For ORMC, the fluid phase of product innovation coincides with the ferment phase and has predominately passed. During the fermentation phase of their innovation cycle there were a wide variety of structural, power train and aesthetic variants. The dominate product design took root in the 1930s and remains a defining aspect of ORMC products and their competitors imitations.

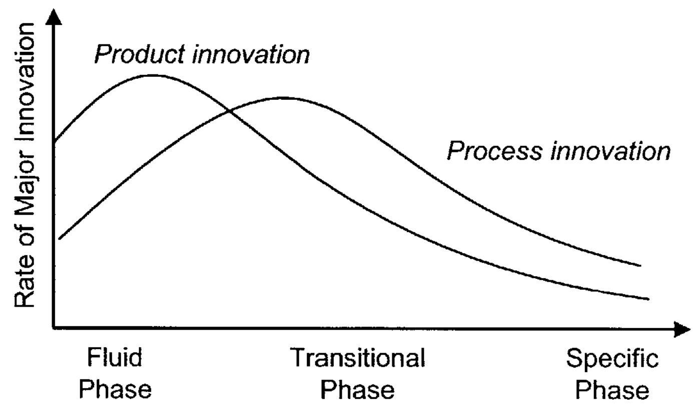


Figure 10. Dynamics of Innovation Model from Utterback and Abernathy.

Following a period of major product innovation the transitional period occurs when process innovation takes root to enable the firm to focus on efficiency and manufacturing systems. For ORMC the first wave of this cycle culminated in the specific phase occurring during the time when aggressive growth of capacity occurred, in response to intense competition from entering competitors, without a corresponding growth of process or product innovation from ORMC. This resulted in significant loss of market share to the entrants. Figure 11 shows ORMC's evolution through these phases. An interesting feature of ORMC's evolution is that they were able to revitalize their innovative efforts and resurrect the company from near extinction without a major disruptive innovation in their core product.

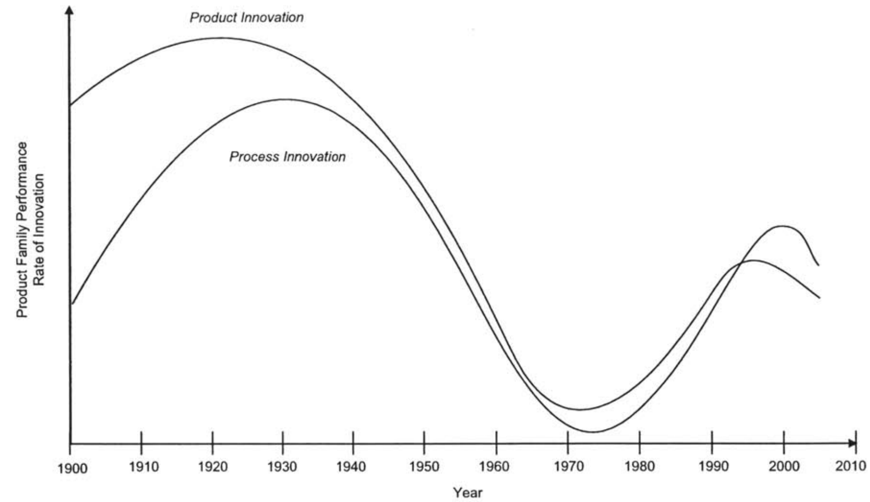


Figure 11. Illustration of the two waves of innovation cycles occurring for ORMC.

Instead, as detailed in Market Dynamics section, a number of smaller product innovations fueled this reinvigoration. Concurrent with this second wave of product innovations was a significant focus on process innovation. ORMC implemented a production system based on manufacturing principles gleaned through benchmarking of Japanese production methods. Statistical process control, employee empowerment and just-in-time operations were critical elements in enabling ORMC to integrate quality in order to create and sustain a premium product, sold at a premium price. The combination of product and process innovation marks the second wave of the innovation cycle for ORMC.

Viewing ORMC within the innovation cycle framework will demonstrate that they have entered the specific phase. Utterback classifies product, process, organization, market and competition within this general framework. For this analysis, detailing the product and process traits through these phases will suffice. Table 1 summarizes Utterback's characterization of each phase and highlights the evidence of how ORMC is demonstrating these characteristics.

Table 1. ORMC characteristics in relation to Utterback's Three Phase Model

	Fluid Phase	Transitional Phase	Specific Phase
Product Definition	*Diverse designs, often customized*	*At least one product design, stable enough to have significant production volume*	*Mostly undifferentiated, standard products*
ORMC Product	Rapid introduction of new technical features: suspension, engine, transmission	Production volumes in all products increasing ~15% per year	Despite high number of models within each product family, year-over-year differentiation for each model is low
Process Definition	*Flexible and inefficient, major changes easily accommodated*	*Becoming more rigid, with changes occurring in major steps*	*Efficient, capital intensive, and rigid; cost of change high*
ORMC Process	Changing from batching, high inventory, low quality to sequenced, JIT, SPC based production system	Focused factory (focus assembly line), changes occur through construction of new factory or line	Cost of changes becoming prohibitive

Utterback's model is useful for understanding the dynamics of ORMC's current situation. One distinction to note is that in Utterback's model the specific phase is characterized by price competition amongst competitors. In ORMC's case they learned during the specific period of their first wave that they could not effectively compete on price. Their competition effectively copied their products and offered them at a lower price. ORMC made the conscious decision to maintain a high quality, high price strategy. Material selection, retention of craftsmanship in critical components and maintaining core competency in product differentiation features contribute to the high quality. This luxury status does not invalidate the use of the three-phase model for ORMC; instead, the model must be applied to this case deliberately. Recommendations that might be given to a commodity product producer may not be applicable in ORMC's case.

Despite this, the three-phase model is a useful framework for assessing ORMC position in their evolution. One final piece of evidence that ORMC has reached their second specific phase is the stabilization of their market share. Utterback characterizes the specific phase as a stabilization of market share. Figure 12 shows ORMC's domestic market share stabilizing over this time period.

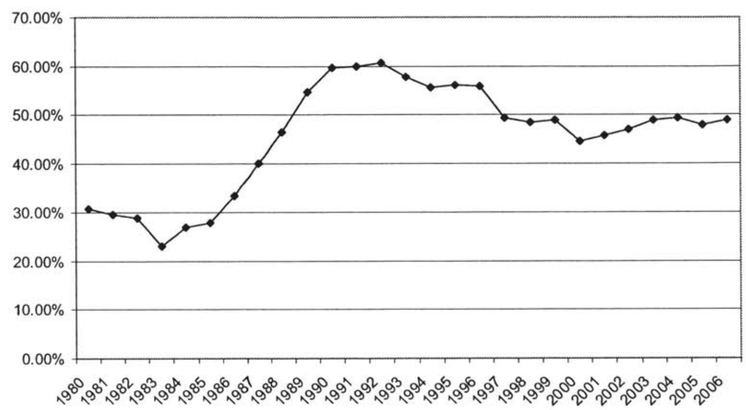


Figure 12. Domestic market share in ORMC core industry segment (Source: Annual reports)

Market dynamics, product innovation and Utterback's three phases of innovation provided multiple frameworks with which to determine what motivating factors were driving a shift in the strategic direction for the company. The slowing of incremental innovation in production process and product capabilities and the maturation and slowing growth of the domestic market indicate that ORMC has entered a state of maturity in the majority of its core products. Disruptive innovation, achieving take-off in non-traditional markets or diversification are potential options for sustaining the business results ORMC investors have come to expect. This thesis does not have recommendations for which option or by what means ORMC should plan their corporate strategy. However, it is noted that many options are currently being pursued. Instead, this thesis provides recommendations for efficiently sustaining the manufacture of the current product families without compromising the quality or inter-family differentiation the market demands. Before delving into the details of these recommendations there is one final topic that provides a high level of motivation for changing the current manufacturing strategy. This issue is more tactical in nature and is specifically related to the capacity requirements in the near future.

Future Capacity Challenges

ORMCs focused factory manufacturing strategy resulted in dedication of assembly lines to product families. This dedication allows manufacturing teams to build competency and engineering teams to maintain subcomponent differentiation. This has created rigid systems, with inefficient capital overhead, and inefficient supply chains. While each of these issues has an associated cost, the most urgent issue created is the inability to respond to product demand.

Fluctuations in demand require adaptability in production systems; however, ORMC is not currently structured to manage this. The following scenarios highlight this misalignment. If demand drops, then assembly lines are underutilized and the cost per unit rises significantly. In this case the intrinsic motivation of the assembly line managers is to maintain productive employees and highly utilized equipment. This can result in over production relative to market demand. On the other hand, if demand exceeds capacity slightly then costs increase due to overtime. In this case the assembly line managers have the incentive to reduce overtime to control their direct costs, potentially resulting in missed demand or delays in fulfilling this demand. Finally, if demand greatly exceeds capacity this will result in product shortages and potential lost sales or low customer service. The economics of mismatched supply and demand are problematic. Each of the above is made worse due to the organizational motivation that results in amplifying these issues as opposed to working towards correcting them.

Finally, focused assembly lines represent single points of failure in the system. Unexpected equipment downtime, major upgrades, new model introductions or labor shortages have ripple effects throughout the value chain for this product family. A significant event resulting in an assembly line stoppage can result in direct market impact because the value chain has been built to minimize system inventory.

From a tactical perspective, there is a sense of urgency due to the projected demand in the near future. Figure 13 shows the projected demand for the five product families together with the available capacity for each assembly line.

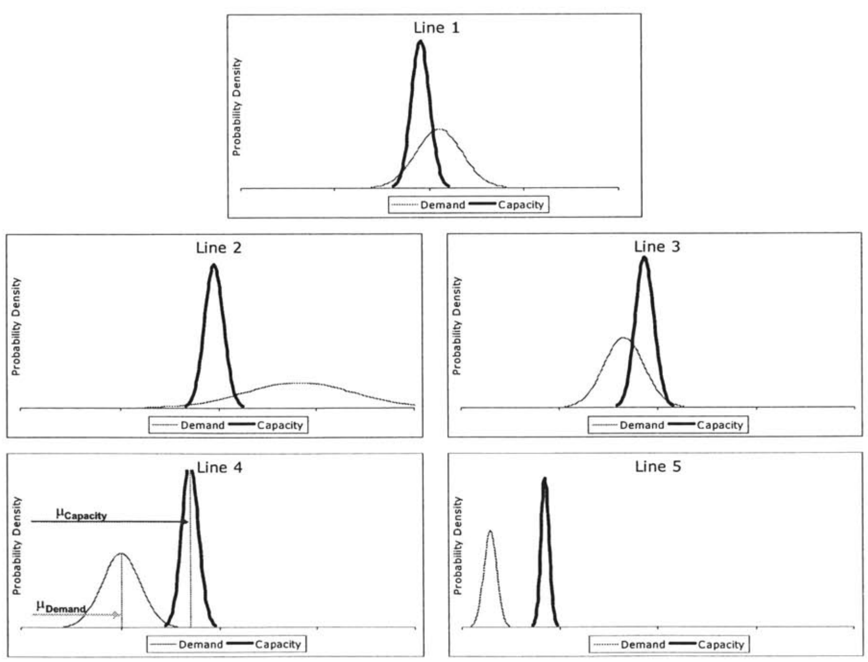


Figure 13. PDF of forecasted demand relative to projected capacity.

Projected demand and available capacity are shown as probability density functions given by Equation 1.

$$N(\mu,\sigma^2) = f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \tag{1}$$

In the case of capacity, the mean value, μ, of the capacity distribution is the average yearly unit production capacity of each line. The standard deviation, σ, of the capacity represents 5% variability for each line. In the case of demand, the mean value is the unit volume projection generated by ORMC for a particular year. This is the best guess that ORMC can make based on current and projected market conditions. The variability around this mean is the sample standard deviation of the yearly production for each product family. Actual production variability is used as a proxy for demand variability rather than an arbitrary percentage in part due to ORMC's history of limited supply. Limited supply has historically masked demand and the limited time since supply has been balanced makes historical experience unreliable. When modeling the supply and demand as normal distributions and plotting each product family on the same scale it is clear to see that the capacity of each assembly line is not matched to the projected demand[1]. This will necessarily result in higher than optimal unit cost throughout the product base. These distributions are the input into the simulation used to model the manufacturing network and will be discussed in detail in the Modeling Description section of this document. They are shown here to illustrate that there is opportunity to

[1] Note that the location of the mean for each PDF is of interest in the plots shown in figure. Then mean, μ, of capacity and demand are highlighted in family 4. This can be read as capacity exceeding demand for this product since the $\mu_{capacity} > \mu_{demand}$.

experience all of the inefficient scenarios explained above, underutilization, overtime utilization and exceeding available utilization if no action is taken.

Motivation for Change Summary

ORMC's history has been strategically analyzed to provide a compelling argument that there is a need for change. This need has been recognized at a corporate level as evident through the modification of the leadership structure, the emergence of flexibility as a priority, and the desire to be more responsive to the customer. A change in corporate strategy requires a change in manufacturing strategy (Skinner 1969). The design of the changes in manufacturing should fit with ORMC's current industry stage. They need to service and sustain a large domestic customer base in a mature market while being responsive and receptive to emerging demographic and geographic markets in hopes of tipping these market segments into a take-off phase of growth. This will require approaching the design of their flexibility strategy carefully and deliberately. One way to setup the topic of flexibility is to think about it in relation to the system dynamics model previously presented. Figure 14 shows a new approach that is focused on customer desires and flexibility in manufacturing.

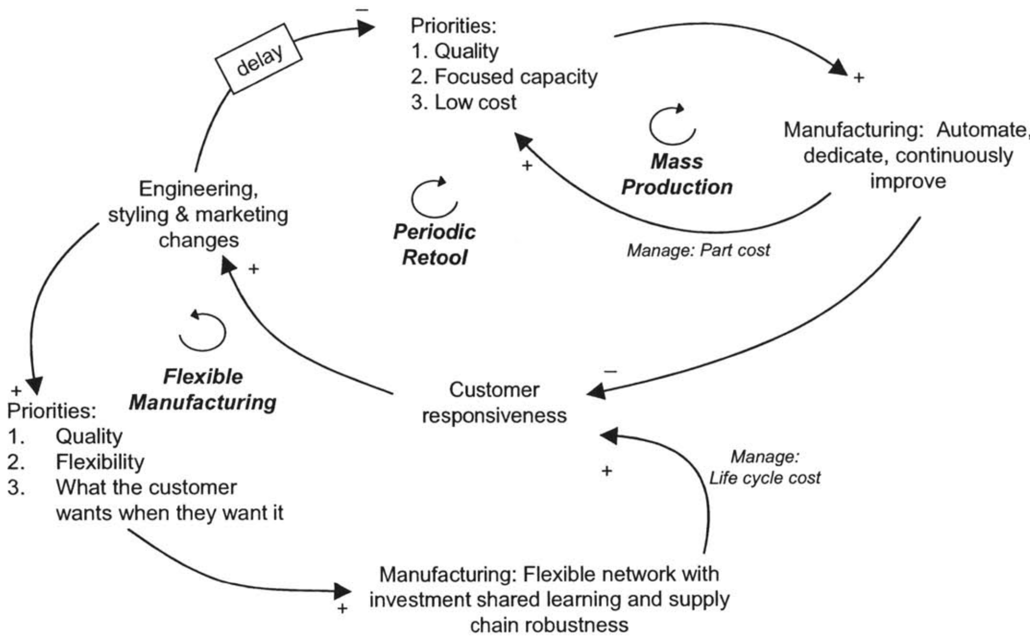


Figure 14. Innovative operational strategies necessary to incorporate customer demand

This system dynamic model shows that flexibility is not an incremental process innovation; instead there is a need for a new way of thinking about manufacturing. The old model was based on quality and output. Quality must remain the predominant priority but when flexibility and understanding of customer needs replaces output and growth as priorities, the ability to achieve customer responsiveness becomes part of a reinforcing loop that is inherent in the manufacturing design.

Manufacturing Flexibility Frameworks

Literature Review

In the literature, flexibility has emerged as a critical component of manufacturing strategy. In a statement, "Ten to fifteen years ago, quality was much like flexibility is today: vague and difficult to improve yet critical to competitiveness." (Upton 1995) While a decade has past since this statement, there remains a lack of definition associated with the term flexibility. This is due to there being a multitude of applications, systems and operations that can in themselves be flexible. These dimensions of flexibility have been explored in seminal papers (Sethi and Sethi 1990) and (Gupta and Goyal 1989) and further refined in (Koste and Malhotra 1999). Figure 15 shows a graphical framework that encompasses the totality this topic space.

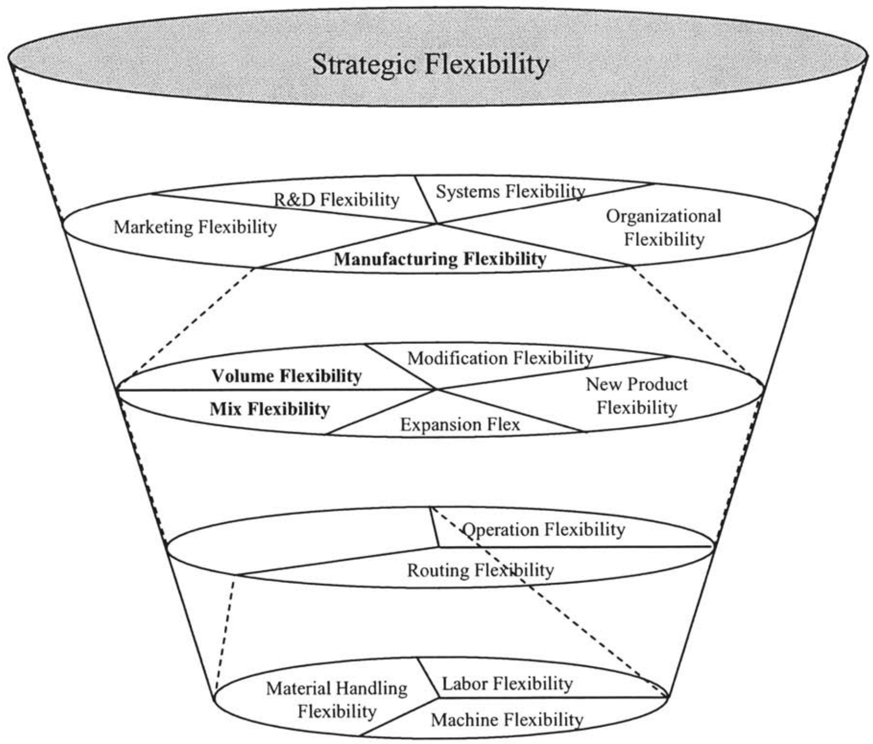


Figure 15. Breadth of flexibility within a firm's strategic objective. Adapted from Koste and Malhotra (1999).

Numerous studies have focused on providing decision frameworks. These frameworks are used to determine how a given part can be made or fabricated to support a flexible strategy (Hauser 2004). Others have provided guidance on how flexibility can enable better service levels. “Flexibility is loosely defined as the ability to alter important operations characteristics of the equipment of features of the item it is making.“ (Whitney 1995)

While still others approach this topic from the perspective of minimizing the impact of unknown events, "The flexibility of a manufacturing system indicates its capability to respond to the changing circumstances and/or to the instability caused by the environment" (Gupta and Goyal, 1989). On the other hand, Atkinson and Meager (1986) have taken the tact of addressing flexibility through labor.

A class of studies has focused on the interaction between the sub-classes of flexibility. Volume and product (mix) flexibility at the machine level is examined in detail in (Pelaez-Ibarrondo and Ruiz-Mercader, 2001). Goyal and Netessine (2006) model the interaction between volume and product (mix) flexibility to address market uncertainty. They derive a number of interesting relationships between product and volume flexibility, however, their closed form solutions present formidable barriers to practical application needed for a real-world problem. In contrast to the academic analysis performed in many of the cited works, Jordan and Graves (1995) focused on volume and product flexibility and developed a model and simulation that is readily adaptable to the complexities of a multi-platform/multi-line manufacturing problem.

The Jordan and Graves approach is used to analyze ORMC's flexibility options because it fits ORMC's objective of enabling responsiveness to customer needs. Before detailing the application of volume and mix flexibility, a brief case study of the automotive industries adoption of flexible manufacturing practices will illustrate why it is important to be clear about what flexibility means to manufacturing operations and how this fits with the corporate strategy that manufacturing is supposed to enable.

Know What Should be Flexible Instead of How to be Flexible

A recent trend in automotive manufacturing is the pursuit of flexibility. A review of popular literature reveals the following benefits of flexibility:

- Produce more and better cars– more economically (Vasilash 2004)
- Launch more products more rapidly (Vasilash 2000)
- Boost quality and efficiency (Waurzyniak 2003)
- Respond more quickly to changing market demands while increasing factory utilization (Teresko 2006)

While it is possible to achieve each of these objectives through flexible manufacturing, the specific definition and implementation must be matched to the specifics of the firm. A review of a non-ORMC domestic automotive power train manufacturing plant provides an example of the implementation of an aggressive flexibility plan that has failed to deliver the return on investment expected. According to Waurzyniak, this plant expects to realize initial cost savings of 10-15%, up to 50% cost reduction in mid-cycle changeovers, and nearly $2 billion in cost savings over the coming decade. An on site visit revealed that the plant is designed for manufacturing flexibility along nearly all dimensions. Mix, volume, modification, expansion and new product flexibility are possible through the implementation of numerous enabling capabilities: Automated material handling with standardized carrier designs, machine flexibility with automated recipe management, cross-trained labor pool, standardized layout, redundant cell capacity, and additional floor space available for expansion. The cost of this project was not revealed during the visit, however, it was discussed that since the completion of the plant redesign, the engine that is produced at Windsor has not changed. A "50% reduction in mid-cycle changeover" has little value if mid-cycle changeovers do not occur. This plant provides a valuable lesson in ensuring that the flexibility investment addresses the flexible needs of the corporation. A misalignment in the manufacturing flexibility strategy can result in costly investments with little return.

An additional consideration is that flexibility cannot be pursued in lieu of other manufacturing priorities. Chrysler's President and CEO, Tom LaSorda, launched an aggressive flexibility transformation in 2003, investing billions of dollars in flexible manufacturing systems (Terescko 2006). In contrast to the Ford Winsor example, Chrysler's flexible strategy is consistent with their operating strategy. Their intention was to be able to produce a lower volume of vehicles while maintaining scale economies in their assemble plants. This was accomplished by standardizing processes across models and ensuring that model changeover could be accomplished with robotic end effector change-outs as opposed to retooling entire automated cells. Lasorda, in his Chrysler Group Overview presentation (2004) defines flexibility as: plant-to-plant flexibility (chaining), volume flexibility, architecture/platform flexibility, model flexibility, supplier/component flexibility and business model flexibility. The recognition that the entire manufacturing ecosystem needs to comprehend flexibility was a crucial aspect of enabling Chrysler to accomplish this transformation. Each of their major US and Canada assembly plants have 3 models in production with the capability of concurrently launching a fourth. In (LaSorda 2006) Chrysler reported capacity utilization of 95% in 2005 relative to 84% in 2001. However, it appears now that the focus on flexibility may have contributed to a defocus in quality. Chrysler currently has 3 separate recalls totaling over 500,000 units from plants undergoing flexible upgrades (Krolicki 2007). The key take-away from this case study is that flexibility cannot be viewed in isolation nor can it be pursued at the expense of quality. To be clear, it is not suggested that the financial challenges Chrysler is currently facing are the result of their flexible manufacturing but rather that their excitement over this capability may have caused them to overextend their product portfolio and lose focus on other critical operating elements. In their recovery plans (LaSorda 2007) they intend to leverage their flexible manufacturing network to increase their new model introduction while reducing the number of platforms. This will allow each plant to focus on quality while maintaining their flexibility.

Knowing what needs to be flexible to enable the corporate strategy is a necessary component of achieving the corporate objectives. Maintaining flexibility as a part of the holistic operational environment will allow the organization to maintain all critical operational priorities. Finally, recognition that flexibility is not a panacea for whatever ails the firm will maintain perspective and allow the design of the flexible network to be contained within the feasible realm of possibilities. This has been the goal in the approach to ORMC's flexibility recommendations. Included in this recommendation are the critical flexibility components, ensuring that they are consistent with ORMC's operating strategy, and seeking implemental solutions that comprehend the structural, political and cultural environment of the organization.

Volume and Product Mix Flexibility

In order to sustain mature operations ORMC needs to increase the aggregate utilization of their assembly lines. This will allow them to fulfill demand of high-valued products without investing additional capital in focused assembly systems. In this mature market, repurchase may become a more dominate market feature and as such model trade-off may become a more prevalent. For these reasons, volume and product mix is the most appropriate type of flexibility needed in the assembly network at this time.

Volume and mix flexibility are shown in Figure 15 on the same level as expansion, modification and new product introduction. Focusing on volume and mix is not intended to ignore these other components, rather they are the items in focus because they are the least evident components in ORMCs capabilities today. The modification and new product introduction processes in existence today have opportunity for improvement but are functioning sufficiently to support the operational strategy. An in-depth analysis of these systems is beyond the scope of this thesis. In addition, expansion flexibility is also a component that is peripheral to this thesis. If volume and mix flexibility are effectively achieved then expansion needs will be minimized in a mature market. If demand greatly increases in emerging markets then expansion will be required outside of the existing network, in which case growing the network to be consistent with the recommendations herein will suffice. Therefore expansion flexibility is not explored in any further depth.

Flexibility Summary

Flexibility has been defined along numerous dimensions. For ORMC, manufacturing flexibility is defined as the ability to effectively respond to variable market demand. In order to achieve this flexibility it is proposed that volume and mix flexibility be pursued within ORMC's existing assembly network and by doing so increase the utilization of the current manufacturing assets. This recommendation is an attempt to define the manufacturing strategy consistent with the corporate strategy within ORMC. Therefore it is important to be clear that this flexibility is not being recommended as a reaction to or in opposition to the existing focused factory strategy. Instead it can be viewed as an updated focus in alignment with new business strategy. This thesis is also not advocating flexibility as a means to handle randomness or ability to produce every product on every line. The recommendations that are detailed in the next section should be viewed as an approach that continues to embody the focused factory approach (Skinner 1974), but also enables the realization of responsiveness to the volatile market and increasing product discrimination from the customer as needed.

Achieving this objective will enable benefits beyond revenue and capacity utilization. A strategy of flexibility allows a firm to take advantage of new technologies or new market opportunities (Sanchez 1995) and will position ORMC to take the necessary risks in pursuit of disruptive technologies that may allow them to capture new markets. Furthermore, flexibility can be ORMC's competitive advantage in a dynamic market where traditional competitive advantages are temporary (Fine 1998). The clock speed of the industry is quickening. ORMC's major component refresh cycles are contracting, as shown in Figure 16. This figure shows the time between major engine releases.

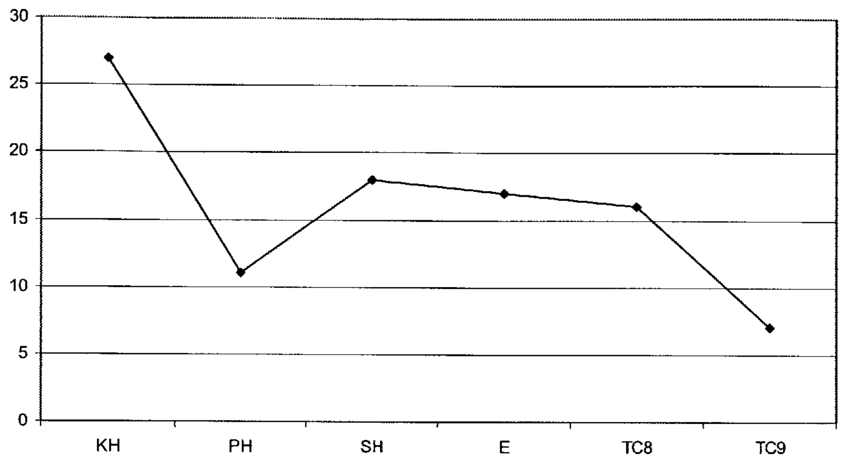


Figure 16. Increasing clock speed as shown by years between major engine refresh.

Finally, there is an implicit concern that flexibility will lead to inefficiency. At the operator level there may be lost efficiency. An assembly technician may be responsible for additional steps in their area. Line side inventory or the material handling of multi-family components may increase. Both of which may lead to increase localized inefficiency. However, the trade-off between efficiency and flexibility can be resolved by focusing on the firm wide efficiency and not merely the efficiency of the production system (Carlsson 1989). The quantification of the firm wide efficiency was not attempted but anecdotally can be viewed in relation to the assembly line capacity. The inefficiency of an assembly line operating at 30% of its designed capacity seems to out weigh the cumulative inefficiency associated with operator task complexity.

Quantifying the Benefits of Flexibility

Flexibility Benefit Overview

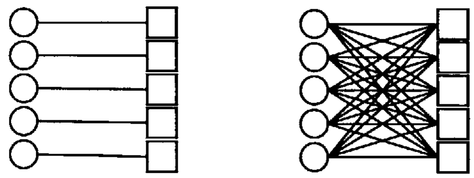
The analysis used to quantify the benefits of volume and mix flexibility resulted in a number of key benefits. Each of these benefits will be detailed in the following sections and are summarized here for clarity.

- Flexibility benefits can be achieved with low complexity. Full chain flexibility provides a structure that achieves 96% of the benefits possible in a fully flexible assembly network.
- Aggregate capital utilization can be increased from 82% to 95%.
    - This improves line loading on each line.
    - In addition, labor utilization is stabilized and can therefore be standardized.
- Increase in customer fulfillment increases revenues and avoids the cost of lost sales.
    - Even with worst case scenario conditions where operating costs increase on a per unit basis, operating margins can be maintained.

The basis for this analysis is a linear model and Monte Carlo simulation that heavily draws from Graves and Jordan (1991) and Jordan and Graves (1995).

Modeling Description

ORMC product families are dedicated to a single assembly line. This purpose of this model is to aid in the planning decision of determining which product families should be put on which assembly line. The goal of this allocation decision is to achieve the level of flexibility required to most effectively respond to changes in product demand. This can be formally describe as a collection of ordered pairs, A, where $(i, j) \in A$ such that assembly line j can produce product family i. This can be thought of as a collection of nodes connected by arcs with one node for each product family and one node per assembly line. The connection of a pair of nodes by an arc denotes the capability for the production of that family by the assembly line. Figure 17 shows a network diagram of the current ORMC manufacturing network (a) and a network diagram for total flexibility, such that all models being produced on all lines (b).



(a) (b)

Figure 17. Network diagram representation of no flexibility and total flexibility.

The evaluation of configuration A will be in terms of the amount of demand that can be fulfilled. For a given demand, the amount of production will be determined by minimizing the cost of maximally fulfilling the demand with the given configuration, A. The function $V(A)$ will be the minimized cost for the configuration A and will be solved with the following linear program:

$$V(A) = \max \sum_{i}^{m} \sum_{j}^{n} r_{ij} x_{ij} - \sum_{i}^{m} c_i s_i$$

Where:

m is the number of product families

n is the number of assembly lines

x_{ij} = unit from family i produced on line j

r_{ij} = net revenue per unit from producing family i on line j, equal to the per-unit revenue from family i minus per-unit production cost$_{ij}$

c_j = cost of lost sale$_i$

Subject to the following constraints:

$$\sum_i x_{ij} \le k_j \qquad \forall j = 1,2,\ldots,n$$

$$\sum_i x_{ij} + s_i = D_i \qquad \forall i = 1,2,\ldots,m$$

Where:

k_j is the capacity of assembly line j

s_i is the shortfall of product family i

D_i is the actual demand for product family i

Heuristically, to determine the best configuration of products to assembly lines and determine how much flexibility is needed the following procedure is utilized

1. Model family demand and final vehicle assembly capacity as normal distributions
2. Randomly sample a specific demand and capacity from the distributions for each product and assembly line
3. Determine the capability of the manufacturing network to fulfill demand with the given capacity by optimizing the network to minimize the cost of operations and the cost of lost sales
4. Compute the revenue generated and the overall utilization of the given manufacturing network

This process is then repeated multiple times in order to compute a statistical result. Figure 18 shows the one of the output variables, revenue, generated from a 1000 iteration simulation run for a given network design.

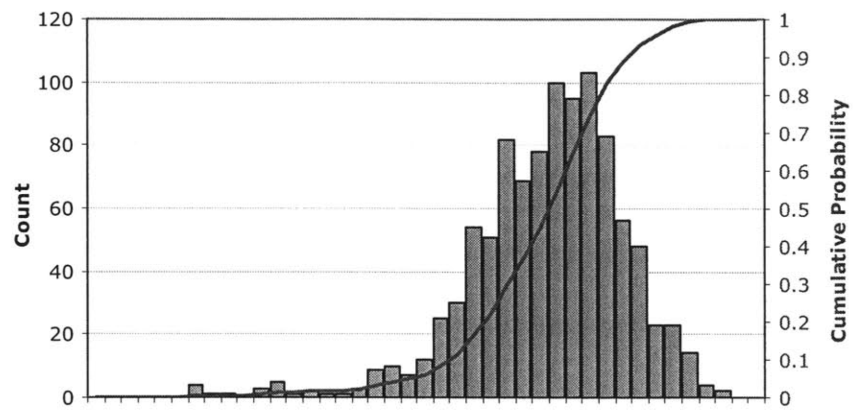


Figure 18. Histogram of revenue resulting from 1000 run simulation

Model Details

Significant time and effort were dedicated to obtaining accurate model parameters and model input to provide accurate and useful results. For this study a year within the next five years was chosen. This allowed the analysis to be based on reasonable projections while still being informative to the current operation. Input parameters include product demand forecast and assembly line capacity. Model parameters are defined by financial variables. These include revenue, operating cost and opportunity cost. Each of these parameters will now be explained.

Demand is modeled as a truncated normal distribution, $N(\mu_d, \sigma_d^2)$ where μ_d is given by the unit volume projection (UVP) for each product family for the year under analysis. The UVPs are generated by the ORMC sales and marketing analysts and are traditionally used for planning purposes and therefore represent the best available projections available. The standard deviation, σ_d, is the sampled year-over-year variability in production from model year 2004 through 2007, in addition to the variability in UVP from model year 2007 through the year under analysis for each product family. The distribution is truncated at $\pm 2\sigma_d$ to avoid the influence of extreme samples.

Capacity is modeled as a truncated normal, $N(\mu_c, \sigma_c^2)$ where μ_c is equal to the current operating capacity for each assembly line. The total capacity of the line is scaled to 85% to account for standard efficiency factors applied by ORMC's manufacturing engineers. Each line is modeled as a standard eight hour shift with two shifts per day, five days per week. This standardization represents the ideal operating state, not the current operating state where some lines are staffed for single shift operations while others consistently run over two shifts per week with overtime. The variability, σ_c, of each line has a standard 5% variation applied to it based on historic fluctuation. This distribution is bound by a single shift operation at the low end and two shifts plus 25% overtime at the high end. Random samples below or above these values are scaled to the minimum or maximum accordingly.

The financial parameters enable the calculation of the output parameters as well as define the arc weights used in the optimization algorithm. Each financial parameter is defined on a per unit basis and is constant across each simulation and each network scenario.

Revenue from sales is equal to the weighted average of models within a family. Recognized revenue is the revenue generated from sales to ORMC's dealer network at the time of shipment. Their dealer network consists of independent dealerships. ORMC does not sell products directly to consumers.

Cost management is an integral component of ORMC's manufacturing structure. For each product family an operating cost is accounted for and updated quarterly. Operating cost consists of two main categories as follows:

- Material cost is the cost of all the purchased parts but does not include parts fabricated by ORMC. In addition, this includes plant scrap, supplier support, raw material surcharges, prototype costs, funds generated from selling scrap, etc.
- Conversion is each plant's budget and all that this entails. This includes fabrication of parts, transportation costs, in addition to four larger categories of expense roughly split by the shown percentage:
  - Spending such as part fabrication, labor, travel, training, office supplies, phones, etc. (60%)
  - Fringe (24%)
  - Depreciation (15%)
  - Taxes (1%)

Focused manufacturing ensures that the account for each product family is maintained separately, therefore, the structure of this information is well formed for this analysis. This cost is used as the production cost for assembling a product family on its primary assembly line. Secondary assembly is defined as the line that has not historically been capable of producing a given product but that has been assigned a new product family in a given flexible network configuration. The cost of secondary unit production was estimated for modeling purposes as a 5% increase if the assembly line is located at the same plant and a 10% increase over primary production if it is located at another site. This was determined by thorough analysis of the necessary assembly line modification, supply chain modifications and labor modifications required to produce a single model on a secondary line. This analysis was performed by manufacturing engineers at ORMC's Site 1 assembly plant that produces Family 3-5 and verified by a manufacturing engineer at Site 2. 10% is a conservative estimate that incorporates a safety factor for unknown elements that may have been overlooked during this cost analysis.

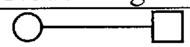
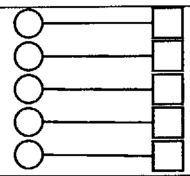
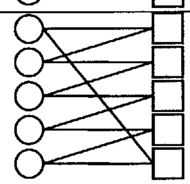
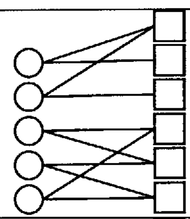
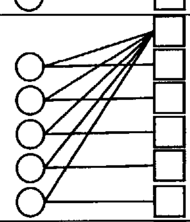
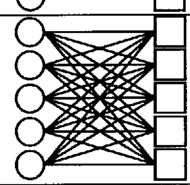
The last cost component is the opportunity loss or cost of lost sale. For the purposes of this study shortages equate to lost sales. This is a simplification of the complexities associated with demand management. However, it is used to provide a basis for comparison between the modeled scenarios. Three possible results can occur from unfulfilled demand. 1) A demand goes unfulfilled (a true lost sale), 2) a demand fulfilled with the wrong product (resulting in the customer being less than 100% satisfied due to content), or 3) a demand fulfilled with the right product but at a time and cost penalty due to inventory transfer (a customer less than 100% satisfied due to time delay and cost of carrying excessive inventory). The amount by which demand exceeds supply and the exact amount of marginal customer satisfaction is not known exactly but has historically been high. Recall that customer waiting lists were excessively long in the 1990's. Waiting lists and customer product elasticity are no longer being observed in the market place. Demand for particular models and features are being observed and the dealer network confirms that customers are less flexible than they have been in the past. This is an interesting dynamic. ORMC is facing competition from external entrants in the market as well as from its own products in some sense. This may be a driving force behind ORMC's shifting priority to provide the customer what they want, when they want it. Therefore, valuing production shortages represents a gross approximation of these market dynamics in financial terms that can be compared across each modeling scenario. Specifically, the cost of a lost sale is valued at the selling price (recognized revenue) plus 15% to represent the revenue generation from complementary ORMC parts, accessories and merchandise. This is based on historical estimates of the lifetime investment per product above and beyond the purchase price.

From these inputs and parameters the linear program can be solved to determine the minimal cost configuration that maximizes the operating profit. The total cost weighted arc values result in the fulfillment of the highest margin product families over lower margin families, which is the desired planning objective. The result is a specific amount of products produced in each family from each assembly line. From this the following output are computed:

- Sales (units): Number product sold or manufactured
- Shortfall (units): Number of missed sales or production target
- Utilization: Total capacity utilization of entire network
- Total Cost ($): Sum of operating cost per unit plus the amount of lost revenue due to shortfalls
- Net Revenue ($): Amount of revenue generated from Sales net Total Cost
- Shortfall With Total Flex (units): A reference point generated by the same input but assuming a total flexibly network in which each line can produce all of the product families.

For the determination of how much flexibility is required each simulation was iterated 10,000 times for each scenario. Scenarios were generated based on the creation of beneficial combinations as well as influenced by the structural, cultural and political aspects of the ORMC manufacturing environment. These factors will be discussed in detail in the barriers to change section. To summarize, Table 2 shows the beneficial scenarios created and defines the node network diagrams used to illustrate each scenario.

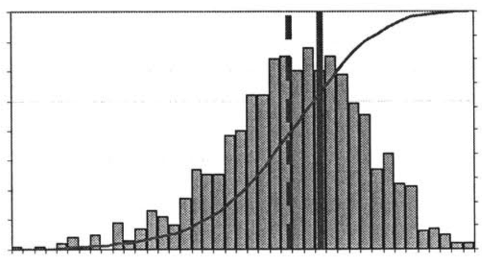
Table 2. Summarized flexible network designs used in this analysis

Node Diagram	Description
	**Key:** Circle represents a product family Square represents an assembly line Connecting arc indicates a product family can be produced on the assembly line
	**Status Quo** Current focused manufacturing operations Capacity limited in future time period under analysis
	**Full Chain** Capability on each assembly line for 2 families (product mix constant), models distributed so that a closed loop is created Achieves 96% of Total Flexibility benefits, consistent with the optimal solution derived by Jordan and Graves (1995)
	**Hybrid** Avoid inter-plant platform mixing with Dedicated Flexibility at Site 1 and full chain at Site 2
	**Dedicated Flexibility** Additional assembly line with ability to assemble all product families
	**Total Flexibility** Ability to produce all models on all lines Used for benchmarking purposes, not a recommended scenario

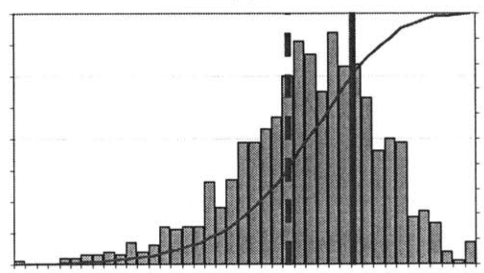
These scenarios provide a range of possible options sufficient to compare against each other. Prior to reviewing the result of these simulations a review of the validation of the model will be given.

Model Validation

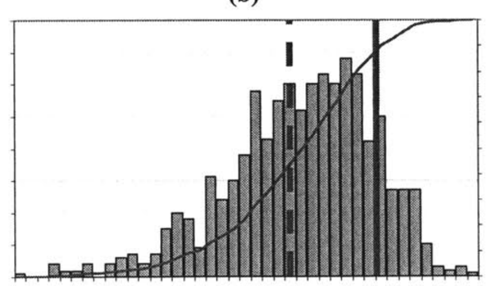
To validate this model the input distributions and model parameters were updated to 2006 actual shipments, capacities and costs. Figure 19 show the distribution of unit sales, production cost and operating profit of the simulation output relative to ORMC's actual 2006 performance. By comparing the actual outputs to the expected value from the simulation, we obtain a percent error of 2.87%, 3.61% and 6.49% respectively.



(a)



(b)



(c)

Figure 19. Results of simulation validation. Dashed line represents the output distribution mean, solid line represents ORMC 2006 actual for (a) unit sales (b) production cost (c) operating profit.

This shows that the simulation results are accurate while remaining conservative estimates.

Modeling Results

The results of the simulation show that a limited amount of flexibility can achieve the desired result of being more responsive to market demands through volume and product mix flexibility. Customer fulfillment can be increased while the utilization of manufacturing assets is stabilized and increased. Figure 20 shows the results of simulating each scenario.

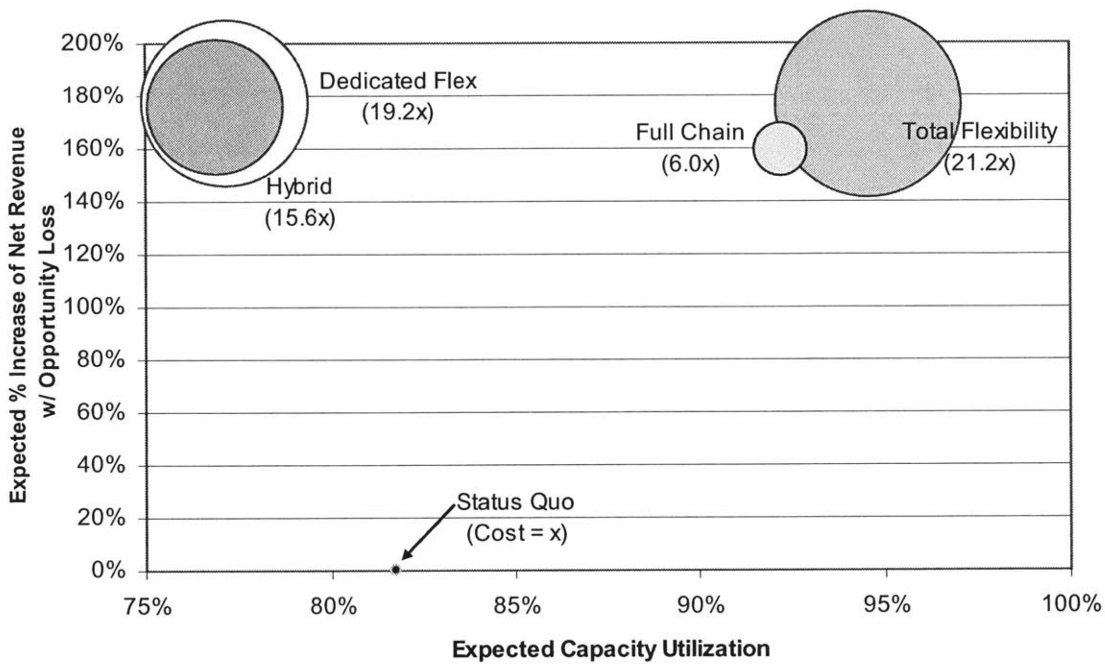


Figure 20. Revenue versus utilization for each scenario. Diameter of the circle is proportional to implementation cost.

Utilization is shown as a percentage of the aggregate utilization of all assembly lines. For the time period being analyzed, maintaining the status quo (doing nothing) will result in a utilization of 82% even though shortages are excessive, as shown in Figure 21. This is due to the inflexibility of the current network. Response to fluctuations in demand is not possible.

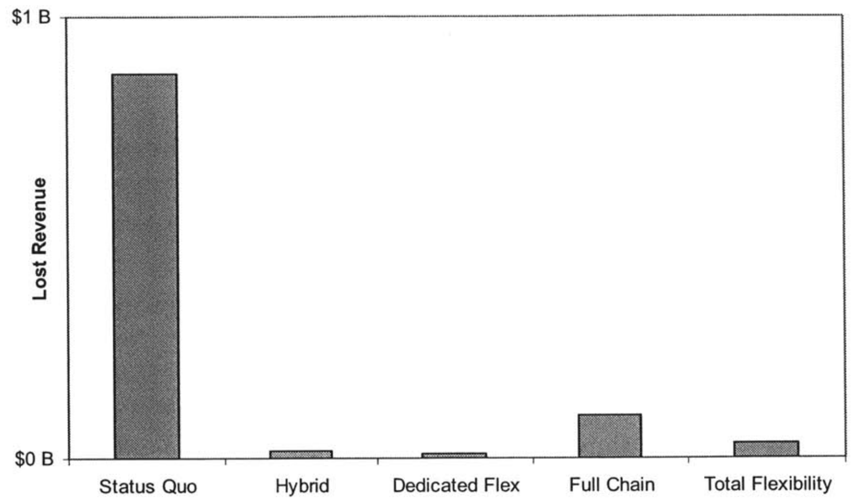


Figure 21. Lost revenue due to unfulfilled demand for each scenario

Revenue, in Figure 20, is expressed as a percentage increase relative to the status quo. For example, total flexibility would enable revenues of 1.76 times the status quo based on the increase in sales and the ability to prioritize the highest demand and highest margin products to the market. Figure 22 shows the unfulfilled products by family and by scenario. Family 2 is the family with the highest projected demand as well as the highest average selling price and unit profit margin. Therefore, the cost of doing nothing amplifies the impact of being inflexible.

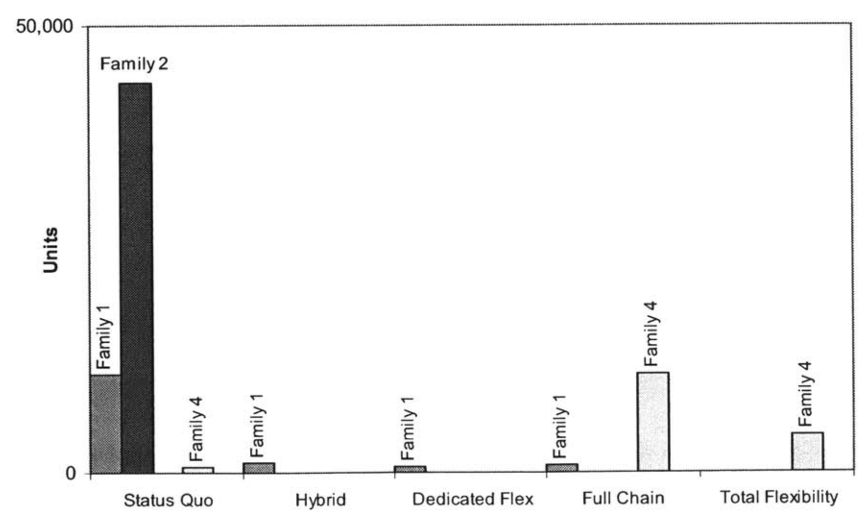


Figure 22. Unit shortages of each product family in each simulation scenario

Unfulfilled demand of the top tiered product has the dual impact of loss of a high margin product and reduced customer service to the top sector of the customer base. Figure 22 shows that trade-offs for these high value product shortages with lower margin/lower demand products (family 4) occur in the chained and total flexibility scenarios and thus minimize the impact of shortfall.

These results show a level of robustness that allows for a clear recommendation to be made as to which option is best to pursue. As shown previously in Figure 20, there is a clear distinction between flexible scenarios and inflexible options. All options result in greater than 1.5 times increase in revenue over doing nothing, representing billions of dollars of revenue. There is also a clear differentiation between the hybrid/dedicated flexibility scenarios and full chain flexibility scenario. The hybrid and dedicated scenarios both require significant investment in an additional assembly line. Whereas the full chain scenario is the utilization of existing capacity. The cost of implementing these scenarios is based on the same analysis that was used to derive the increase in operating cost. This invested capital is not included in the optimization algorithm. This is represented in the graph as the parenthetical multiplicative factor for each scenario. For example, full chain flexibility will cost 6 times as much as the status quo in implement, whereas total flexibility would cost 21 times as much. The cost associated with the status quo is simply the cost of balancing labor to the standardized shift schedule previously described. The diameter of each datum is proportional to this cost relative to the status quo point. Finally, full chain relative to total flexibility shows that chaining is the best approach to implementing limited flexibility for ORMC. Nearly all of the benefits of total flexibility are achieved at significantly lower cost and complexity. For these reasons it is recommended that full chain flexibility be pursued by ORMC.

Full Chain Flexibility Details

Full chain flexibility as presented by Graves and Jordan (1991) shows that limited flexibility can achieve major benefits in the ability to respond to market uncertainties. There are additional motivations for pursuing full chain flexibility for ORMC. Likewise, there are caveats that must be stated to avoid potential long term impacts.

Profit Margin

Profit margin per unit is a critical management indicator. When the aggregate margin per family is computed and compared across the simulation scenarios it can be seen that the fully chained flexibility model provides the best opportunity to maintain margins in the face of potentially increased production cost. Figure 23 shows the per unit percent change in cost and margin of simulation results relative to the projected cost model. In addition to the 5%/10% production cost increase these same simulations were run with a 2%/5% cost increase. Recall that the cost of secondary unit production was estimated a 5% increase if the assembly line is located at the same plant and a 10% increase over primary production if it is located at another site. There are two reasons for evaluating a reduced production cost, first the ORMC cost managers felt that the 5%/10% burden rate was excessive and second the 2%/5% comparison allowed for the simulation of a potential learning curve effect in secondary production. Figure 23 shows that for both conditions full chain has the least impact on average per unit margin even with the higher cost associated with increased cross-site secondary assembly. Further there is the possibility of actually improving margins as the learning curve is traversed.

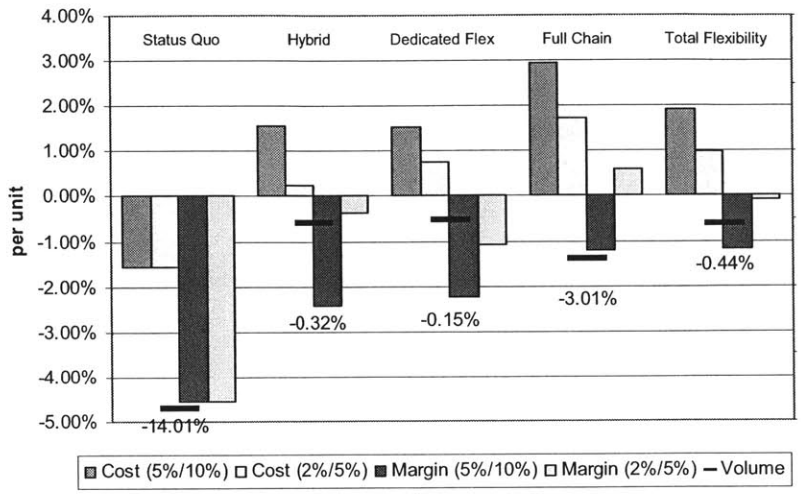


Figure 23. Impact of production cost on per unit profit margins. Volume is relative to demand.

Phased Implementation

Implementation of the full chain network can be accomplished in a phased approach. This is a desirable condition from a cost and impact perspective. Implementation occurring by building links one at a time allows learning to be gained though the process. This also allows the cost of the implementation to be spread out over time. However, caution must be taken to avoid the temptation to judge the success of this flexibility prior to the completion of the last link in the chain. Figure 24 shows that the full benefit of this network is not realized until the closed loop link enables the network to trade-off production capacity across each assembly line. Intuitively, a phased implementation is a risk adverse approach to implementing this type of flexibility. However, if judgment is not reserved until the final link is enabled then the benefits of this investment may never be gained due to losing organizational support for this effort.

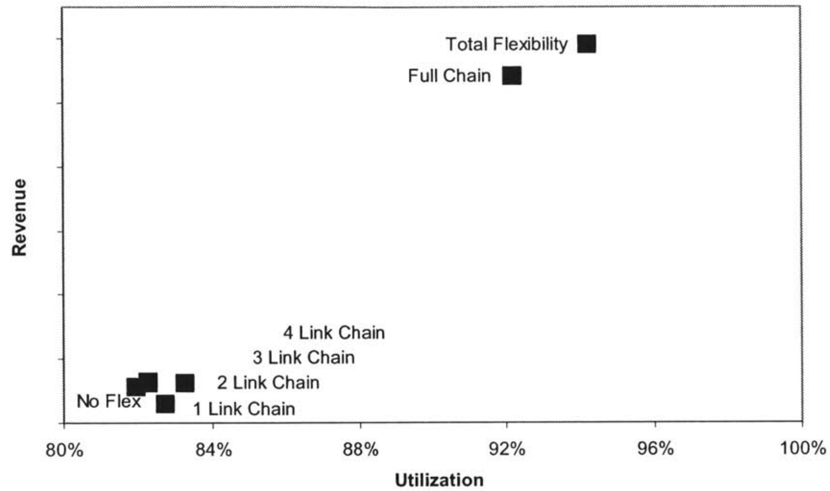


Figure 24. Delayed benefits of implementing phased flexibility.

Sensitivity

The full chain model, relative to the hybrid scenario, is less sensitive to radical fluctuations in demand. The full chain model is beneficial for all demand scenarios up to the full capacity of the network. In fact, beyond the capacity of the network a full chained model allows for the continued optimal allocation decisions to occur enabling the trade-off of high value with low value models. In contrast, the hybrid scenario is more sensitive to product family demand fluctuations. For example if the combined demand for Family 1 and Family 2 drops then utilization of Site 1 will decrease. The full benefit of the full chain design relies on the ability to utilize all assembly capacity with limited flexibility.

Robustness

The full chain model, in relation to the dedicated flexibility scenario, is more robust in daily operations. The full chain model consists of a stable combination of product families on a given line. For example, Assembly Line 2 will always have Family 1 and Family 2 as its production portfolio. This will enable proficiency to be obtained by the technicians on this line. Assembly Line 2 will see shifts in the relative quantities of one family over another but over time this will become no more visible to the line operator than model sequencing is today. In contrast, the dedicated flexibility model is a network dominated by primary line production. The hyper-flexibility required of the new line will require developing and maintaining the capability of producing all product families. It is unknown how feasible this is but if it is taken as possible then there will remain a high degree of variability in this line's daily operations. The quantity of Family 1 and 2 production will be high with the given demand profile. This will make Family 3-5 production a lower priority on the flexible line. Quality concerns on low running products will increase significantly.

Knowledge Transfer

Full chain flexibility will also allow for knowledge sharing between the platform organizations. Using Line 2 as an example again, Family 1 and Family 2 will be the new mix of sequenced products. This daily operation will give rise to continuous improvement opportunities that will be the means by which platform knowledge is shared back and forth. Furthermore, knowledge transfer will also become fully chained allowing for the proliferation of ideas throughout all platforms. In contrast, knowledge transfer will be isolated by site in the hybrid model or limited by the ability for the dedicated flexibility organization's ability to absorb knowledge and subsequently distribute it back through the platform organizations.

Simulation Model Summary

The modeling of demand and capacity as normal distributions allows for the random sampling of feasible combinations for use in evaluating a number of flexibility scenarios. This evaluation is based on the optimization of a linear program based on a node network model with weighted connecting arcs representing the unit production costs of producing a given product family on a given assembly line. Minimization of the cost of maximally fulfilling market demand for all families results in a set of value measures that are compared to scenario extremes of no flexibility and total flexibility.

The optimal results derived by Graves and Jordan (1991) are supported by results obtained here. The full chain flexibility model is recommended as the best method for ORMC to deal with their current capacity constrained forecast, as well as, a network design that will enable them to adequately respond to changes in product demand beyond the $\pm 2\sigma$ constraints applied in this model.

The benefits of this recommendation extend beyond the ability to satisfy demand and effective capacity utilization. Variability in labor management will be reduced due to the ability to operate each assembly line with a standard two shift schedule. Knowledge transfer across platform organizations will be possible. Furthermore, this knowledge transfer will be reinforced through the network design and will ultimately allow best known methods to propagate to all platforms without modification to the platforms which could jeopardize platform uniqueness.

Finally, it is recommended that an accelerated implementation phasing approach be utilized. Phased implementation will enable project learning to occur and be utilized in subsequent modification efforts. However, the duration of the roll-out of this initiative should be minimized due to the fact that the full flexibility benefits are not obtained until the final link of the chain is put in place. If a phased approach is to be utilized then a clear and deliberate expectation should be set regarding the performance of the network.

Barriers to Change

Implementation of these recommendations was not possible in the timeframe of this internship. However, considerable stakeholder management was conducted as a means of preparing ORMC for a potential change of this magnitude. In addition, preparation for this analysis included significant informal interviewing conducted as a method for determining the critical aspects of flexibility from the wider ORMC employee base. This outsider on the inside perspective (Klein 2004), enables this information to be summarized in an organizational process analysis. Figure 25 is a stakeholder map of the ORMC employees that were pertinent to this study during the internship.

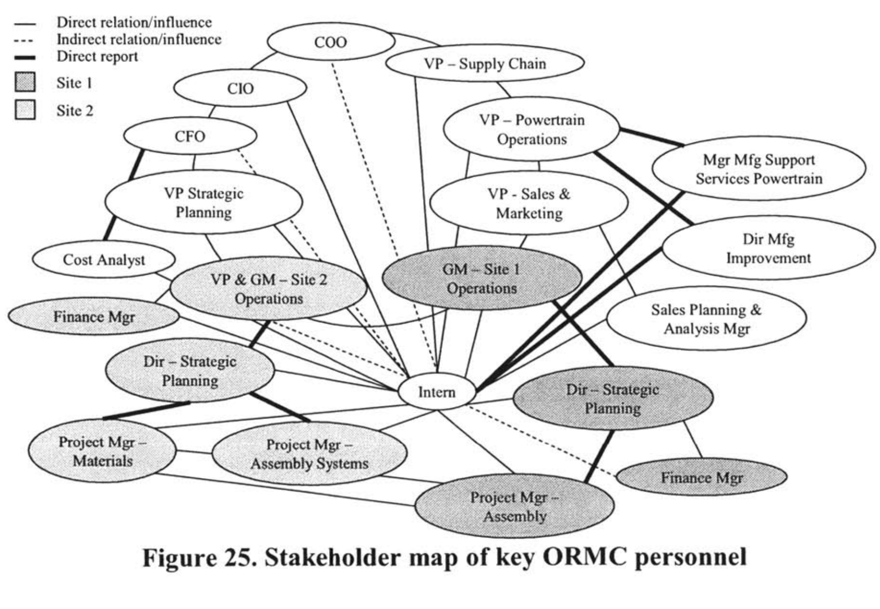


Figure 25. Stakeholder map of key ORMC personnel

These stakeholders are representatives from throughout the leadership structure at ORMC and shown in Figure 26.

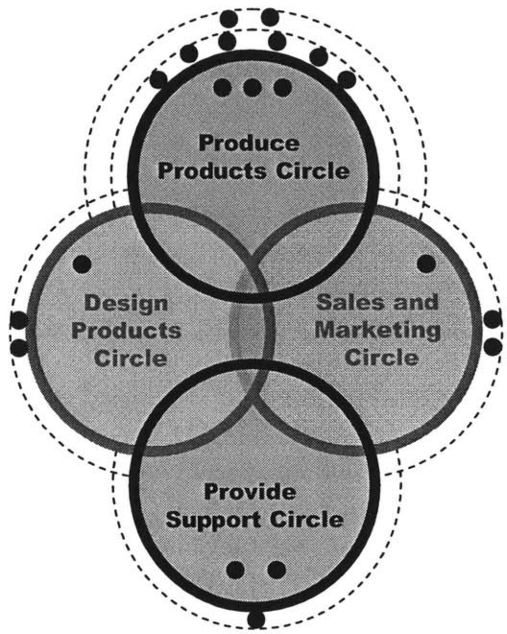


Figure 26. Stakeholder alignment to the leadership structure of ORMC

The three-lens framework for this analysis is based heavily on (Ancona, et al 2004) where lenses of strategic (the term structure will be used), cultural and political are used to describe the organizational processes at work within an organization. Three specific areas of consideration will be highlighted and the relevant structural, cultural and political components will be reviewed in relation to how these represent a barrier to implementing this change.

Sites

Structure

ORMC maintains two major sites that contain the five assembly lines. Site 1 was established as the primary assembly facility for the company in 1973. This is the larger of the two sites and employs roughly half of the company's workforce. This site also manufactures the two top selling product families. In 2001 a new building was constructed at Site 1 and dedicated to Family 1 production. Site 2 was built in 1998 in response to the company growth during this time period. Site 2 manufactures families 3-5 and also fabricates and assembles the 3rd generation engine used in Family 5 models. Engines for all other families, at both sites, are supplied from two power train manufacturing facilities located in another state.

Each factory operates independently with minimal salaried employee sharing and no union resource sharing. The factory managers interact via the produce product circle and have shared management incentives but rely on each other to independently contribute to shared incentive targets.

Political

The long history at Site 1 makes it the standard by which Site 2 and other sites are judged. Until 1998 all ORMC products were produced at Site 1 and for most of that time it occurred on a single assembly line. When Site 2 started operations it enabled focused manufacturing to take root due to the possibility of having dedicated assembly lines for each product family. However, this created some tension between the sites because Site 1 was losing work to Site 2.

Cultural

Prior to the production of ORMC products, Site 1 was a heavy machinery manufacturing facility. Safes and locks, 40mm naval ship guns and rocket boosters were among the items produced on this site. This has bread a culture of time and perspective that they say is "in the bricks". Site 1 continues to hand weld structural components that have long since been automated at Site 2. Site 1 also maintains a core competency in a material finishing process that is a critical differentiator for ORMC's products.

Site 2 was a green field startup, designed for the manufacture of ORMC products. ORMC used this plant as an opportunity to implement numerous process innovations that were difficult and costly to implement on the existing line at Site 1. The latest in assembly technology, material handling and ergonomic equipment were installed. In addition, ORMC established a progressive relationship with its unions at Site 2. Union workers were organized into self-sustaining teams without work group supervisors and partnership between union leaders and factory management were unheralded. The site manager and the union leaders share an office to symbolize the commitment to an open partnership.

These site differences led to underlying tension between them. As an example, when Site 1 began construction and startup of their new facility, t-shirts reading "We don't give a **** how [Site 2] does it!" became popular among the employees at Site 1.

An attempt was made to mitigate this tension between the sites by including both sites on the flexibility project team. The team never reached strict consensus regarding the best choice of flexibility as evident by the development of the hybrid and dedicated flexibility scenarios. The hybrid model eliminates the cross-site transfer of material and thus eliminates a source of conflict. In addition it minimized the flexibility requirements at Site 1. Site 1 is conservative its assessment of the viability of multi-family assembly lines due to their past experience with a single assembly line production of all ORMC products. The limited flexibility associated with the full chain model was not sufficient to convince Site 1 that this benefit outweighs the potential tradeoffs in complexity and quality, as such a demonstration of this capability is likely to be required to fully gain their support.

Union

ORMC has a reputation for having good relations with its union not only at Sites 1 and 2 but at the subcomponent manufacturing facilities as well. However, Site 1 has a more traditional relationship with its union relative to Site 2.

Structure

The unions are an integral part of ORMC structure. They agreed to a formal partnership contract that they have maintained since the mid-1990s. In this agreement, union stewards and HMDC management have a formal consensus decision making process.

Political

This relationship has been strained recently. A sub-component facility had a site expansion proposal initially voted down as a rejection of concessions ORMC was seeking, that was later overturned. Site 1 recently ended a multi-week strike that resulted from restructuring their union contract. This political struggle manifests itself in the topic of flexibility by creating boundaries on the possible flexibility components. Labor flexibility is not likely a viable short-term option, the union contracts prohibit employees from flexing from one line to another in other than temporary circumstances.

Cultural

Site 1 has a history of high utilization and plentiful opportunities for overtime. Site 2 has yet to fully utilize its installed capacity. Leveling production across both sites will change this dynamic for both sites. Initial resistance to this change may come from both sites but this should be a win-win-win situation for both sites' unions as well as ORMC management. Excessive utilization in Site 1 can strain the resources, under utilization of resources at Site 2 results in high variability of resource needs. Shift based operations result in discontinuous discrete staffing needs. For example, Family 3 demand is currently at a level that requires either 1 shift plus overtime to marginally fulfill this demand or an under loaded second shift.

Leadership model

The leadership model shown in Figure 26 relies on consensus decision making. This decision making style itself represents a barrier to change in the scope of influence required to gain the necessary support for change. However, there are more subtle challenges that can be revealed with a three lens analysis.

Structure

As previously mentioned the three leadership circles have been reorganized into four leadership areas. These leadership circles: Produce Products, Design Products, Sales and Marketing and Provide Support were redesigned to enable ORMC to be "more customer-driven"[2] The stated structural change is the creation of the Design Products and Sales and Marketing circles from the former Create Demand leadership circle. This allows engineering, to be combined with styling, quality and reliability as part of a consensus group. However, this results in the formalization of the distinction between designing the product and manufacturing the product. This is not an issue in isolation but the following responsibilities have been assigned to the design product circle: bring the right products to market faster, improve product quality and lower the cost to deliver the product. This is a point of potential conflict. In relation to flexibility initiatives there is a misalignment between the produce and design product circles. This analysis has been sponsored by the produce product group without input from the design product group.

Political

Within the leadership circles there are two encamped groups of stakeholders: those that view the manufacturing strategy as sufficient and oppose change and those that believe a change is needed in the manufacturing strategy and support flexibility. This thesis has been written for both audiences in hopes that consensus can be achieved and modifications made.

Cultural

The consensus leadership model makes strategic issues difficult if they are not being delivered in a top-down fashion. In this case generic "flexibility" has been handed down to all groups. The specific flexibility recommendation needs a champion and owner. This is a strategic initiative, should it therefore be owned from within the strategic

[2] From internal ORMC communication regarding the organizational restructuring

planning organization, which is part of the Provide Support Circle? It is a large scale change within the manufacturing network, should it therefore be driven from the Produce Products Circle? Finally, flexibility is an enabler to delivering the right product to the market faster at a lower cost. Does this then imply that it should be owned with the Design Products Circle, consistent with their responsibilities? These questions are not answered here but are raised in recognition that if there is ambiguity in this decision, then reaching consensus will be difficult.

Conclusion

ORMC, a producer of luxury recreational products is being challenged to be more responsive to its customers and fluctuation in the market. ORMC's historic evolution in its industry shows it to be in a maturing market with the rate of product and process innovation slowing. ORMC is now pursuing means of provide products to its mature market while trying to stimulate demand in emerging demographic and geographic markets as well as achieve disruptive innovation with new product families. Urgency to implement change is growing due to the ineffective utilization of capacity. This inefficiency is resulting in the inability to fulfill demand of high value products, creating variability in labor management and becoming increasingly costly to expand.

Flexibility is a means for addressing these particular issues. Flexibility is an often cited as ideal for addressing a great number of issues. For ORMC, flexibility in volume and product mix throughout its manufacturing network is in order. This can be accomplished through the implementation of a limited flexibility strategy known as full chain flexibility. Full chain flexibility will enable the fulfillment of the optimal mix of products in an uncertain market within minimal modification to the existing manufacturing network. This also represents a minimal increase in complexity on each line while achieving nearly the same benefits of a totally flexible network. Simulations reveal that greater than a 1.5 times increase in net revenue is possible over the current dedicated assembly line strategy. An increase in operating profit is possible with modification to the existing network of assembly lines and can result in increases in capacity utilization to nearly 95%. For less than the cost of implementing another dedicated assembly line, which would only alleviate capacity constraint for a single product family, ORMC can transform their assembly network to be flexible enough to deal with their future projected demand. This network configuration is also robust enough to handle dramatically different demand profiles from within its product portfolio.

Many challenges must be faced to realize this level of flexibility. It is recommended that ORMC identify a project champion and clear owner who can oversee the implementation of a single link in the full chain model. Following the successful completion of this phase of the project the learning should be collected in preparation for a final second phase. A concurrent implementation of the remaining links will enable the realization of the benefits of full chain flexibility in a timely fashion. In order to gain consensus for this change a coalition of members from both assembly sites, from the four leadership circles, and from the union representatives should be formed. Engagement of the union is also recommended in the design of how each line should be modified in order to achieve this flexibility. Doing so will reduce apprehension and build acceptance of the initiative, while identifying opportunities for improvement in implementation.

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